



Study on competition for land use and sustainable farming

Final report

Written by: Wageningen Environmental Research; Guidehouse; Fondazione MEDES
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List of abbreviations

Abbreviation	Explanation
AA	Agricultural area
AE	Agro-ecology
AECM	Agri-Environment and Climate measures
AEI	Agri-environmental indicators
AECM	Agri-environment-climate Measures
AEM	Agri-environmental measures
AEI	Agri Environmental Indicators
AES	Agri-environmental scheme
AFOLU	Agriculture, Forestry and Other Land Use
Agri-PV	Agri-photovoltaics
AKIS	Agricultural Knowledge and Innovation System
ANC	Areas facing Natural Constraints
BAU	Business as usual
BISS	Basic Income Support for Sustainability
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CC	Carrying Capacity
CDDA	Nationally designated areas
CEE	Central and Eastern European
CEEC	Central and Eastern European countries
CF	Cohesion Fund
CHP	Combined heat and power
CLC	CORINE Land Cover
CO ₂	Carbon Dioxide
CS	Case Study
CSA	Climate Smart Agriculture
DA	Determined area
DG-AGRI	Directorate-General for Agriculture and Rural Development
DG-ENER	Directorate-General for Energy
EAFRD	European Agricultural Fund for Rural Development
EAGGF	European Agricultural Guidance and Guarantee Fund (EAGGF)
EASA	European Aviation Safety Agency
ECA	European Court of Auditors
EC	European Commission
EEA	European Environment Agency
EFA	Ecological Focus Areas
EIA	Environmental Impact Assessment
EIB	European Development Bank
EIP	European Innovation Partnerships
ECMWF	European Centre for Medium-Range Weather Forecasts
ENRD	European Network for Rural Development

ENZ	Environmental zone
ERDF	European Regional Development Fund
ESF	European Social Fund
ESR	Effort Sharing Regulation
ESTAT	Eurostat
ETC-SIA	European Topic Centre for Spatial information and Analysis
EU	European Union
EU28	Memberships of the European Union in the period 1 July 2013 – 31 January 2020
EU-27	Memberships of the European Union in the period 1 July 2013 – 31 January 2023 (excl UK)
EU15	Memberships of the European Union from 1 January 1995 and as of December 31, 2003
EU-LUPA	European Land Use Patterns
EUR	Euro
F2F	Farm to Fork
FA	Farm area
FAA	USA Federal Aviation Administration
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization
FAOSTAT	Statistics of the Food and Agriculture Organization
FOD	Foreign Object Debris
FSS	Farm Structural Survey
GAEC	Good Agricultural and Environmental Practices
GAP	Good Agricultural Practices
GD	Green Deal
GDR	German Democratic Republic (GDR), or Communist East Germany
GDP	Gross domestic product
GHG	Greenhouse gas
GHSL	Global Human Settlement Layer
GIS	Geographic Information Systems
GLAD	Global Land Analysis & Discovery
GNSS	Global navigation satellite system
H2020	Horizon 2020
HNV	High Nature Value
IACS	Integrated Administration and Control System
ICT	Information and communications technology
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
JLS	Local self-government units (Croatian abbreviation)
KET	Key Enabling Technology
KPI	Key performance indicator
LAG	Local action groups
LAI	Leaf area index

LAU	Local Administrative Units
LCF	Land cover flows
LCOE	Levelized cost of energy
LEAC	Land and Ecosystem Accounting system
LPIS	Land Parcel Identification System
LSU	Livestock unit
LUCAS	Land Use and Coverage Area frame Survey
LULUCF	Land use, land-use change and forestry
MAGIC	Marginal Lands for Growing Industrial Crops
MEDALUS	Mediterranean desertification and land use
MS	Member State(s) of the European Union
N2000 or N2K	Natura 2000
NCFF	Natural Capital Financing Facility
NDVI	Normalized difference vegetation index
NECP	National Energy and Climate Plan
NGO	Non-governmental organization
NMR	National ... registration
NRL	Nature Restoration Law
NUAA	Unutilised agricultural area as defined by Eurostat
NUTS	Nomenclature of territorial units for statistics ranging from NUTS0 (EU country level) to 3 (most detailed regional level)
OECD	Organisation for Economic Co-operation and Development
OVAM	Public Waste Agency of Flanders
PCA	Principal component analysis
PEA	Potentially eligible area
PG	Permanent grassland
PPP	Plant Protection Products
PV	Photovoltaic
RALUC	Rural Agricultural land use changes (acronym for this study and also acronym used for referring to the typology of regions developed in this study)
RDP	Rural Development Policy (or Programme)
RED II	Revised Renewable Energy Directive 2018/2001/EU
RES	Renewable energy systems
R&D	Research and Development
R&I	Research and Innovation
SA	Sustainable agriculture
SAA	Special holding areas
SDG	Sustainable Development Goal
SAPS	Single Area Payment Scheme
SGM	Standard gross margin
SI	Sustainable Intensification
SME	Small and medium-sized enterprises
SMR	Statutory management requirement
SMRL	Soil Monitoring and Resilience Law

SOC	Soil Organic Carbon
SP	Strategic Plan
SRC	Woody perennial crops in short rotation systems
TCD	Tree cover density
UAA	Utilised agricultural area
UK	United Kingdom
UNCCD	United Nations Convention to Combat Drought and Desertification
UNECE	United Nations Economic Commission for Europe
USA	United States of America
USD	United States Dollar
USSR	Union of Soviet Socialist Republics
VCS	Voluntary Coupled Support
WA	Wooded area
WFD	Water Framework Directive
WTO	World Trade Organisation

Country codes

Abbreviation	Country
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden

SI	Slovenia
SK	Slovakia

Notation

Numbers:

The point symbol (.) precedes decimal places

Executive summary (English)

This study generated many insights in how agricultural land use has evolved in the EU-27 over the last 30 years, and how it can evolve sustainably in the next 30 years. Agricultural land was analysed in relation to changes in use and land management, competition, and, synergies of agriculture with other land use sectors and also between food, feed, energy, and non-food biomass production. The land use trends were related to the main drivers for past and future changes. The analysis was done for the whole EU-27 at a regional level and for different types of EU-27 regions that were classified in a typology developed in this study. In-depth data collection and analysis was also done in 12 case studies spread across the EU-27 and over the different regional typology classes.

Land use trends and drivers in past 30 years in EU-27

A RALUC typology (Rural Agricultural Land Use Change) of regions (at Nuts 3 level) was developed in this project with the aim of better understanding whether combinations of land use changes and drivers are territorially specific. The typology is produced based on three dimensions: dominant land use dynamics, environment and, socio-economic characteristics. In almost half of the regions in the EU, urbanisation has been the main land use change followed by afforestation (31%), intensification (14%), extensification and nature creation (5%). A principal component analysis (PCA) was performed to confirm and statistically support the RALUC typology. In the PCA, the RALUC typology data were combined with 27 different factors identified from literature and case studies, that have potentially driven land use changes in rural areas in the last 30 years, and for which data was available. The conclusion is that the RALUC typology is a good reflection of classes of NUTS3 regions that have experienced similar combinations of land use changes and drivers. The RALUC 'Urbanisation type', which was also reflected in the first component identified by the PCA, indeed experienced the higher conversion rates of agricultural areas into urban areas because of similar socio-economic characteristics. They all have in common a (very) high population density, a stable GDP and high to moderate accessibility. These regions are mostly in Germany, France, Northern Italy, Belgium, Netherlands, Poland, Czech Republic, Denmark and Greece, mostly corresponding to the largest cities, urban agglomerations, and metropolitan regions. On the other end of the urban-rural gradient were the regions with more 'rural' and 'natural' character (in RALUC classes: Afforestation, Intensification, Extensification and Nature creation) and these were more concentrated in both Western Europe (Spain, Portugal, Ireland), and CEEC Europe (Hungary, Romania, Bulgaria, a part of Poland, Baltic countries). From the analysis of different data sources on how agricultural land evolved in built-up area, it was also confirmed that farmland conversion to built-up areas has been a dominant factor in practically all regions of the EU. Although here, the scale of farmland loss varies strongly between countries, Nuts3 regions and also within regions. 'Coastalization', the land take process that affects coastal areas, was largest in Spain, France, Italy, and to a lesser extent, in Portugal, Denmark, Netherlands, Poland and Sweden. Here tourism is a main driver, and this factor has also driven the transformation of agricultural land into built-up areas. Beside demographic and economic pressures, weak normative and regulatory constraints may also be major factors for the conversion of agricultural land to urban areas. The most relevant impacts of agricultural land take by built-up areas are a loss and further fragmentation of agricultural land, possibly leading,

among other impacts, to reductions in agricultural production and the competitiveness of farms.

The second component resulting from the PCA is an agricultural-forest gradient of regions confirming a geographical polarization between 'dynamic' and 'advanced' agricultural regions (with a dominant production model based on crop intensity, mechanization and irrigation) and more remote regions. In the latter case, we observe a greater representation of extensive agricultural models with organic farming, woody features, the prevalence of natural habitats over intensive large scale cropland, and a slight expansion of forest land. Examples belonging to the 'dynamic agricultural regions' are concentrated mostly in the RALUC Intensification type regions - which are flat and largely accessible districts of Romania, Hungary, Italy, Atlantic France, Spain, and in some small parts of Germany where dynamic and intensive farming systems have consolidated and possibly expanded. On the forest side of the gradient, most dominated by RALUC Afforestation type regions in Sweden and, less regularly, other Northern countries, as well as in Austria and the surrounding Alpine regions of other countries and, more sparsely, mountainous and remote districts of France (Massif Central and Alps), Italy (Alps and Apennines), Germany, Spain (Pyrenees), and Greece. The third component, resulting from the PCA, represents a geographical gradient that reflects the East-West divide with demographically dense regions, typical of Western Europe, and regions experiencing an above-average increase in per-capita income levels in the last two decades, corresponding to the new European Union. The fourth component of 'agro-forestry vs extensive cropping systems' is found mostly in the North and as a selection of Mediterranean regions having more woody landscape features in and along agricultural land. At the same time, the latter regions have extensive cropping systems with more open agricultural landscapes which mostly occurs in parts of Romania and Bulgaria, and more sparsely in Germany and Poland. The fifth component confirms the geographic gradient of drylands vs humid climate divide, and the sixth gradient is agricultural intensification vs solar park developments.

Analysing land and production flows in last 30 years shows that between 1990 and 2022 the area of cropland (arable + permanent cropland) in the EU-27 declined going from 120 million ha to 111 million ha. Over this same period agricultural production went from 488 to 510 Mtonnes dry mass. In some regions, especially the newer EU-27 countries lands were brought back into production, while in others these decreased. The largest share of cropland is taken up by the production of feed in the EU-27 - this land share amounts to 53% in 2022, but 60% in terms of production (in tons dry mass). In 1990, the area used for production of feed was lower at 50% and 54% in terms of production, but the total production of feed only amounted to 262 Mtonnes dry mass, while this became 304 Mtonnes dry mass in 2022. Between 1990 and 2022, feed production has always shown an increasing trend in contrast to food production in the EU-27. The decline in land used for food production between 1990 and 2022 was clearly related to competition with feed for livestock and biomass production for energy. The amount of land used for energy increased from 57 000 ha to almost 5 million ha in 2010, which is related to a strong increase in production of crops for first generation biofuels and for biogas. The Directive on Biofuels for Transport came into force in 2003 and led to an accelerated growth until 2009-2010, which is when the first Renewable Energy Directive (RED, 2009/28/EC) came into force. This was followed by a small dip

in the agricultural area used for biofuel feedstock in 2015, with the introduction of the ILUC Directive which introduced a cap on food and feed-based biofuel, and from then on the area used for biofuel feedstock flattens to 6.2 million ha in 2022. Competition for land between non-food uses, other than for energy, is very small, and in 2022 it amounts to not even 1% of UAA and mostly involves industrial crops like cotton, flax and hemp. Given the dominant position of feed production in EU-27 agricultural land use, it is clear that diets, particularly in relation to animal protein consumption levels, have influenced the changes in agricultural land use since 1990.

Expansion of forest at the expense of agricultural land was one of the most prominent changes observed in land use in the last 30 years. Ireland, Spain, Portugal and Hungary are typically countries with active afforestation, all due to CAP and national support. In other EU countries, natural revegetation of abandoned farmland is likely to have been the predominant mode of afforestation. Drivers for afforestation are a complex mixture of different, often connected, factors of which unfavourable agro-ecological and socio-economic circumstances, at farm level, are playing a key role in combination with economic policy support or (new) market demands to make the investment in afforestation attractive. Afforestation helps building-up and/or restoring above ground biomass that contributes to carbon storage and that can contribute to biodiversity restoration. On the other hand, afforestation may have adverse effects on biodiversity if it takes place on e.g., ecologically valuable permanent grasslands.

Abandoned agricultural lands are described in this study as lands that were previously used for agricultural production but are no longer used for that purpose. The largest land abandonment occurred especially in post-socialist countries, and led to rewilding and afforestation, with a resurgence of agricultural activities in some regions since joining the EU. Drivers of various types underlaid farmland abandonment. Apart from the mentioned land abandonment taking place in hilly and mountainous, low productive lands, there was also intensification of agricultural land use, occurring in the lowlands - where better soils are usually found.

Intensification has been a very influential process of land use change in most agricultural areas in almost all regions of the EU. It was mostly concentrated in the better agricultural areas; however, also occurred in areas with more natural constraints, such as those caused by low precipitation, that have experienced strong intensification thanks to technical innovations. The main driver for intensification is the market, including through the large influence of retail on agricultural markets. Also important, is the reduction of the labour force in the agricultural sector and the declining rural population leading to the adoption of labour-saving and agritech innovations. Positive impacts of intensification are those on agricultural production and food security and often also on the economic income of farmers, although this is not the case when accompanied by high investments that lead to high debts and interest payments. The negative impacts for biodiversity and environment have been widely reported in literature and were also reported for the CSs.

Extensification can be seen as the opposite of intensification and reflects the process of a decrease in the use inputs, usually relative to land area. Extensification trends varied across MS, without a clear geographic pattern.

From the older MS, countries showing clear increases in agricultural area managed by low input farms are Belgium, Greece, Denmark, and Finland. The opposite is seen in countries like Netherlands and Austria, where the area under high input farms increased over the same period. Farm consolidation into larger units has been common across the EU, with significant reductions in mixed farming and overall negative impacts on biodiversity.

With the introduction of the renewable energy targets, the demand for land to place wind turbines and PV panels has increased also on agricultural lands in certain regions. Agricultural area loss due to renewable energy from wind and PV is very small, not reaching even 0.1% of UAA in the last 20 years. In certain regions, the land use impact can be larger of course. Even though land take is small, the perceived negative impacts on the landscape and (possibly) biodiversity need to be considered and this calls for more consideration of RES energy development in regional rural development plans.

Future land use for sustainable agriculture

To analyse the best way forward towards sustainable agriculture in 2050, this study developed two scenarios, business as usual (BAU) and Sustainable Agriculture (SA) for which land use change trends were modelled towards 2050 and KPIs were assessed to understand environmental impacts, socio-economic trade-offs and policy guidance needs. In the BAU scenario, current trends of drivers of urban sprawl, climate change, land degradation, land abandonment, intensification, extensification, diets, are expected to continue. Also Farm to Fork (F2F) and wider Green Deal policy goals are not addressed with new policy instruments. Society's interest to adopt changes in lifestyles and pay for maintenance and improvements in ecosystems services connected to production of food does not increase. In the SA scenario, drivers are expected to be brought in line with the Green Deal and the Farm to Fork strategy and all associated targets are expected to be met also in combination with societal changes supporting these.

Modelled land use changes for both scenarios show that by 2050 it can be expected that farmland area loss can be limited with active policy interventions to reach the F2F goals and broader Green Deal goals. However, if no active policy interventions take place, as modelled in the BAU scenario, the decline of farmland will be more than 8 million ha. A large decline in agricultural land also goes together, in BAU, with a larger increase in urban land because no policy measures are implemented to reach zero land take by 2050. The amount of agricultural land converted to urban areas between 2020 and 2050 amounts to 2.3 million ha, while this can be 1.4 Million ha with the implementation of the zero-land take measure in the SA scenario. With no policy intervention, the largest loss in agricultural land can be expected in in the Alpine zone, followed by the Mediterranean and Continental zone - the Northern region (Baltics and Scandinavia) will practically experience no decline in farmland. With F2F policy implementation in SA scenario, losses in farmland will be much smaller, however the Mediterranean will still lose 2.3% of agricultural area while the North and Continental zones will show gains of 3.7% and 0.7% of the land area respectively. One factor, amongst others causing this continuation of farmland decline in the Mediterranean and farmland increase in the North, is climate change. It leads to lower precipitation levels in the Mediterranean but also longer growing season towards the North.

As to the goal of ensuring food security this works better in the SA scenario where more land will remain in agricultural production in the EU. Also, the production of food that is sufficient, safe, and healthy will work out better in the SA scenario since a larger share of food is assumed to be produced organically and with lower use of pesticides or artificial fertilizers. However, impacts on food security and healthy food also depend on changes in lifestyles. The KPI which was chosen to express this, i.e. the total calories produced from the harvested land resource, is lower in the SA scenario compared with the BAU scenario. It is also worth noting that both scenarios show a declining trend in calories produced compared to 2020. This has to do with an overall decrease in feed production because of declining livestock numbers, but also climate change impacts on crop choices and yields. In the SA scenario this decline is bigger because expectations for larger shifts in diets towards less meat and more vegetal proteins are assumed. This should not represent a problem if the protein transition is really going to advance. However, if people continue consuming meat at current levels, the F2F targets in relation to more organic farming and lower fertiliser and pesticide inputs will be difficult to reach. Higher livestock production levels also require much higher calories from crop production to feed the livestock. This can only be reached with larger production volumes of feed crops on agricultural lands, or through higher imports of feed from outside the EU. Feed from outside the EU also increases the environmental footprint of EU food, particularly where it may lead to further deforestation elsewhere.

KPI scores confirm that in the SA scenario, the lowering of fertilizer and pesticides inputs, more organic land use, and lower livestock numbers, are likely to lead to better water quality, lower ammonia emissions, reduction in GHG emissions on agricultural lands, most strongly caused by reduction of enteric fermentation (livestock-based emissions) but not necessarily to GHG emissions related to land use shifts expected between 2020 and 2050. In this respect, the SA scenario leads to a significant improvement in environmental quality. On the other hand, the KPI scores for soil health, namely SOC scores and soil erosion risk index, are likely to worsen in the SA scenario because more lands remain in agricultural use than in the BAU scenario. This implies that in the future, more effort needs to be made to maintain SOC and decrease soil erosion through a wider uptake of soil management practices in agriculture.

To understand the territorial differences in potentially reaching a sustainable agriculture in the future, the RALUC Nuts 3 regions were further classified in so called carrying capacity (CC) classes. The CC is based on three dimensions representing (i) future climate conditions (namely climate aridity), (ii) demography (a combination of current population density and expected population trends towards 2050), and (iii) the intrinsic capacity of the territories to invest in their future agriculture (current GDP). From this CC classification it became clear that increased aridity is expected in 227 (15%) RALUC regions which cover as much as 26% of the agricultural area of EU-27. These are all located in the Mediterranean basin but also in Romania and Bulgaria. Beside strong declines in water availability, extremes in weather events are also expected. Climate adaptation is the most urgent focus in agriculture and therefore in policy guidance, and in private and public investments. Moreover, more than 50% of the regions, which cover 61% of the EU farmland, have an unfavourable demographic trend which implies that they must cope with very low population density and/or a strong declining trend in population toward 2050. Most of these regions are in 'new EU' countries. Here, a stable and

sustainable farming sector can only be maintained, through reaching the F2F goals, if the right combination of CAP guidance and investments are made, in combination with policy successes to improve rural livelihoods, stop population declines, particularly where it concerns loss of young people. Active rural development and population policy is imperative. From the CC classification it is also clear that 15% of the regions have very low investment capacity and they cover 21% of the farmland. These regions rely more strongly for this aspect on EU CAP support. According to this carrying capacity model, the regions that will have the most difficulty in achieving a condition of sustainable agriculture in the future are obviously those where low CCs are found for all three dimensions. This applies for 4% of the regions covering 7% of the EU farmland area and are all in Bulgaria, Romania and Greece. The opposite is true for 43% of the regions with 29% of the agricultural land where no threshold for CC is exceeded and they are mostly spread over the 'old EU' countries.

Main recommendations

The study makes several recommendations which are also specific according to the regional profiles identified and described for the different CC classes identified. All the territorially different conditions intrinsically influence agricultural dynamics and drive territories to answer in a possibly different way to policy stimuli e.g. CAP in one case, and demography or general infrastructure and service policies in the other.

Another very important aspect, that needs to be consolidated more strongly in policy development, is that reaching multiple F2F targets can be achieved through implementation of multiple effective territorial policy instruments. For example, a pre-requisite to restore nature in many places is to ensure the environmental quality of water, air and soil is restored. The advantage is that measures reducing losses of nitrogen to water and air (methane) also contribute positively to reaching nature restoration and GHG mitigation. The introduction of new and novel crops for climate adaptation and/or production of non-food biomass in marginal lands, may also be better than conventional food crops in providing ecosystem services such as the build-up of soil carbon or pollination functions. Also, the restoration of peatland areas can create win-wins and can be created with nature restoration targets which also require peatland areas to be restored by 2050. Extensive grazing practices and paludi cultures are alternatives which may both reduce land based GHG emissions and provide opportunities to recover semi-natural habitats and related biodiversity values. The orientation towards agroecology and investments in precision farming may create climate adaptation but may also increase farm efficiency and lower production costs. Modern mono-digestion installations to produce biogas and biomethane, for energy, would ensure that direct GHG emissions in agriculture are reduced by lowering fossil-based emissions in the sectors where the biogas and biomethane is consumed. This measure can create win-win situations with reduction of nitrogen losses in livestock systems, reduction of enteric fermentation based GHG emissions and production of renewable energy. In regions confronted with growing aridity, crop growth can benefit from the PV panel shade to lower water losses from evapotranspiration. The trade-off between yields in both crop production and electricity generation should be better studied in different climate zones to come to optimal designs of agro-PV through the EU.

Finally, the balance between livestock production levels, land use for feed and food production needs to be addressed at regional level. In several regions of

the EU a reduction in livestock production will create win-wins as it reduces losses of nitrogen to water and air (methane) and contributes positively to reaching nature restoration and GHG mitigation targets. In other regions however maintenance and even increase in livestock numbers is necessary to reach win-wins with farmland biodiversity that depends on continuation of traditional grazing practices and/or to generate enough local manure resources to supply the nutrient needs in organic farming practices. Overall however, the reduction of livestock numbers in the EU can only be effective in reaching GHG emission mitigation if it is accompanied by a partial protein transition from animal to vegetal diets. Without it, the EU will export the GHG emissions related to livestock rearing to regions outside the EU, thereby not mitigating global climate change.

Executive summary (French)

Cette étude a généré de nombreux aperçus sur l'évolution de l'utilisation des terres agricoles dans l'UE27 au cours des 30 dernières années et sur son évolution durable possible pour les 30 prochaines années. L'utilisation des terres agricoles a été analysée au regard des changements d'usage et de la gestion des terres, la concurrence et les synergies de l'agriculture avec d'autres secteurs d'utilisation des terres, ainsi qu'entre la production de nourriture, de fourrage, d'énergie et de biomasse non alimentaire. Les tendances d'utilisation des terres ont été liées aux principaux facteurs de changement passés et futurs. L'analyse a été réalisée à l'échelle régionale pour l'ensemble des pays de l'UE27 et pour différents types de régions de l'UE27, classées selon une typologie développée dans cette étude. Une collecte et une analyse de données approfondies ont également été menées dans 12 études de cas réparties dans l'UE27 et couvrant différentes classes de typologie régionale.

Tendances de l'utilisation des terres et facteurs d'évolution dans l'UE27 au cours des 30 dernières années

Dans ce projet, une typologie RALUC des régions (au niveau Nuts 3) a été développée pour mieux comprendre si les combinaisons de changements d'utilisation des terres et des facteurs d'évolution sont spécifiques aux territoires. La typologie est fondée sur trois dimensions : la dynamique dominante de l'utilisation des terres, les caractéristiques environnementales ainsi que les caractéristiques socio-économiques. Au sein de près de la moitié des régions de l'UE, l'urbanisation a été la cause principale du changement d'utilisation des terres, suivie par l'afforestation (31 %), l'intensification (14 %), et l'extensification et la création de zones naturelles (5 %).

Une analyse en composantes principales (ACP) a été réalisée pour confirmer et appuyer statistiquement la typologie RALUC. Dans cette analyse, les données de la typologie RALUC ont été combinées avec 27 facteurs potentiels identifiés dans la littérature et les études de cas, qui ont pu influencer les changements d'utilisation des terres en zones rurales au cours des 30 dernières années et pour lesquels des données étaient disponibles. La conclusion est que la typologie RALUC reflète bien les classes de régions NUTS3 ayant connu des combinaisons similaires de changements d'utilisation des terres et de facteurs de changement.

La typologie « Urbanisation » RALUC, reflétée également dans la première composante identifiée par l'ACP, a en effet montré des taux plus élevés de conversion des zones agricoles en zones urbaines, dus à des caractéristiques socio-économiques similaires. Ces régions partagent une densité de population (très) élevée, un PIB stable et une accessibilité de moyenne à élevée. Elles se situent principalement en Allemagne, France, Italie du Nord, Belgique, Pays-Bas, Pologne, République tchèque, Danemark et Grèce, et correspondent aux grandes villes, agglomérations urbaines et régions métropolitaines. À l'autre extrémité du gradient urbain-rural se trouvent des régions plus « rurales » et « naturelles » (catégories RALUC : Afforestation, Intensification, Extensification et Création de nature), majoritairement concentrées en Europe occidentale (Espagne, Portugal, Irlande) et en Europe centrale et orientale (Hongrie, Roumanie, Bulgarie, une partie de la Pologne, pays baltes). L'analyse des différentes sources de données sur l'évolution des terres agricoles dans les zones bâties confirme également que la conversion de terres agricoles en zones bâties a été un facteur dominant dans presque toutes les régions de l'UE, bien

que l'ampleur de cette perte varie fortement entre les pays, les régions Nuts3, et même au sein de ces régions. La littoralisation (ou « coastalisation »), processus d'exploitation de terres dans les zones côtières, a été particulièrement conséquent en Espagne, France, Italie et, dans une moindre mesure, au Portugal, au Danemark, aux Pays-Bas, en Pologne et en Suède. Dans ces situations, le tourisme a été le moteur principal de transformation des terres agricoles en zones urbaines. En plus des pressions démographiques et économiques, des contraintes normatives et réglementaires faibles peuvent également contribuer de manière significative à la conversion des terres agricoles en zones urbaines. Les plus grands impacts de la conversion des terres agricoles en zones bâties comprennent la perte et la fragmentation accrue des terres agricoles, entraînant potentiellement une réduction de la production agricole et de la compétitivité des exploitations agricoles.

La deuxième composante résultant de l'ACP représente un gradient agricole-forestier des régions, confirmant une polarisation géographique entre les régions agricoles « dynamiques » et « avancées » (caractérisées par un modèle de production dominant basé sur l'intensité des cultures, la mécanisation et l'irrigation) et des régions plus éloignées. Dans ces dernières, on observe une plus grande représentation de modèles agricoles extensifs, incluant l'agriculture biologique, des caractéristiques forestières, la prévalence d'habitats naturels par rapport aux grandes cultures intensives ainsi qu'une légère expansion des surfaces forestières. Les principaux exemples de « régions agricoles dynamiques » se concentrent majoritairement dans les régions de type « Intensification de la RALUC », qui sont sans reliefs et largement accessibles en Roumanie, Hongrie, Italie, France atlantique et Espagne, ainsi que dans certaines petites parties de l'Allemagne où des systèmes de culture dynamiques et intensifs se sont consolidés et ont peut-être même été étendus.

Du côté forestier du gradient, on trouve principalement les régions de type « Afforestation de la RALUC », notamment en Suède et, de manière moins régulière, dans d'autres pays nordiques, ainsi qu'en Autriche et dans les régions alpines environnantes d'autres pays, et plus éparpillé dans des districts montagneux et éloignés de France (Massif central et Alpes), d'Italie (Alpes et Apennins), d'Allemagne, d'Espagne (Pyrénées) et de Grèce. La troisième composante de l'ACP représente un gradient géographique qui reflète la fracture Est-Ouest, avec des régions démographiquement denses, typiques de l'Europe occidentale, et des régions connaissant une augmentation au-dessus de la moyenne des niveaux de revenu par habitant au cours des deux dernières décennies, correspondant aux nouveaux États membres de l'Union européenne.

La quatrième composante, « agro-foresterie vs systèmes de culture extensive », se trouve principalement dans le nord et dans certaines régions méditerranéennes ayant plus de caractéristiques paysagères boisées en milieu agricole. Parallèlement, ces régions possèdent des systèmes de culture extensive avec des paysages agricoles plus ouverts, surtout dans certaines parties de la Roumanie et de la Bulgarie, et de manière plus éparse en Allemagne et en Pologne. La cinquième composante confirme le gradient géographique entre les terres sèches et les climats humides, tandis que la sixième composante met en lumière le contraste entre l'intensification agricole et le développement de parcs solaires.

L'analyse des flux de terres et de production au cours des 30 dernières années montre qu'entre 1990 et 2022, la superficie des terres arables dans l'UE27 est diminué, passant de 120 millions d'hectares à 111 millions d'hectares. Durant cette même période, la production agricole a augmenté passant de 488 à 510 millions de tonnes en masse sèche. Dans certaines régions, en particulier dans les pays récemment intégrés à l'UE27, des terres ont été remises en production, contrairement à d'autres Etats qui ont vu ce nombre diminuer.

La plus grande part des terres agricoles est dédiée à la production de fourrage, représentant 53 % de la surface en 2022, et 60 % en termes de production (en tonnes sèches). En 1990, cette proportion était de 50 % pour la superficie et de 54 % pour la production, avec une production totale de fourrage s'élevant à 262 millions de tonnes sèches à 304 millions de tonnes sèches en 2022. Entre 1990 et 2022, la production de fourrage a toujours montré une tendance à la hausse, contrairement à celle de la nourriture dans l'UE27. La diminution des terres utilisées pour la production alimentaire entre 1990 et 2022 est clairement liée à la concurrence avec la production de fourrage pour le bétail et à la biomasse destinée à l'énergie.

La superficie utilisée pour l'énergie a considérablement augmenté, passant de 57.000 hectares à presque 5 millions en 2010, en raison d'une forte augmentation de la production de cultures destinées aux biocarburants de première génération et au biogaz. La directive sur les biocarburants pour le transport, entrée en vigueur en 2003, a entraîné une croissance rapide jusqu'en 2009-2010, lorsque la première directive sur les énergies renouvelables (RED, 2009/28/CE) a été mise en œuvre. Cela a été suivi d'une légère baisse de la superficie agricole utilisée pour les cultures de biocarburants en 2015, avec l'introduction de la directive ILUC, qui a plafonné la production de biocarburants produits à base de nourriture et de fourrage. Depuis la promulgation de la directive, la superficie utilisée pour les cultures de biocarburants s'est stabilisée à 6,2 millions d'hectares en 2022.

La concurrence pour les terres entre les utilisations non alimentaires, autres que l'énergie, est très faible, représentant en 2022 moins de 1 % de la surface agricole utile (SAU), et concerne principalement des cultures industrielles comme le coton, le lin et le chanvre. Étant donné la position dominante de la production de fourrage dans l'utilisation des terres agricoles de l'UE27, il est évident que les régimes alimentaires, les niveaux de consommation élevée de protéines animales ont influencé les changements dans l'utilisation des terres agricoles depuis 1990.

L'expansion des forêts au détriment des terres agricoles a été l'un des changements les plus marquants observés dans l'utilisation des terres de 1990 à 2022. Des pays comme l'Irlande, l'Espagne, le Portugal et la Hongrie se distinguent par des efforts d'afforestation actifs, soutenus par la PAC et des politiques nationales. Dans d'autres pays de l'UE, la régénération naturelle des terres agricoles abandonnées a probablement été le mode d'afforestation prédominant. Les facteurs d'afforestation sont un mélange complexe de divers éléments, souvent interconnectés, où des circonstances agro-écologiques et socio-économiques défavorables jouent un rôle clé, combinées à un soutien politique économique ou à de nouvelles demandes du marché qui rendent l'investissement en afforestation attractif. L'afforestation contribue à la constitution et à la restauration de la biomasse aérienne, participant ainsi au stockage du carbone et à la restauration de la biodiversité. Cependant, elle peut

également avoir des effets néfastes sur la biodiversité si elle se fait sur des terres de type prairies écologiquement précieuses.

Les terres agricoles abandonnées, telles que décrites dans cette étude, sont celles qui étaient précédemment utilisées pour la production agricole mais ne le sont plus. L'abandon de terres a été particulièrement marqué dans les pays post-socialistes, entraînant une réwilding et une afforestation, avec un regain d'activités agricoles dans certaines régions depuis leur adhésion à l'UE. Divers facteurs ont contribué à l'abandon des terres agricoles, notamment dans des zones montagneuses et collines peu productives, tandis qu'une intensification de l'utilisation des terres agricoles s'est produite dans les basses terres, où l'on trouve généralement de meilleurs sols.

L'intensification a été un processus très influent de changement d'utilisation des terres dans la plupart des zones agricoles de presque toutes les régions de l'UE. Elle s'est surtout concentrée dans les zones agricoles les plus fertiles, mais a également eu lieu dans des régions soumises à des contraintes naturelles, comme celles à faible précipitation, qui ont connu une forte intensification grâce à des innovations techniques. Le principal moteur de l'intensification est le marché, influencé notamment par le secteur de la distribution. De plus, la réduction de la main-d'œuvre dans le secteur agricole et le déclin de la population rurale ont conduit à l'adoption d'innovations technologiques visant à économiser le travail. Les impacts positifs de l'intensification incluent l'augmentation de la production agricole et la sécurité alimentaire, souvent au bénéfice des revenus des agriculteurs, bien que cela ne soit pas toujours le cas si cela s'accompagne de lourds investissements entraînant des dettes et des paiements d'intérêts élevés. Les impacts négatifs sur la biodiversité et l'environnement ont été largement documentés dans la littérature et ont également été rapportés dans les études de cas.

L'extensification peut être considérée comme l'opposée de l'intensification, reflétant une diminution des intrants utilisés, généralement par rapport à la superficie des terres. Les tendances d'extensification varient d'un État membre à l'autre, sans schéma géographique clair. Parmi les anciens États membres, des pays comme la Belgique, la Grèce, le Danemark et la Finlande montrent des augmentations claires de la surface agricole gérée par des exploitations à faibles intrants. À l'inverse, aux Pays-Bas et en Autriche, la surface des exploitations à forts intrants a augmenté au cours de la même période. La consolidation des exploitations en un plus grand nombre d'unités est une tendance commune dans toute l'UE, entraînant des réductions significatives de l'agriculture mixte et des impacts globalement négatifs sur la biodiversité.

Avec l'introduction des objectifs en matière d'énergie renouvelable, la demande de terres pour la construction d'éoliennes et de panneaux photovoltaïques a également augmenté sur les terres agricoles dans certaines régions. La perte de surface agricole due aux énergies renouvelables d'éoliennes et de panneaux photovoltaïques demeure cependant très faible, ne dépassant pas 0,1 % de la surface agricole utile au cours des 20 dernières années. Toutefois, l'impact de l'utilisation des terres peut être plus important dans certaines régions. Bien que l'occupation des terres soit minime à ce jour, les impacts perçus sur le paysage et (éventuellement) la biodiversité doivent être pris en compte, ce qui appelle à une meilleure intégration du développement des énergies renouvelables dans les plans de développement rural régional.

Future utilisation des sols pour une agriculture durable

Pour analyser la meilleure voie vers une agriculture durable d'ici 2050, cette étude a développé deux scénarios : « Business as Usual » (BAU) et « Agriculture Durable » (SA). Les tendances de changement d'utilisation des terres ont été modélisées pour ces scénarios, et des indicateurs clés de performance (KPI) ont été évalués afin de comprendre les impacts environnementaux, les compromis socio-économiques et les besoins en matière de politiques publiques. Dans le scénario BAU, les phénomènes actuels tels que l'étalement urbain, le changement climatique, la dégradation des terres, l'abandon des terres, l'intensification et l'extensification des régimes alimentaires se poursuivent. Il est également considéré qu'aucun nouvel instrument politique n'est mis en place pour répondre aux objectifs de la législation « Farm to Fork » (F2F) et du Green Deal. De plus, le scénario considère que la société n'effectue pas de changements dans son mode de vie et ses consommations pour financer l'entretien et l'amélioration des services écosystémiques liés à la production alimentaire. Dans le scénario SA, les facteurs de changement sont alignés sur les priorités du Green Deal et la stratégie F2F, et tous les objectifs associés devraient être atteints, soutenus par des changements sociétaux.

Les changements d'utilisation des terres modélisés pour les deux scénarios montrent qu'il est possible de limiter la perte de terres agricoles avec des interventions politiques actives pour atteindre les objectifs F2F d'ici 2050. Cependant, si aucune intervention politique active n'est réalisée, comme modélisé dans le scénario BAU, il apparaît que la perte de terres agricoles dépassera 8 millions d'hectares. Le même scénario met également en lumière que la diminution des terres agricoles est provoquée par l'augmentation de la superficie urbaine et l'absence de mesure mise en œuvre pour atteindre l'objectif de zéro artificialisation d'ici 2050. La superficie de terres agricoles converties en zones urbaines entre 2020 et 2050 s'élève à 2,3 millions d'hectares ; ce chiffre pourrait être réduit à 1,4 millions avec la mise en œuvre d'une politique zéro artificialisation dans le scénario SA. En l'absence d'intervention politique, la plus grande perte de terres agricoles est attendue dans la zone alpine, suivie des zones méditerranéennes et continentales, tandis que la région nordique (États baltes et Scandinavie) devrait pratiquement ne pas connaître de déclin. Avec l'application de la politique F2F dans le scénario SA, les pertes de terres agricoles seront beaucoup plus faibles. Cependant, la région méditerranéenne perdra encore 2,3 % de sa surface agricole, tandis que les zones nordiques et continentales afficheront des gains de superficie respectivement de 3,7 % et 0,7 %. Le changement climatique est l'un des facteurs contribuant à cette poursuite de la perte de terres agricoles dans la Méditerranée et à l'augmentation dans le Nord. Il provoque une baisse des niveaux de précipitations dans la Méditerranée et une saison de croissance plus longue vers le Nord.

L'objectif d'assurer la sécurité alimentaire est davantage garanti dans le scénario SA, où plus de terres demeurent en état d'exploitation agricole dans l'UE. La production de nourriture suffisante, sûre et saine sera également plus favorable dans le scénario SA, car une plus grande part de la production alimentaire devrait être réalisée de manière biologique et avec moins de pesticides ou d'engrais artificiels. Cependant, les impacts sur la sécurité alimentaire et sur la qualité des aliments dépendent aussi des changements de mode de vie. Le KPI choisi pour l'exprimer, soit le total de calories produites à partir des terres cultivées, est plus bas dans le scénario SA par rapport au

scénario BAU. Il convient également de noter que les deux scénarios montrent une tendance à la baisse des calories produites par rapport à 2020, due à une diminution globale de la production de fourrage en raison de la baisse des effectifs de bétail, mais aussi aux impacts du changement climatique sur les choix de cultures et les rendements.

Dans le scénario SA, cette baisse est plus importante en raison des hypothèses de transitions de mode d'alimentation tendant vers moins de viande et davantage de protéines végétales. Cela ne devrait pas poser de problème si la transition protéique progresse réellement. Cependant, si les consommateurs continuent à consommer de la viande à leur fréquence actuelle, les objectifs F2F concernant l'augmentation de l'agriculture biologique et la réduction des engrais et pesticides seront difficiles à atteindre. Des niveaux de production de bétail plus élevés nécessitent également beaucoup plus de calories provenant de la production végétale pour nourrir le bétail. Cela ne peut être réalisé qu'avec des volumes de production plus élevés de cultures fourragères sur les terres agricoles ou par le biais d'importations de fourrage en dehors de l'UE. Les importations de fourrage augmentent également l'empreinte environnementale de l'alimentation en UE, notamment lorsqu'elles peuvent conduire à une déforestation supplémentaire ailleurs.

Les scores des indicateurs clés de performance (KPI) confirment que dans le scénario d'agriculture durable (SA), la réduction des engrais et pesticides, l'augmentation de l'agriculture biologique, et la baisse des effectifs d'élevage devraient améliorer la qualité de l'eau, réduire les émissions d'ammoniac et entraîner une réduction significative des émissions de gaz à effet de serre (GES), principalement grâce à la baisse des émissions liées à la fermentation entérique (émissions provenant du bétail). Cependant, ces améliorations n'entraînent pas nécessairement une réduction des émissions de GES pour le secteur AFOLU (Agriculture, Forêts et Autres Affectations des Sols). Le scénario SA conduit donc à une amélioration notable de la qualité de l'environnement. Cependant, les scores KPI pour la santé des sols, notamment les niveaux de carbone organique du sol (SOC) et l'indice de risque d'érosion des sols, sont susceptibles de se détériorer dans le scénario SA. En effet, plus de terres restent en utilisation agricole comparé au scénario BAU, ce qui indique qu'il faudra davantage d'efforts pour maintenir le SOC et réduire l'érosion grâce à une adoption plus large des pratiques de gestion des sols en agriculture.

Afin de saisir les différences territoriales dans la perspective d'atteindre une agriculture durable, les régions RALUC de niveau NUTS 3 ont été classées en différentes catégories de « capacité de charge » (CC). La CC est définie selon trois dimensions : (i) les conditions climatiques futures (notamment l'aridité climatique), (ii) la démographie (combinaison de la densité de population actuelle et des tendances démographiques prévues jusqu'en 2050), et (iii) la capacité intrinsèque des territoires à investir dans leur agriculture future (PIB actuel).

Cette classification montre que 227 régions RALUC (15 %), représentant 26 % de la surface agricole de l'UE27, sont exposées à une aridité accrue. Ces régions se situent principalement dans le bassin méditerranéen, ainsi qu'en Roumanie et en Bulgarie, où l'on s'attend également à des événements climatiques

extrêmes. L'adaptation au changement climatique devient ainsi une priorité urgente pour les politiques agricoles et les investissements publics et privés.

De plus, plus de 50 % des régions, couvrant 61 % des terres agricoles de l'UE, montrent des tendances démographiques défavorables, caractérisées par une faible densité de population et/ou une forte baisse de population d'ici 2050. Cela est particulièrement présent dans les pays de la "nouvelle UE", où une agriculture stable et durable, en ligne avec les objectifs F2F, nécessite des politiques de développement rural et des investissements pour améliorer les conditions de vie rurales et inverser le déclin démographique, en particulier pour retenir les jeunes.

En outre, 15 % des régions, couvrant 21 % des terres agricoles, présentent une capacité d'investissement très faible et dépendent donc davantage du soutien de la PAC (Politique Agricole Commune) de l'UE. Les régions les plus vulnérables à l'atteinte d'une agriculture durable dans le futur sont celles ayant une faible capacité de charge pour les trois dimensions ; ces zones représentent 4 % des régions et couvrent 7 % des terres agricoles de l'UE, situées principalement en Bulgarie, Roumanie et Grèce. À l'inverse, 43 % des régions, représentant 29 % des terres agricoles, ne présentent aucune limite de capacité de charge et sont principalement réparties dans les pays de la "vieille UE".

Principales recommandations

L'étude formule plusieurs recommandations spécifiques en fonction des profils régionaux identifiés et des différentes classes de capacité de charge (CC) décrites. Les conditions territoriales distinctes influencent intrinsèquement les dynamiques agricoles et orientent les territoires à répondre de manière différente aux stimuli politiques, par exemple la PAC dans un cas, et les politiques démographiques ou d'infrastructure générale dans un autre.

Un aspect très important qui doit être renforcé dans le développement des politiques est que l'atteinte de plusieurs objectifs du F2F peut être réalisée par la mise en œuvre de multiples instruments politiques territoriaux efficaces. Par exemple, un prérequis pour restaurer la nature dans de nombreux endroits est de garantir la qualité environnementale de l'eau, de l'air et des sols. L'avantage est que les mesures visant à réduire les pertes d'azote dans l'eau et l'air (méthane) contribuent également positivement à la restauration de la nature et à l'atténuation des GES. L'introduction de nouvelles cultures pour l'adaptation au climat et/ou la production de biomasse non alimentaire sur des terres marginales peut également s'avérer plus bénéfique que les cultures alimentaires conventionnelles pour fournir des services écosystémiques tels que l'accumulation de carbone dans le sol ou les fonctions de pollinisation. De plus, la restauration des zones de tourbières peut créer des synergies positives et peut être intégrée aux objectifs de restauration de la nature qui requièrent également la restauration de ces zones d'ici 2050.

Les pratiques de pâturage extensif et les cultures paludicoles représentent des alternatives qui peuvent à la fois réduire les émissions de GES d'origine terrestre et offrir des opportunités de rétablissement des habitats semi-naturels et des valeurs de biodiversité associées. L'orientation vers l'agroécologie et les investissements dans l'agriculture de précision peuvent favoriser l'adaptation au climat tout en augmentant l'efficacité des exploitations et en réduisant les coûts de production. Des installations modernes de mono-digestion pour produire du

biogaz et du biométhane, utilisés pour l'énergie, permettraient de réduire les émissions directes de GES dans l'agriculture en abaissant les émissions liées aux énergies fossiles dans les secteurs où le biogaz et le biométhane sont consommés. Cette mesure peut créer des situations gagnant-gagnant en réduisant les pertes d'azote dans les systèmes d'élevage, en diminuant les émissions de GES liées à la fermentation entérique, et en produisant de l'énergie renouvelable.

Dans les régions confrontées à une aridité croissante, la croissance des cultures pourrait bénéficier de l'ombre des panneaux photovoltaïques pour diminuer les pertes d'eau par évapotranspiration. Le compromis entre les rendements en production de cultures et en production d'électricité doit être mieux étudié dans différentes zones climatiques afin d'optimiser les conceptions agro-PV au sein de l'UE.

Enfin, l'équilibre entre les niveaux de production animale, l'utilisation des terres pour l'alimentation animale et la production alimentaire doit être abordé au niveau régional. Dans plusieurs régions de l'UE, une réduction de la production animale sera bénéfique car elle réduira les pertes d'azote dans l'eau et dans l'air (méthane) et contribuera positivement à la réalisation des objectifs de restauration de la nature et d'atténuation des GES. Dans d'autres régions, cependant, le maintien, voire l'augmentation du cheptel, sont nécessaires pour parvenir à des conditions gagnant-gagnant avec une biodiversité des terres agricoles qui dépend de la poursuite des pratiques de pâturage traditionnelles et/ou pour générer suffisamment de ressources locales en fumier pour couvrir les besoins en nutriments des pratiques agricoles biologiques. Dans l'ensemble, cependant, la réduction du cheptel dans l'UE ne peut être efficace pour parvenir à la réduction des émissions de GES dans l'agriculture que si elle s'accompagne d'une transition partielle des protéines animales vers les régimes végétaux. Sans cela, l'UE exportera les émissions de gaz à effet de serre liées à l'élevage vers des régions situées en dehors de l'UE.

1. Introduction

1.1. Motivation for the study

Rural areas in the European Union (EU-27) are important for food and biomass production, management of natural resources, protection of natural landscapes, recreation, tourism and renewable energy production. Rural areas are also the living environment for a large part of the population in the EU-27. Rural areas represent 83% of the EU territory (EC, 2021). Within this rural territory, 90% of the area consists of agricultural, forest and natural areas (EC, 2021). About 47% of the terrestrial area of the EU consists of agricultural land. In the last decades, changes in societies and economies have increasingly been influencing the character and functioning of rural areas.

There is an increasing demand for land in the EU from various sectors: agriculture, forestry, energy, nature and biodiversity, tourism and recreation, activities in the biobased economy, development of urban areas and infrastructure. The Russian invasion of Ukraine and the Covid-19 crisis have shown the importance of ensuring food, feed and energy provision within the territory of the EU.

These developments increase the competition for land and alter the capabilities and functioning of rural areas for the range of intended land uses. Rethinking the design of rural areas in the EU is therefore necessary. This is reflected in the *Communication on a long-term vision for the EU's rural areas* (EC, 2021a) - in short the *EU Rural Vision*¹ -, which directs attention to rural communities and the development of rural areas. The European Commission, DG for Agriculture and Rural Development, requested a study on land use and sustainable agriculture to support the *EU Rural Action Plan* under the *EU Rural Vision*.

This study examines competition between land uses in the rural areas of the EU and assesses how policies including for optimal land use planning, zoning (based on territorial characteristics) and sustainable farming can be promoted. The study also explores scenarios (to 2050) for land use and policy instruments that will enable sustainable agriculture and other land uses to co-exist within 'safe operating spaces' of sustainability.

1.2. Influences on agriculture and rural areas in the EU

Rural areas space for food production

Almost all agricultural land is concentrated in rural areas and therefore rural areas have a key role in the production of food and ensuring food security. At the same time, there are many diverse challenges for agriculture in rural areas. On the one hand there are regions that face an ever-increasing pressure on agricultural land from increasing land prices (in addition to difficult access to credit) complicating accession of young farmers into the sector. On the other

¹ https://rural-vision.europa.eu/rural-vision_en

hand, there are many rural regions suffering from depopulation, particularly loss of young people and land abandonment. Lack of farmers and labour force in the primary sector make it ever more challenging to keep agricultural lands in production.

Dynamics in demography and consumption patterns and urban land take

Demographic dynamics, changes in diets and lifestyles all have impacts on agricultural markets and land use. Urban sprawl and infrastructure continue to consume agricultural and rural land in some areas, whereas depopulation is a factor leading to land abandonment in other rural areas. Lifestyles and diets change and influence the consumption preferences. These influence on the mix of food products preferred and consumed in relation to vegetal and animal protein mix, local products versus imported products and also the way products have been produced in e.g. conventional, organic and/or traditional production systems.

Climate change requires adaptation of land use in rural areas

Climate change is influencing the suitability of land in rural areas for agriculture. By 2050, 10% of the global land area currently fit for crops and livestock is projected to be climatically unsuitable for these land uses (IPCC, 2019). The modelled land use trajectories that limit warming to 1.5°C or below 2°C require land use changes, including combinations of reforestation, afforestation, adoption of new crops, mixed farming systems and agroforestry, reduced deforestation, new water use and regulating technologies and water governance structures.

Soil health in rural areas is at risk

Limitations for agriculture are expected to arise from the poor status of soils. According to an estimation from the Mission Board for Soil health and Food (EC, 2020), soil degradation is highly prevalent in the EU with 60-70% of soils considered as unhealthy, which means not being able to deliver vital functions including food production.

Nature conservation and restoration

The need to reverse loss of nature and biodiversity in the EU is acknowledged. Member states have created networks of protected areas and are making efforts to increase natural components in agricultural systems. This leads to the interlacing of natural areas and agricultural land or to the conversion of agricultural land to nature and/or more natural areas.

Biomass and space for renewable energy

The bioeconomy requires biomass for bio-based materials, fibres, chemicals and fuels. Renewable energy sourced from biomass or forest is developing. These activities may compete with food or feed production or tap into carbon sinks. Other renewable energy production also requires space, such as land-based solar fields or concentrated solar power.

New technologies

The development of new technologies in agriculture that help to cope better with climate change such as new forms of paludicultures, new crops that can cope better with water shortages, new water saving systems but also vertical farming, precision fermentation and insect farming which could reduce pressure

on agricultural land. However, as to the latter technologies it is difficult to estimate the potential magnitude of these new sources of food, given that the current potential to grow staple crops is limited. The overall environmental footprint of new technologies for food production requires assessment of their uptake in the future and aspects like energy consumption.

1.3. An evolving policy system for rural areas

Agriculture and rural areas in the EU are subject to a range of policy instruments in different domains, that have been developing since the inception of the European Union. Several of these are briefly mentioned below.

- The *Common Agricultural Policy* was reformed for the period 2023-2027 to support the transition towards sustainable agriculture and forestry in the EU², with more focus on results and performance. The new legislation has ten objectives for social, environmental and economic sustainability in agriculture and rural areas. These are addressed in the national *CAP Strategic Plans*, designed by the EU countries.
- The *Birds and Habitats Directives* were adopted respectively in 1979 and 1992. These directives are the legislative framework for all EU countries to protect species and restore habitats. The areas in the Natura 2000 network are designated under the two directives.
- Most recently, the Nature Restoration Law was approved (June 2024), as part of the GD and F2F package, setting binding nature restoration targets for specific habitats and species, including those occurring in agricultural land. At least 30% of the land should be protected to preserve biodiversity. Particular attention is required for green infrastructure connecting agricultural areas that contribute to biodiversity.
- The EU Farm to Fork and Biodiversity Strategies were launched in 2019 as part of the European Green Deal. The Farm to Fork Strategy aims to accelerate a transition to a sustainable food system that should have a neutral or positive impact on environment, help to mitigate and adapt to climate change, reverse loss of biodiversity, ensure food security, nutrition and public health, making sure that everyone has access to sufficient, safe, nutritious, sustainable food and preserve affordability of food while generating fairer economic returns, fostering competitiveness of the EU supply sector and promoting fair trade. It sets targets for increasing the organic farmland share, reducing chemical pesticide use and reduce nitrate and other nutrient losses from agriculture.
- The *EU Soil Strategy for 2030* was adopted in 2021 in response to the need to protect and restore soil at EU level (EC, 2021c). In July 2023, the European Commission proposed a *Directive on Soil Monitoring and Resilience* to achieve the vision that soil ecosystems are in a healthy condition by 2050.
- The *EU Water Framework Directive*, *Groundwater Directive* and the *Nitrates Directive*. prescribe environmental objectives that are based on EU standards of nitrates and pesticides, and on threshold values established by member states. In cases where requirements are not met,

² https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en

measures need to be taken to prevent or limit inputs of pollutants into groundwater. This may lead to further zoning of agricultural lands according to restrictions for certain farming activities or practices.

- At the global scale, the *United Nations Convention to Combat Desertification (UNCCD)* set a target to reduce land degradation (*Zero Net Land Degradation*). This target was adopted by the EU and included in the *2030 Agenda for Sustainable Development* by the United Nations³.
- The revised *LULUCF Regulation* has a target for land-based net carbon removal of 310 Mtonnes of CO₂-equivalents by 2030 in the EU.
- The Renewable Energy Directive (RED) sets targets for renewable energy sources in all European Member States. Biomass (in forms of biofuels, biogas and solid biomass) can be used to fulfil these targets.
- The Bioeconomy strategy (2018) requires a transition to an economy that is based on renewable (non-fossil) resources such as biomass that can be converted to biomaterials and biochemicals, especially in sectors that still rely strongly on fossil resources (oil, gas, and coal).

For more detail on all these policy instruments also see Annex 10.

Sustainable agriculture, as envisaged in the various policy instruments, should find its place among the influences on rural areas. How will the implementation of the policy instruments affect agricultural land use and rural areas in the EU? This question is central in this study.

1.4. Research questions

The Commission has formulated four main questions on land use and sustainable farming in the EU which will be answered in this study. The questions are listed below in Box 1.

Box 1 Research question of this study

Q1: What were the dominant factors in the evolution of land use in the last thirty years in the EU, in general and for agriculture in particular?

Q1.1 To what extent have energy use or production, urban sprawl and other forms of soil sealing and conservation of natural areas competed with or synergised with agricultural production in land use? Which have been the main drivers?

Q1.2 To what extent and where have population development, and changes in lifestyle and consumption patterns influenced agricultural production and land use? Which have been the main drivers?

Q1.3 Within agricultural land, how have food, feed, bioenergy and bioeconomy competed? Which have been the main drivers?

Q2: How have agricultural landscapes in Europe evolved, particularly with regard to crop diversity, including permanent crops and permanent grassland,

³ <https://sdgs.un.org/2030agenda>

concentration of livestock, plot size, high-diversity landscape features on agricultural land and high nature value agriculture? On the basis of these developments, what scenarios for the evolution of agricultural landscapes are possible?

Q3: What will be the dominant drivers of land use change, in particular agricultural land use, in the coming decades (up to 2050)? What are the different scenarios for each of the factors identified?

Q3.1 To what extent will energy use or production, urban sprawl and other forms of land sealing and conservation of natural areas compete or synergise with agricultural production in land use?

Q3.2 To what extent and where will population development, and changes in lifestyle and consumption patterns influence agricultural production and land use?

Q3.3 Within agricultural land, how will food, feed, bio-energy and bio-economy compete?

Q4: How sustainable is the current land use in Europe's rural areas for agricultural production, energy production, nature conservation and climate change? How can land use be optimised to enable the development of sustainable agriculture in the light of the Farm to Fork strategy? Which policy instruments can be mobilised to optimise land use?

In order to answer the four main research question for this study there is a need to reach the two principal objectives of this study presented in Box 2 underneath.

Box 2 Main objectives of this study

- To provide a comprehensive analysis of the main impacts of sectoral developments on land use in the EU's rural areas (agricultural, forestry, energy, protection of natural areas, urban sprawl and infrastructure, climate action, mining, consumption patterns)
- To identify recommendations for optimal land use, in particular to promote sustainable farming (SI) through the Farm to Fork goals and in light of other demands on land.

1.5. Scope of the study

Geographic scope

The geographic scope of the study is the EU-27. This implies that the most recent figures, trends, and drivers on land use and areas are evaluated at the level of EU member states, and for the EU-27. Where data are available and where appropriate, the analysis is at the regional level (NUTS 1-3).

The study addresses the themes in the objectives at different geographical scales to understand trends in land use that have environmental consequences:

- Trends in drivers and impacts are analysed at regional level in the case studies and in other parts of the study, where possible. This is done to avoid that results conceal contrasting transitions over aggregated areas (NUTS-regions or member states) in cases where data and trends are heterogeneous.
- Underlying processes are identified with their specific factors and drivers, and these are linked spatially to sectoral developments that lead to land use transitions and sustainability impacts.
- Where possible, we use regional information in the spatial and statistical analysis tools and models that we apply.

Temporal scope

Historic and future trends in drivers of land use and impacts in rural areas are investigated over the periods 1990-2020/22 and 2020/22-2050.

Case studies

Case studies are applied to investigate relationships between drivers (or combinations of drivers) and land use transitions in more detail and examine future drivers and policy instruments to support sustainable agriculture. In total 12 case studies (CS) were selected for the study (see also Annex 3). The case studies are performed by case study managers (in and outside the project team) acquainted with the region and with expertise in land use and agriculture.

Involvement of stakeholders

Stakeholders in rural areas were involved through the 12 CSs. The categories of stakeholders approached include local government officials working in agriculture and rural development issues at municipal or regional level, farmers' associations (regional departments); Farm advisors; Nature protection organisations operating locally; representatives from local rural development organizations; representatives of forestry and wood processing companies, energy producers; local NGOs, civil society organisations; farmers and companies involved in carbon farming, carbon removal certification, organic and agro-ecological farming, ecotourism and recreation.

1.6. Reading guide

This report consists of 8 chapters and 14 Annexes which are available in separate documents. This is the introductory chapter to the study.

- Chapter 2 presents the typology of regions which was developed for this study to understand and classify patterns of land use change and their drivers in the EU-27 and to make a selection of 12 case study regions representing diverse patterns of land use changes in the last 30 years. This typology is referred to in the rest of the study as the 'RALUC typology'.
- Chapter 3 presents the main patterns of land use change identified in rural areas in the last thirty years and in particular in agricultural landscapes.
- Chapter 4 is about the different drivers of land use change in the past 30 years which is based on collection and analysis of EU wide literature and data but also on information collected in the 12 case studies. It also presents the results of a multivariate analysis of indicators on land use changes, drivers of land use changes and main factors characterizing the different RALUC region types.
- Chapter 5 presents an overview of how land to food, feed, energy and other non-food uses have shifted in the last 30 years and what the exact drivers were for either competing or synergizing land uses.
- Chapter 6 provides an overview of the policies that have driven land use changes in the last 30 years and how they are expected to continue influencing this in the future. This chapter is supported by more detailed descriptions of past policies in Annex 9 and future policy targets stemming from Green Deal and F2F in Annex 10.
- Chapter 7 presents the different drivers that are expected to have an important effect on future land use changes in rural and agricultural lands and based on these the two different scenarios are presented for which the future land use changes have been modelled.
- In chapter 8 the modelled land use changes in the two scenarios are presented together with the potential impacts expressed in KPIs in order to understand how they work out in terms of reaching the Farm to Fork (F2F) policy goals.
- More detailed modelling results are also presented in Annexes 12 and 13.
- The overall detailed approach and methodologies used in the study are presented in a separate Annex 2 and Annex 14 for KPI assessments.
- An extensive literature review done as part of the study is presented in a separate report in Annex 5.
- The approach to data collection in the 12 case studies is presented in Annex 4 and a full summary of the 12 case study reports is presented in Annex 11.

2. Territorial typology of regions in EU-27

2.1. Introduction

The objective of developing a territorial typology is to divide the EU territory into classes which represent the biophysical, rural and land use change diversity of Europe. The typology enables to identify regions with similar challenges in terms of land use dynamics and to cluster regions with similar characteristics and comparable policy needs related to land use change. The typology developed in this project is referred to as the **RALUC** (Rural Agricultural land use changes) typology.

The typology nomenclature has the following purposes:

- showing the diversity in dynamics in agricultural landscapes in the EU-27;
- selecting case study regions distributed over the EU-27, covering the diversity in rural land use and agricultural contexts;
- supporting the integration, summary and profiling of results of the (spatial) analysis at the level of the EU and in the case studies:
 - upscaling/extrapolation of case study results to EU-27;
 - extrapolation of effects of (regional) policies to other regions.

The approach to generating the typology of regions is presented in Annex 2. The generation of the typology step by step is discussed in Annex 3. In this chapter the resulting typology is presented according to the main classifying characteristics. It is then explained how the typology was used to come to the selection of the 12 case study regions used in this study.

2.2. Typology of land use change diversity in EU-27

The RALUC typology classified the total 1166 NUTS3 regions in EU-27 in different multi-dimensional classes. The selection of variables to build the typology resulted in three dimensions:

- I. the land use dynamics dimension,
- II. the environmental dimension and
- III. the socio-economic dimension.

The land use dynamics dimension shows *what* type of processes are taking place and are relevant in relation to the agricultural domain. The environmental dimension is about *where* the NUTS3-region is located in relation to biophysical or environmental variables. The socio-economic dimension gives an indication *why* certain land use dynamics take place.

The resulting RALUC typology discerns 27 different types of NUTS3 regions based on a combination of the dominant land use process, population density, population change and GDP (see Figure 1). For the identification of dominant land use changes in every region CORINE Land Cover (CLC) was used. It provides harmonised European wall-to-wall land cover/use data at 6- yearly intervals. The land use dynamics for the period 2000-2018 are calculated by EEA's Land and Ecosystem Accounting system (LEAC) after harmonizing the CLC

timeseries from 2000 onwards⁴. The CLC changes between 2000-2018 were grouped in land cover flows (LCFs), that describe specific processes. For the classification the land use processes (LCFs) were grouped in 6 classes that are relevant for the agricultural domain:

- Land take by urban expansion;
- Land take by afforestation (either from agricultural or other non-agricultural land);
- Land take by nature creation (but very small and likely not to be captured by LCFs)('rewilding');
- Extensification of agriculture; please note that this class may also cover some shifts to land abandonment;
- Intensification of agricultural land;
- No relevant changes.

Urbanisation is by far the most dominant land use processes and almost half of all regions have it as most dominant land use change followed by Afforestation in 367 NUTS3 regions (Table 2). Extensification of agriculture is only dominant in 45 NUTS3 regions, while intensification is the dominant process in 162 NUTS3 regions. Only 8 NUTS3 regions have nature creation as the dominant process.

Table 1 Absolute numbers of NUTS3 regions by dominant process characterized as dynamic and stable. LU: land use

Lu Change Dominant Type	Total number of regions	% of regions
Afforestation	367	31%
Extensification	45	4%
Intensification	162	14%
LU change not relevant	5	0%
Nature creation	12	1%
Urbanisation	575	49%
Grand Total	1166	100%

Source: CLC-LEAC data 2000-2018 and own data elaboration in this study

The 27 different regions of the typology are presented in Table 2 according to the four dimensions determining the classification.

⁴ The reason for not using the CLC1990 as starting point, is that this dataset was not taken into account in this harmonisation process (Ivits et al., 2020).

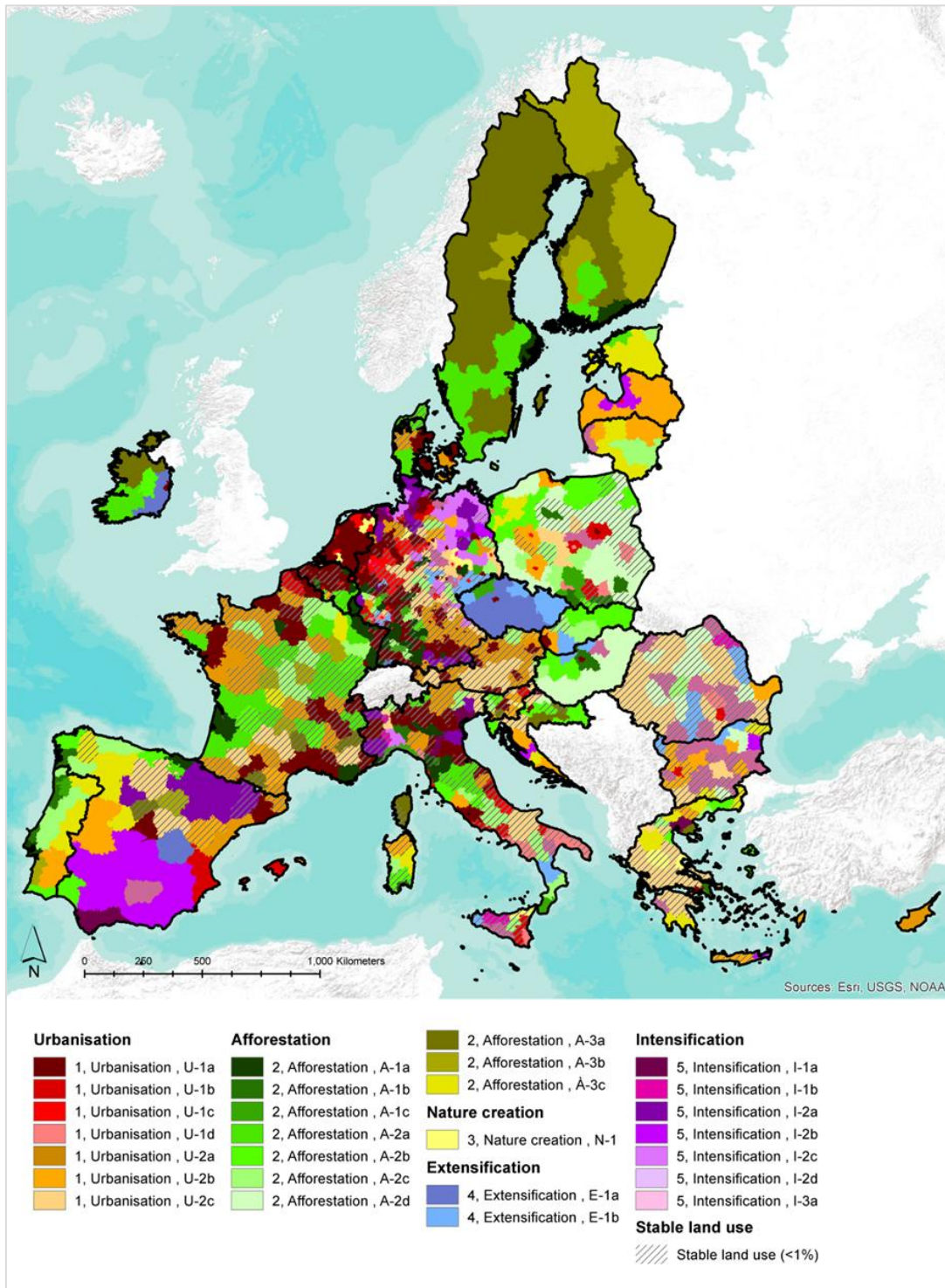


Figure 1 RALUC territorial typology for NUTS3 regions. For online consultation see: [RALUC Typology map viewer \(arcgis.com\)](http://RALUC Typology map viewer (arcgis.com))

Table 2 RALUC typology according to 27 different classes presented in the map in Figure 1

Code	Luchange	PopulationDensity	PopulationChange	GDP	Example regions
U-1a	Urbanisation	Dense	Stable & Increase	High	Milan, Hamburg, Utrecht
U-1b	Urbanisation	Dense	Stable & Increase	Moderate & Low	Trier, Sofia, Mallorca
U-1c	Urbanisation	Dense	Decrease	High	Riga, Bucarest, Dortmund
U-1d	Urbanisation	Dense	Decrease	Moderate & Low	Taranto, Katowice, Kaiserlautern
U-2a	Urbanisation	Moderate	Stable & Increase	High	Parma, Cyprus, Wiener Umland
U-2b	Urbanisation	Moderate & Sparse	Stable & Increase	Moderate & Low	Gdanski, Viterbo, Dubrovačko
U-2c	Urbanisation	Moderate & Sparse	Decrease	High, Moderate & Low	Vercelli, Görlitz, Sieradzki, Helmstedt, Stara Zagora
A-1a	Afforestation	Dense	Stable & Increase	High	Firenze, Helsinki, Karlsruhe, Gironde
A-1b	Afforestation	Dense	Stable & Increase	Moderate & Low	Porto, Aveiro, Pavia, Pest
A-1c	Afforestation	Dense	Decrease	High, Moderate & Low	Reggio di Calabria, Heidenheim, Kentrikos Tomeas Athinon, Sosnowiecki
A-2a	Afforestation	Moderate	Stable & Increase	High	Södermanlands län, Bastogne, Arezzo
A-2b	Afforestation	Moderate	Stable & Increase	Moderate & Low	A Coruña, Grosseto, Zakynthos
A-2c	Afforestation	Moderate	Decrease	High & Moderate	Douro, Asturias, , Ardennes
A-2d	Afforestation	Moderate	Decrease	Low	Bács-Kiskun, Starogardzki, Radomski
A-3a	Afforestation	Sparse	Stable & Increase	High, Moderate & Low	Åland, Värmlands län, Haute-Corse, Požeško-slavonska
A-3b	Afforestation	Sparse	Decrease	High	Alentejo Litoral, Haute-Marne, Västernorrlands län
A-3c	Afforestation	Sparse	Decrease	Moderate & Low	Zamora, Meuse, Alto Alentejo, Nuoro
E-1a	Extensification	Dense, Moderate & Sparse	Stable & Increase	High, Moderate & Low	South-East Ireland, Pardubický kraj, Cuenca
E-1b	Extensification	Dense, Moderate & Sparse	Decrease	High, Moderate & Low	Bad Dürkheim, Moravskoslezský kraj, Olomoucký kraj, Cosenza
I-1a	Intensification	Dense	Stable & Increase	High & Moderate	Ammerland, Málaga, Venezia, Leer
I-1b	Intensification	Dense	Decrease	High	Oberhausen, Eisenach, Delfzijl en omgeving, Bochum
I-2a	Intensification	Moderate & Sparse	Stable & Increase	High	Zaragoza, Rovigo, La Rioja, Schleswig-Flensburg
I-2b	Intensification	Moderate & Sparse	Stable & Increase	Moderate & Low	Granada, Cordoba , Havelland, Murcia, Splitsko-dalmatinska županija
I-2c	Intensification	Moderate	Decrease	High	Cuxhaven, Alessandria, Elbe-Elster, Oberspreewald-Lausitz
I-2d	Intensification	Moderate	Decrease	Moderate & Low	Burgas, Greiz, Braşov, Mansfeld-Südharz
I-3a	Intensification	Sparse	Decrease	High, Moderate & Low	Latgale, Salamanca, Tulcea, Alentejo Central
N-1	Nature creation	Dense & Moderate	Increase & Decrease	High & Low	Noord-Drenthe, Nordsachsen, Zeeuwsch-Vlaanderen, Magnisia, Sporades

For the further characterisation of the typology the environmental dimension is chosen. The Environmental Stratification of Europe (EnS) dataset (Metzger, 2018) and consists of 13 environmental zones. The environmental zones are relatively homogeneous regions regarding climate variables, elevation data and the geographical location (northing and oceanicity).

For this study, the environmental zones are aggregated to five larger zones (see Table 3):

- Alpine (Alpine South);
- Atlantic (Atlantic North, Central and South);
- North (Alpine North, Boreal and Nemoral);
- Continental (Continental and Pannonian);
- Mediterranean (Mediterranean Mountains, North and South).

Table 3 Dominant land use change processes per environmental region, divided over dynamic (>1%) and stable regions (<1% land use change)

ENR	Dominant land use	Total regions
Alpine	Afforestation	15
	Extensification	2
	Intensification	2
	Nature creation	1
	Urbanisation	29
Alpine Total		49
Atlantic	Afforestation	80
	Extensification	9
	Intensification	29
	Nature creation	6
	Urbanisation	211
Atlantic Total		335
Continental	Afforestation	142
	Extensification	31
	Intensification	76
	Nature creation	2
	Urbanisation	213
Continental Total		464
Mediterranean	Afforestation	79
	Extensification	3
	Intensification	46
	LU change not relevant	5
	Nature creation	3
	Urbanisation	119
Mediterranean Total		255
North	Afforestation	51
	Intensification	9
	Urbanisation	1
North Total		61
#N/A	Urbanisation	2
#N/A Total		2
Grand Total		1166

Alpine

The Alpine environmental zone contains 49 NUTS3 regions. Urbanisation is the dominant process in 29 NUTS3 regions. Afforestation is the dominant land use change process in 15 NUTS3 regions (of which none have dense population, i.e. A-1a/b or c type). Extensification of agriculture is the dominant process in two NUTS3 regions. Intensification of agriculture and Nature creation are only dominant in respectively 2 and 1 NUTS3 region. The U-2c type, which are NUTS3 regions where urbanisation is dominant process with moderate or sparse population density, decreasing population and a high, moderate or low GDP, are the type of NUTS3 regions which form the largest group (11 NUTS3 regions).

Atlantic

The Atlantic environmental zone contains 335 NUTS3 regions. Urbanisation is dominant in 211 of the Atlantic NUTS3 regions. Afforestation stands at the second place (80 NUTS3 regions with 51 classified as dynamic). Extensification of agriculture and nature creation are in 9 respectively 6 NUTS3 regions the dominant process. Although only six NUTS3 regions have nature creation as dominant process, the Atlantic environmental zone has by far the highest number of regions with nature creation as dominant process. The U-1a type, which are NUTS3 regions where urbanisation is the dominant process with having a dense population density, stable or increasing population and a relatively high GDP, are the type of NUTS3 regions which are forming the largest group (125 NUTS3 regions). With 43 NUTS3 regions the U-1c type, which means NUTS3 regions where urbanisation is dominant process with dense population density, decreasing population and a relatively high GDP, is on the second place. The A-2a and A-2c types are the dominant types in the Afforestation type with 20 respectively 18 NUTS3 regions. They have both a moderated population density but differ in population development and GDP.

North

The North environmental zone contains 61 NUTS regions and Afforestation is by far the most dominant land use change. Intensification of agriculture is the second dominant land use process. Urbanisation is dominant in only 1 NUTS3 region. Extensification of agriculture and nature creation as dominant processes are absent. The A-3a and A-3b types are the most prominent types and are present in 17 respectively 10 NUTS3 regions. These two types are both characterized by sparse population density. They differ in population change and GDP. The A-3a has a stable or increasing population and a high, moderate or low GDP. The A-3b has a decreasing population and a relatively high GDP.

Continental

The Continental environmental zone contains 464 NUTS3 regions and Urbanisation and afforestation are the dominant processes in 213 respectively 142 of the NUTS3 regions. Also 76 NUTS3 regions are in Intensification class. Characteristic for the Continental environmental zone are the 31 NUTS3 region where extensification of agriculture is the dominant process. This is relatively high compared to other environmental zones. Nature creation is only dominant in 2 NUTS3 regions. Regarding urbanization the U-1a, U-2a and U-2c are the most relevant types with 88, 34 and 45 NUTS3 regions. Main discriminating variable between the three is population density and to a lesser extent population change. Most prominent Afforestation type is A-2d with 42 NUTS3 regions where afforestation is the dominant process with moderate population density, decreasing population and a low GDP. In Intensification I-2c and I-2d

types most represented which refers to moderate population density and decreasing population. The GDP is the discriminating factor between both. In Extensification E-1b type is the most prominent one with 21 out of 31 NUTS3 regions referring to moderate or sparse population density, decreasing population and a high, moderate or low GDP.

Mediterranean

The Mediterranean environmental zone contains 250 NUTS3 regions for which Urbanisation is the dominant process in the majority of the NUTS3 regions. Afforestation is the second most important process with 79 NUTS3 regions. Also, Intensification of agriculture is dominant in 46 NUTS3 regions. Extensification of agriculture and nature creation are only dominant in 3 NUTS3 regions each. The U-1a, U-2b and the U-2c types are by far the most dominant types with 31, 25 and 22 NUTS3 regions. Regarding afforestation the types A-2b, A-2c and A-3c are the most prominent with 14 (8 dynamic), 15 (9 dynamic) and 15 (11 dynamic) NUTS3 regions. All 7 intensification types are present in the Mediterranean environmental zone. None of these is clearly dominating.

2.2.1.Characterization of typology regions

The characterization of regions in the territorial typology aims to support the analysis of past and ongoing changes in rural areas of the EU and to assess impacts of sectoral developments. Based on the ratings of information layers in the expert elicitation, the following layers are considered most important for the characterization:

- Accessibility,
- Marginal lands.

Accessibility

Table 4 gives the number of NUTS3 regions falling in specific accessibility class for each of the 27 RALUC types. The NUTS3 regions where afforestation is dominant are characterized by moderate to low accessibility (especially the A-2 and A-3 types, which are also characterized by low population density). Also, for NUTS3 regions in which the other land use change processes are dominant, accessibility is mainly moderate to low. The exception are the NUTS3 regions where urbanisation is dominant. Many of these NUTS3 regions are characterized by high accessibility (223 out of 575 regions).

Table 4 Characterization of the 27 RALUC types regarding accessibility

Accessibility, % of NUTS3 region	High	Moderate	Low	Total
Afforestation	16.3%	44.7%	39.0%	100.0%
A-1a	44.4%	50.0%	5.6%	100.0%
A-1b	64.7%	29.4%	5.9%	100.0%
A-1c	58.3%	37.5%	4.2%	100.0%
A-2a	11.1%	66.7%	22.2%	100.0%
A-2b	9.3%	44.2%	46.5%	100.0%
A-2c	3.3%	57.4%	39.3%	100.0%
A-2d	0.0%	53.2%	46.8%	100.0%
A-3a	0.0%	22.6%	77.4%	100.0%
A-3b	0.0%	18.8%	81.3%	100.0%
A-3c	0.0%	13.8%	86.2%	100.0%
Extensification	11.1%	55.6%	33.3%	100.0%
E-1a	30.8%	61.5%	7.7%	100.0%
E-1b	3.1%	53.1%	43.8%	100.0%
Intensification	17.3%	34.0%	48.8%	100.0%
I-1a	42.1%	52.6%	5.3%	100.0%
I-1b	42.9%	28.6%	28.6%	100.0%
I-2a	20.0%	60.0%	20.0%	100.0%
I-2b	11.8%	23.5%	64.7%	100.0%
I-2c	12.5%	50.0%	37.5%	100.0%
I-2d	8.6%	20.0%	71.4%	100.0%
I-3a	0.0%	0.0%	100.0%	100.0%
Nature creation	25.0%	50.0%	25.0%	100.0%
N-1	25.0%	50.0%	25.0%	100.0%
Urbanisation	38.8%	42.6%	18.6%	100.0%
U-1a	61.2%	34.0%	4.8%	100.0%
U-1b	47.5%	27.5%	25.0%	100.0%
U-1c	41.0%	47.5%	11.5%	100.0%
U-1d	31.8%	63.6%	4.5%	100.0%
U-2a	14.9%	64.9%	20.3%	100.0%
U-2b	4.9%	36.6%	58.5%	100.0%
U-2c	6.9%	49.4%	43.7%	100.0%
Total	27.5%	42.6%	29.9%	100.0%

Source: Own elaboration of different data sources in this project. For details see Annex 3.

2.3. Selection of 12 case study regions from the typology

Following the RALUC classification, the CS were selected in 12 different EU countries (Table 5). In the Mediterranean ENZ four CSs were selected located, in both the Continental and Atlantic ENZ three CSs and in the both the North and the Alpine ENZ one CS is selected. Since afforestation is the most frequent type in the RALUC typology, 5 of the 12 CSs are of this type followed by 3 CS with intensification as dominant land use change, 2 CS with urbanisation, and

finally one CS in the extensification class and one in the nature creation class. As to population density there are 2 CS with high population density, 5 CS with very low (sparse) population density and the remainder 5 have a moderate density. The 2 densely populated CS also have an increasing population and the remainder CS have either a stable (4) or a decreasing population (6). The GDP level is high in half of the selected CS, moderate in 3 and low in the remainder 3 CS. There are 5 CS with a remote location, so low accessibility, 5 CS are moderately accessible and 2 central, overlapping with the 2 CS with dense population. In the following every CS is further characterised.

A detailed description of the case studies and the information collected in these case studies is presented in a separate Annex 11. But the information from the case studies is also summarized in several places in this main report including in boxes.

Table 5 Case Study regions and overview of their characteristics and scoring in relation to typology characteristics and other selection criteria

Region name & code	Country	ENZ	Code RALUC type code	Dominant use change	Land	Population density	Population change 2000-2021)	GDP	Accessibility
Arr. Sint-Niklaas	Belgium	Atlantic	U-1a	Urbanisation		dense	increase	high	high
Montana	Bulgaria	Continental	I-3a	Intensification		sparse	decrease	low	low
Wittenberg	Germany	Continental	I-2c	Intensification		moderate	decrease	high	moderate
Imathia	Greece	Mediterranean	U-2c	Urbanisation		moderate	decrease	low	moderate
Albacete	Spain	Mediterranean	A-3c	Intensification		sparse	stable	moderate	low
Hautes Alpes	France	Alpine	A-3a	Afforestation		sparse	stable	high	Moderate
Šibensko-kninska županija	Croatia	Mediterranean	A-3c	Afforestation		sparse	decrease	moderate	low
West Ireland	Ireland	Atlantic	A-2a	Afforestation		Moderate	stable	high	moderate
Siena province	Italy	Mediterranean	A-2a	Afforestation		moderate	stable	high	moderate
Šiaulių Apskritis	Lithuania	North	A-3c	Afforestation		Sparse	decrease	Moderate	Low
Zuid-west-Drenthe	Netherlands	Atlantic	N1	Nature creation		dense	increase	high	high
Argeș	Romania	Continental	E-1b	Extensification		moderate	decrease	low	low

3. Evolution of land use in the last thirty years, with a focus on agricultural landscapes

3.1. Introduction

In this chapter, the focus is on past and ongoing changes to land use in the EU's rural areas, with a focus on agricultural land, forests and natural areas. The areas are identified, quantified (where data sets are available), and a link to the drivers discussed in chapter two is further explained and illustrated with examples in the case studies.

Drivers of land use changes in the period 1990-2022 were grouped under the main categories of land use change distinguished in the territorial typology of regions. The land use trends were derived from the literature review (see Annex 5) and from the case study reports.

3.2. Land take in built-up areas

Agricultural land take in built-up areas occurs in all EU countries and regions. In the period 2000-2018 the level of land take was between 0.2% and 0.6% of the agricultural land in 2000 (Figure 2 and Figure 3). Four countries had a land take level lower than 0.2% for the period 2000-2018 (Latvia, Finland, Slovenia and Bulgaria) while for six countries it was above 0.6% (Cyprus, Czech Republic, Denmark, Spain, Luxembourg and Netherlands).

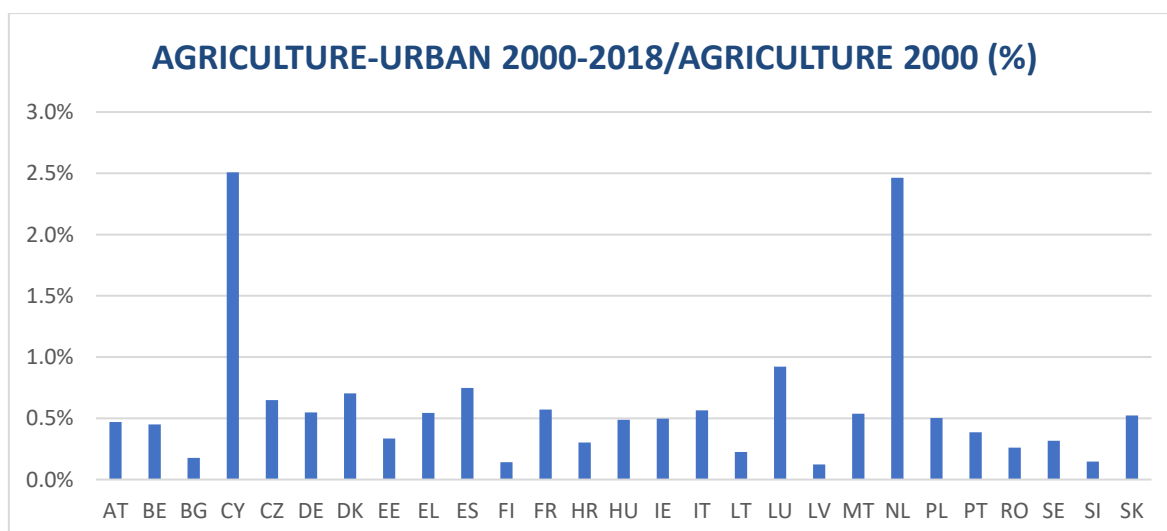


Figure 2 Share of land taken by artificial surfaces as % from total agricultural land in 2000 in Europe. Source: CLC-LEAC

The share of agricultural land in built-up areas at NUTS3 level within the period of 2000-2018 ranges from 0 – 52%. The protectorate of Spain in Northern Africa (Ceuta) demonstrates the highest urbanisation level. On the EU mainland the regions with highest land-take levels are Seine-Saint-Denis (FR106) (19%) followed by Agglomeratie 's-Gravenhage (NL332) (16%). Regions with high land take shares are scattered all over Europe (see Figure 3), but some clear patterns

can be detected. High urbanisation shares are seen in all regions in the Netherlands, in coastal regions in especially France and Spain and main population concentration regions like Copenhagen – Malmö region, Peloponnese, Po plains, Ruhr area and a band through central Spain from north to south (Bilbao – Madrid – Malaga).

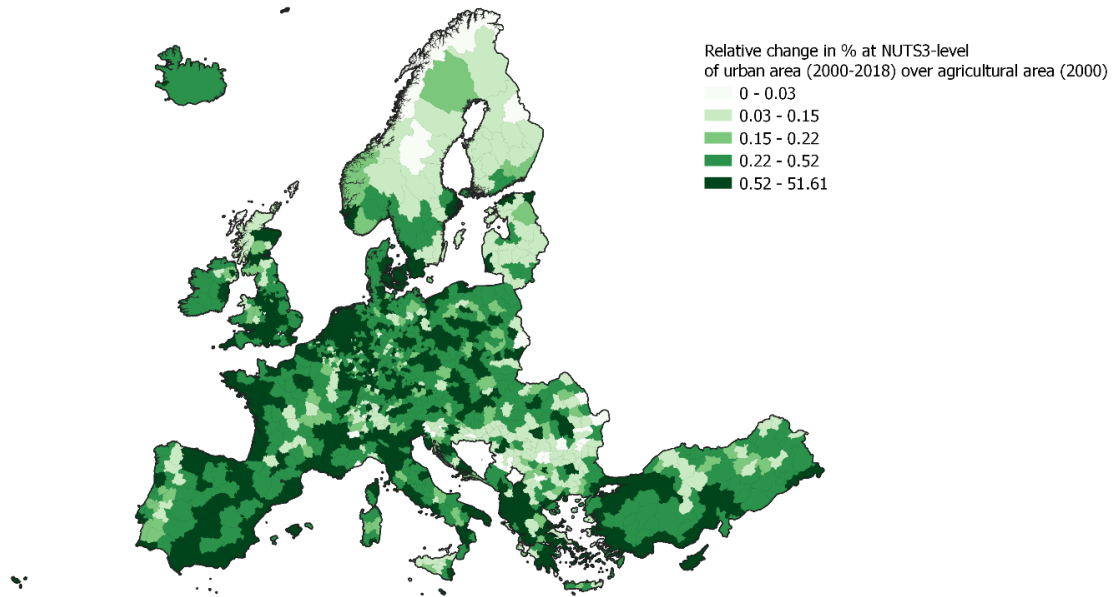


Figure 3 Proportion of land taken by built-up surfaces as % from total agricultural land in 2000 (quantiles ?) at NUTS3 level (Source CLC2000 and CLC2018 - <https://www.eea.europa.eu/data-and-maps/dashboards/land-cover-and-change-statistics>)

The process of agricultural land taken in built-up areas as mapped and quantified above using the CLC based LEAC data. GHSL data can also be used to quantify the land take process and covers the increase over a period of 30 years (1990-2020). In most MS for this reason GHSL data indicate larger areas converted into artificial land than LEAC (the exceptions are Cyprus, Estonia and Spain) (see Figure 4). The RALUC data on urbanisation levels (used for the typology presented in Chapter 2) show higher surface areas than LEAC as land conversions also cover non-agricultural land that is now built-up.

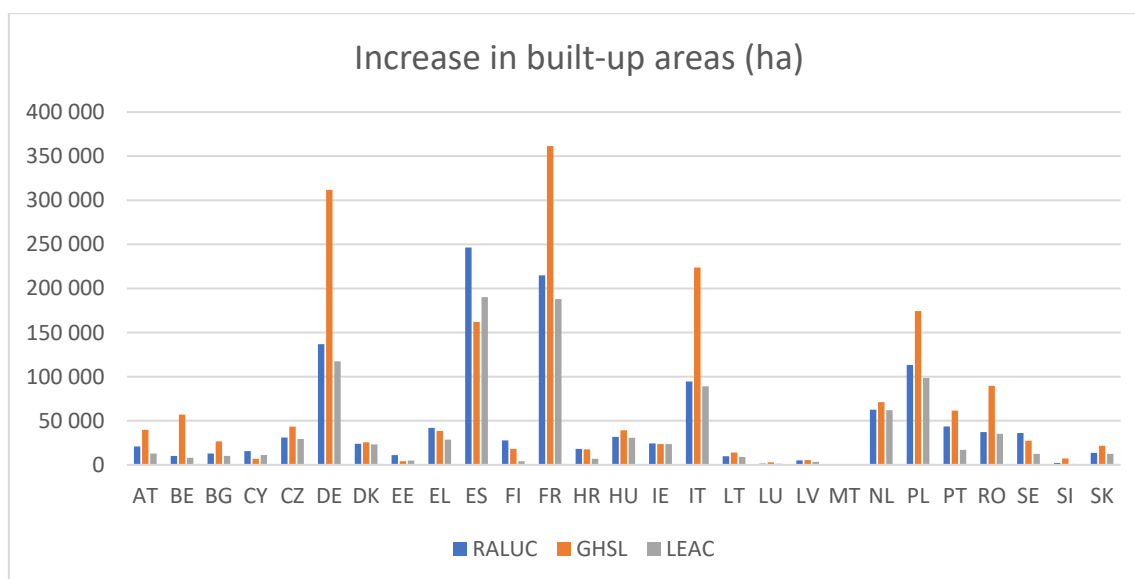


Figure 4 Built-up area increase for period 1990-2020 (GHSL data) or 2000-2018 (CLC-LEAC and RALUC own elaboration for typology, see Annex 3) in hectares

All three sources show that the total amount of hectares converted into built-up land is high in Germany, Spain, France, Italy and to lesser extent Netherlands and Poland (Figure 4). However, when expressing the increase in artificial areas as share of the total area of a country, the picture is a little different with high shares for Cyprus, Denmark, Luxembourg, Malta, Portugal and by far Netherlands. Extremely high GHSL shares compared to LEAC shares are found in Belgium, Germany, Italy, Luxembourg and Malta.

When focussing only on land take of agricultural land in coastal regions, a process referred to as 'Coastalization', the largest changes take place in Spain, France, Italy and also although to a lesser extent in Portugal, Denmark, Netherlands, Poland and Sweden (Figure 5).

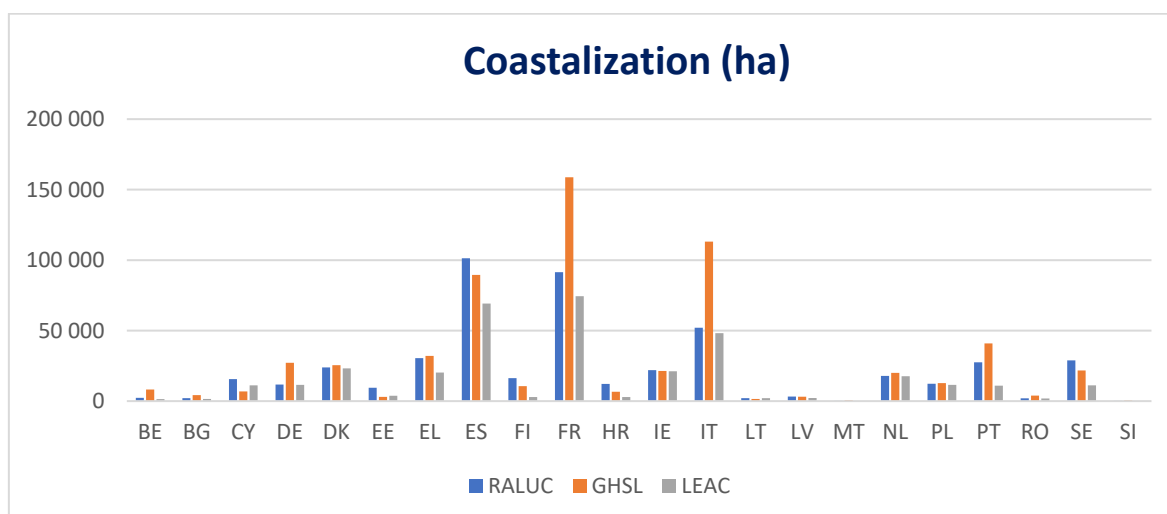


Figure 5 Total amount of areas (in ha) converted into artificial land for the coastal NUTS3 regions. Based on GHSL data, CLC-LEAC data and RALUC dominant land use change data from own elaboration for typology (see Annex 3)

The RALUC regions with high population density (indicated with 'U') show higher shares of agricultural land converted into built-up land than less densely populated regions (Figure 6). The largest number of hectares converted into built-up land is, as expected, for the urban RALUC types (and especially the type with high population density, high population change and high GDP (U-1a)). The effect of GDP is clearly visible (high amounts in U-1a, U-2a, and A-2a, and suffix 'a' denoting the highest class of GDP) (Figure 6).

The literature review (see Annex 5) and the analysis with EU wide regional data on trends in land use and drivers (see Annex 6), including the multivariate analysis presented in chapter 4 and Annex 8, have confirmed there are clear drivers for land-take. These relate most strongly to population growth, income growth, changing housing preferences, particularly the decrease in number of persons per household leading to smaller households and demand for more dwellings.

At the same time, urbanization increases have also been detected in these new EU member countries but generally they have been of a more recent nature and were mostly corresponding to the largest cities, urban agglomerations, and metropolitan regions. In several of these new EU countries they have also led to increasing urban-rural differences in welfare as is illustrated by the rural versus urban development in Romania (see Box 3).

Box 3 Rural versus urban development in Romania

The simple reality is that rural Romania – although richly endowed with natural resources – continues to be impacted by poverty and a huge gap in living / social standards between rural and urban areas. This is another 'global' driver of change which limits the attractiveness of rural areas and helps to drive the continued migration from rural to urban areas and abroad.

According to the Ministry of Agriculture and Rural Development (MADR, 2023):

- Basic services are much less developed in rural areas than urban areas. For example, only a third of rural inhabitants have access to public water and sewerage networks, and the quality and reliability of water supply and wastewater services are generally poor. The majority of rural households continue to use water pulled/pumped from shallow wells, but in some regions the poor quality of drinking water from shallow wells continues to pose a significant health hazard (e.g. due to nitrate concentrations and microbial contamination).
- The basic social infrastructure (health and education systems, finance and credit provision etc.) is also much less developed than in urban areas. For example, only 7% of the total number of kindergartens registered at national level are located in rural areas, whilst the number of rural inhabitants per doctor is estimated to be 1 722 – almost 7 times more than in urban areas.
- The poor condition of physical infrastructure is one of the most critical factors limiting development possibilities in rural Romania, especially in the mountain areas and less developed regions of the country. For example, of the 31 639 km of village rural roads that are essential for linking many villages to county and national roads, only 7% have been modernized in recent years with the remainder being poorly maintained asphalt or gravel/dirt roads (around 30%). An estimated 25% of villages are inaccessible for long periods of the year due to snow or heavy rain.
- GDP per rural capita (€ 5,880) in Romania is 30% of the average for rural regions (€ 19 302) in the EU-27 and 29% of that generated in Romania's urban areas (€ 20 221). Around 46% of the rural population is estimated to be at-risk-of poverty or social exclusion

- compared to an average of 24% for rural regions in the EU-27 and 19% for cities in Romania⁵.
- Rural poverty and social exclusion are manifested in many different ways in Romania – from the poverty of the urban unemployed who returned to family smallholdings to practice subsistence agriculture as a social safety net to that of rural pensioners with low and inadequate pensions to marginalized communities characterized by generations of low human capital, low formal employment and inadequate housing. There are also the challenges faced by Roma families which constitute a large, young and extremely poor ethnic minority group in many rural areas and face continued exclusion from markets and services.

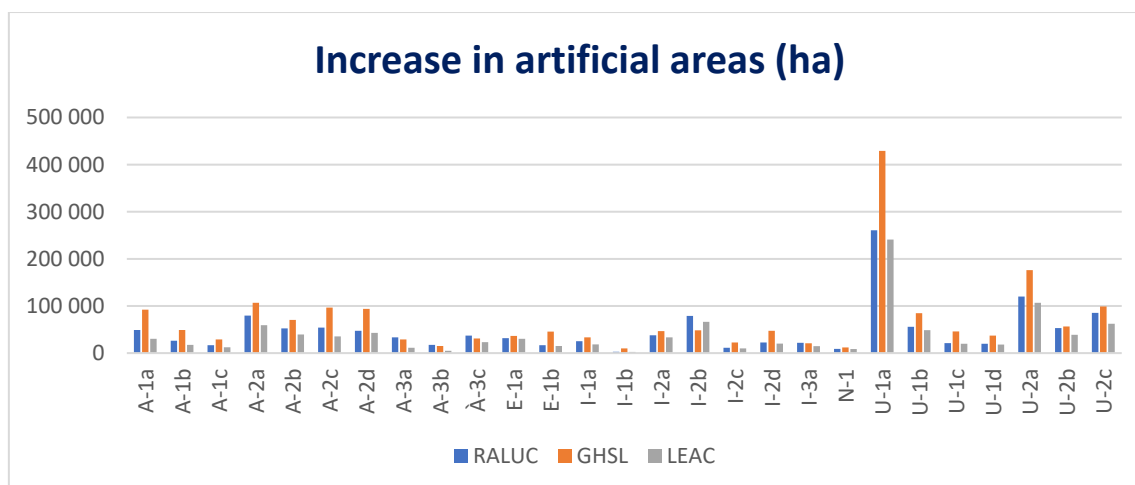


Figure 6 Artificial area increase (i.e. conversion of land into artificial areas) for period 1990-2020 (GHSL) or 2000-2018 (LEAC and RALUC) per RALUC type in hectares

The trends in agricultural land-take in built-up areas were also analysed for the combination of MS and RALUC type, and this resulted in a top 10 RALUC regions with the highest land conversions. These coincided with RALUC types U-1a, U-1b and U-1c spread over several different countries. They all have in common a very high population density, a stable GDP and high to moderate accessibility. As to the factor population change, there were two regions in the top 10, where the agricultural land to built-up area is very high, but population number and population density (calculated as a weighted area density) decreased strongly. This is typically a situation found in Romania and Poland for class U-1c and implies that the surrounding rural areas are losing population to the central city in the same region. This same situation is also seen in more regions in Poland, Latvia, Estonia, Bulgaria, Romania in U-1c and U-1d regions.

The case study regions that experience the largest urbanisation pressure are Arr.Sint Niklaas and Zuidwest Drenthe although also mentioned in other case studies but as a localized land use change process. In Arr. Sint Niklaas (also called Waasland) the most important land use trends reported is land take by built-up area (23%). This is related to the region in the "triangle of Gent-Antwerpen-Brussel" and is experiencing major urbanization trends. In addition, the harbour of Antwerp is also requiring more land which impacts agricultural

⁵ All data cited are updated from the datasheets of the EC Common Context Indicators for Rural Development Programmes (2014-2020): https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/cap-context-indicators-table_2019_en.pdf

land or natural areas, which requires compensation by developing other nature protection areas which goes at the expense of agricultural land. This urbanisation is a more localized but challenging problem. In Albacete, for example where fast land take is taking place around the four bigger urban conurbations. In Argeş, urbanisation in the region is also a considerable land use change and mostly involves land take for urbanisation, but also industries, roads in the peri-urban areas where industries are well developed.

For 'Coastalization' the data analysis (Annex 6) and the case study data collection have both confirmed that growth in tourism is an important driver of the process. Tourism does not only drive land take in coastal regions, but also in mountain regions such as in Hautes Alpes and Argeş where transformation of agricultural land into built environment around settlements and touristic mountain villages was seen. Also, land take by built-up areas was mentioned to be driven by agro-tourism developments in Šibenik-Knin and in Siena region.

3.3. Afforestation of agricultural land

To understand the process of afforestation different data sources were collected and processed in this study. Efforts were made to distinguish between active and natural reforestation, the latter being the result of abandonment of agricultural activities in agricultural lands. Afforestation and agricultural land abandonment may have the same outcome, namely a forest cover, but are often driven by a different mix of drivers.

Results of the data analysis in this study (see also Annex 5) have shown that the countries in EU-27 that had the highest relative increase in afforestation of agricultural land are Hungary, Portugal, Ireland, Estonia, Poland, Lithuania, Finland and Slovakia (Figure 7 and Figure 8). In Ireland, Poland, Lithuania and Hungary this went together with a strong increase in the overall forest cover and can conclude that the afforestation of agricultural land is a factor contributing to a positive forest area growth. There are also countries where there is afforestation activity on agricultural land, but it still forms a relative decline in overall forest areas such as in Portugal, Estonia, Finland and Slovakia.

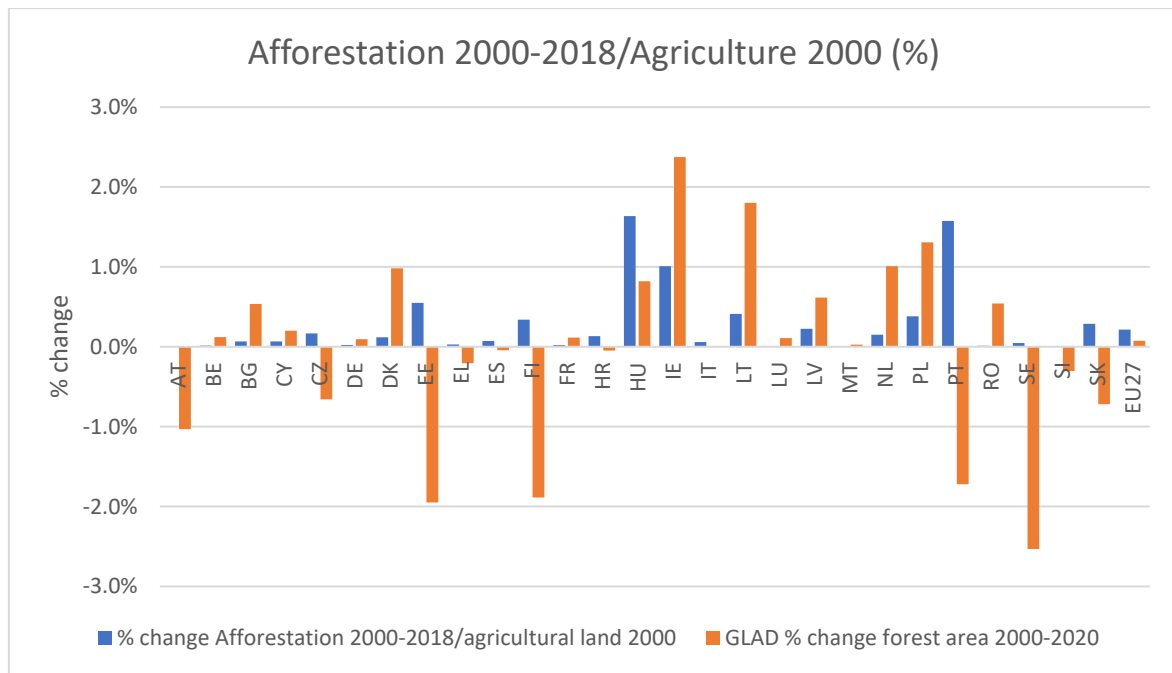


Figure 7 Relative afforestation of agricultural land 2000-2018 (% of agricultural land in 2000) (Source: LEAC-EEA) and relative change in forest area 2000-2020 in all EU-27 countries (GLAD⁶)

When combining afforestation trends to the RALUC types (see Figure 9), the share of agricultural land that has become afforested is higher in all RALUC types classified as afforestation (A-1a, A1b, etc.). One exception is the I-3a class, in which agricultural intensification was the dominant land use change, but it still has a relatively high afforestation of agricultural land. This is the only intensification type that combines intensification with a sparse population density and a declining population.

In the RALUC afforestation types, the percentage forest area calculated for the whole region with GLAD data is showing a negative trend (see Figure 9). This is the case for all RALUC afforestation types except for type A-2d. This type is located mostly in Hungary, Romania, Poland and Bulgaria and goes together with moderate population density, decreasing population and a low GDP. The RALUC types A3a and A3b are mostly found in France, Finland, Sweden, Spain. In all other RALUC regions where afforestation is not the dominant land use change, forest land is not declining, with exception of one RALUC urbanisation region (U2c). This suggests that afforestation of agricultural land concentrates more strongly in regions where there is an overall trend in decline of forest area.

⁶ <https://glad.umd.edu/dataset>

Afforestation LEAC

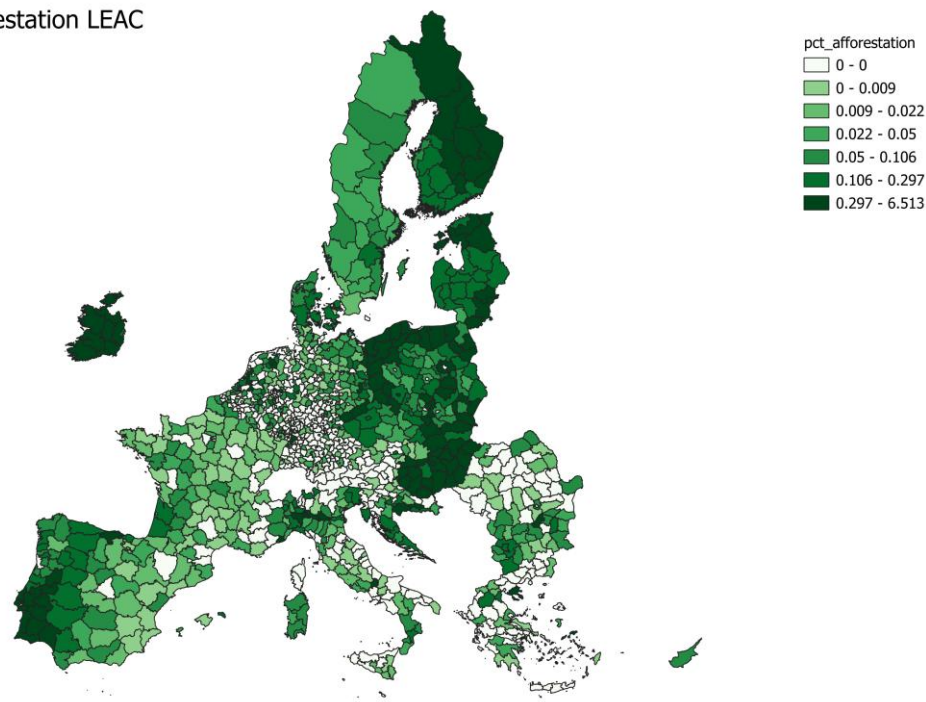


Figure 8 Share of agricultural land afforested between 2000 and 2018 based on LEAC

Only 12 regions were identified with a very high level of afforestation of agricultural land (>1% of agricultural land 2000). These regions are all located in Portugal, Hungary, Ireland, Estonia and Poland. In Portugal, this goes together with a negative trend in forest area 2000-2020 according to GLAD data while this is in a positive trend in all other regions having high afforestation shares. In 10 of these 12 high afforestation regions it concerns an RALUC afforestation type, but there is also one Intensification type (I-3a) in Portugal and one Urbanisation type (U-1a) in Hungary. Also, in several other countries relatively high to moderate afforestation of agricultural land levels are seen in combination with negative trends in overall forest area such as in Estonia, Sweden, Finland, Slovakia and Greece, but it is most pronounced in Portugal.

The literature review (see Annex 5) and case study outcomes, confirm that the drivers for active afforestation are a complex mixture of different, often connected, factors. The most mentioned drivers were unfavourable agro-ecological and socio-economic circumstances at farm level in combination with economic policy support and/or (new) market demands for wood to make the investment in afforestation attractive. Unfavourable socio-economic conditions at farm level have other underlying causes and unfavourable agro-ecological conditions may be aggravated by climate change factors.

The case study of West Ireland was typically a region where there was large scale active afforestation which was driven by the complex mixture of bad socio-economic prospects for farmers, unfavourable agro-ecological circumstances and government support.

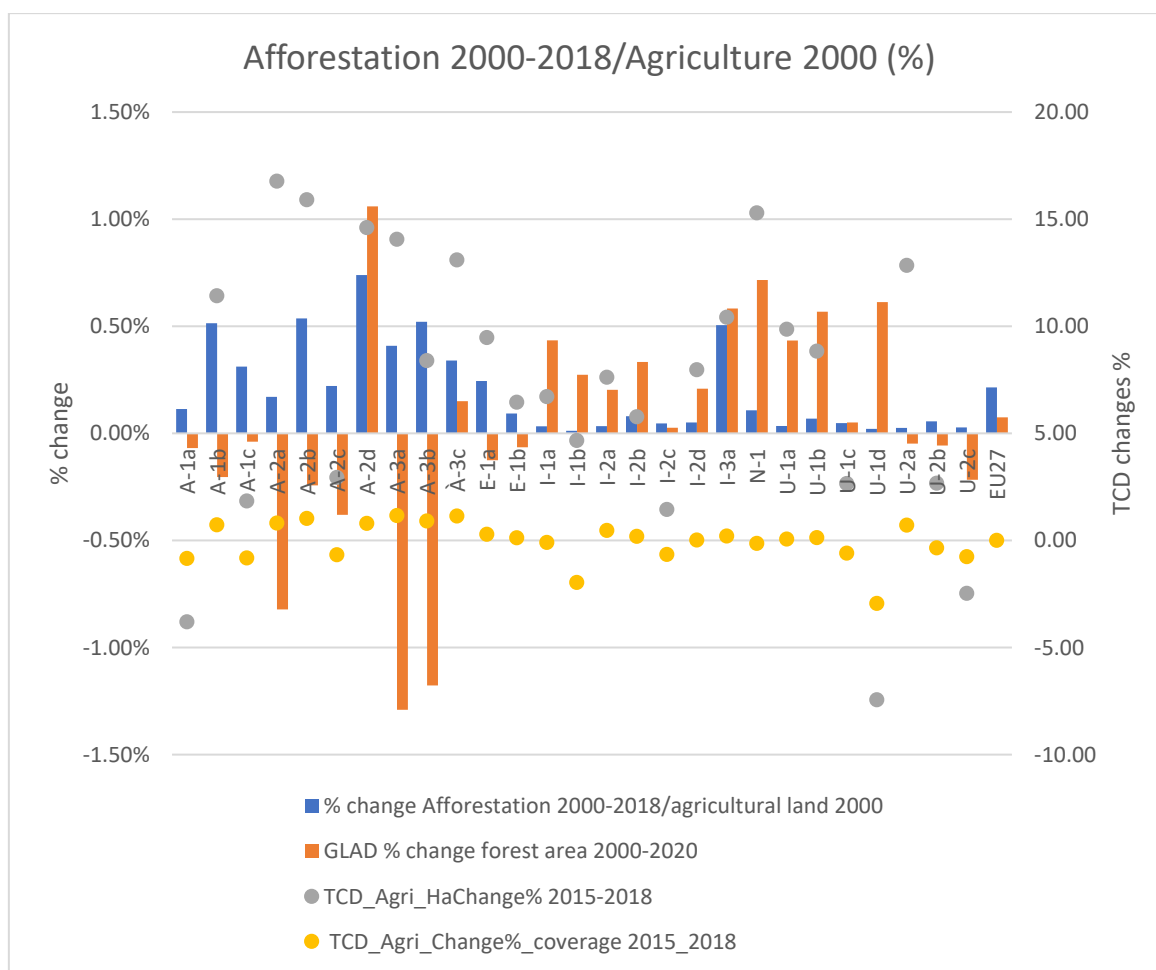


Figure 9 Relative afforestation of agricultural land 2000-2018 (% of agricultural land in 2000) (Source: LEAC-EEA), relative change in total forest area 2000-2020 (GLAD⁷) and changes in tree cover density (TCD⁸) per RALUC type in the EU.

In relation to drivers in the category of agro-ecological limitations, EU data analysis showed that the RALUC regions with the highest afforestation share is overlapping with presence of large marginal land share and moderate to severe erosion land shares. This confirms that in certain regions, agro-ecological limitation may be a strong driving factor for afforestation. However, this overlapping trend was certainly not applicable to all regions with high afforestation scores.

Box 4 Afforestation in West-Ireland

1. Planting of trees on private land, the Western Package and MacSharry/CAP2000 reforms (1980s through early 2010s)

Through a general shift in policy to a more free market approach from the post-Thatcher years, efforts to encourage planting on private lands prevailed. This included several relatively unrestrictive (in terms of soil type) grants to plant private land that was otherwise deemed uneconomical. These policies were instated to improve economic prospects in the region and were very successful in encouraging this type of land use change. The unrestrictive nature of the policy allowed, for example, farmers to plant the uneconomic parts of their lands, e.g., peat bogs and hillsides while retaining the more economical parts for farming. All grant schemes followed largely the same set-up where farmers would be compensated for planting the land

⁷ <https://glad.umd.edu/dataset>

⁸ [Tree Cover Density 2018 \(raster 10 m and 100 m\), Europe, 3-yearly — Copernicus Land Monitoring Service](#)

with high-value, non-native, commercial conifer species, e.g., Sitka spruce (*Picea Sitchensis*), for a certain number of years, after which income would be earned through felling.

Later during this period, changes in farming income substitution schemes – namely the 1992 MacSharry reforms increasing the significance of direct payments in farm incomes and the CAP 2000 reforms (part of Agenda 2000) putting larger emphasis on environmental policy objectives in farming subsidy schemes – contributed to a stable planting rate of agricultural land across Ireland.

2. Loss of social license for forestry amongst farmers (late 2010s onwards)

During this period, the perception of afforestation by agricultural landowners started to change due to multiple factors, leading to a significant decline in afforestation of agricultural land. Where from the farmer's perspective, initially forestry was seen as a way to earn more income from low-value farmland (especially relevant in the West region of Ireland with relatively unproductive soils), trust in the forestry sector to actually deliver that value was being lost. For example, due to the handling of the ash-dieback crisis. Ash trees only started to be planted after the restrictions on high-nature value soils came in, e.g., peat bogs, and so where typically planted on relatively valuable land for farmers. Their cost-benefit analysis would typically heavily rely on cashing in on the crop at the felling stage. However, when the ash-dieback reached Ireland and severely impacted the value of these plantations, farmers came up short due to what was often perceived as government mismanagement, inaction in addressing the crisis and lack of adequate compensation. Additionally, lingering issues at the forestry regulator (the Forestry Service under the Department of Agriculture, Food and the Marine (DAFM)) have led to loss of faith in the role of the Forestry Service. Government has recognised these issues and has recently developed a new forestry strategy for the next decade that should address the identified issues.

Of the 5 CSs in the afforestation class, only in West Ireland the afforestation process was characterised as an active practice. West Ireland has significant amounts of marginal lands on uplands/hillsides, relatively unproductive soils, inaccessibility, and poor weather conditions. The case study region of Albacete, although not classified as RALUC type A (Afforestation) but as I (Intensification), also reported strong active afforestation activity. In this region there is strong land abandonment in all mountainous and steeper hilly parts, and this also goes together with active afforestation supported by CAP payments in part, although not on all abandoned farmlands, and natural revegetation leading to forest cover in a climax stage.

In two other afforestation case studies, Siena and Šibenik-Knin, the spontaneous afforestation after agricultural land abandonment is most often mentioned as the dominant land use change. In Siena it was reported to be typical for the hilly and mountainous regions with more marginal lands often used for extensive grazing and also traditional olive production. It is a process that is happening in all periods and currently also continuing. In the remaining afforestation case studies, Hautes Alpes and Šiauliai afforestation was present either through active or natural reforestation but was not reported as a large land use change. In Šiauliai, at the same time several more opposite land use changes have taken place since 2008 when Lithuania joined the EU, which include the process of intensification and extensification in farmlands and still bringing back abandoned and overgrown farmland into agricultural production.

The impact of afforestation of agricultural land is the loss of agro-biodiversity, particularly where afforestation happens on ecologically valuable permanent (peatland) grasslands or agroforestry areas. In the longer term, it may help to (re)store below and above ground carbon and lower erosion risk and help to recover degraded lands. For example, in West Ireland and Šiauliai establishment of plantation forests, often with non-native fast growing tree species, on

abandoned grasslands took place on (deep) peatlands. This has had adverse effects for both biodiversity but also added to additional GHG emissions which may not be compensated for by the additional built-up of above and below ground biomass with trees. In the last decade, stricter requirements for afforestation were set to use native species and avoid deep-peatland afforestation in West Ireland.

3.4. Abandonment of agricultural land

In the literature review (see Annex 4), abandoned agricultural lands were described as lands that were previously used to produce economic output (agricultural production) but are no longer used for that purpose. Thus, abandoned land can be reclaimed back to the original use or converted for other uses, in the future. In this definition, abandonment of agricultural lands can be an outcome of land used for urbanization or afforestation whereby the land is not used for agriculture. It is this latter situation that is the focus of this section. This type of agricultural land abandonment is a complex process of gradual reduction in farming activities and see for more details Annex 4 and 5.

It is challenging to obtain a good understanding of the location and scale of land abandonment in the EU and in the case study regions. This is because data is missing at EU, national and regional levels. The only EU wide data on land abandonment is from Eurostat and is based on LUCAS points. The spatial and temporal resolution of this information is limited. However, we prepared a selection of LUCAS points from different years (2009, 2012, 2015, 2018 and 2022) and combined those point data with NUTS3 region in order to summarize LUCAS point shares in every NUTS3 and to the RALUC region types. Other sources that can provide information on the process of abandonment (indirectly) are the LEAC-Corine based data and the long term changes in Utilised Agricultural Area (UAA). The UAA data were not available at NUTS3 level, but they have been collected and NUTS2 level and normalised to NUTS3 for the period for which data were available (mostly 2000/2005-2020, as data for 1990 were not available at regional level or missing for a large number of CEEC countries) to also link them to the RALUC region types. However, the long term UAA changes are informative for identifying agricultural land abandonment in general, but not in the narrow definition of complete disappearance of land management. After all, large parts of UAA declines were transitions to urban uses and to afforestation. Again the LEAC information and the case study information collection needs to be used to obtain a better understanding of the real process and causes of farmland lost (for further details see Detailed case study results report in Annex 11).

Despite all the data limitations, a rough quantification of land use changes associated with farmland abandonment could be conducted (see Figure 10). The largest loss of agricultural farmland was in Cyprus, Netherlands, Portugal, Hungary and Ireland. However, in Cyprus this was caused by urbanisation (see also previous section). In the Netherlands, it is both urbanisation and rewilding. While, Hungary, Ireland and Portugal show high farmland losses were mostly caused by land cover flows lcf's that were classified here to farmland abandonment and for some part also to rewilding. Interestingly the EU-LUPA project found that abandonment processes have also been most pronounced in the central-south and north-east regions of Hungary (between 2000 and 2006),

on the Italian island of Sardinia (between 1990-2000), and in Ireland and southern Portugal to differing degrees throughout the 1990-2006 period.

Countries with medium shares of farmland loss, of between 0.5% and 1%, are Czech Republic, Denmark, Estonia, Spain, Spain, Italy, Lithuania, Luxembourg, Greece, Italy, Finland, France, Poland and Slovakia (Figure 10). For Estonia, Finland and Lithuania the largest contributor was through lcf's classified here as farmland abandonment. In the other countries urbanisation was mostly the largest cause.

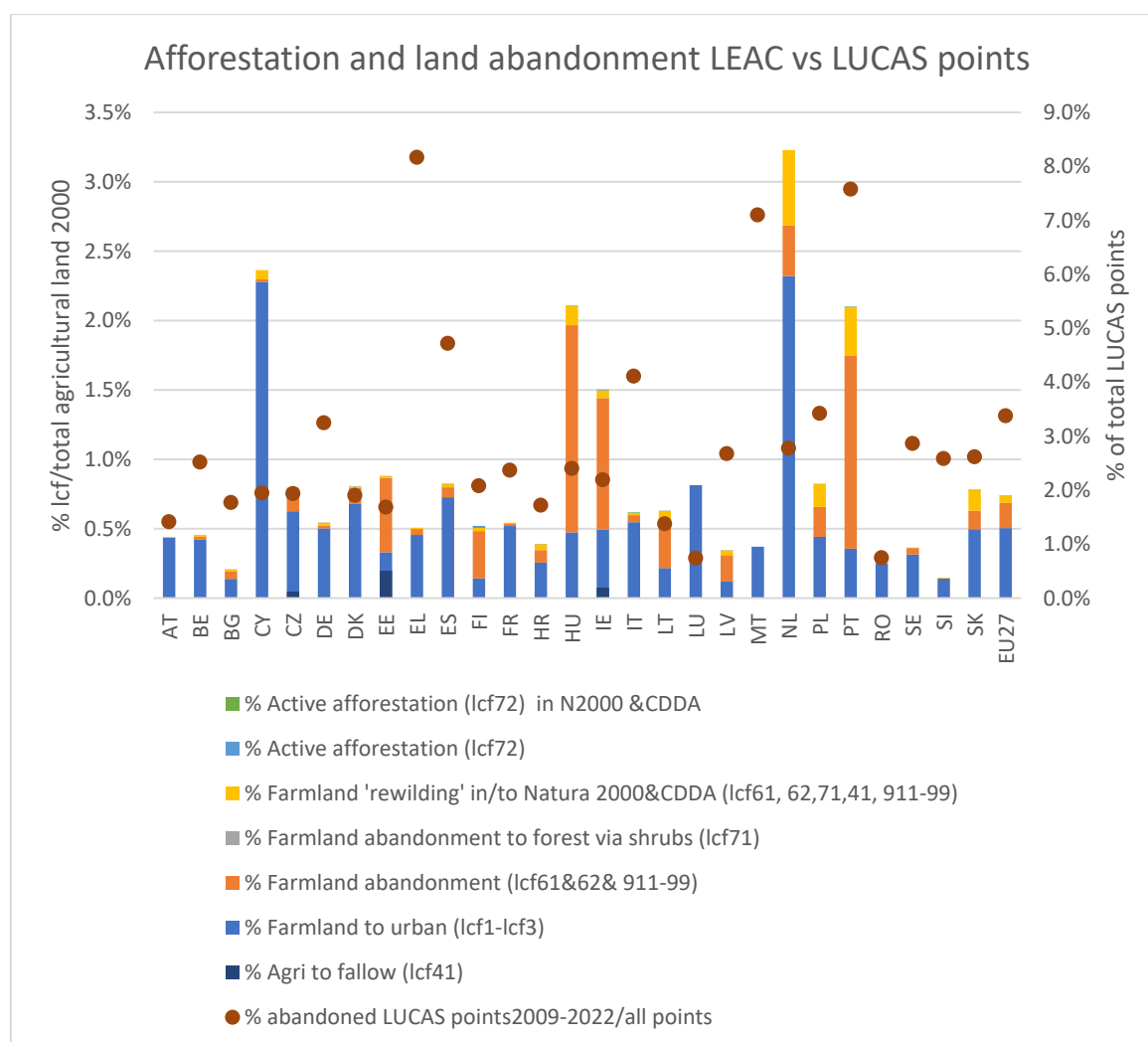


Figure 10 Relative agricultural land decline and land abandonment according to different CLC-LEAC land cover classes (%/total agricultural CLC 2000) and LUCAS points classified as abandoned presented for the EU-27 countries

It is surprising that some countries like Spain, Bulgaria and Romania come out as countries with relatively low agricultural land abandonment, while in other studies discussed in the first interim report they were mentioned as countries where this process was rather large. There are three aspects that need to be mentioned in this regard: Firstly, this may have to do with the fact that these countries are very large and have large total agricultural land in 2000. In relative terms the abandonment share is small but in absolute terms they are likely to harbour the largest area of abandoned farmlands. This was therefore also

plotted in Figure 10 with an absolute number. Secondly, it may also be caused by the resolution level⁹ of the CLC data that is used for the LEAC flow analysis. Only changes are recorded that cover 25 hectares at minimum which implies that smaller changes in land use are not recorded. This implies that LEAC is always an underestimation and may well lead to smaller and larger underestimation of land use flows depending on the relative scales the changes are taking. It is well known that in areas where field and farms are very small the risk of abandonment is larger (Terres et al., 2014¹⁰).

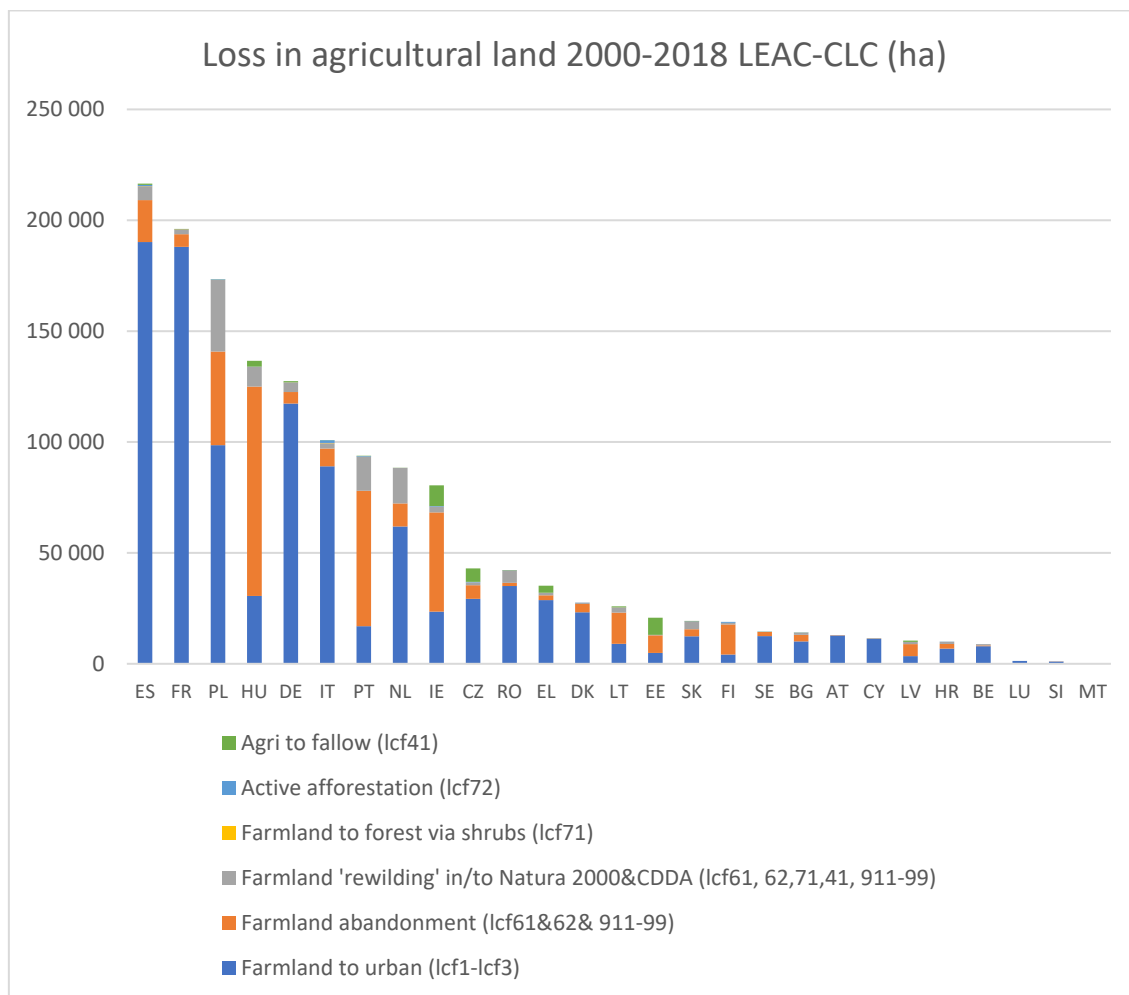


Figure 11 Absolute agricultural land take and land abandonment according to different CLC-LEAC land cover classes (hectares) for the EU-27 countries

Thirdly, this analysis has considered land abandonment between 2000 and 2018, given trend data availability. It is known, certainly for countries like Romania, Bulgaria and other CEEC countries, that the largest agricultural land abandonment took place after collapse of socialism and subsequent institutional reforms were introduced in the 1990s. Entry into the EU, most since 2004, saw agricultural lands brought back into production. This was also shown DG ENER (EC, 2023) since 2005, there were significant increases in UAA again in Bulgaria,

⁹ The dataset has a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a Minimum Mapping Width (MMW) of 100 m for linear phenomena and is available as vector and as 100 m raster data.

¹⁰ Terres J.M., Anguiano E, Nisini L (2013) Assessing the risk of farmland abandonment in the EU Technical assistance to define key factors and drivers, process data sets and provide results Administrative Arrangement #AGRI-2011-0295 between DG Agriculture and Rural Development and JRC Study on farmland abandonment – Deliverable 1

Estonia, Croatia and Latvia. In older EU countries positive UAA trends were also recorded, but these were more related to overall increases in permanent grassland areas which were related to changing definitions of this category of land, also increasing the land area that became eligible for CAP payments. Schuh et al. (2020) also confirmed the occurrence of a positive UAA trend in recent years (2013-2018) in especially 'newer' EU countries.

The Lucas information in Figure 10 reveals very high abandonment shares for Greece, Malta, Portugal, Spain and Italy. It actually confirms that LEAC is likely to underestimate land the agricultural abandonment especially in Spain, Greece and Italy.

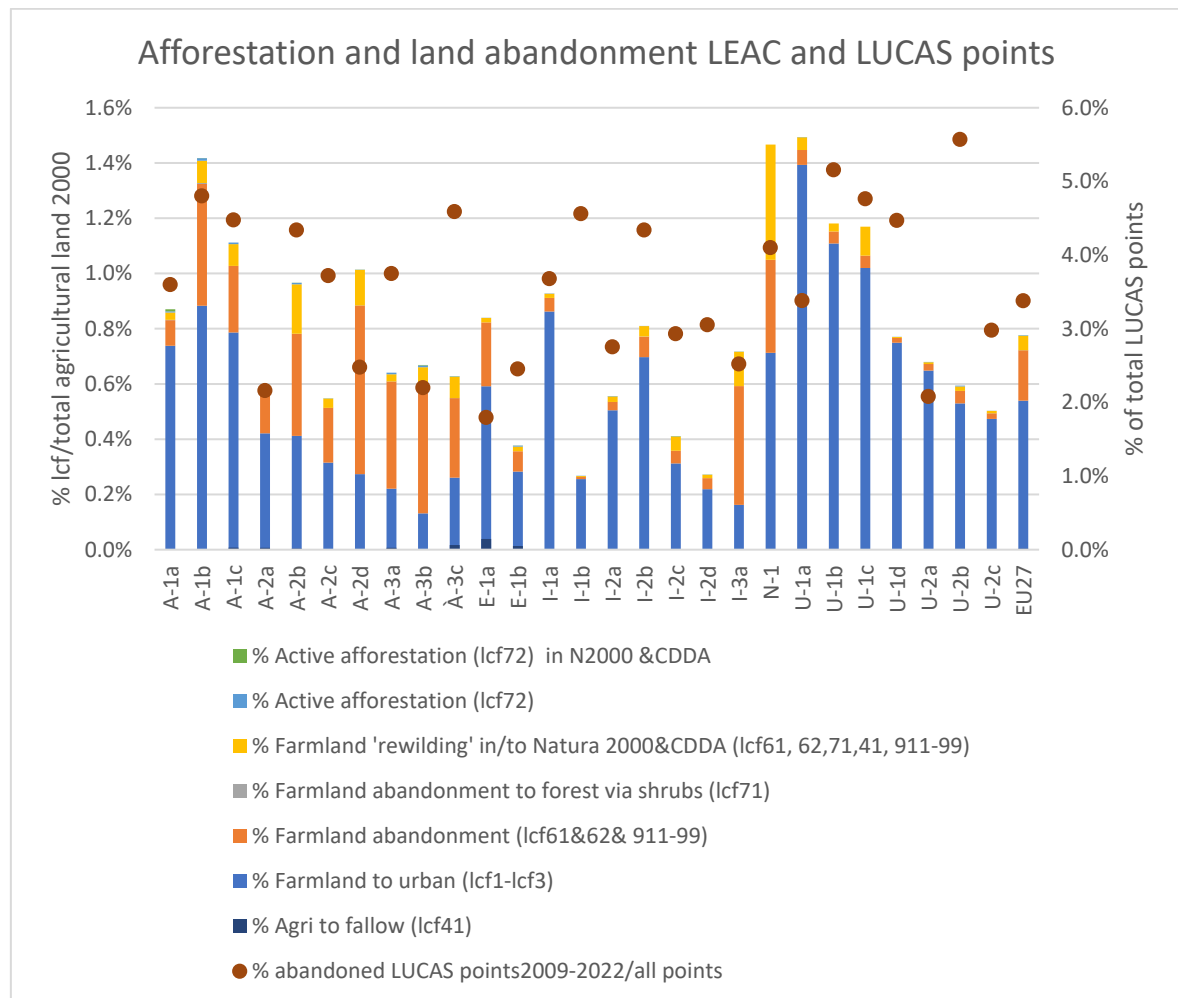


Figure 12 Relative agricultural land decline and land abandonment according to different CLC- LEAC land cover classes (%/total agricultural CLC 2000) and LUCAS points classified as abandoned presented for the RALUC regions in EU-27 countries

When looking at the patterns of agricultural land abandonment (Figure 12) the largest agricultural land abandonment is caused by lcf's that were classified as farmland abandonment, and also rewilding, which are largest in RALUC types Afforestation Nature formation (N-1) type. Exceptions are one Intensification type (I-3a), where abandonment of agricultural land is most important reason for farmland loss. The three exceptions in the Afforestation group are A-1a, A1b, A1c and A2a which are all characterised by a high to moderate population

density. This factor was already identified in the former and is related to conversion to built-up land take.

The LUCAS point information in Figure 12 reveals highest shares in four of the seven RALUC Urbanisation types and also the Afforestation types. Relatively lower LUCAS land abandonment shares are registered in afforestation types where urban land take is small and also in most Intensification and Extensification types.

The information collected in the case studies confirms that land abandonment has been widespread over the EU and will continue into the future. All regions where abandonment is prominent confirm that it is mostly taking place in marginal and mountainous areas. Often the case studies report two extremes of land use changes taking place in different landscapes. The one extreme is the intensification of agricultural land use by bringing formerly abandoned land back into use (e.g. in case studies in the newer EU countries). The other extreme is land abandonment, mostly in hilly and mountains low productive lands. In Tuscany, including in Siena province, several attempts were and are made to address land abandonment, but this has not always been a success, in the first place because monitoring the process itself turned out to be very challenging (see Box 5). In the mountainous and hilly part of Imathia, Albacete, Montana and Argeş similar processes of land abandonment are seen. Generally, this process of land abandonment was seen in the past but is ongoing and goes together with a continuous decline in the traditional, often semi-subsistence grazing activities. In Šibenik-Knin land abandonment of karstic permanent grasslands continues to be the largest land use change process also in the recent decade going together with a further decline of grazing animal numbers.

Box 5 Approach to land abandonment in Tuscany (including Siena province)

Challenges in the monitoring and policy response to land abandonment can be illustrated by the experience in Tuscany where a Tuscan Regional Law 80/2012 Law was implemented. In this Law Article 5 aimed to counteract the degradation of the agricultural landscape and the risks associated with abandonment. Additionally, it aimed to mitigate hydrogeological and forest fire risks. The law entrusted municipalities with the task of surveying abandoned lands and when identified adding them to the "Banca della Terra della Regione Toscana". This 'Land Bank' then tenders land lots to people interested to bringing these back into use either for agriculture or forest production.

Following the survey, the municipality was supposed to identify the owner, contact them, and enter direct negotiation regarding the status of the land. Three possible outcomes could emerge:

1. The owner informs the municipality that there was an error in photo interpretation and asserts that the land is in use. The municipality must then verify the accuracy of this assertion.
2. The owner of the abandoned plot confirms it is not in use but commits to put it back into production within a few months.
3. The owner makes no declaration, and the Land Bank can include it in its database. This mechanism also involved the municipality sending a list of cadastral parcels to the Ente Terre to be included in the Land Bank. The individual interested in taking over the unused land is then required to contact the municipality, which, after an inspection, allows temporary management for a predetermined number of years, requesting a small contribution for the owner.

The outcome so far is that 9 700 hectares have been included in the land bank, with 80% already under management, totalling around 8 000 hectares of land being put back into operation. Most of these plots of land belong to the regional agricultural forestry heritage and are leased through specific tenders. A small percentage consists of lands owned by some municipalities, which seek lessees through the Land Bank to manage municipal assets. An even smaller percentage concerns lands owned by private individuals. In relation to this last group, which is likely to cover the largest area of abandoned lands, the approach has been rather unsuccessful. This has several reasons.

Firstly, most municipalities refused to participate due to lack of funds and unclear definition of abandoned lands. What dimension should the parcel have and what territory is to be surveyed and how? Law 80/2012, lands not subjected to cultivation operations for at least three years are considered abandoned. Through photo interpretation, one may observe land that appears abandoned, such as overgrown shrubbery, yet there is no confirmation of its abandonment. Secondly, what actions can municipalities take if the owners of the parcel are deceased, unknown, or have moved to another country?

Consequently, a decision was made to collaborate directly with ARTEA (Regional Agency for Agricultural Payments), considering all agricultural parcels in Tuscany and excluding those that received subsidies for any reason in the past three years. This mechanism operates under the assumption that if any type of subsidy (for olive groves, organic farming, integrated farming, set-aside, cover crops) is received, the land is being utilised, although this is not always the case. Following this initial screening, the Ente Terre established that the minimum parcel size should be half a hectare. ARTEA involvement yielded a list of thousands of plots totalling almost 100 000 hectares. In the municipalities, joining the initiative, such as Siena municipality, the parcels on the list were then screened through photo interpretation. It turned out that some land were indeed abandoned and others were regularly utilised by individuals for private vegetable gardens, home vineyards, or olive groves for personal use even though no CAP subsidies were declared. For the abandoned plots the owners were identified and contacted to offering them the opportunity to include their plots in the Land Bank database. Most owners either did not respond or had their lawyer respond on their behalf. In Siena, another scenario occurred: many owners hired a third-party contractor to clear the land of shrubs and then responded to the municipality, indicating that they had cleaned their field.

In this case, the Land Bank has partially achieved one of its objectives, namely, if the owner has cleared their land, for one or two years, they have reduced the risk of landslides or wildfires. The land bank is perceived both as an expropriation agency by landowners and as a failure due to its inability to intervene in the plots of land that are still perceived as abandoned. The failure of abandoned lands' survey and the intervention on privately owned plots also casts a shadow on the positive achievements, such as the successful revitalization of 8 000 hectares of land. Next steps are now taken to build on the learnings from the past and started experiments in four very different areas of Tuscany. The chosen areas are Mount Amiata (in Siena Province), characterized by pure forest and chestnut groves; Lunigiana, with its inclination towards pasture; an area in the province of Grosseto, which encompasses both agricultural and forested lands. Ente Terre has identified areas with different criticalities, but they are still at the beginning, having held initial meetings and conducted initial inspections. It will take time to identify a possible path that leads to an effective regional regulation.

In all newer EU countries the first part of the analysis period (1990-2005) was characterised by large scale land abandonment in the post-communist period followed by difficult processes of privatisation and land restitution. Initially, this led to an enormous decline of agricultural land and rural population, agricultural production loss and strong decrease of livestock activities. The latter have been the most challenging to recuperate in most of these zones.

A specific category of agricultural land abandonment seen only in the Dutch and Flemish case studies is that of abandonment of agriculture land for nature conservation which will be discussed in the next section. In most EU regions nature conservation and agricultural activities continue to be combined, but in the Netherlands and Flanders the combined functions are less frequent.

The literature review, but also the case studies show that impacts of land abandonment are diverse and can be both positive and negative for environment and biodiversity. The impact of land abandonment is in the first place leading to a decline in agricultural land and production. As to production, the impact is likely to be limited where it relates to abandonment of marginal lands which are relatively low productive. But where abandonment is for built-up development, it is likely that good agricultural land is lost along with a carbon sink. On the

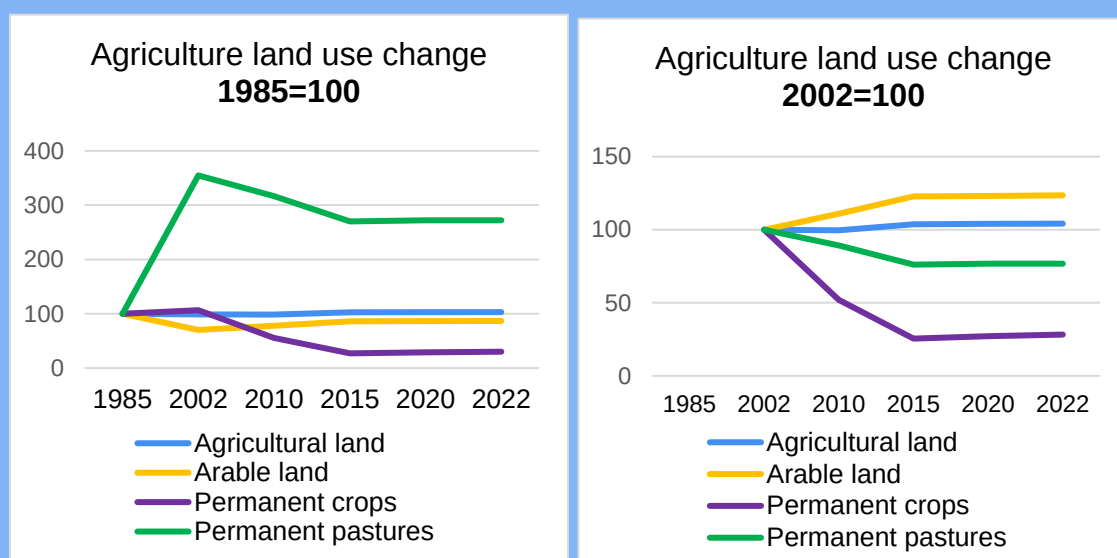
other hand, land abandonment leading to a natural revegetation of land may also contribute to capturing carbon. In an analysis presented in section 3.3, abandoned farmland trends were compared to trends in forest area development with GLAD forest data and with NDVI¹¹ Modis data (Figure 9). For some EU countries high NDVI increase trends sometimes go together with high land abandonment trends, such as in Hungary, Estonia, Latvia, Netherlands, and Poland. Portugal and Ireland have very high farmland abandonment and afforestation levels, but relatively modest or even negative NDVI trends. Ireland does show a high forest area increase in comparison to all other EU countries. Very high positive NDVI trends are found in Bulgaria, Czech Republic, Romania with low abandonment and afforestation levels. It is likely that these high NDVI levels are still a result of large land abandonment trends in the 1990 (see also Box 6), as discussed in section 3.3, that created an enormous natural revegetation of former farmlands which continues to produce additional biomass. One would expect this in the Mediterranean countries such as Spain, Italy, Greece, where studies have indicated farmland abandonment to be common in the 1990s and 2020, although underestimated by LEAC. Climatic factors, however, are likely already constraining large biomass development on these lands.

Box 6 Land abandonment, restitution, livestock declines, intensification in Montana

The first period 1990-1999 is the post-socialist period which made an end to the collectivised agriculture for which a process of restitution of land was started, but this took very long before it was working well, so it implied significant agriculture land abandonment across the Bulgaria, including Montana lowlands and uplands alike. As for the large livestock population from the collective farms a process of redistribution of livestock. In most villages, the animals were grouped into several herds, and the owners were rotating animal grazing which meant a re-introduction of traditional grazing systems. The second period 2000-2014 was driven by land restitution and introduction of pre-accession and CAP funding, is dominated by agricultural land, most strongly arable land brought back into use. The process was also quantified using different statistical data sources.

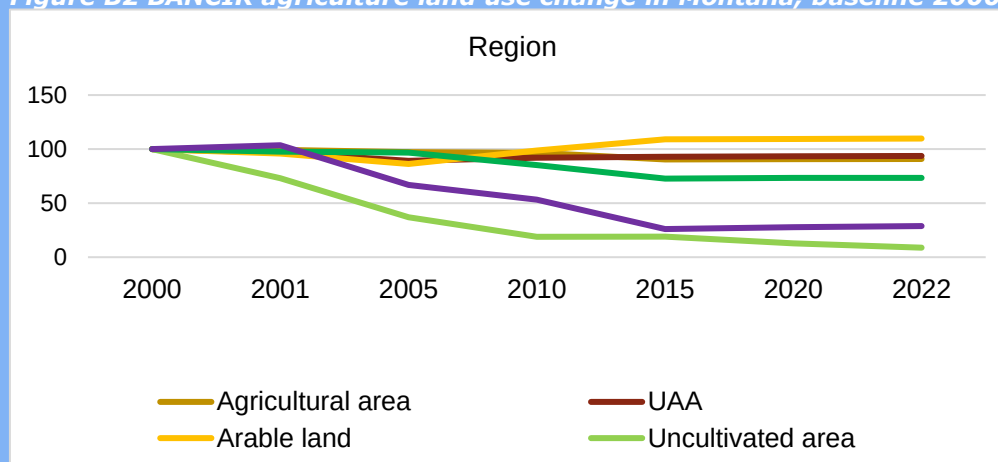
The majority of the agriculture land was arable in the late 1980's – 82%, which reflects the intensive agriculture of the Socialist agri-industrial economy. The areas, which were not suitable for intensive arable were managed as irrigated orchards and vineyards. The mountainous areas in the region had the majority of grasslands, natural meadows and meri. The changes in the 1990's led to abandonment of close to 50 000 ha of arable land across the region – down to 115,884 ha in 2002 from 164 906 ha in 1985. In 2022, the arable land is up to 143 175 ha but still has not reached the highest 1985 level. The biggest loss was for the permanent crops (Figure B1). The trees from the abandoned orchards and vineyards were removed from the land in the early 2000's and some were turned to arable and some to grasslands. New orchards are being established but not at the same scale. The biggest gain from the prolonged land restitution process was the conversion of abandoned arable land to pastures (Figure B1, 1985=100). The Socialist agriculture was too intensified and the decade of land abandonment allowed land to rest resulting in peak grassland coverage in 2002. Since then approximately 20 000 ha of formerly abandoned land was taken back in arable land use (Figure B1, 2002=100).

¹¹ NDVI: Normalized Difference Vegetation Index. It is a widely used metric to quantifying density of vegetation using satellite data.

Figure B1 Agriculture land use change, baseline 1985=100 and 2002=100

Source: Own calculation based on NSI data

BANCIK is the annual monitoring of agriculture land use and production since 1998 carried out by the Agristatistics department in the Ministry of Agriculture. Region-level data is published since 2000. BANCIK also provides information of the uncultivated area. The uncultivated land in Montana region records a tenfold drop since 2000 (Figure B2) and continues to decline from 2020 to 2022 (approximately -2000 ha). Around 500 ha were brought to arable use, and some 100 ha to orchards.

Figure B2 BANCIK agriculture land use change in Montana, baseline 2000=100

Land abandonment may also lead to more fires because of increases in (shrub)vegetation. The increase in biomass, which is positive for carbon sequestration also enhances the risk of wildfires due to an increase in vegetation-biomass that serves as fuel in combination with lack of maintenance of access roads and fire breaks. After the fires, land becomes even more vulnerable to the soil degradation processes through erosion and extreme (weather) events resulting in landslides. Climate change will only enhance all these negative processes further. To verify the relationship, abandonment and burned area shares were compared for EU-27 countries and for RALUC types. Largest burned area shares are found in Portugal, Italy, Spain, Greece, Malta and Romania. In some countries this coincides with high abandoned land shares such as in Portugal. In general, however, fires are more frequent in Mediterranean countries. In several case studies the relationship between land

abandonment and increased fire risk was also reported and this involved all case regions situated in the Mediterranean, Šibensko, Siena province, Albacete, Imathia.

On the other hand, it should be mentioned that land abandonment with natural revegetation does not need to be negative for biodiversity in all regions as it also creates wild vegetation of which several species, such as small and large mammals, may profit. In the region of Zuidwest Drenthe a policy of actively buying out farmers to rewild land again is done to increase nature areas and improve the connectivity between the different nature protection areas. In regions like Argeş and also Šibensko the revegetation also involves invasive species which is not beneficial however for native biodiversity (see Box 7). Removal of this biomass would be a win-win if combined with the use in generation of energy or other biobased uses.

Box 7 Land abandonment and impacts in Šibenik- Knin county

Generally, after the war, a noticeable trend of decrease in agricultural production is evident, both due to water scarcity and the continuous decline in the number of active population. Abandonment of agricultural areas for cultivating vineyards, olives, almonds, cherries, and cereals, as well as the decline in sheep and goat farming, led to the disappearance of characteristic agricultural landscape forms, such as dry stone walls, small rectangular fields, and the overgrowth of pastures and meadows into shrubland and forest, including by invasive species, consequently resulting in the loss of a valuable part of the landscape diversity and biodiversity of the area.

Overall, the continued abandonment of agricultural land, even if marginal land is involved, is affecting the agricultural production capacity of land negatively in almost all case study regions. At the same time this is also having a negative effect on rural villages. There are still many factors that adversely impact on the capacities of farmers to make profits and therefore enhance land abandonment and these include dependence on volatile markets, low prices paid by retail, the absence of a labour force, increase in climate change where it leads to drought and other extreme weather events.

3.5. Nature creation on agricultural land

In the section 3.4 attention was paid to the process of rewilding because it is a category that overlaps or can be seen as a sub-category of 'actual abandonment of agricultural land'. It is a process in which land is moving (back) to a natural state but in combination with incorporating these abandoned farmlands into a protected area either Natura 2000 or other national and regional protected statuses (CDDA status). There are also situations where the incorporation of (former) farmland into a protected area goes together with a continuation of farming management activities. In fact, large areas within Natura 2000 network are actually farmlands. This situation is to be discussed in this section.

When we refer to conversion to Natura 2000 areas, drivers of nature creation on agricultural lands are strongly policy driven. The key policy instruments driving it are the Habitats and Birds Directives that require Member States to bring habitats and species in good conservation status through, amongst others, the instrument of including areas in the Natura 2000 network. Such areas may cover protected areas where strict measures are applied to farming practices

(and other land use activities) on e.g. use of pesticides, herbicides and other chemicals, and ploughing of permanent grasslands. Measures may also be applicable that provide support or compensation to farmers to implement beneficial farming practices that help conserving habitats and species of EC community interest (targeted through the Habitats and Birds Directives). These restrictions and opportunities influence on the economic results of farms and this may make farmers to decide to sell their lands to nature conservation organisations, and/or maintain farming practices that are beneficial to nature conservation. The conversion of farmland to Natura 2000 areas is not a uniform process in the whole EU. Specific national and regional approaches have been applied.

In 2018, almost 30% of the Natura 2000 areas were covered by agriculture. Countries with the largest share of agricultural area under Natura 2000 were Portugal, Hungary, Germany, Poland, France, Belgium and Malta with over 30% are share. Countries with very limited overlap between agricultural areas and Natura 2000 are mostly northern countries like Finland, Sweden, Estonia and Netherlands.

In Zuidwest Drenthe, the only case study RALUC type Nature Creation, much farmland was included in Natura 2000 area. Since the 1990s more nature development took place through the establishment of national parks, Natura 2000 sites, and the enhancement of the 'Natuurnetwerk Nederland' and these were leading to a transformation of parts of the agricultural landscape into natural areas. In Zuidwest Drenthe, like in many part of the Netherlands, nature is strictly protected and often implies that agricultural land management and nature protection becomes separated instead of combined. This conservation effort introduces a new dynamic between agriculture and nature conservation. In recent years, there are also growing concerns over wildlife management, particularly wolves affecting livestock and other animals. Another example where the pressure on agricultural land from urbanisation went together with an increasing area demand for nature conservation was found in the Arr. Sint Niklaas. This is because the harbour of Antwerp is increasingly requiring more land which goes at the expense of natural areas, whose loss require compensation by developing other nature protection areas at the expense of agricultural land.

3.6. Agricultural intensification

Farm intensification can cover a broad list of changes in agricultural management. Measurements were defined by the EUROSTAT Agri-environmental indicator (AEI) fact sheet as 'the increase in farm intensity'. It is expressed as 'the spending in inputs used by the farm per unit of production' and given the scope of this study, per agricultural land surface unit. In this study LEAC data were also used to estimate its extent between 2000 and 2018 (see Figure 13). The land cover flows in LEAC contributing to this process are:

- lcf421 Conversion from arable land to permanent irrigation perimeters
- lcf422 Other internal conversions of arable land: Other conversions between arable land and irrigated perimeters, incl. rice fields
- lcf441 Conversion from permanent crops to permanent irrigation

- lcf451 Conversion from arable land to vineyards and orchards
- lcf452 Conversion from arable land to olive groves
- lcf453 Diffuse conversion from arable land to permanent crops
- lcf46 Conversion from pasture to arable and permanent crops.

As shown in Figure 13 the process of intensification across MS assessed on the basis of LEAC land cover flows (LCFs), ranges from increases of + 0% to + 5% of the agricultural land from 2000 to 2018. Nine countries had values equal or above 1%, of which mostly are MS that entered the EU in 2004. The literature (see Annex 5) associates this to the opening of EU markets, subsidies and development programmes to new countries entering the union. Spain and Portugal had similar values which is in connection to what was also mentioned in the literature review (Annex 5), i.e. member states undergoing major intensification processes with large scale conversion of arable and pasture land into intensive irrigated (perennial) crops (see e.g. Box 8).

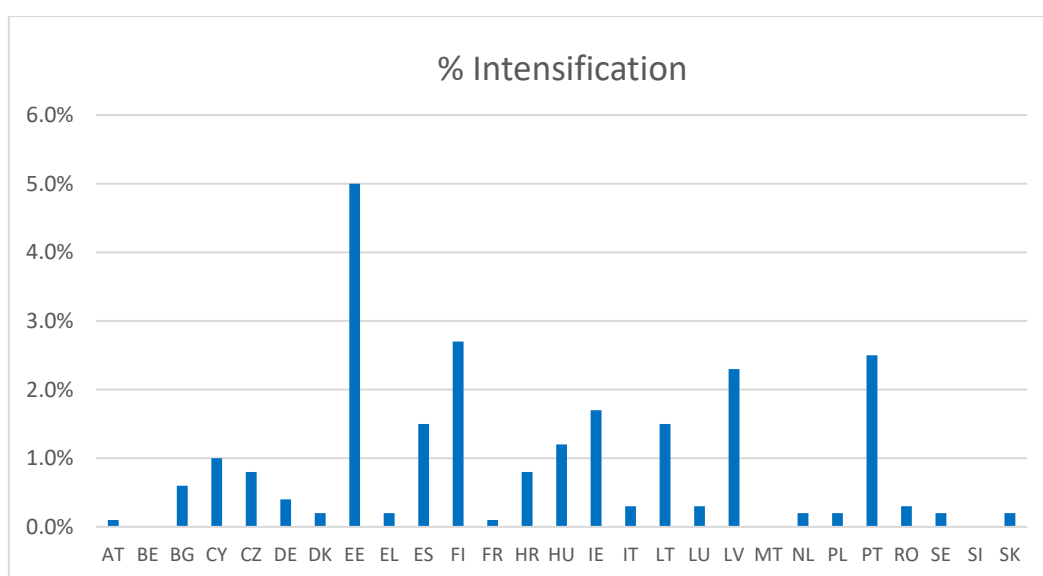


Figure 13: Share of land undergoing agricultural intensification as % of total agricultural land in the different Member States (2000-2018) based on LEAC Lcfs

Box 8 Main changes in agricultural landscape detected in Albacete in last 30 years:

Over the 30 year period the following main changes were detected in agricultural landscape:

- 1) Increase of permanent crops at the expense of arable crops because these permanent crops provide higher economic return opportunities in the market. Also they provide higher local processing options, options to add value to a product
- 2) Several types of the permanent crops selected by farmers in the last decade provide better options to adapt to climate change, can grow with lower water availability.
- 3) Irrigation infrastructure was developed further through joined investments in water reservoirs, irrigation infrastructures but also because of hydrological planning which improved since 1997. It lead to faster development of water and irrigation infrastructure and increase in the irrigated area. In the last couple of years, also under influence of the experienced climate change impact in this region, more investments are made in efficient use of water, through drip irrigation and introduction of water efficient and resilient crops.
- 4) Many permanent crops introduced were set up to grow in more mechanized systems and these were developed making well use of the several CAP support payments. The consolidation of fields also helped in increase efficiency and mechanization.
- 5) Livestock activities , where they relate to traditional grazing, decline strongly and are leading to abandonment of permanent pastures, while there is also a further concentration of livestock in larger industrial farms.

6) On the abandoned areas in mostly mountainous zones forest areas have increased either through support for active afforestation or through natural revegetation.
7) The many changes in agricultural landscapes have generally helped to maintain the economic viability of the sector but have also come at environmental costs of higher herbicides and pesticides use, Also plastics used in agriculture increased very strongly. At the same time there are more farmers converting to organic production systems or more integrated management systems. Apparently, the dry climate in Albacete make organic farming more attractive as the pest pressure is lower.

Using another proxy for intensification i.e. the share of high input farms (based on Eurostat), shows that Czech Republic, Latvia and Estonia, who entered the EU recently, show the largest increases (above 47%) in this indicator and this was also confirmed as a major driver in the multivariate analysis in Chapter 4 and Annex 8. This process of intensification after entrance in the EU is well illustrated in the Montana case study (see Box 9).

Box 9 Summary of main changes in agricultural landscape in Montana for period 2015-2022

In the most recent period 2015-2022, all CAP area-based and other support measures and schemes had a full cycle of implementation. The following changes in agricultural landscapes took place:

1. Conversion of the last remaining plots of abandoned arable land to arable use but at a slower rate as the remaining land was more difficult and expensive to be made 'eligible'. It was either fully overgrown with shrubs and trees or was in more remote areas or areas with difficult access for 'clearing' machines., while some is taken out of agriculture land use for photovoltaics or other industrial land uses.
2. Clear cutting of the trees and shrubs from overgrown pastures but still a large part of the permanent pastures remain ineligible for support as LPIS classifies them as non-agriculture land.
3. Conversion of abandoned arable lands or unused land to arable use and pasture; clearing of vegetation from grasslands to make these eligible for support. This involved removal of trees from agriculture land after permission is issued.
4. Increase in the area of arable land (mainly for cereals) and in the average size of agricultural land plots, driven by Bulgaria's accession to the EU and the start of the EU support/subsidies
5. Drastic decrease in areas with vineyards and permanent plantations; creation of vineyards plantations with a quality variety composition for the production of quality wines;
6. Almost complete loss of the mosaic landscape of small plot of land and the mosaic land use category in LPIS
7. Drastic reduction in livestock and vegetable production in semi-subsistence and subsistence farms. As to livestock activities there is a strong trend of further creating industrial production systems holding livestock entirely indoors and stopping grazing activity. This implied that the remaining pastures were more maintained by mowing only.
8. In this last period there is also simultaneously an opposite trend reported which is towards extensification of agricultural land use. On the one hand it involved a further decline in grazing density because of lower grazing livestock numbers per hectare, but under influence of policy support with stricter sustainability requirements, but also the creation of protected nature.

From the literature review it emerged that over the period 1990-2022 the process of agricultural intensification has occurred in several places across the EU (see also Annex 5). In Spain, Portugal and Greece for instance, large-scale conversion of open arable and pastoral landscapes into vineyards and intensive, irrigated olive orchards or irrigated crops in general were observed, mostly driven by markets and new consumers' need (see e.g. Box 8 and 10). It was also observed that intensification often occurred in MS who entered the EU more recently, because of the opening of markets and investment opportunities (mostly by the EU) (see e.g. Box 9 and 11).

Box 10 Changes in Imathia in the agricultural landscape

The main factors influencing the changes in the agricultural landscape for this case study were presented in three periods:

- * 1990-2000: During this period, there was a notable increase in the mechanization of the agricultural sector, which was accompanied by substantial agricultural subsidies. These conditions fostered the development of the agricultural sector, which was further supported by the establishment of processing units and the formation of producer groups and agricultural cooperatives.
- * 2000-2010: The period between 2000 and 2010 saw periodic reforms of the CAP regarding agricultural subsidies, which contributed to the restructuring of cultivated crops and made farmers to establish crops with lower production costs in order to maintain agricultural income at sustainable levels.
- * 2010-now: From the early 2010s until now, economic and political changes at the national, European, and global levels (such as the economic crisis, changes in the CAP, climate change, the Green Deal, and the Russian embargo) have caused numerous social, economic, and environmental impacts, including:
 - * rising cost of inputs (fertilisers; pesticides)
 - * increased production cost due to the rapid increase of energy cost
 - * establishment of solar parks in agricultural area
 - * ageing of agricultural population
 - * reduction of agricultural income

The drivers were reflected in changes in the landscape as follows. Over the whole 1990-2022 period the total UAA in the region increased from 53 700 ha to 54 500 ha. This however showed strong fluctuation in between with the smallest UAA area in 2016 amounting to only 46,653. Large changes also occurred in the crop mix which showed in time strong declines in crops like sugar beet and tobacco, because of market changes and changes in support schemes. Cotton showed a strong increase between 2011 and 2021, but is now on the decline. Oil crops increased strongly by 11 180 hectares since 2011 which was a response to increased demand for 1G biofuels. In the permanent cropping group there was, like in Albacete, a strong increase in nut trees and peach, kiwi and other fruit trees processed and canned in the area. Over the whole period of time there was an increase in size of farms and also in the irrigated crop area. Livestock intensification went together with an increase in fodder production. Currently in the area 4 567 ha (12% of UAA) is dedicated to fodder crops, while cereals only cover 3 580 ha (9% of UAA).

Box 11 Changes in farming in Šiauliai in post-communist times

Like in all former communist countries the transition from collective to family farming has been and still is a very influential process on the current agricultural landscape. Increase in number of large farms with grain crops and technical crops, disappearance of small subsistence farms. With land now in the hands of private owners, there was a shift towards a more diverse range of crops being cultivated. Previously, under collective farming, there was often a focus on a limited number of crops dictated by central planning. Private landowners were able to choose crops based on market demand, soil suitability, and personal preference, leading to a wider variety of agricultural products being grown. Private landowners had greater incentives to invest in modern farming technologies and equipment to improve efficiency and productivity. This included the adoption of machinery for planting, harvesting, and irrigation, as well as the

use of fertilisers and pesticides to optimize crop yields. Then with Lithuania's accession to the European Union in 2004, the Common Agricultural Policy (CAP) became the major driver of agricultural land use change in Lithuania, providing subsidies, support schemes, and market regulations. Technological advancements have revolutionized agriculture in Lithuania, leading to increased productivity, efficiency, and more sustainable practices and awareness. Also more mechanization and automation of farming operations have reduced labor requirements and increased farm output.

The process of intensification of agriculture is not only linked to periods around entrance into EU and getting access to CAP payment. The Dutch case study of Zuidwest Drenthe confirms that the process also continues in old EU countries and is still promoted through choices made by national government in implementing the CAP and banks traditionally funding investments in agriculture. The financial institutions have been giving preference to production-oriented business cases and therefore have stimulated the farmers to increase size and continue intensification. This choice is likely to be connected to the export oriented country with high-tech modern standards, access to international markets through the harbour of Rotterdam. Trends in the Flemish case study are similar but there are doubts about whether intensification and efficiency improvements are the long term solution (see Box 12).

Box 12 Changes in agricultural landscape reported for Arr. Sint-Niklaas (Waasland)

A focus on efficiency has been the dominant trend for some time. This can also be seen in the livestock sector where cows that were normally in the open space, are almost never outside anymore. These cows are now kept indoors in big stables for increase in efficiency. Also, the development towards agricultural specialization shows the region's shift towards specific high-demand crops. For example, the increase in areas dedicated to grain crops (excluding maize) to 12.7% of the agricultural land in Sint-Niklaas compared to the regional average reflects a targeted response to market demands. There has also been a shift from labour-intensive farming methods to the use of herbicides and big machinery that reduce manual labour but also lead to habitat simplification. Also, the increase of the size of the machines have had clear effects on the landscape. The typical characteristic convex fields from this region require specific ploughing, however because of the current machinery this typical landscape cannot be preserved as it is not possible to meet the ploughing requirements for this landscape. Trends in land ownership and use are also influenced by the consolidation of smaller parcels into larger ones for more efficient farming.

The stakeholders interviewed in the region indicated that farmers have been encouraged for years to scale up (bigger farms) and specialize. In combination with a relative low income for farmers (compared to other sectors) have led that the farmers are looking for alternative income sources, like agro-tourism, to sustain their livelihoods. This in combination with high-land prices, shows according to some stakeholders that agriculture might not be the most profitable way of using the land in Sint-Niklaas.

In summary, the relation between intensification and other potential proxies for agricultural intensification, confirm patterns already identified in the literature review at the MS level, and namely the importance of the EU accession year and consequently, the access to new markets, as well as subsidies and investments such as the CAP and other policies. The relationship with RALUC types however, is not always obvious. There are multiple likely reasons for this: one is the fact that more processes occur in each RALUC type, together with the dominant one. A second one is that determinants underlying proxies such as higher yields, for instance, are more complex and not always well correlated with those of land use transformations identified through LCF flows.

In the case studies the process of intensification was signalled as a major land use process within agricultural landscapes in most regions, but not the sole case. Certainly, in the last decade the process of intensification and extensification has occurred concurrently.

Impacts of the intensification process in farming area well-known and were extensively described in literature (see Annex 5). In the case studies impacts were further discussed. One impact of the intensification process of agriculture and which was reported as a negative impact on biodiversity and often also on water quality in all case studies was the increased use of pesticides, herbicides, fungicides and in several cases artificial fertilisers in agriculture since 1990s, mostly in cropping lands and even more for certain types of crops. The only regions where this was not mentioned as a problem was in Šibensko and Wittenberg. In Šibensko the pollution of habitats is much more related to increases in tourism and urbanization in combination with lack of investments in water and waste treatment.

Another strong adverse impact on biodiversity and nature conservation is from conversion of natural habitats to agricultural lands or destroying landscape elements to create larger fields for more efficient agricultural practices. Especially in the countries that entered in the EU in more recent years such as in the case study regions in Lithuania, Bulgaria, Romania and Croatia there is reporting of this process. The latter is of course a logical consequence of an agricultural sector for which there was ample room for improving the efficiency and productivity of agriculture which was needed to reach the objective of the CAP food production, sufficient agricultural income and affordable food prices and support rural economies. In other older EU countries this also happened in combination with agricultural modernization and intensification, but this was before the 1990s. Unfortunately, this went together in many regions with loss of high nature value farmland.

The adverse effect on water quality were also reported in most case study areas which was also related to the increased use of pesticides in several regions, along with nitrogen depletion. The latter is most significant in the Atlantic case study regions of Southwest Drenthe and Arr. Sint Niklaas where livestock farming, particularly dairy, is very dominant and livestock density is high. Beside water pollution by nitrogen, emissions of ammonia from this same sector is also adversely affecting biodiversity. In both Flanders and the Netherlands this is a very polarized topic leading to large farmers protests.

The opposite is also happening where too low applications of nutrients and organic material on soils used for producing in simple rotations cereals and oil crops are becoming depleted. This is often related to strong declines in livestock numbers in these regions decreasing the availability of manure to be applied for maintaining soil fertility. This is specifically reported for the case study region of Montana and Šiaulių apskritis. Another factor is also of more recent nature and that is the increased in cost of inputs under influence of high energy prices resulting from the Ukraine war making good nutrient management in soils increasingly expensive.

Climate change impacts on water availability is reported in all Mediterranean case studies, but also in the case of Wittenberg and Arr. Sint Niklaas is an increasing problem that is also becoming more pressing in the future. On the one hand it leads to an increase in irrigated crops, but at the same time this

increases the risk for depletion of (natural) water resources and also increased problems with salinization. The latter is already having an adverse effect on certain agricultural lands in the regions of Šibensko, Imathia, Arrondissement Sint Niklaas. It also leads to lower yields in non-irrigated agricultural lands which further enhances land abandonment in the more marginal lands.

Effects of land use changes on climate change GHG emissions are not reported in so many case studies. One important factor that is having an increasing GHG emission impact which is at the same time strengthened by climate change itself is irrigation. Pumping capacity requires a lot of electricity and with increasing irrigated lands and irrigation water demands this is typically and adverse contribution to GHG emissions , if the electricity does not come from renewable sources.

3.7. Scale increase in agriculture

Based on literature and the case studies it was observed that in most EU MS there has been a trend towards land consolidation where in some areas small family farms have given way to larger, more industrialized farm enterprises. For instance, post-socialist countries in Central and Eastern Europe underwent radical land reforms over the past 15 years, first in terms of land tenure with the creation of a mixture of small individual and large-scale corporate farms with, as a consequence, changes in terms of land use orientation as well as broader socio-economic and environmental implications.

Farm size change is illustrated by the ESTAT Figure 14 and illustrates that large farms have increased very strongly between 1990, 2007 and 2020 in the EU. In 2020, more than half of the EU's agricultural land (52%) was managed by farms larger than 100 ha. These farms make out 4% of all farms. The small farms (below 5 ha) using only around 6% of total land. The distribution of these farms is very different however between EU countries. On the one hand, the greatest share of land managed by large farms (more than 100 ha) is in Czechia and Slovakia where large farms account for 86% and 89% of agricultural land respectively), corresponding to 13% and 17% of all farms. On the other hand, Romania has one of the largest shares of agricultural area (23%) managed by small farms (89%). This was also illustrated further by the information collected in the Arges region (see Box 13).

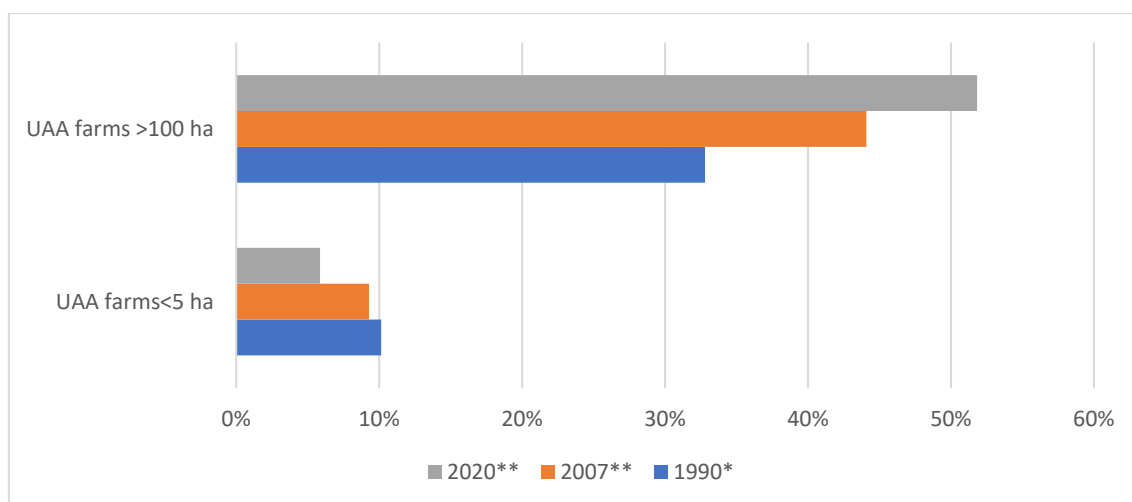


Figure 14 Change in share of total hectares of holdings by the smallest and the largest size class in EU between 1990 and 2020. *Only 9 'old EU countries; **All EU-27 countries included

Box 13 Farm structure in Argeş

The structure of the agricultural sector in Argeş is – in common with all Romania – highly polarised and this is widely acknowledged to impact significantly upon its competitiveness (ADR Sud-Muntenia, 2013). During the 2020 Agricultural Census (INS, 2020) there were 136,779 agricultural holdings recorded in the county – of which 95.8% were holdings of less than 5 hectares occupying 38.6% of total UAA, whilst less than 0.1% of holdings were greater than 100 ha occupying 44.3% of total UAA. Between these two extremes there is a slowly emerging sector of medium-sized (5-100 ha), increasingly professional, “family farms” (4.1% of holdings on 17.1% of UAA) which are the clear focus in recent years of stated governmental commitment to promoting the structural reform and increased competitiveness of Romanian agriculture (MADR, 2023). It is also important to note that less than 1% of all agricultural holdings in the county are registered as legal entities and thereby eligible to benefit from any form of EU-funding support (INS, 2022).

Despite the inclusion of the agricultural sector in the CAP, Romanian agriculture continues to face several challenges. Small-scale farming, fragmented land holdings, lack of access to credit and markets, and inadequate infrastructure remained significant obstacles to the sector's growth.

Farms across EU MS increased in scale, as evidenced by the case studies. The differences in scale distribution were also seen between the case studies which had different historic explanations, of which large farm structures during communist times in many new EU countries is an important factor along with the process of land restitution in the period after entrance in the EU. For example, in the Wittenberg region, part of the former DDR, average farm size is still between 200-500 hectares, while in the communist time it was more than 500 ha per farm (see Box 14).

Box 14 Farm size development in Wittenberg

The average farm size in the region is 272 hectares, whereas the German average is 64 hectares. In addition, half (49.9%) of the area is farmed by legal entities (cooperatives and corporations) in regions formerly attributed to the GDR, incl. the case study region. In other regions in Germany, it is only 1.2%. In the GDR land ownership was transferred into large agricultural cooperation, focused on the maximization of agricultural output. This led to a maximization of arable land with increased field sizes for optimal use, at the cost of

infrastructure and land diversification. Many roads, paths, and drainage channels were covered to increase land available to agriculture and large areas were used monoculturally. These agriculture production cooperatives were often overstaffed and had to rely on old equipment and dilapidated stable buildings. As a result, agricultural production was economically inefficient. The reversal of this shift remains to be a driver of land use change until the present day.

Box 15 Farm scale increase in Siena

Although the Siena case (Italy) intensification went together more recently with an increase in farm scale. In 20 years, the number of agricultural holdings decreased by more than 20 000 and the per unit holding size increased. Especially in the most valued wine producing areas, also due to the very high land prices and limited quotas for establishing new vineyards, this led to scale increase of some farms. Behind this there are mostly large investors often from outside the local farming community, what is recognized as a process of “financialization”.

Several case studies showed that scale increase is actually a very relevant process occurring in several areas across the EU. Trends are not only the ones described, i.e. following the entering of new MS and the opening of opportunities for new markets and investments, but also a process of consolidation related to achievement of economies of scale and what has been referred to as financialization (see Box 15 for Siena).

3.8. Specialization and diversification in agriculture

Almost three-fifths (58.2%) of all farms in 2020 were categorised as specialist crop farms while the share of mixed farms with crops and livestock combined were only at 10%¹². Between 2005 and 2020 however there was a very sharp decline in mixed farms. Although there were fewer EU farms of all types in 2020 than in 2005, declines in some types of farms were much sharper than others; there were 2.6 million fewer mixed farms, 1.6 million fewer livestock specialist farms and 0.9 million fewer crop specialist farms. Of the remaining 9.1 million EU farms in 2020, a higher proportion were crop specialists than in 2005 (58.2% in 2020 compared with 43.2% in 2005) but livestock specialist farms (21.6% compared with 24.9%) and mixed farms (19.3% compared with 30.1%) were less common.

Beside processes of intensification, specialisation and scale increase the case studies reported several other trends that can more be characterised as other forms of specialisation in certain products or markets and also widening of economic activities.

In the following we will illustrate this with the several observations in the case studies. Agro-tourism is a very important driver of land use as it is strictly connected to viticulture and to farming in general, as the area of Siena and Tuscany in general, is globally famous for 'eno-gastronomic' tourism. Vines in the Siena province such as Brunello di Montalcino DOCG and Chianti, have a controlled denomination of origin (DOGC) and have a well-known reputation all over the world. The growth in agro-tourism in the region strengthened the

¹² [Agri-environmental indicator - specialisation - Statistics Explained \(europa.eu\)](#)

market of denomination products and also of their production area, such as happened for vines, but in the slip stream also for local other local products such as for olive oil, cheeses pasta, and other livestock products. This enogastronomic tourism has also helped to further push the development of the organic production sector. Particularly within the province of Siena, this percentage escalates to nearly 46%. While in other regions of Italy, organic production primarily revolves around cereal crops, in Siena, it predominantly involves olive groves and vineyards (see also Box 16).

Box 16 Specialisation on local products and agrotourism in Siena

Wine is a leading product for developing the region and the province of Siena. According to the data released by the Tuscan Region, in Siena, 2 500 companies are operating in the wine industry and covering 20 147 hectares, with an average size of 8.06 hectares. Siena is at the second place in Tuscany, among the provinces, for number of farms. It holds first place for land dedicated to vines and for farms of average size. In Tuscany, the area under vines in 2021 reached similar values to the ones in 2012 (59 821 in 2021 and 59 444 in 2012): besides the peaks of 2018 and 2019 (with respectively 60 513 and 60 905), the dimensions of the land under production have remained almost steady. The 30.9% in 2021 was in Chianti, the 20.8% in the Chianti Classico and the 6.1 under the appellation Brunello.

4) Regarding the “indirect” effects of agritourism for boosting farmers income and revitalizing local products Siena province is a good example. Siena is the second province in Tuscany by the number of agritourism farms. It can host more than 21 000 people (the largest share, in Tuscany, if compared to the other provinces); most of the agritourism offer a wide spectrum of activities, including restaurants.

Agritourism is not the only diversified activity that can be carried out by farmers: farmers can decide to sign contracts for cultivating land for third parties (11.3% of farmers in 2020); the transformation of vegetable products (6.2%); first transformation of agricultural products (prima lavorazione di prodotti agricoli, 4.4%); animal product transformation (3.3%). All the activities in the last ten years had a negative trend if compared to the data collected in 2010. The only positive trends come from those activities related to tourism, including the growth of artisanal craft.

The availability of funds, especially those related to the PNRR, has created the premises for further investment in those leading products. The access to public funds represents a chance to produce Cinta Senese, which, between 2023 and 2023, has published a call for applications for the promotion of precision farming and, in the future, is committed to work on traceability.

The strategy of Siena focussing on local products and agrotourism is also gradually rolled out in the region of Šibenik-Knin in Croatia. The county has specific products that are labelled as Protected Designation of Origin (PDO) and their number is increasing. One such produce is Drniški pršut (prosciutto). Today, in the Šibenik-Knin County, there are 20 registered prosciutto processing facilities.

In several of the case studies adaptation to market changes are also seen that lead to shifts in land use (crop mixes) in response to both markets, but also climate change and labour availability. In Albacete and Imathia regions for example this led to an increase of permanent crops at the expense of arable crops because these permanent crops provide higher economic return opportunities in the market. Also they provide higher local processing options, options to add value to a product. Several types of the permanent crops selected by farmers in the last decade provide better options to adapt to climate change, can grow with low water availability. Many permanent crops introduced were set up to grow in more mechanized systems and these were developed making

well use of the several CAP support payments. The consolidation of fields also helped in increase efficiency and mechanization. Some of these changes have however, also come at the expense of higher environmental pressures through higher herbicides and pesticides use and plastics.

In the Zuidwest Drenthe farmers have also tried to search for alternative income sources within the agricultural sector. In recent years a move is seen from dairy to crop farming due to regulatory pressures (e.g., on peak polluters for nitrogen). It goes together with the introduction of crops like tulips and lilies, which were not traditionally part of the region's agriculture. This change is associated with a higher use of pesticides and groundwater extraction. On the other hand, there is mention of a growing interest among some farmers in adopting nature-inclusive and organic agricultural practices. While this shift is still upcoming, it might lead to a potential transformation towards more diversified and sustainable farming approaches within the landscape. The business case however needs to be made still and gives tension within the diverse farmers population who have different views on how to develop agriculture further.

3.9. Agricultural extensification

The review of literature sources has shown that the extensification process was important for instance in relation to set-aside that was applied between 1998 and 2008 across the EU (see also Annex 5). In recent years, the latest factsheet on the AEI Intensification/Extensification indicator (Eurostat, 2017) has also shown that the share of agricultural area managed by extensive farms (>50% agricultural area), was highest in 2013 for Romania, Spain, Portugal, Bulgaria, Estonia, Latvia, Slovakia and Lithuania. All other EU-27 countries had below 50% shares. The trends since 2004 in intensification/extensification were different for countries that joined the EU after 2004 then the others. The first group of countries showed an intensification process from 2004 to 2006 while from 2007 to 2009 there was a clearer extensification trend, and then again, another period of intensification until 2019 for most. From the older MS, countries showing clear increases in agricultural area managed by low input farms (i.e., a proxy for extensification) are Belgium, Greece, Denmark, and Finland. The opposite is seen in countries like Netherlands, and Austria where the area under low input farms clearly decreased and the of high input farms increased over the same period.

As shown in Figure 15, extensification across MSs on the basis of LEAC land cover flows, ranged from 0% to 3.6% of the agricultural land over the period 2000-2018. Four countries - Czech Republic, Estonia, Hungary and Ireland – have values equal or above 1%. It therefore matches to a certain extent what was observed in literature since 3 MS coincide with the group of countries that entered the EU after 2004.

We also considered other proxies for extensification, like the increase in the area farmed by low input farms, which shows very large increases in this share especially in Cyprus, Belgium, Finland and France. Other countries, including new accession ones, show the opposite trend, hence intensification.

The extensification process does not appear to have a defined geographical pattern. In this case too, it seems partly linked to the date of accession to the EU, configuring a process somewhat occurring in parallel to that observed for intensification. In part it seems to portray different trends and follow other drivers. In all case studies there were several examples given of extensification trends existing beside intensification trends. Developments towards more organic farming were mentioned in 8 of the 12 cases (see Boxes 17 and 18).

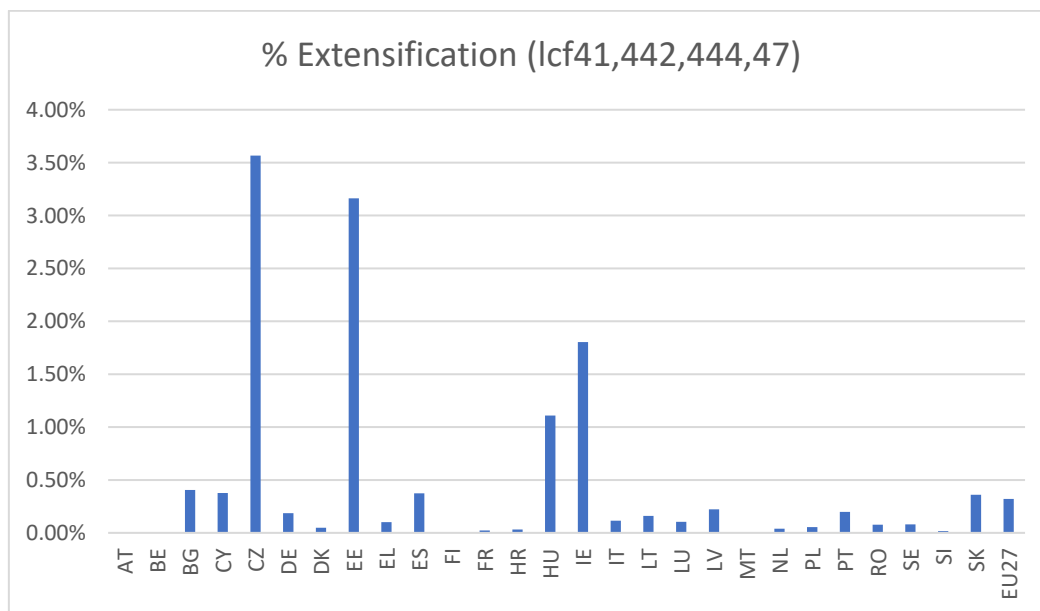


Figure 15. Share of land undergoing agricultural extensification as % of total agricultural land in the different Member States (2000-2018)

Argeş was the only case study region that is classified in the Extensification class of the RALUC typology. The study indeed confirmed that beside intensification practices also extensification processes were seen but not to organic. These practices were reported for very small and medium sized holdings specialised in both livestock breeding and specialist fruit and wine located in the hilly plateau and in the mountains areas of Argeş. These are increasingly moving more to extensification practices to produce for higher quality niche markets.

Box 17 Recent interest in organic in Šibenik-Knin

Organic farming is growing very fast in the region. In 2020 there were 99 organic producers and 37 in preparation for transition to ecological agriculture. Looking at total number of 136 organic agricultural holding, this represents an increase for 2.2 times compared to 2016 (62 organic producer). The reason for this significant increase is the higher number of subsidies from the Rural Development Program 2016-2020 for the Republic of Croatia compared to conventional production, as well as incentives from County agricultural support programs.

Box 18 Organic in Hautes-Alpes

Hautes-Alpes is among the leading regions in France in terms of organic farming, with 40% of its produce organically certified. This is related to high local consumer demand for it and stimulation by local government. The region has a long history with organic farming. The organic farming association of Hautes-Alpes, Agribio05, was created in 1989. The growth has been only in the last decade however, as in 2010 only 8% of the farmers were certified in organic farming which was a 10% growth compared to 2000.

Beside the most well-known conversion to organic also other extensification trends were reported in case studies. In Siena, these concern conversion to practices such as integrated crop management, application of no-till practices, agroforestry, although to a much smaller amount, to other extensive land uses such as from cropping land to permanent grassland or forage land or from irrigated to non-irrigated cropping. In Albacete, there was mention of a shift to organic which in the dry climate in Albacete is an attractive practice since pest pressure is lower. At the same time adaptations are also being done to climate change and these imply extensification practices in terms of shifting to other crops that are more adapted to drier climates and require no or much lower irrigation. The same is seen in Imathia.

4. Drivers behind the evolution of land use change (1990-2022) in the EU

4.1. Introduction

This chapter analyses the main processes and drivers behind changes in the use of agricultural land that occurred over the study period 1990-2022 in the EU-27, observed in the literature, in the case studies and in a multivariate analysis of indicators for European regions. It so responds to parts of research questions Q1. Drivers of land use changes in the period 1990-2022 were grouped under main categories of land use change distinguished in the territorial typology of regions. The drivers were derived from the literature review (Annex 4) and from the case study reports.

4.2. Drivers of changes in land use and in agricultural landscapes

4.2.1. Agricultural land taken by built-up areas

The increase of built-up areas at the expense of agricultural land was one of the most prominent land use changes in the period 1990-2022. The conversion of agricultural land to urban areas, residences, infrastructure, industry, tertiary and commercial services was mainly driven by population growth, economic growth and income growth, and by migration from rural to urban areas. These drivers were also observed in all case studies. Only in the case study in Wittenberg (Germany), was land take to built-up areas also referred to in the case of PV parks (see below).

The concentration of population and economic activities (amongst others tourism) in coastal areas has also driven urban development on agricultural land. Concentration of population and economic activities along the coast was seen in the case study in Šibenik-Knin (Croatia) - the only case study with a coastline. The growth in international tourism has also driven the transformation of agricultural land into built-up areas. This was also seen in the case studies Zuidwest-Drenthe (recreation parks), Hautes-Alpes (development of second homes), and Argeş (built environment around settlements and in touristic mountain villages).

The literature review (see Annex 5) mentioned demographic changes influencing land take from agriculture to urban areas in the form of population growth in urban areas and migration from rural areas, especially by young people, driven by better employment opportunities in urban settings. This accompanied deteriorating access to public services in rural areas. Similar processes were noted in the case studies in Šiauliai, Siena and Albacete.

Lifestyle changes also contributed to the use of agricultural land resources in the form of preferences for detached housing. This was noted in the case studies in Sint-Niklaas (growth of single-person households), Argeş (preferences for better housing), and Hautes-Alpes (city dwellers and third generation landowners moving back to rural areas in second homes).

Weak normative and regulatory constraints appeared, in the literature, as a dominant factor for the conversion of agricultural land to urban areas. This was not mentioned in the case studies with reference to land take for conversion to urban area (residential, industrial, commercial). However, it was mentioned for conversions to nature land into urban land in Sint-Niklaas, and for the placement of windmills and solar panels on agricultural land in Šiaulių apskritis.

Renewable energy development drove the conversion of agricultural land to built-up land with solar parks and wind farms in the case studies in several case studies (Imathia, Zuidwest-Drenthe, Wittenberg, Hautes-Alpes, Šiaulių apskritis). At the level of the EU, the literature review mentions R&I initiatives and the Solar Energy Strategy to encourage Member States to promote agri-PV under the implementation of the CAP.

4.2.2. Agricultural land use changes influenced by afforestation and land abandonment

The expansion of forest at the expense of agricultural appeared from the literature review as one of the most prominent changes in land use in the period 1990-2018. Abandonment of agricultural land has been a dominant factor for the increase in forested area in Europe, mostly in the form of transitional woodland shrub. This was also observed in the case studies in central and eastern Europe and in the case studies in Italy and Spain. Drivers of various types underlaid farmland abandonment, notably depopulation of rural areas, but also through slow processes of land restitution in countries with formerly collectivized agricultural land under the communist Soviet regime, after their entry into the EU.

The literature revealed another part of the afforestation of agricultural land due to support from the CAP between 1992 and 2012. This driver was less reported in the case studies, where policy influence mostly appeared in nationally promoted and financed afforestation or where a lack of policy led to natural revegetation after land abandonment. In the case study in Croatia, parcels overgrown by shrub vegetation and not used for a longer period, entered in forest management plans and became owned again by the state forest company with inconsistencies in policy (Box 20).

Box 19 Example of drivers 'economic pressures', 'demographic changes' and 'policy' for active afforestation from West-Ireland

'The Western Package Grant was part of a strategy to revitalise the area, stricken by poverty and low economic output. The largest share of afforestation over the decades has been through commercial, non-native conifer species. These are largely clear-felling model plantations on relatively unproductive soils, often marginal or with high nature value. The rise of afforestation in the 1980s and '90s, especially in the western counties, coincided with a declining population and poor economic circumstances.'

Box 20 Example of driver 'Inconsistent legislation' for afforestation through land abandonment from Šibenik-Knin County, Croatia

'The Forest Act prohibited any removal of shrub vegetation from parcels of karst pastures leased to animal herders, ... on the other hand, for active payments in agriculture for high nature value farmland, the farmers were required to clear the vegetation from karst pastures. Otherwise the Agency would withdraw the subsidies ...'

'The Nature Conservation Act stimulates controlled burning, whereas the Forest Act prohibited controlled burning. Croatian Forests are not interested in designing areas for controlled burning.'

Afforestation induced by the bioeconomy appeared from the literature in the use of domestic primary forest resources, such as firewood in the residential sector

and was followed by secondary wood residues, mostly used for industrial processes and pellets. This driver was only observed in the case study in Ireland, where financial support was given to the conversion of agricultural land in commercial forest plantations. However, in this case study there was also some grant-funded (small-scale) planting of native tree species for biodiversity purposes.

4.2.3. Nature creation in agricultural land

An important driver of nature creation in agricultural land was the establishment of the Natura 2000 network in 1992 under the Bird and Habitat Directives. This network is partly in agricultural land because there are many habitats that need low-intensity agricultural management for conservation. Creation of protected nature areas under Natura 2000 from, or in, agricultural land was explicitly reported in several case studies (Montana, Albacete, Zuidwest-Drenthe).

Inclinations from farmers towards nature-inclusive farming were reported for the case study in the Netherlands. These were driven by regulations for nitrogen management resulting from EU policy, but also by an increased awareness in society of the importance of nature and landscapes. Societal forces and consumer preferences also induced an increased demand for nature areas in case studies with dense populations following the COVID-19 pandemic (Zuidwest-Drenthe). Nature creation to compensate for development of industry was reported in the case study in Belgium.

4.2.4. Agricultural intensification and expansion of agricultural land

According to the literature, intensification of agriculture in the EU was partly driven by the emergence of new markets and population growth in the EU and globally. Another main driver was globalization and the associated developed global infrastructure, which enabled producers to import/export agricultural goods for a relatively low price.

At the level of farms, the literature on intensification was found to be coupled with positive economic farm performance due to better farm gate prices or to the reduction of farming costs, and therefore with the ability of farmers to invest. In the case studies, market incentives were mentioned as drivers for intensification (Šiauliai, West-Ireland, Zuidwest-Drenthe, Siena). For some regions, this was by a switch to high-value crops (e.g., luxury Italian wines, tulip bulbs, permanent crops). Low farm income in the case study in Ireland led to farmers choosing to intensify to make farming more efficient.

Box 21 Example of driver 'economic pressures' for intensification of agriculture in Sint-Niklaas region, Belgium

'Farmers have been stimulated for years to scaling up (bigger farms) and specialization. In combination with a low income compared to other sectors, this made farmers looking for alternative income sources, like agro-tourism, to sustain their livelihoods. Also the harbor has a major influence on the region and is prioritized above all other uses as it generates much income for the whole country and provides job opportunities.'

The literature mentions declining rural populations as a driver of intensification, leading to a reduction in labour force in the agricultural sector. The decline of rural populations was certainly mentioned as a driver of land use change in the

case studies, but not for intensification. The depopulation of rural areas was rather mentioned as leading to the conversion of agricultural land to urban areas, areas for recreation or nature creation, extensification, or a decrease in agricultural area due to abandonment.

The CAP was found to be an important driver for intensification in the literature, with the direct payments under Pillar I and Pillar II payments for Areas of Natural Constraints (ANCs) as key measures that have helped to maintain land under agricultural use. These contributed towards stabilized markets, provided direct income and investment support at farm level. In the case studies, CAP support in combination with national or regional subsidies was reported as a driver for the expansion of cultivated area and the selection of promising crops to ensure higher agricultural incomes (Imathia, Siena).

The accession of countries in central and eastern Europe to the EU, and their access to CAP measures and incentives, represented a strong driver for the cultivation of new land. Higher shares in CAP payments in farm income influenced the maintenance of agricultural land positively. Literature also suggests that the way in which some Member States define their eligibility criteria has encouraged the removal of scrub and trees to enable the land to become eligible for CAP support. This was clearly stated in the reports from the case studies in Bulgaria and Lithuania.

The development and progressive adoption of agricultural technologies has accompanied agricultural intensification across the EU leading to increases in yields and quality of production as well as a reduction in costs. This was also reported for several case studies (Imathia, Zuidwest-Drenthe, Sint-Niklaas, Šiaulių apskritis, Argeş, Albacete).

The demand of land to produce biomass and energy crops was mentioned in the literature as having influenced intensification of agriculture. In addition to farmland for energy crop cultivation, areas previously set-aside land as well as abandoned land were used for this purpose. Intensification using equipment for renewable energy production on agricultural land was mentioned in two case studies (Imathia and Šiaulių apskritis).

The literature has numerous records of climate change impacts on agriculture (see also Annex 5). Regarding intensification, an East-West divide was mentioned, with eastern Europe experiencing greater cropland declines and lower management intensity compared to western Europe in the years 1990-2006. However, these trends varied across regions, with some areas intensifying their farming practices while others saw cropland reduction, particularly in less suitable areas. In several case studies water shortage for agriculture owing to climate change was mentioned as a driver for a shift to irrigated agriculture (Imathia, Albacete) or to greenhouse horticulture with systems for efficient water use (Sint-Niklaas).

4.2.5. Scale increase in agriculture

Drivers of scale increases in agriculture, observed in the literature, are typically: stable markets, higher costs for labour or lower labour availability, land reforms, opportunities for land consolidation into larger areas and fields because smaller (and older) farmers sell their farms, and technological innovations. Investments

in scale increase have been facilitated via the CAP with market and income support and direct payments.

These drivers were also seen in the case studies. Economic pressures and market forces were mentioned as causing an increase in the number of large farms and a decline in the number of small farms in the case studies in Siena, Argeş and Imathia. Global markets induced a replacement of family farming structures by large cooperatives in Albacete. Another market force came from foreign investors, offering high prices for high-quality vineyards in Siena.

Land reform influenced agricultural land use change in post-socialist countries in Central and Eastern Europe, with the transfer of land rights from state farms and cooperatives to individual farms and the reorganization of cooperatives into new private companies. The land restitution led to the creation of a mixture of small individual farms (oriented to subsistence and with a modest market integration) and large-scale commercial farms. National land-consolidation programmes led to disparities between ownership and use of land (Hartvigsen, 2013). This appeared in agricultural land managed by large entrepreneurial entities and leased to a large group of small owners.

Restitution of land ownership to previous owners, cooperatives and state-owned enterprises was reported for the case studies in Šiaulių apskritis and Argeş. This resulted in a shift towards either more mechanized and specialized agricultural production and a decline in traditional farming practices in Silauiai, but also to a polarized structure of the agricultural sector in Arges (Romania) (see Box 22).

The literature mentions land consolidation having occurred in several member states to reduce property fragmentation and to increase the efficiency of farming. This development was also noted in several case studies.

Box 22 Example of land reform and market forces leading to increasing farm size from Arges, Romania

These reforms aimed to increase agricultural productivity and efficiency by giving farmers ownership rights and the incentive to innovate and invest in their land. However, they also created the highly polarised structure of the agricultural sector that still prevails today. ...

... Big farms from other parts of the country come and win the public auctions, forcing the local farmers to find other solutions for feeding their livestock or give up raising cattle.

4.2.6. Agricultural extensification

The literature review showed that extensification of agriculture since 1990 was mostly driven by policy, consumer preferences and market demands. The gradual decline in extensive farming was more driven by markets and economic variables.

Typical low productive farming practices with high labour input levels have higher costs and are therefore at a disadvantage at agricultural markets. Reductions in livestock because of unprofitable farming were seen in the case studies in West-Ireland, Zuidwest-Drenthe (Netherlands) and Argeş (Romania). Increasing the added value of products, without compromising on ecological or social values, was seen in response to economic pressures in the case study in Siena (Italy).

One of the key drivers for extensification in eastern Europe was the breakdown of socialism in 1989. This triggered a strong decline of capital- and input-intensive farming practices (e.g., lower pesticides and fertiliser applications). Both land reforms, the level and pace of reorganization of agricultural sectors, and state-support for agriculture differed among countries. Intensification occurred in areas highly suitable for farming, and deintensification and cropland contraction occurred in more marginal areas. In the case study in Montana (Bulgaria), a lengthy land restitution process resulted in the conversion of abandoned arable land into pastures.

CAP policy has supported increasing and maintaining low input, organic and HNV farming practices through the set-aside measure and support from Pillar I (Agri-environmental measures and support for Green Infrastructure). This effect was noticed in several case studies (West-Ireland, Montana, Šiaulių apskritis, Siena). EU environmental policy influenced high-nature value farming, which was also seen in the development of nature-friendly agriculture in the case study in Montana.

According to the literature, growing interest among consumers for the mode of production, origin, environmental impacts and animal welfare of their products, opened new opportunities for higher quality products coming from low input traditional farming systems. This effect was observed to lead to an expansion of organic farming or sustainable farming practices in several case studies (Šiaulių apskritis, Imathia, Zuidwest-Drenthe, Siena).

4.3. EU wide data collection on drivers and land use changes

To better understand how the drivers discussed in the former sections influence land use changes, an EU wide quantitative and statistical analysis was also performed. Before this could be done a review of data sources was done, followed by the collection, processing, data gap filling and normalization of the data. The final list of data sources and indicators selected is in Annex 5.

The data sources have then been further processed in the multivariate analysis to understand land use dynamics and the underlying drivers. The results of this multivariate analysis are presented in the next section. The data have also been used for the further trend analysis presented in chapter 5 of this report.

4.4. A summary, multivariate analysis to understand land-use dynamics and the influence of drivers

The present section aims to summarise the main results from the literature review on land-use drivers and the empirical analysis of land-use typologies – corroborated with evidence from case studies (as presented in the previous three sections, 4.1-4.3, of Chapter 4). For this, a Principle Component Analysis (PCA) was carried out on a relatively large sample of indicators covering the study area (Europe as a whole) at a sufficiently detailed spatial resolution coherent with the aims and scope of the empirical exercises mentioned above. More specifically, this paragraph introduces the logical/operational framework

and succinctly illustrates the main results of a summary, multi-dimensional analysis, classifying and ordering statistical units (NUTS 3) at the European regional level (n = 1160 units in 27 member countries). The classification was based on land-use indicators focusing on structural and functional changes in the landscape, with particular emphasis on agricultural landscapes and the socioeconomic reference context. The detailed approach to the PCA and the extensive description of the results is presented in Annex 8. Here only a summary of main conclusions is presented.

From the PCA, 6 components were found representing identified statistically significant patterns of land use dynamics and drivers which are in turn associated with well-defined geographical gradients and socioeconomic conditions. These 6 components are subsequently described and supported by the summary of component scores in Table 6.

Table 6 Average component scores by axis and land-use RALUC class (bold indicates significant average scores per regional type)*

Class	#	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Afforestation	367	0.71	-0.66	0.12	0.36	0.14	0.07
Extensification	45	0.79	0.12	0.48	-0.70	0.27	-0.13
Intensification	162	1.00	0.15	0.11	-0.24	-0.34	-0.82
Nature creation	12	-0.08	0.63	-0.39	-0.55	-0.84	-0.26
Urbanisation	575	-0.81	0.36	-0.14	-0.10	0.00	0.20

* As far as Principal Component Analysis results in terms of RALUC classes, Axis 1 indicates a polarization in regions classified as 'urbanization' and 'intensification', while Axis 2 polarizes regions classified as 'afforestation' against those classified as 'nature creation'. Axes from 3 to 6 indicates specific regional typologies, namely pure 'extensification' (Axis 3), 'extensification' plus 'nature creation' (Axis 4), pure 'nature creation' (Axis 5) and pure 'intensification'. In line with the inherent complexity in land-use changes and landscape patterns in the EU-27, combination of more than one trend in the same principal component confirms the reliability of RALUC classification in five regional typologies.

Component 1: The urban-rural gradient

Component 1 highlights a clear urban-rural gradient, associated with dense settlements and wealth accumulation. In particular, the negative values of Axis 1 were associated with population density, per-capita income, the percentage of built-up areas in the landscape, and the conversion rate of agricultural areas into urban areas - understood as the main reservoir of buildable land. The regions experiencing such dynamics are those entering the European Community most early.

Table 6 specifically reports the average score along Axis 1 (component1) as an indicator of spatial distribution of the five main RALUC type classes. As expected, the regions classified as experiencing 'urbanization' trends in land-use (n = 575) received a substantially negative average score on Component 1 (-0.81), in line with the definition of this axis as reflecting the European rural-urban gradient. Consequently, the regions classified as experiencing 'afforestation' (n = 367), 'extensification' (n = 45), and 'intensification' (n = 162) received positive and similar scores, confirming the polarization in urban and rural locations along this axis. Interestingly, regions classified as 'nature creation' (n = 12) received almost a neutral score (-0.1), on average, likely because of the small sample size and the vast heterogeneity of such land-use dynamics.

The overall increase in settlements, however, was positively associated with Component 1, being in turn linked with the countries that joined the EU later,

which also showed a modest correlation with the growth rate of added value. This indicated accelerated economic dynamics of the 'newcomers' compared with the 'founding' countries of the EU. In this direction (positive values on Axis 1), a high presence of small woody elements in the landscape was also observed, together with the areas of high natural value in rural and agricultural districts, possibly located at greater distances from inner cities (log(Trav)factor).

Component 1 clearly reflects the gradient from the more urbanized and demographically dense areas (negative scores) to rural districts with strong elements of natural landscape (positive scores), generally associated with countries with lower population density and more recently becoming part of the European Community. These places have also shown high anthropogenic pressure in recent years in the face of more stagnant economic growth in the 'founding' countries. It is more evident here how heavily urbanized regions were mainly concentrated in Central and Western Europe, basically in Germany and, with a lesser extent, in France and Italy. Some regions were also classified with similar (negative) scores in Poland, Czech Republic, Denmark and Greece, mostly corresponding to the largest cities, urban agglomerations, and metropolitan regions.

At the country level, the aggregated statistics of component scores (Table 6) confirm the results outlined with the visual scrutiny of the score map (see above). The regions scoring high on the rural side of the gradient are in Bulgaria, Cyprus, Estonia, Hungary, Ireland, Lithuania, and Romania.

Component 2: the agricultural-forest gradient

Component 2 delineates a more subtle land-use gradient based on the geographical polarization in agricultural land (associated with the positive values along Axis 2) and forest land (associated with the negative values along Axis 2) (see Table 6) - see Annex 8 for more detail. The level of remoteness was identified as strictly associated with a high forest cover rate of regions. By contrast, agricultural regions, likely more dynamic from the economic point of view, were predicted to experience a sudden increase in built-up surface areas up to 2050. The percentage of organic farming in the regions was negatively associated with Axis 2 and was thus more frequently observed in areas dominated by forests and natural habitats. The same pattern was observed for the increase in total area covered by trees over a short-term (2015-2018). However, by looking at a larger time window (2000-2020), the most dynamic agricultural regions have experienced a net expansion of total woodland (GLADFor0020). In other words, Component 2 represents the geographical polarization in 'dynamic and advanced agricultural regions' (with a dominant production model based on crop intensity, mechanization and irrigation) and in more peripheral districts dominated by extensive agricultural models with organic farming, farm trees, the prevalence of natural habitats over intense cropland, and a slight expansion of forest land.

The regions at the forest side of the gradient were mainly concentrated in Sweden and, less regularly, in other Northern countries, as well as in Austria, in the surrounding Alpine regions of other countries and more sparsely in mountainous and remote districts of France (Massif Central and Alps), Italy (Alps and Apennines), Germany, Spain (Pyrenees), and Greece. Regions on the agricultural side of the gradient were mainly concentrated in flat and largely

accessible districts of Romania, Hungary, Italy, Atlantic France, Spain, and a small part of Germany where dynamic and intensive farming systems consolidated and possibly expanded in the last two decades.

Component 3: 'Old' vs 'new' Europe: the economic and demographic East-West divide

Component 3 delineates a geographical gradient reflecting the East-West divide and was mostly characterized by a socioeconomic polarization in demographically dense regions, typical of Western Europe, and regions experiencing an above-than-average increase in per-capita income levels in the last two decades, corresponding with the countries accessing more recently to the European Union.

Regions on the 'New' side of the gradient along Axis 3 were indeed mainly concentrated in Eastern Europe (both in the Northern side, e.g. Baltic Republics, and in the Southern side, e.g. Romania and Bulgaria) and Mediterranean-Balkan countries, such as Croatia. Slovenia, showed the same pattern to a lesser extent. Northern countries, such as Finland and Sweden, showed intermediate patterns. Interestingly, few districts – particularly remote but growing rapidly – in Southern Portugal were the only regions classified in the same 'New' side of the gradient. By contrast, the regions on the 'Old' side of the gradient were assigned to remote (or less economically dynamic) regions in the 'founder' countries, such as France (including mostly the Atlantic range of the country), Italy (including all the Southern part of the country) and, more occasionally, Belgium and the Netherlands. Interestingly, similar regions were found more sparsely in remote Spain (Andalusia, Extremadura) and peripheral Greece (Crete).

Component 4: Agroforestry vs extensive cropping systems

Component 4 delineates a subtle land-use gradient with a coherent geographical divide in Western-Northern and Central-Eastern regions. Regions dominated by an above-average share of agricultural land in total landscape, mostly located inland, were associated with the negative part of this axis. These were mostly coastal and especially internal regions across Romania and Bulgaria, but also more sparsely in Germany and Poland. Conversely, regions with a more diversified rural landscape dominated by small woody features and agroforestry, both in terms of average size and gross cover rate in total agricultural area, were classified along the positive side of Axis 4. So, the statistical distribution of component scores document how 'North' and 'Mediterranean' regions received relatively high, positive scores along this Component 4 being, on average, well represented by a latent expansion of agroforest and woody features in their landscapes. By contrast, 'continental' regions seem to be characterized with traditional agricultural systems lacking (or partly lacking) the 'small woody elements' matrix. The countries with the most evident positive scores along Component 4 (so on the agroforestry side of the gradient) were Cyprus, Ireland, the Iberian peninsula, France, part of Italy, Croatia, part of Denmark and, more sparsely, Sweden and Finland.

Component 5: Drylands vs humid climate with woody features/agroforestry

Component 5 delineates a biophysical gradient from drylands to sub-humid lands dominated by mixed agro-forest landscapes (Hungary, Ireland and Luxembourg). Drylands were associated with the negative side of the axis, while

density of agroforest sites more frequently situated inland and received positive component loadings. Concerning RALUC typologies, 'nature creation' was the only trend relatively well characterized along Component 5 (see Table 6) and receiving negative scores on average. The 'Mediterranean' regions of Cyprus, Greece, Malta were most clearly classified along the negative part of the axis, in line with the dominant climate characteristics (toward aridity and drought).

Component 6: Agricultural intensification and solar parks

Component 6 identifies a specific socioeconomic gradient with negative scores assigned to regions experiencing agricultural intensification and sudden expansion of solar power installations and solar parks. Based on RALUC typologies, 'intensification' was the most characteristic land-use trajectory receiving negative scores (-0.82, in Table 6). Additionally, no countries were specifically characterized with significant values of component scores but regions on the negative side of the gradient were concentrated in Southern Spain, Northern Finland, Ireland, Hungary and Estonia. It is likely that, in these regions, their long-term developmental path depends on the specific national policies that leverage investments – and possibly providing subsidies to farmers – for developing solar parks in the agricultural landscape.

5. Land to food, feed, bioenergy and other non-food uses and policy drivers

5.1. Introduction

Central to the bioeconomy is the provision and use of biomass. The concept embodies the notion of transitioning from fossil-based to biobased products and energy across all economic sectors. So, biomass is regarded as a renewable carbon source to replace fossil carbon. In this chapter, information is presented to answer the research question Q1.1: *To what extent have energy use or production in rural areas competed with or synergised with agricultural production in land use? Which have been the main drivers?*

In section 5.2 the land use demands and shifts in land use are presented caused by increased production of bioenergy, including biofuels. In section 5.3 the land demand for the production of solar and wind energy is presented. In section 5.4 an overview is given of changes in the last 30 years in agricultural land use and production in terms of food, feed, energy and other non-food purposes. This is illustrated using a balance sheet describing the different uses of biomass (food, feed, energy, bioeconomy) and their evolution over time.

5.2. Land use changes triggered by renewable energy policy targets and sustainability requirements.

Land use for bioenergy has strongly been driven by the policy targets and sustainability criteria that were implemented between 2003 and 2020. The first EU legislation mentioning the sustainability of bioenergy and aiming to introduce measures to protect related land use came into force in 2003 with the Directive on Biofuels for Transport 2003/30/EC. The Directive required Member States to set indicative targets by 2003 for a minimum proportion of biofuels to be placed on the market: 2% in 2005 and 5.75% in 2010. Member States had to report annually on measures taken to promote biofuels and quantifiable progress. Article 4(2d) included a specific Member State reporting requirement on 'the sustainability of crops used for the production of biofuels, particularly land use, degree of intensity of cultivation, crop rotation and use of pesticides'. This Directive also coincided with the period in which the EU Common Agricultural Policy encouraged farmers to keep some land in "set aside" and not use it to produce agricultural crops. Whilst most farmers left this land fallow, the land could be used to produce feedstocks for bioenergy. When set aside was discontinued in 2008, the area under obligatory set aside amounted to 3.8 Million ha.

In 2007 the European Commission proposed a new energy policy for Europe (Commission of the European Communities, 2007) which was endorsed in that same year by the Member States including:

- a binding 20% target for the overall share of renewable energy in 2020 – the effort to be shared in an appropriate manner between Member States; and
- a binding 10% target for the share of biofuels in petrol and diesel in each Member State in 2020, contingent on 2nd generation technology becoming commercially available and biofuel production being 'sustainable' (Council of the European Union, 2007).

Because of increasing concerns about the sustainability of biofuels, particularly in terms of pressures on land, environment, and biodiversity the European Union introduced sustainability criteria for biofuels for the first time in the Renewable Energy Directive EU 2009/28/EC (REDI) in 2010. The EU introduced mandatory sustainability criteria for liquid biofuels to be counted towards the Directive's renewable transport targets. The sustainability criteria prevent direct land use change (LUC) from highly biodiverse land, high carbon stock lands and peatlands and implement a minimum greenhouse gas (GHG) saving for biofuels, compared to the fossil equivalent. It is the responsibility of Member States to ensure economic operators comply with the sustainability criteria. Note that the ten central and eastern European countries who entered the EU only in 2004 tended to implement support for renewable energy later than those countries who were already in the EU and so did not see significant developments before the implementation of the REDI.

In 2015, the so-called "Indirect Land-Use Change (ILUC) Directive" (EU) 2015/1513 amended the REDI, to ensure that biofuels used in the EU contribute to a more sustainable energy mix, by limiting the amount of food and feed crops that can be used for biofuels and encouraging the use of alternative feedstocks such as wastes and residues. The Directive introduced a cap of maximum 7% on the contribution of biofuels produced from 'food and feed' crops and introduces the concept of low indirect land use change biofuels, which are produced from "additional" feedstock, such as from a yield increase measure or originating from unused land.

With the start of the recast of the Renewable Energy Directive 2018/2001/EC (REDII) in 2020, the sustainability criteria were extended in scope – both in terms of the sustainability criteria and the scope of bioenergy covered by the criteria.

5.2.1. Bioliquids

The review and analysis of data indicate that 3032 kha are estimated to have been used in the EU in 2022 for the production of liquid biofuels. Given that the total UAA was 160 Million ha for EU-27 in 2022, the area share of liquid biofuel is 1.9%. The largest area is estimated to be in France, with 810 kha, followed by Germany (744 kha), Poland (353 kha), and Hungary (239 kha). Figure 16 shows the estimated land use for the cultivation of feedstocks for bioenergy from 1990 – 2022 in the EU.

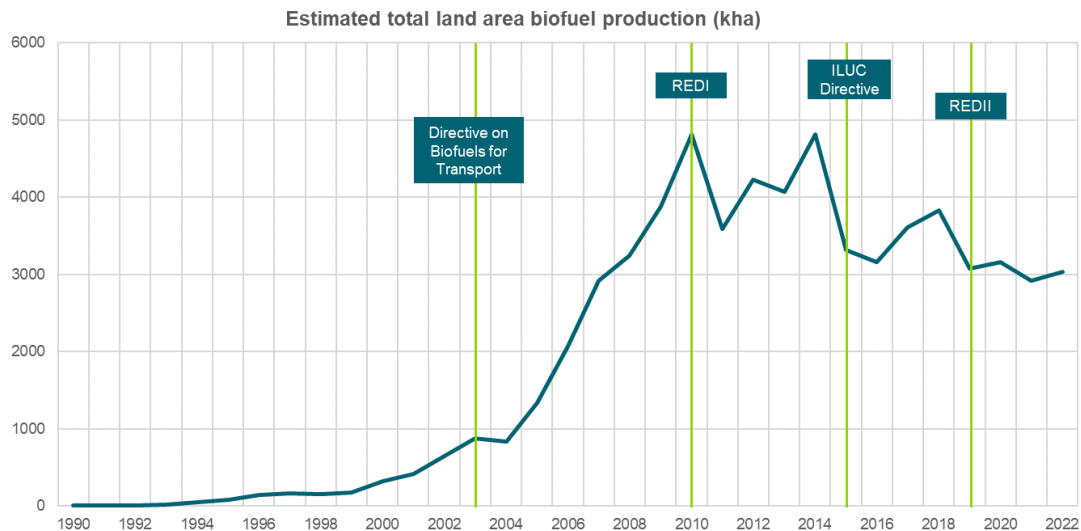


Figure 16 Estimated land use for the cultivation of the feedstock used for domestic liquid biofuel production in the EU from 1990-2022

After the Directive on Biofuels for Transport in 2003, there is an increase visible in the estimated land use for bioliquids. This growth accelerates until 2009-2010, which is when the first Renewable Energy Directive came into account. There is a small dip in 2015 after the introduction of the ILUC Directive, and then we can see the growth line flattens and slightly decreases after 2018-2019 when the REDII became effective.

Figure 17 below provides an overview per 5 years on the development of estimated land use needed in the top 5 Member States. The starting year 1990 is not included in this overview, as only Austria reported domestic production of biodiesel, which amounted to an estimated 5.4 kha. From 1995 onwards, the larger European Member States France and Germany have remained in the top 5. However, as more countries started developing their domestic biofuel production the proportions got more balanced. France, Italy, Germany and Poland remain the largest in estimated land use in this time period. Please note that in this analysis we assumed all biofuel production from crops to be based on domestic produced crops.

Figure 17 Top-5 Member States estimated land use for the cultivation of the feedstock for liquid biofuel production

1995			2000			2005		
MSs	kha	%	MSs	kha	%	MSs	kha	%
France	43	51%	Germany	168	52%	Germany	911	68%
Germany	25	29%	France	91	28%	France	154	11%
Czechia	9	10%	Czechia	49	15%	Czechia	85	6%
Austria	8	10%	Austria	15	5%	Spain	45	3%
						Poland	43	3%
						Slovakia	33	2%
						Austria	27	2%
						Sweden	19	1%
						Italy	11	1%
						Lithuania	10	1%
Total	85 kha		Total	323 kha		Total	1341 kha	

2010			2015			2020		
MSs	kha	%	MSs	kha	%	MSs	kha	%
Germany	1920	40%	Germany	1003	30%	France	685	22%
Finland	580	12%	France	676	20%	Germany	623	20%
France	562	12%	Poland	312	9%	Poland	342	11%
Austria	202	4%	Netherlands	217	7%	Netherlands	192	6%
Poland	194	4%	Finland	192	6%	Finland	182	6%
Belgium	184	4%	Hungary	153	5%	Hungary	173	5%
Czechia	175	4%	Austria	149	4%	Belgium	129	4%
Slovakia	162	3%	Italy	88	3%	Romania	129	4%
Hungary	155	3%	Belgium	74	2%	Sweden	111	4%
Sweden	130	3%	Czechia	70	2%	Austria	104	3%
Total	4811 kha		Total	3317 kha		Total	3161 kha	

5.2.2. Biogas

As previously mentioned, due to the lack of data available on the feedstocks used to produce biogas, it is not possible to give insights and estimates on land use for biogas production per Member State. Germany however does report on the feedstocks used to produce biogas, from 2015-2021. We have therefore focused on estimating the land used for biogas production in Germany (which was also by far the largest biogas producing Member State).

There has been a steep increase in estimated land use for biogas production after the introduction of the Nawaro-Bonus in 2004 until 2015 when the food and feed cap for transport was introduced in the ILUC Directive, see Figure 18. After 2015 there has been a slight growth, however the Directive in combination with the REDII seems to have stabilised the expansion of primary crops for biogas production.

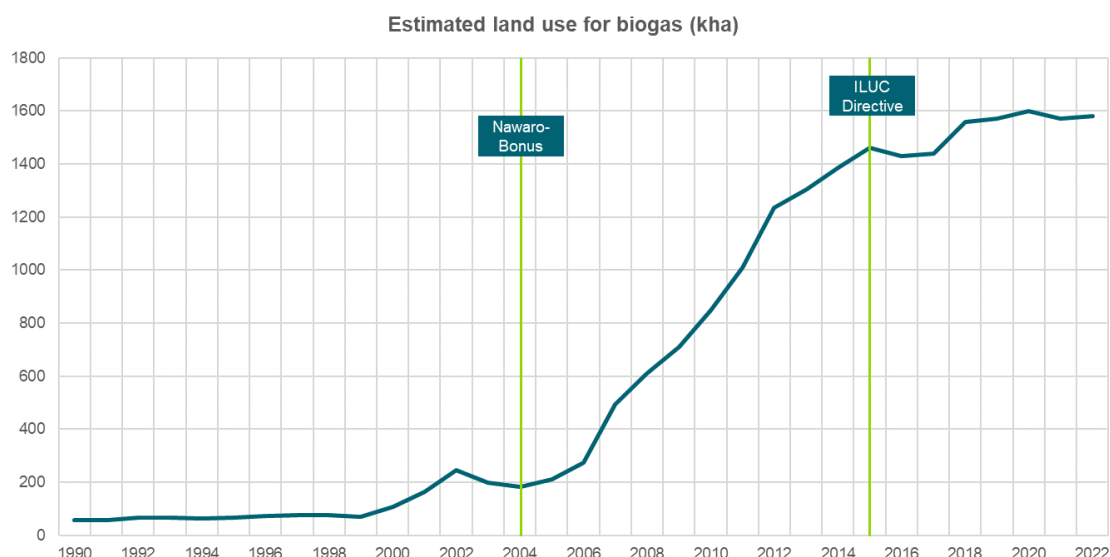


Figure 18 Estimated land use for the cultivation of the feedstock used for domestic biogas production in Germany from 1990 – 2022

5.2.3. Solid/Forest biomass

Member States have to report on the use of solid biomass for the production of bioenergy (in energy content and volume) from 2021 onwards biannually. Land use estimates could therefore only be made for 2021. These estimates are purely indicative, as the Member States report on the use of solid biomass for the production of energy, not on the production of these feedstocks. This is important to note, as certain Member States are likely to be importing or exporting fuelwood¹³ used for energy.

When taking the consumption of fuelwood for energy purposes, Italy has the highest land use estimate required with 221 kha, followed by Finland (163 kha), France (138 kha), Germany (130 kha) and Poland (125 kha) (see Figure 19).

¹³ Roundwood includes both categories Industrial roundwood and Fuelwood

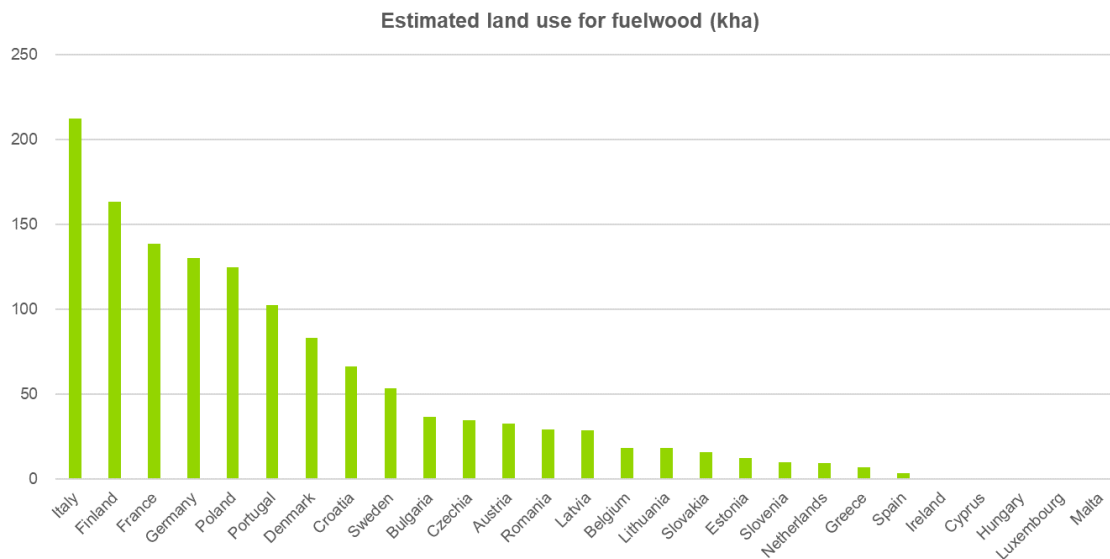


Figure 19 Estimated hectares fuelwood used for energy

Looking at the land area needed in comparison to the current forest of the Member States, Denmark is estimated to require around 13.2%, followed by Croatia (3.4%), Portugal (3.1%), Belgium (2.7%), the Netherlands (2.5%), and Italy (2.2%).

5.3. Land use for renewable energy other than bioenergy

There is currently no EU-wide data regarding Agri-PV spanning the whole time period, as combining PV panels and agricultural activities is a relatively recent development. JRC published the 'Overview of the Potential and Challenges for Agri-Photovoltaics in the European Union' in 2023 that outlines the potential of Agri-PV and compares it to the current total PV capacity of France, Spain, Germany and the Netherlands, it does not provide estimates however of current PV panels on agricultural land. The only data source from which information could be derived on the EU wide spatially explicit presence of wind turbines and PV parks is from the Open Street Map (OSM)¹⁴. From this source data of wind and solar PV could be mapped over Corine Land Cover classes to also determine the position within and outside agricultural land. The results are presented for the EU countries and for the RALUC types in Table 7.

The largest absolute number and highest share of windmills on EU agricultural lands is found in Germany with 41% of all windmills (by number). France has the second largest number with 12% of EU, followed by Spain with 10% of the EU-27 windmills in agricultural lands, then Sweden (9%) and Italy (8%) and Poland (7%). A smaller country with a relatively large capacity and therefore high density in windmills is Netherlands (3% EU windmills in agricultural land).

For PV, the largest absolute area on agricultural land is in Spain with 4142% of the EU PV area on agricultural land in EU-27, followed by Sweden with 12%,

¹⁴ [OpenStreetMap](#)

Germany (128%), Italy (97%), France (7%) and Portugal (7%) by Sweden with 12%, Germany (8%), Italy (7%) and Portugal (7%).

Table 7 Windmills and solar parks in 2020 on agricultural land (so NOT total!) and change trend since 2000 for PV in EU countries (Source: Open Street Map)

MS	Number of windmills on agricultural land	Number windmills outside agricultural land	Sum of Solar_ha_agri	Trend Solar parks (%/ agricultural land 2000)
AT	1 310	195	513	0.02%
BE	846	378	86	0.00%
BG	369	104	2 108	0.04%
CY	12	78	472	0.11%
CZ	209	15	579	0.01%
DE	27 292	3 011	13 384	0.06%
DK	5 588	181	1 488	0.04%
EE	61	108	668	0.05%
EL	162	2 499	4 049	0.08%
ES	6 362	14 784	46 227	0.18%
FI	36	1 023	30	0.00%
FR	7 976	1 293	7 652	0.02%
HR	45	331	100	0.00%
HU	184	16	3 145	0.05%
IE	694	1 901	1 430	0.03%
IT	5 659	2 675	10 034	0.06%
LT	500	16	500	0.01%
LU	75	2	3	0.00%
LV	113	7	47	0.00%
MT	0	3	17	0.10%
NL	1 990	638	4 699	0.19%
PL	4 697	132	4 008	0.02%
PT	265	2 590	7 449	0.17%
RO	1 194	71	1 421	0.01%
SE	1 156	4 192	175	0.00%
SI	4	15	37	0.01%
SK	7	6	268	0.01%
EU-27	66 806	36 264	110 587	0.06%

5.4. Shifts in land use for food, feed, energy and other non-food uses in last 30 years

Between 1990 and 2022 the area of cropland¹⁵ in the EU-27 declined from 120 million hectares to 111 million hectares. Over this same period agricultural production, expressed in dry mass of main product, first increased until 2010 and then started to decline from 2010 onwards. In 1990 it amounted to 488 million ton dry mass to 510 million ton dry mass, excluding residues (see Figure 20). The increase in production is driven by yield increases, but not so much by land increases, at least after 2000 for the whole EU-27. At regional level the situation may be different. In the newer member states of the EU-27 a lot of cropland was brought back into production after entry in the EU, while in other regions agricultural cropland declined.

In 1990 the cropland area share used for food and feed production was almost at the same level at 49% and 50% respectively, while land used for biomass production for energy and other non-food uses did not even amount to 1% (see Figure 21). This distribution changed considerably towards 2022. The food in cropland area share shifted toward 34% in 2022 and this was accompanied by a considerable food production decline from 59 million ton dry mass in 1990 to 45 million ton dry mass in 2022. In the same period the area share for feed production increased to 60% in 2022. In terms of feed production the absolute largest production was reached by 2010 with 327 million ton dry mass feed which then declined towards 304 million ton dry mass in 2022 (see Figure 21).

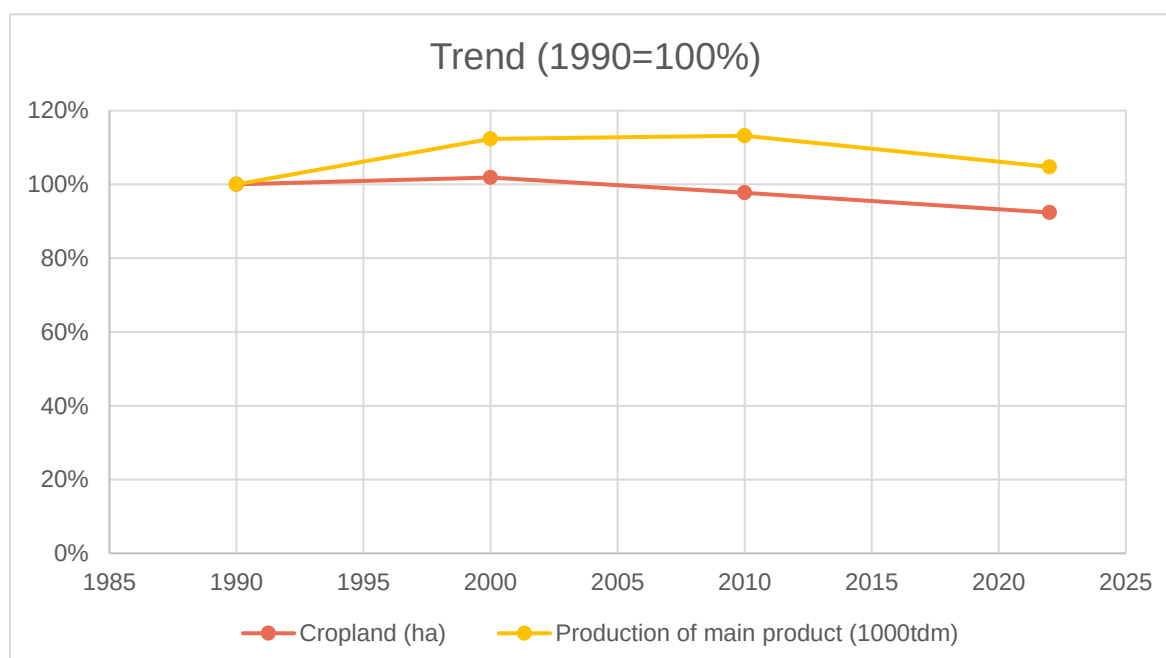


Figure 20 Trend in cropland and agricultural production from cropland (=arable and permanent cropland) (1990=100%)

¹⁵ Cropland refers to the area used for growing arable crops and permanent crops. Permanent grassland areas are not included.

The amount of land used for biomass production for energy increased in this period from 57 thousand hectares in 1990 to almost 5 million in 2010 (see Figure 21). The steep increase in this area is related to a strong increase in land used for production of crops for first generation biofuels and for biogas which was mostly maize based in that period. The Directive on Biofuels for Transport came into force in 2003 and led to an accelerated growth until 2009-2010, which is when the first Renewable Energy Directive came into force. This was followed by a small dip in the agricultural area used for biofuel feedstock in 2015, with the introduction of the ILUC Directive, which capped the use of food and feed crops for biofuels. From then on the area used for biofuel feedstock flattens. The area used for dedicated cropping for energy is now at a good million hectares. In addition, the amount of residues used for energy, mostly straw, amounts to 4.3 million ton dm. The main product produced with this residue still goes to feed and food.

The amount of residues used for feed also increased strongly in the whole period from 64 million ton dm in 1990 to 125 million ton dm in 2022. This use also includes residual biomass use for bedding. Still the use of residues is dominated by livestock production in 2022 with 58% for this purpose, while it is at 40% use for food, 2% for energy and 1% for other non-food purposes. The increase in feed production until 2010 when it starts to gradually level off, although very modestly, seems to have some relationship with EU-27 consumption of meat which seems to stabilise between 2010 and 2022 at around 37 million tons of carcas weight equivalents (DataM commodity flows¹⁶). Production of meat in EU-27 however continues to increase also in the last 12 years according to FAOSTAT data. In total between 1990 and 2022 meat production growth was 16.5% from 36.5 million tons carcas weight in 1990 to 42.5 million tons carcas weight. Since 2010 and 2022 the growth was still 4%. Apparently, the trigger of this recent growth is less driven by domestic consumption, but more by an increased export.

For the EU-27 production and consumption of milk the growth trends are even larger than for meat. For the consumption data of milk, data are only available for 2005 to 2022 (DataM commodity flows¹⁷). In this period domestic use increased by 10% from 97 million tons of milk to 106.5 million tons. Production levels of milk can be derived from FAOSTAT for 1990-2022 and they showed a growth of 13.6%. Between 1990 to 2010 there was a decline of 1% in milk production, but this then turned into a significant growth again between 2010 and 2022 of 14.8%. This growth in milk production seems to be triggered by both increased domestic use and more export of dairy products.

The decline in land used for food production between 1990 and 2010 was clearly related to competition with feed for livestock and biomass production for energy.

¹⁶ [Medium-term Outlook commodity flows](#)

¹⁷ [Medium-term Outlook commodity flows](#)

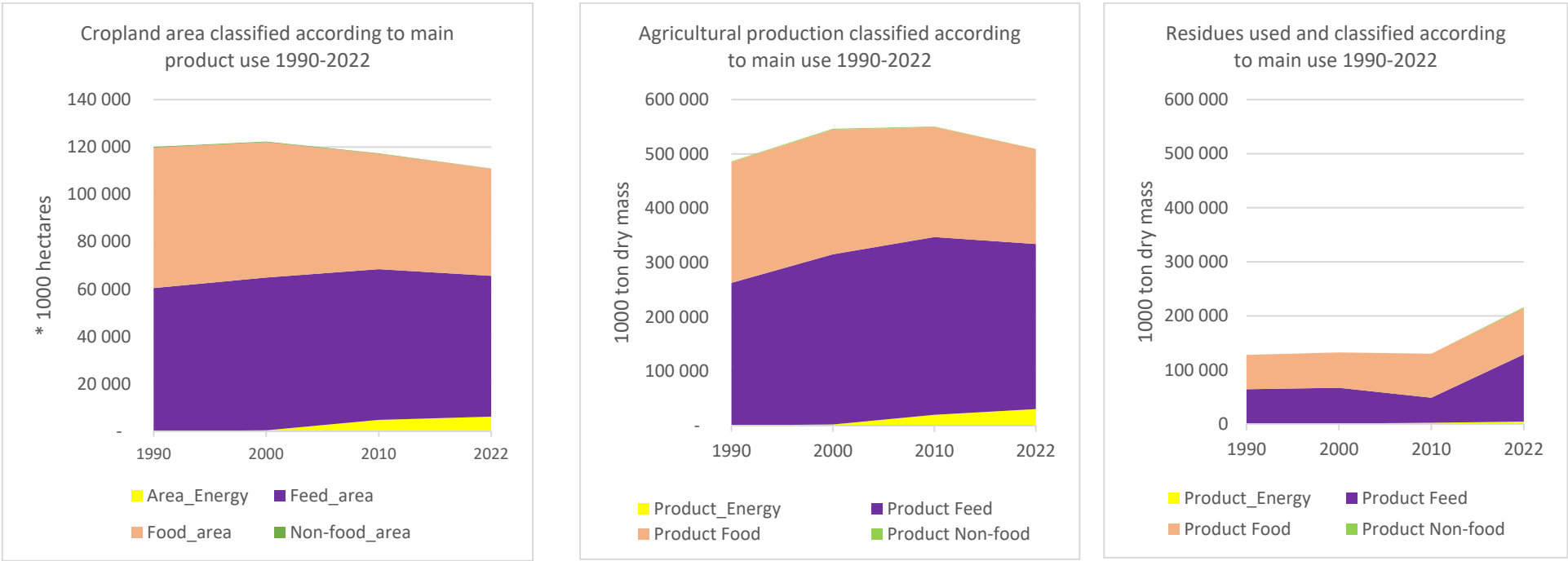


Figure 21 Agricultural cropping area (left, in 1000 ha) and total production main product and residues used (middle and right picture in 1000 ton dry mass) classified according to uses of the primary production for food, feed, energy and other non-food uses 1990-2022 (data source JRC (DataM), FAO, ESTAT, and own elaboration) (

Competition for land between non-food uses, other than for energy, is very small, at least at EU level. The area share does not even reach 1% in the whole period. In 2022 it amounts to 421 thousand hectares with a production of 607 thousand ton dry mass. This is at about one fourth of the non-food production level of 1990. The non-food production mostly involves industrial crops like cotton, flax and hemp which is now recently experiencing an increase again, but in the period between 1990-2022 it mostly declined, because of large declines in cotton area. Non-food uses of residual biomass are practically non-existent until 2010, but after this they start to increase significantly to 1.6 million tons dm.

It should be mentioned however that non-food products like flowers and flower bulbs were not included in the totals of non-food production since data and production volumes in the source data (FAOSTAT and Eurostat) were not specific enough to distinguish these groups of crop areas and production levels. The expectation is however that their area and production volume in tons dm will not be significant at EU-27 level and thus will not change the current non-food totals much. At regional level they can have significant area impact however, such as in certain regions in the Netherlands.

Overall, it can be concluded that land for food production competed with bioenergy production most strongly in the period 2003 to 2010. After 2010 there was still a gradual increase in this land but it was much more modest because of stricter sustainability criteria introduced in the RED from 2015 onwards. Given the dominant position of feed production in EU-27 agricultural land use, it is clear that diets, particularly in relation to animal protein consumption levels have influenced the changes in agricultural land use since 1990.

5.5. Future land use expectations expected from RES targets and transition to a bioeconomy

The demand for biomass for non-food uses is expected to further increase strongly in the future because of the ambitions to decarbonize the fossil intensive sectors, such as energy and chemicals. Residual biomass such as primary residues from agriculture and forests, industrial by-products or organic wastes from households and industries, are seen as the more sustainable biomass feedstocks, particularly because there are no or limited direct and indirect land use effects expected from their use (Overmars et al., 2015; Valin et al., 2015). However, the sustainable supply potential of residual biomass and waste may be limited for the use of residues due to impacts to other uses of the residues or indirect carbon loss in agricultural or forest land (e.g. Valin et al., 2015; Plevin et al. 2015; Pelkmans et al., 2016; OECD, 2018). Furthermore, it is expected that residues and waste sources alone will not be enough to satisfy the expected increases in biomass demands globally (e.g. Valin et al., 2015; Plevin et al. 2015; Materials Economic, 2021). Dedicated crops (not necessarily food or feed crops) will therefore continue to be needed in the future to satisfy the demand for biomass in the transition to a bioeconomy.

These dedicated crops could also be grown in combination with other purposes to reduce impacts on land use. Solar panels can be combined with agriculture (Agri-PV). Another way of growing energy crops with less direct impact on land use would be growing intermediate crops, catch crops or cover crops. These crops are grown in fallow periods in between main crops and should not impact the soil health as not to harm the growth of the main crop. Additionally, growing these types of crops could even improve the soil health by reducing the risk of erosion during fallow periods by covering the soil or bringing/extracting different nutrients to the soil than the main crop would. Chapter 7.3 will further describe possible synergies between renewable energy and agriculture, for example using Agri-PV, wind turbines, intermediate crops or on abandoned or severely degraded land.

However, increasing demand for crops for the biobased industries, including biofuels, will also lead to an additional demand for land, as it already did (see former sections). Particularly the debate surrounding bioenergy, including for biofuels, has become increasingly complex as the world is concerned with issues of food security, climate change, and energy independence. On one hand, biofuels offer a promising alternative to fossil fuels, which are a major contributor to greenhouse gas emissions and climate change. Biofuels also provide an opportunity for countries to reduce their dependence on imported oil, thus increasing their energy security. On the other hand, the production of biofuels has been criticised for its potential impact on food security, environment or indirect effects.

This biofuels debate highlights the need for a balanced approach that takes into account the potential benefits and risks of bioenergy production. Whilst biofuels offer an alternative to fossil fuels, it is important to ensure that their production is sustainable and does not come at the expense of food security or environmental sustainability. Biomass currently represents the largest source of renewable energy in the EU. There are many policies already in place to ensure sustainable production of biomass for bioenergy and prohibit negative land use impacts, such as deforestation or degradation of habitats for the expansion of agricultural land. Some have recently been strengthened or expanded. For example, the recast of the Renewable Energy Directive (REDII) has a food and feed cap in place, to limit the use of fuels in road and rail transport produced from food and feed crops. In the revised REDII, the REDIII, this cap was extended to the whole transport sector including maritime and aviation. Also within the current legislative framework there is an increased focus on stimulating consumption of biomass produced from waste and residues or with no additional land use. There are several more details of bioenergy legislation and its sustainability safeguards covered in the policy framework and further described in Annex 8 and 9.

Electricity generated from wind or solar photovoltaics (PV) can count towards RED targets, however beyond that there is no specific EU-wide policy regarding the integration of photovoltaic systems into agricultural landscapes (Agri-PV). However, the European Commission has launched various Research & Innovation (R&I) initiatives on the potentials of Agri-PV. The Commission has also launched a Solar Energy Strategy, in which it identifies potential barriers and challenges regarding upscaling solar energy. The strategy sets out a target of 730 GW by 2030. To achieve this ambitious goal, approximately 50% of the strategy focuses on implementing solar technologies in agricultural regions as

ground-mounted systems. The Solar Energy Strategy encourages Member States to promote Agri-PV under the implementation of the CAP.

Some Member States give specific support for agri-PV. Currently, 14 Member States have incorporated solar PV under their CAP Strategic Plans. These countries are **Austria, Belgium, Bulgaria, Cyprus, Czech Republic, France, Germany, Ireland, Italy, Luxembourg, Malta, the Netherlands, Spain and Slovenia**. The Agri-PV term was integrated into four Member State Strategic Plans, in Germany, Italy, the Netherlands, and Slovenia. Both German and Italian CAP plans recognise the difference between PV and Agri-PV installations. Germany has defined two categories of Agri-PV, with a cap on 10 to 15% of the farm area for PV panels depending on the type. In France, the legislation only considers Agri-PV in the case where agricultural production remains the main activity of the agricultural parcel and the Agri-PV system must be reversible. Furthermore, the PV-system may only affect the agricultural yield within “acceptable” proportions. The German CAP plan further promotes ‘the installation of elevated PV systems that do not compromise the use of land for agricultural purposes’. Likewise, the Dutch CAP plan promotes Agri-PV, and specifically defines the necessity for PV modules to not change the agricultural function and not to hinder agricultural activities. It also sets criteria for PV module distribution per hectare. The Slovenian CAP plan promotes Agri-PV without including further detail. In 2023, Poland announced an equivalent of €213 M of investments for renewable energy in rural areas, however it is unclear if Agri-PV is included.

6. Scenarios for future land use

6.1. Introduction

This chapter focuses on formulation of the two scenarios for 2050, for which the expected land use changes are modelled and further translated into KPIs. The results of the modelling are discussed in chapter 7. The information derived from the EU-wide and case study (CS) analyses presented in the former chapters is used here to elaborate two scenarios for the future. These two scenarios are strongly driven by the policies of the Green Deal (GD) and Farm to Fork (F2F) package, which are described extensively in Annex 10. The scenarios are also based on the expected drivers identified in the CS that will determine the future land use towards 2050 (see Annex 10 for a description). The policies that drove past land uses are described extensively in Annex 9 and in Annex 11 for the 12 CSs.

6.2. Approach to scenario development in RALUC

Two scenarios are developed in this study to obtain answers to the research questions regarding the future of agricultural land use:

1. **'Business as Usual' ('BAU') scenario:** assumes further extrapolation of trends from the past and is also based on policies in the past (CAP until 2021). In this scenario current trends of drivers of demographic developments, urban sprawl, climate change, land degradation, land abandonment, intensification, extensification, diets, are forecast and no policy targets are set to change or mitigate them.
2. **'Sustainable Agriculture' ('SA') scenario:** assumes that policy drivers are expected to be brought in line with the Green Deal and the Farm to Fork strategy and that all associated targets are met. Drivers that are not (in)directly influenced by policy are considered exogenous and estimated similar to the BAU scenario.

These two scenarios can be positioned along two axes of future developments (see Figure 22):

- The **horizontal axis** refers to the capacity of rural territories to respond to the EU policy targets for the Green Deal and the Farm to Fork strategy (F2F). It is the carrying capacity of the regions that can turn all land use demands and dynamics in a direction that provide as much as possible the synergies between agricultural activities and other land use demands.
- The **vertical axis** refers to the capacity of the political system to develop and implement the policies directed to the achievement of the goals of the F2F, the overall Green Deal goals of climate neutrality in 2050 and the goals of reaching the renewable energy targets and a more circular society as described in the chapter 5 on future policy ambitions.

The narratives of the scenarios are presented below, providing details of the main drivers of land use changes and the outcomes by 2050 that are foreseen through the (lack of) policy implementation in every scenario.

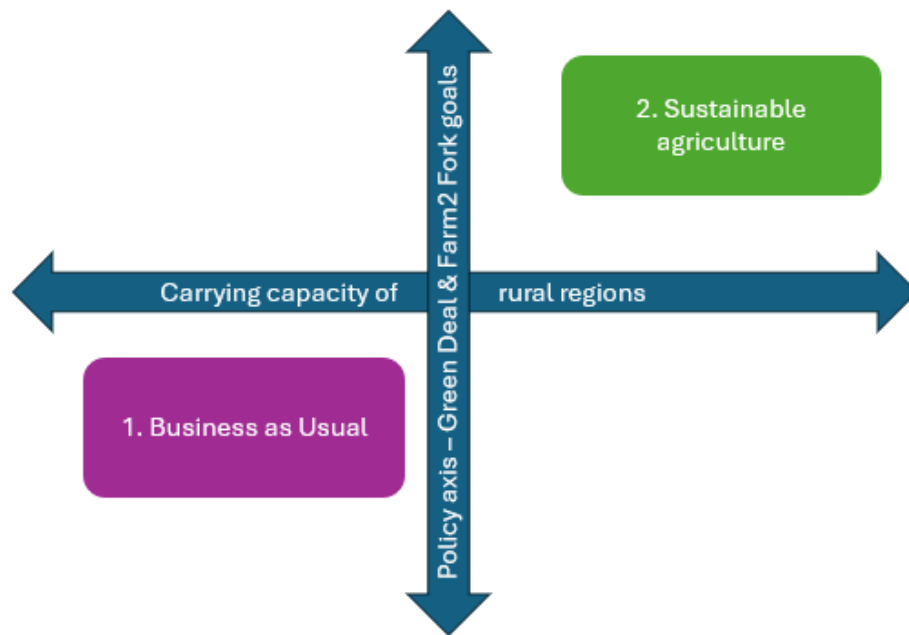


Figure 22 Positioning of the two scenarios along the policy and the carrying capacity axes

6.3. The Business as Usual (BAU) scenario

In the '*Business as Usual*' ('BAU') scenario, current trends of drivers of urban sprawl, climate change, land degradation, land abandonment, intensification, extensification diets, are expected to continue, while CAP 2023-2027, Farm to Fork and wider Green Deal policy goals are not in place.

This scenario strongly follows the narrative of scenario 4 'Do what is unavoidable' for the EU Bioeconomy in 2050 that was developed by an EU expert group and published in Fritsche et al. (2023). In this scenario, like in the BAU in this study, there is a lack of proactive measures by policy makers at EU, national and regional levels to address the many challenges of rural areas related to climate change, loss of biodiversity, water, air, soil quality and resilience and negative demographic changes, loss of services and jobs. Generally, the past policies up to 2021 continue to be in place, and new policy measures are only taken when they cannot be avoided.

The population and local authorities in rural regions are responding to local challenges to the level their carrying capacity allows them to do so. This is very much influenced by the current demographic status and trends in place, such as population density, trend in population numbers and in distribution over age groups, GDP per capita, employment and unemployment rate, diversity and composition of the economic sectors, relative location, intensity of climate change impacts and cultural and natural attractiveness of the region. This local authority and population response is not proactively supported at national or EU level other than by the policies and funds in place up to 2021. There is an overall

lack of long-term vision and the 'short-term visions generate the winners and losers' (Fritsche et al., 2023) in the rural society.

The demographic developments follow the trend as predicted by Eurostat for 2050¹⁸. However, there is lack of local initiatives to enhance a more even population and services distribution, stop land abandonment in certain places, prevent fast land take by built-up areas and attract migrants to rural areas to ensure the presence of sufficient labour to maintain more labour-intensive agricultural activities.

Technological developments continue, certainly in the field of digital, life science and energy technologies but they are more driven by market pressures and societal interests than by government innovation policy and stimulation. Because of the lack of government support and long-term vision, technology and innovation development are not sufficiently directed to main societal needs and challenges. Innovations and technological developments are therefore not necessarily having positive trade-offs on environment and biodiversity or advancing on circularity, climate neutrality and just transitions.

Lifestyles become less healthy, and this implies that the diets remain largely unchanged. Within the EU, there are no important shifts in demand for vegetal and animal proteins (protein transition), while at global level the nutrition transition even continues towards more animal protein consumption, at the expense of plant-based proteins (e.g. population and income growth in especially BRIC countries). Also, the markets for organic products and more healthy foods stagnate. The majority share of agricultural production remains linked to the mass food markets, driven by global competition and the dominant influence of the retail sector on farming prices.

Climate change mitigation measures continue but at a slow pace, leading to a fast continuation of global temperature rise (possibly up to 3.5 °C by 2100). The GHG mitigation measures are not effective because they are not very ambitious, while measures to adapt to increasing climate change impacts, are increasingly needed. The latter leads to an even higher consumption of (mostly fossil based) energy sources. For example, because of extreme drought events, more agricultural areas need to be irrigated and there is an increasing energy demand for desalinisation installations and cooling. The agricultural contribution to mitigating GHG emissions through using agricultural land and soils as carbon sinks is limited since measures to improve soil health and transition to new cropping systems building up more below and above ground biomass remain undeveloped.

Ambitions to develop more renewable energy sources continue but at a slow rate and are mostly focussed on electricity and heat supply, while decarbonisation of the transport sector is slow. Fossil demands continue at the same level because of increasing energy consumption world-wide and the advantage in price level as compared to the renewable alternatives.

¹⁸ https://ec.europa.eu/eurostat/cache/metadata/Annexes/proj_19n_esms_an_26.pdf

Policy stimulation and regulation to address environmental challenges is in place but is not intensified as compared to the 2020 situation. In combination with the increases in climate change and resulting extreme weather events, it implies that environmental problems related to soil health, biodiversity degradation, increased fire risks continue and even worsen in the most sensitive rural regions.

For the farming sector in the EU all these trends lead to a continuation of the restructuring of this sector towards further consolidation into larger farms, specialisation, and investments in technologies to increase efficiency further where possible. The abandonment of agriculture in the more marginal¹⁹ areas of Europe and the reduction of small and medium size farms continues.

6.4. The Sustainable Agriculture (SA) scenario

In the '**Sustainable Agriculture**' ('SA') scenario (policy) drivers are expected to be brought in line with the Green Deal and the Farm to Fork strategy and all targets are expected to be met.

This scenario strongly follows the narratives of scenarios 1 'Do it for us' and 2 'Do it together' that were developed by an EU expert group and published in Fritsche et al. (2023). This implies that in the SA scenario there is a clear proactive policy at the level of EU, national and most regional levels to address the many challenges of rural areas. The goals set in the Green Deal, the Farm to Fork strategy, the Soil Monitoring and Resilience Law (SMRL), the Nature Restoration Law (NRL) and the Renewable Energy Directive (RED III) are met (see Chapter 5 for detailed policy goals). Furthermore, the transition to a more circular society advances well, leading to increased resource efficiency and decarbonisation.

The population and local authorities in rural regions are responding to local challenges to the level their carrying capacity allows them to do so, and are well supported in this process by national and EU policies, incentives, and funds to also implement more long-term visions and ambitions. Again, like in BAU this is much influenced by the demographic trends in place, such as population density, trend in population number and in distribution over age groups, GDP per capita, employment and unemployment rate, diversity and composition of the economic sectors, relative location, intensity of climate change impacts and cultural and natural attractiveness of the region. However, in this SA scenario the regional level authorities, with more support from national and EU authorities, have access to more financial means and policy support and regulation instruments to direct local land use towards a more synergistic outcome between all land use sectors. This is an optimistic assumption, but it will have more positive trade-offs between agriculture, environment, and local socio-economic developments. The Green Deal ambitions and the Farm to Fork will increase payments and technological development stimulation for sustainable and more circular bioeconomic and just rural development.

¹⁹ <https://storymaps.arcgis.com/stories/e57736ed9b9e4458b00356173edc00d6>

Like in the BAU, the demographic developments follow the trend as predicted by Eurostat for 2050²⁰. However, local initiatives are in a better position than in the BAU scenario, to enhance a more even population and services distribution, stop land abandonment in certain places, prevent fast land take by built-up areas and attract migrants to rural areas to ensure the presence of sufficient labour to maintain more labour-intensive agricultural activities.

Also, the societal support and related willingness of EU consumers in this transition to a more climate neutral and circular society is different from that in the BAU scenario. According to Fritsche et al. (2023) 'confidence in the EU green policies has convinced a growing share of EU citizens that green policies are worth higher prices, and they are willing to pay for higher quality'. The combination of policies, mostly in Farm to Fork, forcing and supporting agriculture to introduce more sustainable agricultural practices is also supported by changing markets. The stimulation of organic and other sustainable farming practices goes together with an increasing share of consumers willing to buy these products even though prices are higher. Also, lifestyles become healthier, implying shifts by more people towards more healthy diets and shifting demands for more vegetal and less animal proteins (protein transition) in the EU. In some parts in the rest of the world a similar trend in diets is followed while in other parts the animal protein consumption continues to increase. Because of increased participation of EU consumers to follow healthy diets and pay higher prices for good quality food, there is also more room for short supply chains for local food products, breaking more strongly the dominant influence of the retail sectors on farm product prices.

Technological developments are strongly supported and directed toward 'green' technologies as described by Fritsche et al. (2023) as development strongly driven by principles of circularity in the sense that flows of materials are coordinated well between firms and advanced management models, very high recycling rates and focus on biotechnological developments such as precision fermentation, electrification, and the use of advanced biofuels. The innovations will on the one hand bring 'a profound restructuring of farming and of the food system, with increasing concentration and supply chain integration'. On the other hand, it also creates more room for local short chain supply of food and interest for locally produced food products.

Climate change mitigation measures are implemented widely in all sectors of the economy in combination with a faster transition to a more circular society. This implies that a 55% reduction of GHG emissions compared to 1990 is realised and climate neutrality in 2050 is achieved. The global warming level is expected to remain under 2 °C by 2100. Furthermore, measures are realised to adapt to climate change effects in rural regions and to measures that do not have negative trade-offs in terms of increased water consumption and consumption of fossil energy resources.

Ambitions to develop more renewable energy sources go much faster than in the BAU. They follow the most ambitious targets for renewable energy in the National Energy and Climate Plans (NECPs) of all EU MSs. Also, decarbonisation

²⁰ https://ec.europa.eu/eurostat/cache/metadata/Annexes/proj_19n_esms_an_26.pdf

of the transport sector is much more effective in this scenario, but requiring high shares of biomass based fuels, mostly from residues and advanced (lignocellulosic) biomass as conventional (first generation) biofuels are phased out. The biobased chemicals, plastics and biomaterial industries grow strongly at the same time advancing on the phase-out of fossil resources. This together puts more pressure on biomass resources which enhances the cascading use of biomass resources, the mobilisation of unused residual streams and creates more business models for farmers to focus on sustainable intensification practices to produce additional biomass for non-food through the introduction of intermediate crops and the production of dedicated crops on more marginal lands which would - in the BAU scenario - become abandoned. Also, the production of biomethane linked to animal farming will increase significantly mostly based on mono-digestion of manure. In Fritsche et al. (2023) an increase of biomethane production of 75% between now and 2050 is expected, together with a market increase for digestate of 67%. Also grass biorefineries will increase, generating a multitude of biochemical building blocks and also bioenergy based on grassland cuttings from land that is increasingly abandoned by livestock farming activities, given the protein transition caused by changing diets. More biomass mobilisation and production in the agricultural sector is also necessary in this scenario as it releases the pressure on forest resources which are more under pressure in this scenario and are likely to lead to a potential reduction in forest carbon stock, according to Fritsche et al. (2023).

Policy stimulation and regulations to address environmental challenges and reaching the Farm to Fork goals and NRL goals are intensified, addressing soil health, lowering pesticides and artificial fertiliser use, increasing organic farming area and reaching biodiversity restoration. To reach all these goals, the pressure on agricultural land will increase and it will be challenging to keep agricultural production at the same level as in 2020. For example, the Farm to Fork goals for organic farming and lowering pesticide and artificial fertiliser inputs will lower yields and to keep agricultural production stable will require an increase in farmland. For nature restoration there is a need to increase protected nature in certain places, which may sometimes lead to a reduction in agricultural land but very often to a new combination of (extensive) farming with nature conservation. NRL may also require an increase in trees and landscape elements in certain farming areas and also the restoration of peatlands. These NRL measures may go together with some reduction in farmland in certain regions. Beside these effects which may lead to lower farm production either through reduction of farmland and/or yields, there is also more demand for non-food biomass which will also need to come from agriculture through residue use, sustainable intensification practices, but also through dedicated crops produced on more marginal²¹ land. Therefore agricultural land abandonment in this scenario will be much smaller than in the BAU scenario, provided the right policy and market incentives fall in place.

For the farming sector in the EU all these trends will - like in the BAU scenario - lead to a continuation of the restructuring of this sector towards further consolidation into larger farms, specialisation, and investments in technologies, including for example precision fermentation. At the same time, there will be more market and policy incentives to also keep and increase traditional and

²¹ <https://storymaps.arcgis.com/stories/e57736ed9b9e4458b00356173edc00d6>

sustainable farming practices serving more local niche markets for high quality local and organic products. Land uses will also change significantly, because of new diets leading to significant changes in vegetal protein production going together with declines in livestock production, which is both driven by the markets, but also by the Farm to Fork policy requirements for lower fertiliser losses and NRL requirements for reduction of exceedance levels of nitrate critical loads in protected habitats.

7. Directions of change in agricultural land use towards 2050

7.1. Scenario results iCLUE 2050 in BAU and SA scenario

Changes in future land use work out differently per scenario as will be illustrated in this section. Overall we see that in the Sustainable Agriculture (SA) scenario in which all F2F policy goals are reached, agricultural land use will decline only marginally as compared to 2020 levels (see Annex 12, Tables 26 and 27). This requires serious efforts in terms of policy implementation, but in the SA scenario it is assumed that regions will have the carrying capacity to do so. However, to which extend this expectation applies will be further discussed in section 7.4.

The first outcome of the scenario modelling with iCLUE is that in the SA scenario, by 2050, farmland area loss can be limited to 634 700 ha while, if no active policy interventions take place as modelled in the BAU scenario, the decline will be more than 8 million ha (see Annex 12, Figure 30 and tables 29 and 30). The large decline in agricultural land accompanies a larger increase in urban land. This is because the EU Soil Monitoring and Resilience Law goal of zero urban land take by 2050 is not addressed in the BAU scenario. Because of this, the built-up area can increase in the BAU scenario between 2020 and 2050 by 3.6 million ha (0.9% of the land area) while this is limited to almost 2 million ha (0.5% of the land area) in the SA scenario (see Annex 12, Figure 31 and Table 26). In the BAU scenario, this comes more often at the expense of agricultural land which is most prominently in highly urbanized regions of Belgium, Netherlands, Germany, Northern-Italy and Portugal (see Annex 12, Figure 31).

On average, in the BAU scenario, in the whole EU-27 the agricultural area loss will amount to 4.2% of the agricultural land area in 2020, but above average losses are expected in countries like Malta (57% of agricultural land area), Luxembourg (12%), Italy (9.2%), Finland (9%), Portugal (7%), Czech Republic (7%), Germany (6%), Slovakia (6%), Croatia (5%), Belgium (5%), France (5%) and Austria (5%). Increases in farmland in the BAU scenario are also expected in Sweden (4%), Ireland (1.5%), Lithuania (1%) and Latvia (1%). In the SA scenario the farmland loss for the EU-27 can remain at 0.3% of the agricultural land area in 2020. Still the picture is very different in the countries with large increases in agricultural lands recorded in Latvia (16%), Lithuania (12.5%), Estonia (10%), while losses remain in many countries, but not as large as in the BAU. For example, Italy records a loss of 4.1% instead of 9.2% in BAU, in Belgium it becomes 1.6% instead of 5.4%, Bulgaria gets an increase of 1.7% instead of loss of 4.4%, Germany goes to increase by 1.4% instead of a loss of 5.6%, France goes to 0.1% loss and Croatia to 1.2% gain in agricultural land. There are also countries showing a larger farmland loss in the SA scenario then in the BAU and these are Slovenia (11% of agricultural land area loss in SA and 2.9% loss in BAU) and Sweden (1.8% of land area loss in SA and 4.3% gain in BAU). There are different factors behind it but the main is forest area increases at the expense of farmland (See Annex 12, Tables 29 and 30).

At environmental zone level one can expect the largest loss in agricultural land in the BAU scenario in the Alpine zone (5.5% of land area loss), followed by the Mediterranean zone (4.8% of land area) and Continental zone (4.5% of land area) (see Annex 12, Figure 32). The Northern region (Baltics and Scandinavia) will practically experience no decline in farmland in the BAU. In the SA scenario losses will be much smaller but the Mediterranean will still lose 2.3% of agricultural area, while the North and Continental will even show gains of 3.7% and 0.7% of the land area respectively. One factor, amongst others, causing this continuation of farmland decline in the Mediterranean and farmland increase in the North, is climate change. It leads to lower precipitation levels in the Mediterranean but also longer growing season towards the North.

At RALUC type level it becomes clear that the largest losses in agricultural area are recorded in the Afforestation types and some Urbanisation types (U1C and U1a) (see Annex 12, Tables 31 and 32). This is more pronounced in the BAU scenario, but also applies to the SA scenario, although losses in agricultural land are generally lower in this scenario in most of the RALUC regions. In most Afforestation types the higher agricultural area losses also go together with relatively stronger increases in forest area and sometimes also in built-up areas. In the Urbanisation types that experience relatively higher farmland losses, there is also relatively higher built-up area increases. The Intensification and Extensification types experience generally lower farmland losses, especially in the SA scenario. These also go together with relatively modest increases in built-up area and forest areas.

The largest built-up area increases in the BAU scenario are recorded not surprisingly in Malta (40% of land area). Strongly above EU-27 average increases in built-up land are also expected in the BAU scenario in Belgium (2.1% of land area), Romania (1.6%), Czech Republic (1.5%), Italy (1.5%), Portugal (1.3%), Spain (1.2%), Netherlands (1.2%), Slovenia (1.2%), Greece (1.1%) and Hungary (1.1%). In the SA scenario the additional built-up area development between 2020 and 2050 can be kept far below the 1% land area share with the exception of Malta (31% of land area), Belgium (1.2%) and Netherlands (1%).

The amount of agricultural land converted to urban between 2020 and 2050 is 2.3 Million ha, while this can be 1.4 million with the implementation of the zero land take measure through the soil monitoring and resilience law in the SA scenario (see Annex 12, Tables 31 and 32).

In the BAU scenario, the change in agricultural land goes together BAU with an increase in forest and shrubland area. This is caused by the fact that more agricultural land, which becomes abandoned by agriculture, converts to mostly (unmanaged) forest land and little or no unmanaged and formerly abandoned agricultural lands covered with trees are turned back to agricultural use (see Annex 12, Tables 31 and 32). The opposite happens in the SA scenario. Because of this high agricultural land abandonment in the BAU, the area covered by trees increases by an extra 5.8 million ha while this is limited to 1.4 million ha in the SA scenario, leading to a forest area increase of 3.4% in BAU and only 0.8% in SA scenario.

The Environmental zone with the largest relative forest area increase in the BAU scenario is the Atlantic (5.1%), followed by the Mediterranean (4.8%) zone. In the SA scenario the largest relative increase is found in the North (2.6%), while the largest loss is in the Continental (-2.1%). The latter is no surprise since in the SA scenario more abandoned farmland is brought back to agricultural management in places where it became abandoned after the fall of the communist system. Basically it is a trend that was already ongoing in many former communist countries because of the entry into the EU and the introduction of the CAP. This trend of bringing back agricultural lands into production again can be expected to be stronger in the SA scenario, while in the BAU this is likely to stop or even reverse. This becomes clear if we look at the country level trends in forest area development between 2020 and 2050 (Annex 12, Tables 26 and 27). In the BAU the largest relative increase in forest area is in Luxembourg (15%), Italy (9%), Portugal (8%), Czech Republic (6.5%) and Germany (6%). There are also countries with Forest area losses such as Malta (-90%), Ireland (-5%), Hungary (-1%) and Denmark (-1%). As mentioned before this forest area increase often concerns agricultural land becoming abandoned and grown over with trees.

In the SA scenario the losses in forest area are differently distributed over countries because of many different policy interventions. The strongest losses in forest area are found in Lithuania (-6%), Latvia (-6%), Poland (-3%), Germany (-3%), Hungary (3%) and Croatia (-2.5%). There are also several countries showing increases in forest area which are not necessarily the same as those expecting an increase in the BAU scenario. The largest increases are found in Sweden (5%) and Slovenia (4.5%), Italy (3.5%), Finland (3.5%), Spain (3%) and Greece (2%).

The shrubland vegetation amounts to 29.4 million ha in 2020 and in the SA scenario it will decrease by 3.2 million ha by 2050, while this decline will be limited to 1.3 million ha in the BAU scenario. Declines in shrubland in both scenarios are mostly taking place in unmanaged shrubland. In the SA scenario these are either converted (back) to agricultural use or built-up areas, while in the BAU scenario it is more related to conversions to built-up areas and forests (see Annex 12, Table 32).

Changes expected within agricultural land

The shifts in land use within agricultural land between 2020 and 2050 for the SA and BAU scenarios are presented at country level (Annex 8, tables A8-5 and A8-6) and at RALUC type level (Annex 12, Tables 30 and 31). As mentioned, at EU level between 2020 and 2050 in the BAU scenario a decline in agricultural area can be expected of 8.2 Million ha, which is a 4.2% decrease of agricultural land compared to 2020. In the SA scenario it is expected that this decline can be limited to 0.6 Million ha (-0.3% loss in agricultural land).

The decrease in agricultural land in the BAU scenario is largely caused by an overall decline in annual crops as these will decrease by 7 Million ha between 2020 and 2050. The share of annual crops in farmland will still remain at 47% though and this was 48% in 2020. Also, the grazed grasslands and pastures will decline in this scenario by 1.7 Million ha as will the agroforestry and rough grazing areas by 0.6 Million ha. These declines are only partly related to an increase in perennial cropping area which will increase by 1.2 Million ha. In total

this results in a net loss of agricultural land of 8.2 Million ha between 2020 and 2050 in the BAU.

In the SA scenario there is practically no farmland loss between 2020 and 2050 at EU level, although this is different between countries and regions. This also goes with a large decline in annual crops which is largely compensated for by a large increase in the perennial crop area. The loss in annuals amounts to 7.9 Million ha, shifting the share of annuals in agricultural land from 48% in 2020 to 44% in 2050. In addition, there will also be a strong decline in grazed grasslands and pastures of 4.3 Million ha and of agroforestry and rough grazing land of 3.6 Million ha. The large loss in annuals and the other categories is almost completely compensated for by a steep increase in perennials of 15 million ha at EU level. The perennial area share in agricultural land will therefore shift from 8% in 2020 to 16% in 2050. Shifts towards less annuals and more perennials are seen in both the BAU and the SA, so it is a trend expected as already modelled in the baseline of the CAPRI model, the basis for the BAU scenario in this study. In the SA scenario the shift towards more perennials and less annuals is however more pronounced for the policy and agricultural resilience goals incorporated in the SA scenario. Firstly, the goal for agriculture to become more resilient to climate change which implies that lower water demanding crops are introduced, particularly in regions most strongly hit by droughts. After all, in the perennial group there are more crops with relatively lower water demands, e.g. olives, nuts, biomass crops. Secondly, because in the SA scenario water quality challenges in relation to nitrates and nature restoration goals, such as nitrogen load exceedance are addressed by lowering the livestock numbers in certain regions. Together with this decrease in livestock it is expected that because of lifestyle changes there is more demand for vegetal proteins shifting land use from feed and fodder more to oil crops and fruits and vegetables.

In the BAU scenario the largest decline is in Malta. But when focusing on the largest absolute and relative declines in annuals they are found in Portugal (-70%), Greece (-25%), Austria (-19%), Finland (-16%), Poland (-13%), Slovakia (-11%), Spain (-10%), Italy (-10%) and Czech Republic (-10%). There are also countries gaining annual cropping area. These are Estonia (16%), Lithuania (8%), Latvia (6%), Belgium (4%) and Denmark (2%). In the SA scenario the trends are the same, but the losses and gains are higher (see Annex 12, Tables 30 and 31).

The crop group that makes up the largest share of annuals is cereals and their share in farmland will decline from 28% in 2020 to 27% in the BAU and 25% in the SA scenario (see Annex 15). The maize area share will remain stable for the BAU at 12% in 2050, the same EU-27 level area share as in 2020, and will decrease to 11% in the SA scenario. Root crops will remain relatively stable at EU level (see Annex 15) Other annual crops, in which all other annual crops such as oil crops are included, will increase in SA and decline in BAU. These shifts are not as influential because the total area share of this group of crops is relatively small in comparison to the cereals and maize groups (see Annex 15). At country level the shifts in crop groups can be more extreme. For example, root crops cover relatively large areas in Belgium, Netherlands, Germany and Poland and towards 2050 their area shares grow in these countries and most strongly in the SA scenario. The area of cereals will decline towards

2050 in most countries, at least in relative area shares, but there are also exceptions where large increases are expected such as in the Baltic states, and this increase is larger in the BAU than in the SA scenario. (Grain)Maize area will generally decrease in almost all countries, but there are some exceptions such as Belgium, Cyprus, Netherlands and Slovenia. There seems to be a trend towards further specialization and this may also be an outcome of the iCLUE modelling which find this crop the most economic in these places in comparison to other annual crop land uses.

Perennials increase both in BAU and in SA, although in SA scenario the increase is considerably higher from 8.4% in 2020 to 16.2% of the agricultural area (see Annex 12, Figure 34). In the BAU this increase is only from 8.4% to 9.4%. Although the overall trend in BAU is towards a mild to considerable increase in perennials in almost all countries, there are also countries showing a negative trend like in Malta (-92%), Ireland (-35%), Luxembourg (-23%) and Cyprus (-6%). In the SA scenario there is generally a more than doubling of the perennial area, but there are countries with even higher increases like Poland (398%), Denmark (313%), Germany (307%), Slovakia (292%), Hungary (284%), Netherlands (274%), Bulgaria (207%), Romania (206%), Austria (196%), Czech Republic (192%) and Belgium (161%). There are also countries where perennials decrease even in the SA scenario and these are Ireland, Latvia and Lithuania. These are the same countries where annuals continue to increase both in BAU and SA scenarios because this annual land use remains to have a competing advantage in these countries according to both CAPRI and also iCLUE modelling.

Within the perennials, shifts in crops are generally larger between 2020 and 2050 for the SA scenario than for the BAU. It is especially the other perennial crop group that shows large increases in all EU countries. This is because of the larger protein transition in the SA scenario in which there is more room for fruit and nut trees and also dedicated perennial crops for non-food purposes on marginal lands no longer in demand for food production.

Productive use of grasslands, pastures and also rough grazing lands decreases in both the BAU and SA scenarios, but this does not apply to all countries (see Annex 12, Figure 35). Countries that show relatively large declines in grazed grassland and pastures in the BAU scenario are Slovenia (-22%), Denmark (-22%), Greece (-17%), Belgium (-16%), Bulgaria (-15%) and Italy (-11%). These countries are also the ones with the strongest downward trends in the SA scenario, but their trend is even more negative. However, strong gains in grazed grasslands and pastures are also found in the BAU scenario like in Portugal that shows a significant increase in grazing land (17%). More modest but positive trends are also seen in Cyprus, Czech Republic and Slovakia.

In the SA scenario there is a much larger downward trend of grazed uses which are related to the overall downward trend in livestock production and a transition to more vegetal protein production in this scenario. The countries showing a decrease in the BAU are generally also showing a (larger) decrease in grazed grasslands and pastures in the SA scenario. There are also several countries with a steep decline in land used by livestock systems in SA while in the BAU there is no or only a modest decline such as Hungary (-20%) and Sweden (-54%), Netherlands (-13%), Poland (-15%), Spain (-15%). The only countries where grazed grasslands and pastures increase in the SA scenario are

the three Baltic States. Grazing systems had practically disappeared in these countries, but with the F2F ambition of increasing the organic farmland share, there is a need to also develop the livestock sector again to ensure there is enough organic manure from local sources.

When the focus is on land use change patterns in RALUC types (see Annex 12, Tables 32 and 33) it becomes clear that most Afforestation types are experiencing the largest losses in annuals both in the BAU and the SA scenarios. The opposite is true for the Extensification, Intensification and Nature RALUC types that mostly show modest declines in annual crops. In the Urban RALUC types the picture is more diverse with both high and moderate losses in annuals. In the SA scenario there is an overall higher level of decline in annual crops than in the BAU scenario.

As to the changes in perennials, one can see that in the SA scenario they increase in all RALUC types, with exceptionally high growth levels in type A2d, which is mostly concentrated in Poland, Romania, Bulgaria and Hungary, and in type I2c, mostly found in Germany. In the BAU scenario in almost all RALUC types the trend is also towards an increase in perennials, but the level is more modest than in the SA scenario. There are however three RALUC types that show negative growth in perennial area in BAU and these are A3b, mostly located in Finland, E1a, mostly in Ireland and I2a, mostly located in Southern Germany, Northern Spain and Northern Italy (see Annex 12, Tables 32 and 33).

Losses in grazed grasslands and pastures are common in all RALUC regions with higher overall losses in the SA scenario than in the BAU. In the BAU the smallest losses in grazed grasslands and pastures are recorded in most Afforestation types. In the SA scenario the largest losses in grazed grasslands and pastures are found in the RALUC Intensification and the Urbanization types and less in the Afforestation ones.

Regional land use changes

To understand better how the future land use changes work out regionally some explanation is also provided on several regional shifts in land use in both BAU and SA, and there is focus on what typical land use changes were found in the 12 case study regions of this study as illustrated by the Table 8 and Table 9.

Table 8 Land use changes 2020-2050 in BAU scenario for the 12 case studies

BAU	Name	RALUC_Code	ENR	Agricultural land change	% urban land take	% Stable Agricultural	% Agriculture Annuals to Perennials	Conversion grasslands to cropland
BE236	BE-Arr. Sint-Niklaas	U-1a	Atlantic	-3.9%	3.9%	87%	2%	2%
BG312	BG-Montana	I-3a	Continental	1.1%	1.8%	92%	1%	1%
DEE0E	DE-Wittenberg	I-2c	Continental	-10.2%	1.2%	81%	1%	1%
EL521	EL-Imathia	U-2c	Mediterranean	-11.8%	3.0%	81%	4%	5%
ES421	ES-Albacete	I-2b	Mediterranean	-0.2%	1.7%	91%	1%	1%
FRL02	FR-Hautes-Alpes	A-3a	Alpine	-22.3%	0.4%	67%	0%	0%
HR034	HR-Šibensko-kninska županija	A-3c	Mediterranean	64.8%	0.2%	90%	0%	0%
IE042	IE-West Ireland	A-3a	Atlantic	1.1%	0.0%	93%	0%	0%
ITI19	IT-Siena	A-2a	Mediterranean	-20.8%	2.4%	70%	0%	0%
LT026	LT-Šiaulių apskritis	A-3c	North	6.8%	0.0%	99%	0%	0%
NL133	NL-Zuidwest-Drenthe	N-1	Atlantic	-2.2%	0.0%	92%	0%	0%
RO311	RO-Arges	E-1b	Continental	-2.9%	3.0%	88%	1%	1%

Table 9 Land use changes 2020-2050 in BAU scenario for the 12 case studies

BAU	Name	RALUC_Code	ENR	Agricultural land change	% urban land take	% Stable Agricultural	% Agriculture Annuals to Perennials	Conversion grasslands to cropland
BE236	BE-Arr. Sint-Niklaas	U-1a	Atlantic	6.1%	0.0%	87%	0%	0%
BG312	BG-Montana	I-3a	Continental	13.0%	1.3%	83%	3%	4%
DEE0E	DE-Wittenberg	I-2c	Continental	18.3%	0.6%	73%	9%	12%
EL521	EL-Imathia	U-2c	Mediterranean	-1.3%	0.3%	65%	16%	25%
ES421	ES-Albacete	I-2b	Mediterranean	20.2%	0.2%	79%	4%	5%
FRL02	FR-Hautes-Alpes	A-3a	Alpine	2.3%	0.2%	66%	2%	3%
HR034	HR-Šibensko-kninska županija	A-3c	Mediterranean	56.8%	0.0%	89%	1%	1%
IE042	IE-West Ireland	A-3a	Atlantic	2.2%	0.0%	96%	0%	0%
ITI19	IT-Siena	A-2a	Mediterranean	-13.5%	0.8%	51%	8%	16%
LT026	LT-Šiaulių apskritis	A-3c	North	22.1%	0.3%	96%	0%	0%
NL133	NL-Zuidwest-Drenthe	N-1	Atlantic	1.0%	0.0%	87%	2%	2%
RO311	RO-Arges	E-1b	Continental	7.5%	1.4%	81%	4%	5%

The largest declines in agricultural land use in the BAU scenario are expected in the Hautes Alpes (- 22%) and Siena (-21%) regions and this loss leads to a shift from agriculture to more natural classes such as forest and shrublands. In Siena a small part of this decline (2.5%) involved land take by built-up areas, while in Hautes Alpes it is practically all shifting to more natural classes. In the SA scenario the loss of farmland in Hautes Alpes is expected to turn into an increase in farmland again of 2.3%. In the Siena region, the farmland loss remains large at 13%, but in this scenario, it is also expected that (semi-)abandoned grasslands and shrublands can be converted back again to arable and perennial land uses. Both regions belong to the Afforestation RALUC group and confirm that the dominant land use change of afforestation will continue to be dominate

also in the future in both regions. The other three case studies in the Afforestation type, Šibensko, West-Ireland and Šiaulių apskritis, are experiencing an increase in farmland both in the BAU and in SA scenarios. In Šibensko this increase is very large with 65% in BAU and 57% in SA. In Šiaulių apskritis it is also significant with 7% and 22% increases in BAU and SA respectively. This outcome is not surprising since both regions can experience a continuation return of abandoned farmland into agricultural use as was already reported for the regions in the post-EU accession period. For Šibensko however, the question is very much if this reclaim will also happen, given that keeping young people interested in working in agriculture is challenging with the competing demands for labour in the local tourism industry and adverse effects of climate change on water availability. In Šiaulių apskritis labour is also a challenge, given decreasing population trends, but alternative labour opportunities are limited and the capacity of the land to produce more is good, also under the influence of climate change with the extension of growing seasons in the North. In West-Ireland the agricultural land is relatively stable with a slight increase expected of 1% in BAU and 2% in SA. The expectation is that agriculture can remain relatively stable in both scenarios with relatively stable agricultural land use, meaning limited internal agricultural land changes. The same applies to Šiaulių apskritis where arable land will remain mostly arable also in the future. In Šibensko more internal agricultural shifts are expected in the SA scenario where grasslands are converted to crop land. The largest agricultural reclaim is however from abandoned agricultural lands that were shrublands in 2020 to cropland.

Built-up land take from agriculture in BAU is largest in Sint Niklaas (3.9% of agricultural area), Imathia (3%), Argeş (3%), Siena (2.4%), Montana (1.8%) and Albacete (1.7%). The two regions with the highest land take belong to the RALUC Urbanisation types. In Siena, Montana and Albacete this mostly involves built-up area increases around urban nuclei where competition with other land uses is relatively limited explaining higher land take levels than in the SA scenario where the zero-soil sealing goal requires stricter policy measures. In this scenario, the agricultural land take by built-up areas significantly declines in all regions, but Montana and Argeş become the regions with highest land take levels of 1.3% and 1.4% respectively. This is likely related to lower competing uses with agriculture, forestry and protected nature.

Largest shifts from arable to perennial crops are seen in the Mediterranean regions of Imathia, Albacete, and Siena in the SA scenario, while in the BAU scenario this only happens in Imathia. In the SA scenario this shift is driven more strongly by assumptions about adaptation to climate change which can more logically be done by introducing certain perennial crops that can cope with lower water demands, but also under the influence of the protein transition expectation in which markets for protein, fruit and vegetables will grow while feed production for livestock goes down. In the case study region of Wittenberg the BAU scenario and SA scenario trends differ in size but not direction, as in both more perennials appear and grasslands are converted to cropland. This can be the response to future market changes, provided that enough labour and investment capacity can be developed however to keep the agricultural sector economically healthy. In Montana there is also an expectation that more grasslands will be converted to cropland in the SA scenario. This is a trend already reported for this region in the historic analysis of recent land use

changes. This may come at the expense of losing high biodiversity value grasslands. Maintaining these grasslands is a challenge in general also because grazing went down strongly because of livestock declines. However, in the SA scenario it is expected that livestock numbers may increase again with the growth in organic farming activities, which requires more mixed farming systems producing their own nutrient resources. In a part of the pasture lands this may improve management of the semi-natural grasslands. Policy guidance and support is needed to make this happen.

7.2. Trade-offs measured in KPIs for BAU and SA scenarios

The previous section discussed the modelled land use changes between agriculture and other land uses and within agricultural lands. This section describes the trade-offs in terms of the different impact fields covered by the KPIs selected for the sustainability assessment of land use in 2020 and in 2050 in both the BAU and SA scenarios. The overview of the KPIs assessed is presented in Annex 13. In KPI scores in the BAU and SA scenarios per Impact field are discussed below.

KPIs for agricultural land use and production

The overall objective of F2F is to 'ensure food security, nutrition and public health' and 'preserve affordability of food while generating fairer economic returns, fostering competitiveness of the EU supply sector and promoting fair trade'. Following the invasion in Ukraine and the COVID-19 pandemic, the EC also developed a contingency plan²² to ensure food supply and food security. This plan aims to 'ensure a sufficient and varied supply of safe, nutritious, affordable and sustainable food to citizens at all times'. These general objectives lead to the following KPIs selected and possible to assess from the modelled land use change results:

- 1) Land take from agriculture by built-up area (KPI1) (see Annex 13);
- 2) Agricultural land abandonment; Net change in agricultural land through abandoned to non-managed land and agricultural land restoration 2020-2050 (KPI2) (see Annex 13);
- 3) Relative change in production of food expressed as change in calories produced on agricultural lands in EU-27 between 2020-2050 (KPI3). (see Annex 13).

For KPI1, there is much lower land take in the SA scenario than in the BAU situation. At EU level built-up land take from agriculture amounts to 0.8% in the SA and 1.3% for the BAU scenario. At environmental zone level there is highest agricultural land take in Continental and Mediterranean zone and lowest in North. This applies to both BAU and SA situation, with one exception for Alpine which has the highest land take level of 1% in the SA scenario, but is not among the highest in the BAU scenario (see Annex 13). Countries and RALUC types with the highest land take from agriculture have already been discussed in former Section 7.1. RALUC Afforestation and some Urbanisation types (U1C and

²² [Ensuring global food supply and food security - European Commission \(europa.eu\)](https://ec.europa.eu/food/food/food_security_policy/contingency-plan_en)

U1a) have the highest losses in agricultural land. This is more pronounced in the BAU scenario, but also applies to the SA scenario. The Intensification and Extensification types experience generally lower farmland losses, especially in the SA scenario. These also go together with relatively modest increases in built-up areas and forest areas.

At country level the largest built-up area increases on agricultural land occur in Malta, Belgium, Romania, Czech Republic, Italy, Portugal, Spain, Netherlands, Slovenia, Greece and Hungary. In the SA scenario the additional built-up area development between 2020 and 2050 can be kept far below the 1% land area share in all countries with the exception of Malta (31% of land area), Belgium (1.2%) and Netherlands (1%).

For KPI2 in BAU there will be more agricultural land abandonment to natural land use classes such as shrubs and (eventually) forests, as already discussed. On average net agricultural land abandonment to non-managed lands will be 3.2% of agricultural area in 2020, while in the SA scenario agricultural land will increase by 8% as compared to 2020 (see Annex 13). The largest relative agricultural land abandonment level is in the Alpine region (7.5%) and lowest in North (0.9%) in BAU. In the SA scenario agricultural land increases are seen in all ENRs with highest gains in North (14% gain), Continental (13% gain) and smallest in Alpine and Atlantic (both 3%). The RALUC types and countries with largest net agricultural land abandonment have already been discussed in section 7.1 (see Annex 13, Tables 39-41). The higher land demands in the SA scenario which translate eventually into agricultural land gains are most importantly the result of the scenario assumption that production needs to remain relatively stable. So for the main production, more land is needed and therefore the agricultural land demand increases at least to a level to compensate for 50% of the production loss incurred because of the 2020-2050 conversion to organic production.

KPI3 on agricultural production change is expressed in relative change in Megacalories of production from agricultural lands (see Annex 13, Figure 39). Between 2020 and 2050 it is clear that in the BAU scenario this is much higher than in the SA scenario. In the BAU there will be an increase in calories produced between 2020 and 2050 of 30%, while in the SA scenario calories produced decrease by 16%. The difference is caused by the fact that in the BAU scenario there is no protein transition and livestock numbers do not need to decrease in order to reach good environmental conditions under the nitrogen critical load levels and nitrogen levels in waters. Because of this, much more feed production remains to be produced which adds significantly to the number of calories that need to be produced. In the SA scenario, production shifts more to food products that yield generally lower calories per hectare. Furthermore, in the SA scenario all goals for a 25% organic area share and lower inputs in terms of fertilisers and pesticides are reached and this leads to a reduction in yields per hectare of agricultural land used. The latter is compensated for only 50% by an increased demand for land in this scenario however.

As for the higher calorie production in the BAU that is related to higher feed production, these calories are not used as efficiently in terms of conversion to calories available in food. This is because the feed will only become food after the feed is consumed by animals and converted into animal products. In this

conversion many calories are lost since they do not all end up in the final animal product consumed.

KPIs for pesticide and fertiliser use and sustainable production practices

The Farm to Fork strategy (F2F) sets as goal that 25% of farming needs to be organic by 2030 (but given the very small share regions have reached now, it was assumed to be reached in all regions in the SA scenario by at least 2050). This will lead to lower input levels, but also a yield reduction per hectare. In addition, targets are set for reducing fertiliser application and nutrient losses by 20% and a 50% reduction of pesticides used to achieve good water quality status in all regions. All these targets are expected to be reached in the SA scenario, while in the BAU the current practices continue as they are. In addition to this, the Farm to Fork strategy (F2F) is linked to the Nature Restoration Law (NRL) that requires restoration measures in place for all nature that needs restoration by 2050 and this also implies a reduction of nitrogen emissions where critical nitrogen loads are exceeded. In the places where this is exceeded, it is assumed that in the SA scenario the nitrogen emissions are reduced through a necessary reduction in livestock numbers. On the other hand, livestock numbers are also increased where loads are not exceeded and where livestock is required to the extent of additional manure needs required for additional organic agricultural land transitions. All these different assumptions result in the following KPI scores.

For KPI4 on the distance to an organic farmland share of 25% of UAA, the BAU falls behind, while in the SA scenario it is reached everywhere by 2050. In the BAU situation, on average the distance remains at 17% of UAA which implies that it is 34 Million ha of farmland away from the 25% organic farmland target. This, together with an overall lower application of inputs also outside organic farmland in the SA scenario, leads to significantly lower pesticide use (KPI5) and nitrogen losses than in the BAU scenario, as becomes clear from Annex 13 figures 40 and 49. For the KPI7 on reduction of livestock density in total agricultural area (Annex 13, Figure 42), in total in the BAU scenario a 2% reduction in average livestock density in EU-27 takes place while the reduction is 31% in the SA scenario. Regionally, this reduction is very different. With higher reductions in SA in regions with high current nitrogen critical load exceedances, while there are also regions where the livestock density increases which is mostly in regions with currently low livestock activities (see Annex 13, Figure 42). With the reduction of livestock numbers, the GHG emissions for enteric fermentation will also significantly reduce (see next section).

KPIs for soil health

Improved soil health targets are set in the Soil Monitoring and Resilience Law and these are also linked to the overall F2F goals of reaching sustainable agriculture in the EU. Two KPIs have therefore been assessed that evaluate how the land use changes 2020 to 2050 in the BAU and SA scenario for soil organic carbon status and for soil erosion risk. These indicators have been assessed purely based on land use changes. They do not take specific soil management measures into account although we do assume that these will be in place in at least the SA scenario in accordance with the Soil resilience Law and F2F targets.

For KPI8 on change in SOC status, the total land use changes (both inside and outside agricultural land) will result in an overall increase in SOC status in the

BAU scenario by 1%. In the SA scenario it will lead to a decline in SOC status of 7% in the total EU (Annex 13, Figure 43 and tables 45-47). ENR regions with highest SOC factor changes in the SA scenario are Continental (-10%) and Atlantic zone (-8%). In the Alpine region no decline is expected in the SA scenario on average. At country level the highest declines because of SA land use changes are expected in Denmark (-14%), Poland (-1%), Germany (-11%) and Belgium (-10%). At RALUC type level the largest losses in SOC because of land use changes are expected in the Urbanisation types as in 3 of the 6 Urbanisation type a decline of 11% is expected. In the Afforestation types the overall decline in factor is relatively limited as compared to other RALUC types (See Annex 13, Tables 45 to 47).

For KPI9 on change in the soil erosion risk factor similar trends are seen with significantly higher risk increases for the land use changes expected in the SA scenario (see Annex 13 Tables 45 to 47). On average for the whole EU-27 the risk factor increases by 11% while this risk factor decreases by 3% in the BAU scenario. Again, the Alpine region shows a decline in this factor also in the SA scenario, while in the other regions the change is most pronounced in the continental regions.

For both KPI8 and KPI9 the increases in risk of soil erosion and loss of SOC are not surprising as in the SA scenario the land managed by agriculture will increase cropping land, while in the BAU scenario there is a larger shift from farmland to non-managed shrubland and forest land. This confirms the need for strict application of soil management practices in the SA future to ensure that the sustainable future of farming as foreseen in the F2F also leads to reaching the soil health goals of the Soil Monitoring and Resilience law. Furthermore, good maintenance of SOC in agricultural soils is also crucial for reaching the GHG mitigation targets for agriculture (see next KPIs 10 and 11).

KPIs for GHG mitigation

Following the NIR report (EEA, 2023a) the largest agricultural sources of GHG emissions in 2021 are methane (CH₄) emissions from enteric fermentation coming from (dairy) cattle, sheep and goats (46% of agricultural GHG emissions), direct N₂O and CH₄ emissions from managed agricultural soils (25% of agricultural GHG emissions), manure management both in stables, storage and application on lands which leads to CH₄ and N₂O emissions (17% of agricultural GHG emissions) and indirect GHG emissions on managed soils which are linked most strongly to nitrogen leaching and run-off and atmospheric deposition (6% of agri GHG emissions). This means that regions with high livestock concentration will likely have the highest GHG emissions and therefore need to bring their enteric GHG emissions down through reductions in livestock numbers. This is exactly introduced in the SA scenario where this was done from the perspective of bringing nitrogen losses and ammonia emissions below the critical load levels. This measure is therefore not only effective for nutrient loss reductions but also for GHG mitigation. In Annex 13 (Figures 49 and 50) one obtains an overview of the regions where nitrogen losses are reduced and this goes together with a reduction of enteric GHG emissions too. Logically these reductions will be more significant in the SA scenario. Beside the reduction in enteric fermentation GHG emissions which will be significant in the SA scenario because total livestock numbers as compared to the 2020 will reduce by 29% towards 2050. In the BAU scenario the total livestock population will increase

by 2% in the BAU scenario. Given that in 2021 in the NIR (EEA, 2023a) estimated the GHG emissions from agriculture at 378 Mt CO₂ eq, and that 46% of these emissions come from enteric fermentation, we can expect that a reduction of livestock population by 29% towards 2050 in the SA scenario will at least lead to a reduction in agricultural sector based emissions of 50 Mt CO₂ eq²³. In the BAU scenario, with the livestock increase of 2% as compared to 2020 level it can be expected that GHG emissions from enteric fermentation will at least not decrease.

Beside enteric fermentation emission changes there will also be emissions related to direct land use changes only. These emission changes are only related to the land use conversions (see Table 10) to which GHG emission default values could be connected from the IPCC default value emissions specific per EU country.

Table 10 Land use conversions

Conversion	Code	Category Description
Stable Forest	A1	Forest Land Remaining Forest Land
Cropland - Forest	A21	Land Converted to Forest (from Cropland)
Grassland - Forest	A22	Land Converted to Forest (from Grassland)
Stable Cropland	B1	Cropland Remaining Cropland
Forest - Cropland	B21	Land Converted to Cropland (from Forest)
Grassland - Cropland	B22	Land Converted to Cropland (from Grassland)
Grassland	C1	Grassland Remaining Grassland
Forest - Grassland	C21	Land Converted to Grassland (from Forest)
Cropland - Grassland	C22	Land Converted to Grassland (from Cropland)
Stable Settlement	E1	Settlements Remaining Settlements
Forest - Settlement	E21	Land Converted to Settlements (from Forest)
Cropland - Settlement	E22	Land Converted to Settlements (from Forest)
Grassland - Settlement	E23	Land Converted to Settlements (from Grassland)

Based on the land use conversions (that were traced for the 2020-2050 changes in the BAU and SA scenario) two KPIs were introduced. KPI10 reflects the total change in GHG emissions between 2020 and 2050 related to AFOLU (Agriculture, Forest and Other land use) and is expressed in million tons (Mtonnes) CO₂-eq. KPI11 is the same as KPI10, but expresses the GHG emission change caused by the land use change, but also by the change in management in the SA scenario in which lower fertiliser and pesticides inputs are assumed and a higher share of land is converted to organic agriculture. For these changes in management a simple and conservative 20% reduction factor in GHG emission per hectare of crop land is assumed as compared to the 2020 situation and also the management of cropping land in 2050 in the BAU. In Annex 14 it is explained in more detail how the land based GHG emissions in KPI10 and 11 were calculated. The detailed results of the KPI 10 and 11 are also presented in diagrams and maps in Annex 13 (Figures 45 and 46).

²³ Calculated as follows: 29% * 46% * 378 Mt CO₂ eq = 50 Mt CO₂ eq

In summary the results of the KPI calculation tell us that if only the land use change related changes in GHG emissions are considered in KPI10, one can conclude that in the BAU in the total EU-27 a reduction of 1788 Mt CO₂-eq will be reached, which is largely related to larger land use shifts to non-managed shrub and forest land as already discussed. In the SA scenario the decline in GHG emissions is only 527 Mt CO₂-eq, without taking management changes into account. If management changes are included in SA, in the KPI11 this reduction will be 682 Mt CO₂-eq. Overall, one can conclude that for land based GHG emission reduction the best strategy is to keep less farmland in production as is happening in the BAU situation, unless significant measures for GHG reduction from management are introduced and more measures for carbon capture and storage in agricultural land. On the other hand, GHG reductions from enteric fermentation will be significantly larger in the SA scenario given significant reductions in livestock heads and this leads to a reduction of at least 50 Mt CO₂-eq as was already discussed in the beginning of this section. However, this will still not compensate for the larger GHG emission reduction related to conversions of agricultural lands to non-managed shrub and forest lands. Furthermore, this however will not necessarily lead to a total GHG emission decline in all regions, given that intensive livestock production is concentrated in only some regions.

Overall one can therefore conclude that in the SA scenario the GHG emissions in agricultural lands will go down significantly through reductions in GHG emissions related to livestock production activities and lower input levels. This results in overall lower GHG emissions per hectare. In the BAU scenario the GHG emissions in agriculture will likely increase certainly when expressed per hectare since livestock number will not go down, nor input levels per hectare. However in the BAU scenario the carbon capture effects of conversions of farmland to unmanaged (abandoned) forest and shrublands will be higher and these will likely compensate for the higher GHG emissions related to farmland conversions to built-up areas and the increase in GHG emissions within the agricultural sector because continuation of high input levels and increase in livestock numbers. In the SA scenario much more land will be in agricultural use, so less carbon is captured in other land conversions than in the BAU. This is partly compensated for by lower GHG emissions from livestock and lower input levels per hectare. Overall however the GHG emissions will decrease more strongly in the BAU than in the SA scenario. This implies that in the SA scenario more measures will need to be taken to capture carbon within agricultural lands. Still, there are also several countries and regions that will experience higher GHG emission reductions in the SA scenario than in the BAU. This will be the case in regions where the reductions in livestock numbers in the SA scenario are significant and needed to reach below critical load nitrogen losses and where conversions to abandoned are not large in the BAU.

KPIs for Nature and landscape restoration

One of the goals of F2F is also to reverse the loss of biodiversity. To understand how the changes in land use in both the BAU and SA scenarios contribute to nature restoration, two KPIs are assessed. KPI12 considers how the changes in land use change impact the flora and nesting indicators. The higher the combined indicator is, the better the opportunities are for development of floristic and bird diversity. KPI13 expresses the landscape evenness changes

because of land use changes. It illustrates how diverse a landscape is. The more diverse the landscape, the more attractive to different natural species.

Comparison of the scores for KPI12 in flora and nesting factor for BAU and SA at EU average increase by 5% in the BAU and decrease for EU average by -1% in SA (see Annex 13, Figure 47). In the BAU this trend is most positive for the Alpine region (2%) and lowest in Atlantic with 0% change. In the SA scenario the index for flora and nesting will decrease mostly strongly in the Continental region (-9%) and least in the Alpine (0%). The worst performing country in terms of this factor is Malta with a 35% and 31% decline in BAU and SA scenario respectively. Other countries with relatively large relative declines mostly in the SA scenario are Cyprus (-17%), Lithuania (-10), Germany (-9%), Denmark (-8%) and Hungary (-8%). Stable trends in this index in the SA scenario are seen only in Italy, Portugal, Italy and Sweden (see Figure 47). In the BAU scenario, increases are seen in the countries with stronger conversions of farmland to non-managed shrubland and forest classes.

The change in evenness for landscape diversity more often shows a positive trend in SA than in BAU in most countries, except for Slovenia and Sweden where the trend is quite strongly decreasing by -9% and 8% (see Annex 13, Figure 48). Overall the average trend for evenness at EU level is -3% in BAU and -1% in the SA scenario.

KPIs for Nitrogen emission reductions to water and air

One of the goals of F2F is also to reduce nitrogen losses to water and reduce fertiliser application by 20%. To understand how these reductions in losses and gifts are going to work out in the BAU and SA scenarios, two KPIs are assessed. KPI14 considers the losses of nitrogen to surface and ground water levels in terms of their distance to critical loads as specified in the Nitrogen Directive which prescribes a maximum of N concentration in runoff to surface water of 2.5 mg N/Liter and nitrate (NO₃) concentration in leachate to groundwater of 50 mg NO/Liter. KPI15 expresses the distance to the critical nitrogen (ammonia – NH₃) deposition level above which terrestrial biodiversity is negatively affected.

For KPI14 it becomes clear that highest average per hectare exceedance levels for nitrogen in surface and/or ground water are seen in the actual situation and continue to be so for the BAU in Belgium and the Netherlands (see Annex 13 Figure 49). Medium exceedance levels for water are also found in Poland, Czech republic, Germany, France, Hungary, Cyprus and Bulgaria. In the SA scenario through the implementation of the measures to reach clean water status exceedance levels become negative (so no exceedance) in all countries. Given the selection of countries with the highest water quality exceedance levels in BAU it is logical that on average these are highest in the Atlantic region and the Continental. This however shifts to below exceedance levels in the SA scenario in all ENR.

For KPI15 on critical nitrogen (ammonia – NH₃) deposition exceedance we see the highest average per hectare exceedance levels in the BAU in Finland, Netherlands, Sweden, Belgium, Slovenia, Luxembourg, Ireland and Italy (see Annex 13 Figure 50). Medium exceedance in BAU is found in Germany, Denmark, Poland and Portugal. In the SA scenario the exceedance is reduced in most countries below the critical load with exceptions in Finland, Sweden and

Ireland. This is related to the relative small farmland area in comparison to the total area of the regions (in which forest land is mostly dominating). The ammonia exceedance is therefore a very local exceedance in Sweden and Finland. The reduction in livestock numbers as implemented in the SA scenario is not sufficient to reduce emissions below critical deposition levels in the limited agricultural surface, but it is sufficient to bring the exceedance level for the total region below the threshold.

7.3. Options for synergies between agriculture and RES Energy production

As described in Chapter 5 there was a growing concern surrounding the land use needs from bioenergy. Partly this is already curbed with the increased focus on Annex IX feedstocks in the RED as well as the introduction of the food and feed cap, which limits the amount of competition between crops going to food and feed and crops going to bioenergy. There are, of course, additional measures that can be used to limit the amount of land use needs for bioenergy as well as increase the growth of a more sustainable feedstock mix to meet all the renewable energy targets.

There can be synergies between agriculture and solar energy. Growing biomass (potentially for energy purposes) alongside solar panels can not only increase the energy yield per hectare, but also provide additional sustainability benefits such as reducing soil erosion or degradation prevention by covering the soil²⁴ and can even lead to an increase in yield up to 16% when the PV panels are placed over fruits and berries.²⁵ A combined economic value increase of over 30% has been reported over the use of traditional agricultural practises.²⁶

The synergy between wind farms and agriculture is less strong than with Agri-PV, but so is the potential competition between the two. There are some general benefits of adding wind turbines to agricultural land, such as an increase of economic value. The wind turbines take up less space than solar farms, making it easier for farmers to combine renewable energy production with cattle or crop farming. There are few negative effects of the additional wind energy production to the crop yield – it may even increase yields between 1-2% by reducing extreme temperatures.²⁷

Beyond renewable energy production, there are other ways to ensure negligible (indirect) land use change risks when growing biomass for bioenergy. As included in the newly updated Annex IX of Directive (EU) 2018/2001, using intermediate crops, crops grown on severely degraded land or damaged crops

²⁴ <https://www.rwe.com/en/research-and-development/solar-energy-projects/agri-pv/>

²⁵ <https://ember-climate.org/insights/in-brief/empowering-farmers-in-central-europe-a-case-for-agri-pv/>

²⁶ <https://www.sciencedirect.com/science/article/abs/pii/S136403211501103X>

²⁷ https://ace.illinois.edu/sites/ace.illinois.edu/files/JMP_V6_upload_V2_0.pdf

would not result in additional pressure on agricultural land. The ILUC Delegated Act (2019/807) further adds crops grown on unused or abandoned land as having low risk of (indirect) land use change. Using marginal (abandoned, unused, degraded or contaminated) land for bioenergy crops has significant potential across Europe.²⁸ Putting these lands back into productive use could even provide temperature and soil benefits, such as covering the soil to prevent soil erosion and removing contaminants through phytoremediation.

Lastly, growing intermediate crops²⁹ may provide more benefits than only additional biomass for bioenergy. Growing intermediate crops in fallow periods provides soil covering to prevent soil erosion and provided that the biomass partly remains on the soil, may increase soil organic carbon. Intermediate crops may even increase the soil moisture, improve nutrient retention, reduce soil compaction and can reduce the amount of weeds.³⁰

7.4. Carrying capacity

In addition to the KPIs, analysis was introduced to reflect the overall capacity of RALUC regions, to respond to the **“carrying capacity”** (CC) of a given territory and its community. This reflects the overall assessment provided in this report and summarizes the explicit content of the whole information set analysed. Focusing on agricultural land-use, the proposed notion of carrying capacity is intended to evaluate holistically the potential of any European territory to reflect changes in both environmental and socioeconomic issues, and answer future challenges, stemming from internal changes in the agricultural sector. Along with ecological modifications (e.g. climate change), societal transitions, and (expected and unexpected) economic dynamics.

To fulfill this policy objective three dimensions were selected: (i) future climate conditions (namely climate aridity); (ii) demography (mainly capturing rural population dynamics, in connection with broader demographic dynamics at both urban and country scale, as a proxy of socioeconomic dynamics at large); and (iii) the intrinsic capacity of the territories to invest in their future agriculture. The current GDP is the proxy indicator for this dimension, as a general measure of responsiveness of the social and economic system to address future issues in the agricultural field – from climate and environmental crisis to depopulation, from market uncertainties to modifications in consumers’ preferences and lifestyles.

The intersection of the 3 dimensions above generates a classification of the European space (NUTS-3 level based) with the specific occurrences profiled and

²⁸https://www.europeanbiogas.eu/wp-content/uploads/2024/04/Biogases-towards-2040-and-beyond_FINAL.pdf

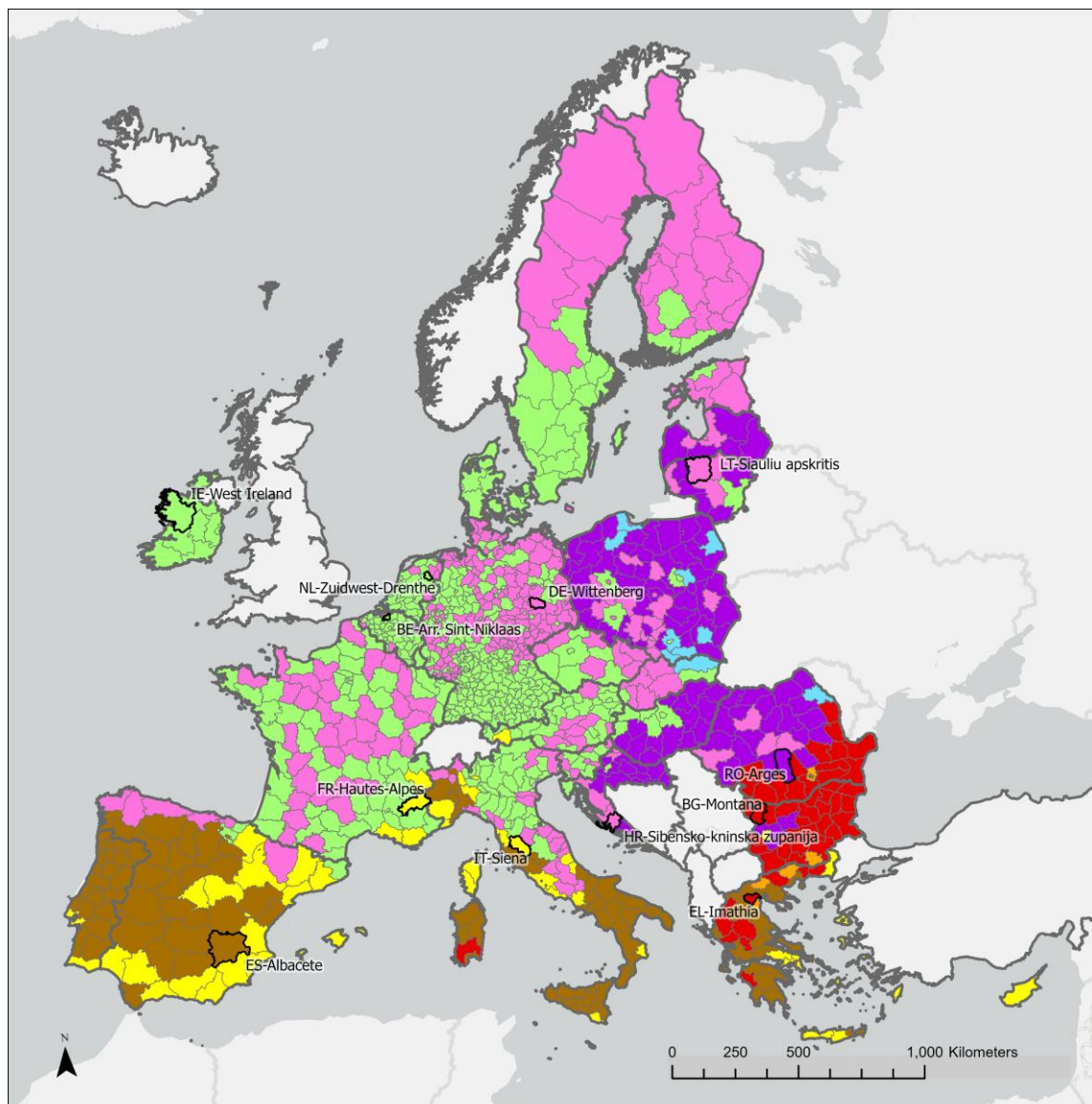
²⁹ Such as catch crops and cover crops that are grown in areas where due to a short vegetation period the production of food and feed crops is limited to one harvest and provided their use does not trigger demand for additional land, and provided the soil organic matter content is maintained

³⁰<https://www.climatehubs.usda.gov/hubs/northeast/topic/cover-cropping-improve-climate-resilience#:~:text=Cover%20crops%20increase%20soil%20organic,even%20help%20suppress%20some%20pests.>

mapped in Figure 23 and summarized in Table 11. For the CC classes a specific linkage can be traced with the RALUC region types and the assumed expectations on future land use changes and KPI scores. This provides a better insight on how future policies can address territorially specific land use trends in the context of their carrying capacity asset. This will be briefly described by CC class. In the last section of Chapter 8, specific policy recommendations will then be made taking account of the combined characteristics of CC classes and RALUC regions described here.

Climatic conditions will particularly affect agriculture negatively in regions having to cope with increased aridity conditions. This is the case in 227 RALUC regions which are 15% of the total RALUC regions but cover 26% of the agricultural area in the EU-27 (see Table 11). These are all located in the Mediterranean basin and particularly in the Iberian peninsula, Southern Italy, Greece, Cyprus, but also in the Eastern regions of Continental Europe, namely in Romania and Bulgaria (see Figure 23). The increase in extreme weather events are also expected, with regards to precipitation and high temperatures, while the latter are applicable to all EU regions, long term and increasing aridity is specific to the regions classified in the CC typology as having increasing aridity problems. In these areas aridity is seen as a future major challenge for agriculture that requires serious adaptation actions and investments. On the other hand, there are also regions, particularly to the North of the EU, in e.g. the Baltics, Finland, Sweden and Ireland, that will likely experience an increase in length of growing season which may broaden agricultural crop choice as was shown in the MIDAS project for 2050 (see van Eupen³¹). The regions to which this applies are classified in the CC classes 'Stable climate' (see Figure 23).

³¹ [Europe's Marginal lands \(arcgis.com\)](http://arcgis.com)



RALUC_LCF

CarryingCapacity

- Stable climate - Stable Demography - Medium or high investment capacity
- Stable climate - Stable Demography - Low investment capacity
- Stable climate - Low population density or Depopulation - Medium or high investment capacity
- Stable climate - Low population density or Depopulation - Low investment capacity
- (Increase in) arid climate - Stable Demography - Medium or high investment capacity
- (Increase in) arid climate - Stable Demography - Low investment capacity
- (Increase in) arid climate - Low population density or Depopulation - Medium or high investment capacity
- (Increase in) arid climate - Low population density or Depopulation - Low investment capacity
- raluc_case_study_area
- Countries

Figure 23 EU-27 classified in Carrying Capacity classes

Table 11 Carrying capacity dimensions, occurrences, and link to policy recommendations

Climate trend	Demography trend	Investment capacity	CC class no.	General Characterisation	Dominant RALUC regions, MS and general characteristics	Number & % of regions & % area in the EU-27	Case studies present (column K)
Stable or improving	Stable or improving	Medium-high	1.1.1	Regions with best CC with high scores on all three CC factors. Hence high capacity to implement several EU policies and limited (or moderate) external support needed. It is the largest CC class.	RALUC Urbanisation regions (U-1a, U2a) dominate mostly located in 'Old' EU. Land-take by built-up area is strong and most important factor for agricultural land decline towards 2050.	507 RALUC regions (43% of regions), 29% of agri area and 28% of total area in EU-27	BE-Sint Niklaas NL-Zuidwest Drenthe IE-West Ireland
		Low	1.1.2	Regions with good CC in relation to favourable climatic and demographic conditions; but not in terms of investment capacity. Hence investments in the agricultural sector both at farm and sectoral, rural community levels will be more difficult to implement. It is among the smallest CC class only covering 1% of regions and area in EU-27.	Most represented RALUC regions are in Afforestation (60%) (A2b, A-1d) and Urbanisation (30%) (U-1b, U2b) all located in PO, SL & SK. In BAU scenario agricultural land abandonment expected. In SA significant options for agricultural land reclaim.	10 RALUC regions (1% of regions), 1% of agri area and 1% of total area in EU-27	-
	Worsening (Depopulation)	Medium-high	1.2.1	Regions with good CC in relation to favourable climatic and investment capacity, but unfavourable demographic conditions;	This CC class is relatively evenly spread over all RALUC types RALUC regions are in Afforestation (60%) (A2b, A-1d) and	310 RALUC regions (27% of regions), 22% of agri area and 32%	HR - Sibensko LT -Šiaulių apskritis

Climate trend	Demography trend	Investment capacity	CC class no.	General Characterisation	Dominant RALUC regions, MS and general characteristics	Number & % of regions & % area in the EU-27	Case studies present (column K)
				needing focussed policies to tackle depopulation trends, possibly attracting new population, and favouring labour saving land uses and related technologies. Large CC class.	Urbanisation (30%) (U-1b, U2b) all located in Poland, Slovenia & Slovakia. In BAU scenario agricultural land abandonment expected. In SA significant options for agricultural land reclaim.	of total area in EU-27	DE- Wittenberg
		Low	1.2.2	Regions with only good CC in relation to favourable climate conditions but unfavourable for both demographic and investment capacity conditions. Need for focussed policies to tackle depopulation and favour labour saving land uses and related technologies. Medium size CC class covering 9% of regions but relatively more agricultural land.	This CC class is strongly concentrated in the Afforestation group (60%) (A2d, A-2b) and practically all regions are in 'New EU' in Poland, Romania, Hungary, Latvia, Lithuania and Croatia. In BAU scenario agricultural land abandonment expected. In SA significant options for agricultural land reclaim.	98 RALUC regions (9% of regions), 13% of agri area and 13% of total area in EU-27	RO- Arges
Worsening (towards increased)	Stable or improving	Medium-high	2.1.1	Regions with relatively good CC in relation to demographic and investment capacity conditions, but not in terms	This CC class is strongly concentrated in the Urbanisation group (53%) and the rest is either in the Afforestation (32%) or in	Small size CC class covering 60 RALUC regions (5% of regions), but	IT- Siena, FR- Hautes Alpes

Climate trend	Demography trend	Investment capacity	CC class no.	General Characterisation	Dominant RALUC regions, MS and general characteristics	Number & % of regions & % area in the EU-27	Case studies present (column K)
aridity conditions)				of climatic conditions. It is a small CC class, covering around 5% of the RALUC regions	the Intensification (14%) groups. All regions are located in southern Europe countries (Italy, Greece, Spain, France and Malta) but one region in BG. Especially in the BAU scenario agricultural land loss is mostly due to urban sprawl.	relatively large agricultural land (9%) or 7% of total area in EU-27	
		Low	2.1.2	Regions with bad CC status in relation to climate and investment capacity, but good in relation to demographic conditions. This is the smallest CC class, representing less than 0.5% of the regions	This CC class is strongly concentrated in the Afforestation group (80%) and the rest, 1 of the 5 regions, is in Urbanisation. All 5 regions are located in Macedonia (Greece and southern Bulgaria) and Romania (Bucharest capital).	This CC class covers only 5 regions (0.4% of the total) which corresponds to less than 0.5% of the agricultural land and around 0.3% of total area in EU-27	-
	Worsening (Depopulation)	Medium-high	2.2.1	Regions with bad CC status due to unfavourable climatic as well as demographic conditions, but medium to high investment conditions. Thus these territories have, to a certain extent, the	The dominant RALUC regions belong mostly to the Afforestation group (42%), followed by Urbanisation (33 %) and Intensification (20%). A distinctive feature is that	Consist of 111 RALUC regions (10% of regions represented), covering as much as 19%	ES-Albacete

Climate trend	Demography trend	Investment capacity	CC class no.	General Characterisation	Dominant RALUC regions, MS and general characteristics	Number & % of regions & % area in the EU-27	Case studies present (column K)
				capacity to co-invest in measures to counteract the negative conditions above. It is a medium size CC class covering 10% of regions and relatively more agricultural land.	regions are almost all located in Greece, Spain, Portugal and Italy they actually include half of Italy and Spain, and almost all Portugal), with only one region each in Malta, Romania and Croatia. They can be characterized as Mediterranean regions that are better off only for investment capacity.	of the agricultural area and 14% of the total area in EU-27	
		Low	2.2.2	Includes regions with the worst CC status due to unfavourable climatic as well as demographic conditions combined with low investment capacity. These regions consist of particularly fragile territories and rural communities. It only comprises 4% of the regions although the share of agricultural land is larger.	The dominant RALUC regions mostly belong to the Intensification group (45%) followed by the Urbanisation group (24%). The remaining ones are classified either as part of the Afforestation (18%) or Extensification (12 %) groups. Most of the regions are located in Bulgaria, Romania and Greece and in the ENZ Continental and Mediterranean.	This is a small CC class consisting of 51 RALUC regions in the EU-27 (4% of regions), a relatively large agricultural area (7%), corresponding to 5% of the total area.	EL - Imathia

The CC classification also splits regions according to **demographic conditions** (current and future trends) where regions that are already experiencing low population densities and/or will be coping with a declining population in the coming years will have more challenges to keep sufficient people in the agricultural sector. This process will lead to a lower number of people interested in managing a farm and to work in the agricultural sector. This will jeopardize options to keep farmland in production and to make farming fit for the future through adaptations to new markets, climates, improvements in environmental sustainability and provisioning of ecosystem services through farming. This unfavourable demographic trend applies to around 50% of the region, and is projected to involve as much as 61% of the farmland in the EU-27 (See Table 11). The trend implies that in a large majority of the farmland areas, the problem of continuation of farming and farm labour needs need to be addressed. Recommendations to address this will be discussed in the last section of this report.

The last class in the CC classification is the **investment capacity** of regions expressed in below or above average GDP per head. This is a proxy for the ability of local rural communities, including local governments, to support investments in agriculture needed to future proof the sector and to adjust to market changes, improve sustainability of the farming sector and adapt to changes in climate. The CC classification shows that investment capacity is low in 164 regions (15% of the total) and that that 21% of the farmland in the EU-27 is located in these (see Table 11). Most of the regions to which this applies are in the 'new EU' but also several Greek regions belong to this group. These regions are often lacking local investment capital and rely more strongly for this aspect on EU CAP support and other investment mechanisms such as the European Regional Development Fund (ERD), European Social Fund, Interreg, Just Transition Fund (JTF) and Cohesion Fund.

The CC classes are also expected to experience typical future land use shifts, particularly in agricultural lands, under the influence of a combination of drivers and contexts leading to different scores on specific future KPIs assessed in this study.

The regions in the biggest **CC class have a stable climate, a stable population, and a medium-high investment capacity**. This class covers 43% of the regions and 29% of the agricultural area in the EU and will typically experience relatively high land take of agricultural land coupled, amongst other factors, to high population pressure in this class. The regions in this class are all located in the 'old EU'. There are three case studies located in this large CC class: Arr. Sint Niklaas, Zuidwest Drenthe and West Ireland. The regions in this CC class will have to invest more effort in managing the different competing land use claims putting pressure on agricultural lands. These are not only related to built-up land for living and economic activities, but also to nature conservation and restoration needs, which need to synergize with agricultural activities and which are also needed to facilitate the recreational demands for the populations living in relatively densely populated areas. This is for example illustrated by the land use trends seen in the cases of Zuidwest Drenthe and Arr. Sint Niklaas where competing land use claims were quite strong between agriculture and built-up land, particularly for increases in harbour of Antwerp related economic activities in Arr.Sint Niklaas, and also agriculture and nature

conservation in both cases. In West Ireland, the competition is between agriculture and afforestation, but not between agriculture and built-up areas. Furthermore, in this West Ireland case there is a need to recover peatland areas leading to loss of grazing lands and a ban on afforestation of these lands. Given that the number of farmers is declining fast this will not be so much of a challenge, rather the opposite, which is continuing extensive grazing in moors and heathlands in which nature conservation actually depends on continuation of traditional farming practices.

Overall, however, in this CC class future agricultural land changes can be quite extreme; and involve, like in most EU regions, a decrease in grazed grasslands in many of the regions, a shift in annual crops from feed to food markets, and an increase in perennial crops. Decreasing livestock numbers and therefore feed demands are expected in the SA scenario to meet the F2F goals, especially in very intensive livestock production areas which are also part of this CC class, such as in the Netherlands, Po valley, Brittany, and Denmark. Both in BAU and SA the livestock numbers will decrease strongly over this CC class, but in the SA the decrease is considerably larger as it leads to an average livestock unit density decrease of -26% (in BAU -11%). This decline is necessary as in 2020 and in BAU, this class has the highest average exceedance of critical ammonia emissions of all CC classes and in the SA scenario the exceedance will reach zero. In the SA scenario this will provide options to make stronger shifts toward more food, and less feed production but will also come with a decrease in grazed (mostly intensive) grasslands. This implies that parts of the grasslands are converted to cropping land in both BAU and SA scenarios. In SA this conversion is going to be larger and this implies that the AFOLU based GHG emissions towards 2050 will decrease less in the SA scenario than in the BAU. On the other hand, the GHG emission reduction because of the strong decline in animal heads will decrease the enteric fermentation emissions very strongly in the SA scenario. The loss of managed grazing lands also brings some increased risk of loss of high biodiversity semi-natural grassland becoming unmanaged or converted to crop lands. It is important to address this through targeted policy to ban conversions of low input grasslands to croplands or forests through active afforestation. If livestock grazing is declining, to continue managing the grasslands an option could be to shift to cutting the grasslands to provide biomass for biorefinery applications for biomaterials and biochemicals. This however needs to be addressed through policy measures and market developments and will be further discussed in the recommendations. Most interesting opportunity for this class of regions is that it has a good CC to make shifts towards a more sustainable agriculture, as required to reach the F2F goals. There is enough access to CAP, regional and national government support and access to funding and R&I to continue making investments in agricultural technologies, more sustainable intensification options and conversions to organic agriculture. Also in this CC class, most of the regions are still far away from the target of 25% share of organic farmland. Nevertheless, it is also likely that more local markets can be developed for organic and local products because of a nearby presence of large urban populations and overall larger representation of higher income groups and/or groups of 'more conscious' consumers.

The next CC class is the **stable climate, a stable population and a low investment capacity (CC class 1.1.1)** covering only 10 regions and 1% of the agricultural area in EU. It is among the smallest CC class and the regions

included are all located in Poland, Slovenia and Slovakia. There are no case studies located in this class. In the BAU scenario, loss of agricultural land in most regions in this class is expected through land abandonment which is foreseen to be large if policy measures and market developments continue as they are now. Certainly, the area with cereals is likely to witness a strong decrease by 17% in the BAU and 13% in SA scenario. Grazing land declines could be between 3% in BAU and even 17% in SA scenario. This is related with needs to decline livestock heads in some of the regions in this class to reach below critical loads. On the other hand, in the SA scenario this CC class shows high agricultural land reclaim levels because of the large land resource that was abandoned in post-Soviet times. This reclaim also goes together with strong shifts in land from grazing to cropping land and from annuals to perennials. Both the potentially large increases in managed agricultural land and shifts from grasslands to crop lands in the SA scenario comes with a strong increase in the AFOLU based GHG emissions, while in the BAU these emissions are expected to decrease very strongly under the influence of large land abandonment trends. On the other hand, the GHG emissions related to enteric emissions through animals will significantly decrease in the SA scenario and these will by far compensate for direct and indirect AFOLU GHG emissions. Nitrogen losses to water are relatively high in this CC class but will decrease significantly towards 2050 in the SA scenario, because of significant declines in livestock heads, although still not sufficiently to bring these under the critical nitrogen loads for water in all regions in this class. Ammonia emissions will shift under the critical loads level in the SA scenario, while these are above in 2020 and in the BAU scenario.

The land use shifts in the SA scenario provide better opportunities to keep rural livelihoods stable, but this can only happen if enough support through policies and local investors goes to agricultural improvements and access to agricultural markets also improves. In principle, these regions have a good demographic situation to ensure access to available labour for farms, while also creating local markets for organic products, although the purchasing power of the population is not high. Measures to support young farmers to take over farms and invest in this sector is crucial for the future of farming. A core consideration when agricultural land reclaim is successful in these regions, as expected in the SA scenario, is the appropriate policy support and guidance to ensure sustainable agricultural practices are used that minimize soil erosion, SOC is increased in agricultural soils, GHG emissions and nitrogen losses are mitigated and more land is converted to organic farming. Special attention through policy support is recommended as this class is among the CC classes with the greatest effort required to achieve the organic farmland share of 25%. Especially in Natura 2000 areas where strict policies are needed for sustainable farming practices as these areas are relatively large in most of the regions in this CC class and land reclaim will also take place in these in the SA scenario.

The third CC class is the **stable climate, medium to high investment capacity but with a worsening demographic condition (CC class 1.2.1)** either because of already low population density or because of declining population. It is among the larger CC classes as it covers 27% of the regions and even 32% of the land, although only 22% of the agricultural land in the EU. These regions are spread over all types of RALUC types. Most of the regions in this class are found in Germany, France, Austria, Czech Republic, Estonia,

Lithuania and a few in Finland, Atlantic Spain and central Italy. They can be categorized as mostly continental and better off except for demographic trends. It includes several regions in the 'new EU' that have above average GDP. There are three case studies located in this CC class namely Sibensko, Siauliai apskritis, and Wittenberg. Within this class in the BAU scenario, so with unchanged policy, agricultural land abandonment is realistic in most of the regions, while the opposite is expected in the SA scenario although not as strong as in the second CC class (1.1.2). The latter will only happen if working in farming will remain attractive enough among (young) people who choose to remain living in a rural area, instead of choosing a job in another sector.

Loss in annuals and increases in perennials will happen in this CC class in both BAU and SA scenario, but levels of change are a bit more elevated in the SA scenario, although more modest than in the other stable climate CC classes. Also, significant declines in livestock numbers can be expected in this CC class, particularly in the regions belonging to the 'old EU', as they are a cause of high water and ammonia emissions. Given the targets of the F2F of reducing nitrogen losses, their number will therefore decrease strongly in the SA scenario through which nitrogen to water losses will reach below critical load levels. For ammonia emissions reduction will also be very large but will not be sufficient to reach below critical load levels in 2050. In 2020 and in BAU, the nitrogen in water and ammonia emissions are among the highest of all CC classes. The decline in livestock heads will also bring the GHG emissions significantly down in the SA scenario. Also AFOLU based GHG emissions are expected to be significantly reduced in this CC class both in BAU, but also in SA scenario in spite of some land reclaim and grasslands to cropping land expectations.

A factor to maintaining agriculture in these regions that needs to be addressed seriously is the negative demographic trend. Further introduction of innovation and (labour saving) technologies is recommended. In the case study of Sibensko for example the issue of the lack of interest among young people to work in farming was already mentioned as a big challenge for agriculture, particularly because local jobs in tourism are available and better paid. Also in Siauliai apskritis and Wittenberg case studies the strong declining and ageing population was a challenge and made the future of agriculture in the regions more uncertain. In these two regions, the options for increasing mechanization and efficiency are more likely, given the current farm structure. These are, respectively, specialized arable farming in Siauliai apskritis and specialized arable and dairy farms in Wittenberg. Certainly, in the latter region, farm size is very big and production is generally quite efficient. In Sibensko it involves more small-scale permanent cultures with grapes and olives and (traditional) grazing livestock systems on Karstic grasslands which are relatively labour intensive and not easy to modernize. Furthermore, in all three case studies there is a risk that further intensification and improvements in efficiency go together with increasing the pressure on water, soil and biodiversity. Policy guidance will be necessary in all regions, but certainly in the regions in this CC class, for ensuring that farm activities do not adversely affect the environment and biodiversity, but rather synergize with ecosystem service provision. A route towards more integrated and sustainable intensification practices and organic agriculture should be followed and this can be facilitated through a combination of private, CAP and national resources which are in principle available in these regions with a moderate to high investment capacity.

The fourth CC class is the last **stable climate class but with a worsening demographic condition and low investment capacity (CC class 1.2.2)**. It is a medium size CC class including 98 regions (9%) and 13% of the land and of the agricultural land in the EU-27. Practically all regions in this class are in the 'new EU' in Poland, Romania, Hungary, Latvia, Lithuania and Croatia and are concentrated most strongly in the RALUC Afforestation regions. They can also be categorized as mostly Continental countries but with lower investment capacity than the former group and a similar negative demographic trend to tackle. There is one case study located in this CC class which is Arges. Also in this class in the BAU scenario, so with unchanged policy, some agricultural land abandonment will happen and the opposite is expected in the SA scenario with good land reclaim expectations. Clear shifts are also expected within agricultural lands in the class of which the most prominent are the overall declines in annual crops by 9% and 12% in BAU and SA scenario respectively and an increase in perennials by 24% and 273% in BAU and SA scenario respectively. Grazing lands will remain stable in the SA scenario and will decrease by 3% in the BAU which implies that it is the CC class with the lowest expected changes in this agricultural land class. Livestock production is present but only in a selection of these regions where it is associated with higher levels of nitrogen losses to water and ammonia emissions to air, even above critical thresholds. But on the other hand, the class consists of many regions with very small livestock production and even requires livestock production to increase to support the development of organic farming to provide local organic nutrient sources. In most of the regions in this CC class there is a very large distance to the organic farmland share of 25%. Much emphasis through policy is needed to stimulate (young) farmers to continue farming and ensure availability of local labour for example through attraction of migrants. Also further introduction of innovation and (labour saving) technologies, and clear guidance on sustainable practices including more organic farming is necessary. This will not be an easy challenge in most of the regions as is illustrated by the case study of Arges. In Arges the agricultural sector is highly polarized, with over 95% of the farms being below 5 ha while only 0.1% of the holdings are over 100 ha. This polarized pattern is common for the whole of Romania and also common, although not to the extreme of Romania, in other 'new EU' countries included in this CC class. Rural poverty in many of these regions in this CC class can be quite severe, as illustrated in the Box 3 'Rural versus urban development in Romania' in chapter 3.

The next CC classes all face climatic challenges related to increasing aridity problems. The first in this group has a **worsening climate but otherwise stable or good CC in relation to demographic trends and investment capacity (CC class 2.1.1)**. It is a small size CC class including 60 regions (5%), but a higher share of 9% of the agricultural land area and 7% of the land area in the EU-27. The regions in this class are most concentrated in RALUC group Urbanisation, followed by Afforestation. The regions are also practically all located in the Mediterranean and 'Old EU' countries such as Italy, Greece, Spain, France, and Malta. The only region from the 'New EU' in this class is the Bulgarian region where the capital Sofia is located, with a relatively high investment capacity and population density and growing population number. Two case study regions are in this CC class – Hautes Alpes and Siena. It is the class with the highest expected built-up land take levels in agricultural lands. Also, very high declines in grazed grasslands and pasture lands are expected.

The urbanization is more extreme in the BAU, with a 3.9% loss of agricultural land to built-up areas between 2020 and 2050 (down to 2.8% in SA). The loss of grazing land is much higher in the SA scenario between 2020 and 2050 amounting to 38% loss, while it is 25% loss in the BAU. Within cropping land, the observed shift from annuals to perennials is also applicable to this class, with clear declines in cereals and maize production and increases in olives and other perennials but decreases in vineyards. It is worth observing that the latter is expected to occur across all Mediterranean regions. It is also a CC class with a high representation of regions with very high per hectare levels of pesticide uses in 2020 and this will become even higher in the BAU scenario to 2050. A focus on decreasing pesticide use, as aimed for in the F2F, certainly need extra attention in this CC class. Some regions in this class cope with relatively high nitrogen and ammonia emissions but through declines in livestock heads and lower fertiliser application levels in the SA scenario it will be relatively easy to reach below critical load losses on nitrogen to water and air. In the BAU scenario above critical loads will remain however. Likewise the GHG emissions will go down in SA scenario where it related to enteric fermentation related emissions, but AFOLU based GHG emissions are expected to increase both in BAU and in SA and that this is not only related to shifts in agriculture but most strongly to built-up land take effects.

Investing in adaptation to climate change is an absolute must in all these regions. On the one hand the choice of crops needs to shift to types and varieties that can cope better with low water availability. On the other hand, improvements in irrigation and water collection systems also need to be made to ensure that farming activities survive through longer and drier periods. Given the relatively high investment capacity in the regions belonging to this class, climate adaptation measures should be feasible both through access to appropriate R&D and support to farmers through CAP, regional and national government funding. The CC class is in the best position of all regions with increasing aridity problems, to make shifts towards a more sustainable agriculture possible as required for reaching the F2F goals. Also options for more sustainable intensification and conversions to organic agriculture are necessary. Several regions in this class are already near or at the 25% organic farming target as is illustrated both by the case studies of Siena and Hautes Alpes. This is because local markets are already mature for organic and local products because, for instance, of the presence or attraction of larger (often urban) population segments with overall larger representation of higher income groups and/or 'more conscious' consumers.

The next CC class has a **worsening climate in combination with a stable demographic situation and a low investment capacity (CC class 2.1.2)**. It is a very small size CC class including only 5 regions (0.4%) and a very small share of the agricultural and total land areas, again less than 0.5% of the EU-27 total. This is because the combination of stable demographics (given by either a current high population density or a growing population trend) with low investment capacity is not very common. The regions in this class are most strongly concentrated in the RALUC group Afforestation. They are all located in the Greek or Bulgarian Macedonia and in Romania, in the region of Bucharest. There is no case study located in this very small CC class. Urbanisation levels leading to land-take by built-up areas are medium to high in this class. For 2050, patterns of change in agricultural land use are expected to be similar to those of the previous CC class. In SA there is expectation for high agricultural

land reclaim which will increase strongly the AFOLU based land emissions. Also declines in pasture with conversions to arable land and increases in perennials are expected both in BAU but stronger in SA. Like for all CC classes with an over representation of 'new EU' countries, there is still a very large distance to the organic farmland share of 25%. For the regions in this CC class the same policy recommendations apply as in the former class, but access to funding for investments in adaptation to climate change, sustainable intensification practices and organic agriculture will be more challenging and need more active CAP policy targeting. On the one hand investments in modernization and sustainable intensification options and conversion to organic combined with strict guidelines for sustainability are strongly needed. On the other hand, there will generally be more labour force available for agriculture in these 5 regions, and this may also provide opportunities to develop sustainable agricultural activities that are labour intensive. Agricultural products would respond well to the wider EU market demand, although not necessarily to the demand of local markets where income levels will likely remain relatively low.

The third CC class that is expected to experience worsening **climate also needs to cope with declining demographic conditions** combined with a **higher investment capacity (CC class 2.2.1)**. It is the third CC class in terms of regions (111 or 10%) and agricultural area (11%) and total area (14%) involved in the EU-27. The regions in this class are spread quite evenly over all RALUC types. Practically all regions are concentrated in Spain, Portugal, and Italy with one region each in the countries of Malta, Romania and Croatia. There is one case study belonging to this CC class which is Albacete. The expected land use shifts in agricultural lands are again similar to others CC regions. However, in the BAU scenario this CC class is the only one that is expected to increase its grazing land. There is also an expectation for an increase in perennials, although very modest. In the SA scenario this region is not expected to show strong differences in land use shifts in agricultural lands when compared with other classes experiencing worsening aridity conditions. Like for the first aridity class, pesticide use is exceptionally high in 2020 and expected to continue increasing to 2050 in the BAU. A focus on strategies to decrease pesticide uses, as aimed at in the F2F and implemented in SA, is strongly recommended for regions in this CC class. Nitrogen losses to water and air are not a big issue in this class. GHG emissions are not expected to decline towards 2050 both in BAU and SA scenario, so this implies that more policy efforts should be implemented here to introduce measure to capture carbon in agricultural soils.

Both climate and demographic developments are challenging for the regions in this class. However, these have the advantage of a relatively high investment capacity, which makes local private investments available alongside the combined support of the CAP, national and regional policies for the necessary investments, evidently directed both towards labour saving and more sustainable agricultural practices, as well as towards adaptation to changing climate conditions. Also, there are good expectations about the possibility to develop local markets further for organic and local high-quality products. For the case study of Albacete for example, it became clear already that conversions to more climate resilient cropping patterns and varieties is already happening and there is also growing interest among farmers to convert to organic and/or more integrated practices which are more easily taken up in drier climates. On

the other hand, there are strong concerns as to whether, in low-input systems, the lower expected yields and higher labour costs will be compensated by markets in the future. These expectations were clearly expressed for instance in Albacete, where a lot of emphasis was placed by the farmer organizations and farm advisors on developments in biotechnology and technical innovations which would make the goals of F2F become reality, while maintaining farming economically viable.

The last CC class experiencing a **worsening climate** encounters at the same time **worsening demographic conditions and low investment capacity (CC class 2.2.2)**. It is a small size CC class consisting of 51 regions (4% of the total) although covering a relatively large agricultural area amounting to 7% of the agricultural land and 5% of the total area in the EU-27. The regions in this class are most spread over the RALUC types Intensification and Urbanisation. Most regions are located in Bulgaria, Romania and Greece. Imathia is the case study located in this class. It is the only CC class where annual crops are not expected to decrease between 2020 and 2050. Perennial crops will show a clear positive trend toward 2050 and grazing lands are expected to strongly decline. Hence these trends will increase the AFOLU based GHG emissions which require compensating measures to capture carbon in the future. Distance to the organic farmland share of 25% is the largest of all CC classes as not even 1% of the land is certified as organic in 2020 and in the BAU scenario. In some regions in this class, loss of nitrogen to water is an issue which relates more to relatively high fertilization losses than high livestock numbers. Measures in the F2F will provide a solution to this problem, but in the BAU scenario these losses remain above critical load levels.

The whole set of measures cited above (promoting climate change adaptation, contrasting depopulation, and sustaining investments) would need to be mobilized to support sustainable land use. With a lack of well targeted policies and measures, these regions risk to continue losing population. Consequently, the prospect is that there is not enough manpower to manage farms, nor to develop sustainable agriculture, and perhaps not even to ensure that rural communities themselves survive a fate of abandonment and further marginalization. Maintaining an agriculture that is both viable and sustainable in these, which are the most vulnerable rural areas and communities in the EU as a whole, is therefore particularly complex.

In the following final chapter (policy) recommendations are further presented and also made specific to the CC classes described here.

8. Conclusions and recommendations

8.1. Introduction

There is increasing demand for land in the EU from various sectors: agriculture, forestry, energy, nature and biodiversity, tourism and recreation, activities in the biobased economy, development of urban areas and infrastructure. Also, the Russian invasion of Ukraine and the Covid-19 crisis have shown the importance of ensuring food, feed and biomass, space for renewable energy provision and further development of a de-fossilised circular bioeconomy within the territory of the EU.

This study generated many insights in how agricultural land use has evolved in the EU-27 in the last 30 years and how it can evolve in the next 30 years. For the last 30 years this was analysed in relation to changes in land use and land management, how agricultural land use competed and synergized between food, feed, energy and non-food biomass production and with other non-agricultural land uses, and what the main drivers were for these trends and changes. It was specified for the different types of EU-27 regions that were classified in a typology of regions developed in this study, and more deeply in 12 case study regions. The main conclusions on past trends are presented in section 2 of this chapter. In section 3 the conclusions are presented for the future of agriculture in the context of the EU-27 and in the context of the ambitions of the F2F. Section 4 presents the main recommendations as to how the F2F goals can best be worked out in a territorially specific approach to leave no EU regions behind.

8.2. Conclusions on land use change patterns and drivers in rural areas in past 30 years

The dominant land use changes in the last thirty years can be summarized according to five main land use change processes. These five were used to generate a typology of regions in this project called the 'RALUC typology' and cover land take to build up areas, afforestation, intensification, extensification and nature creation. In addition to these five, there are other processes of change that can lead to large changes in land use in specific EU regions, which are: coastalization, agricultural land abandonment, scale increase via consolidation of farms and fields, specialisation and diversification of farming activities. Finally, land use was also influenced through the increased demand for biomass for bioenergy and, more recently, for the larger scale establishment of wind turbines and PV panels stimulated through the setting of EU targets for renewable energy.

Typology of rural regions

A RALUC typology of regions (at Nuts3 level) was developed in this project with the aim of better understanding whether combinations of land use changes and drivers are territorially specific. The typology is produced based on three dimensions: dominant land use dynamics, environment and socio-economic

characteristics. It turned out that in almost half of the regions in the EU urbanisation has been the main land use change, followed by afforestation (31%), intensification (14%), extensification and nature creation (5%). A principal component analysis was performed in which the RALUC typology data was combined with 27 different factors that have potentially driven land use changes in rural areas in the last 20 to 30 years, identified from literature and case studies and for which data was available. Several clusters of trends in a combination of land use and drivers could be derived and confirm that the **RALUC typology is a good reflection of classes of Nuts3 regions that have experienced similar combinations of land use changes and drivers.** This is well illustrated by the results of the average component scores per RALUC class generated in a principal component analysis. The first component from the principal component analysis highlights a clear urban-rural gradient, with mostly regions of the RALUC 'Urbanisation type' indeed experiencing the higher conversion rates of agricultural areas into urban areas because of similar socio-economic characteristics. They all have in common a very high population density, a stable GDP and high to moderate accessibility. These regions are mostly in Germany, France, Northern Italy, Belgium, Netherlands, Poland, Czech Republic, Denmark and Greece, mostly corresponding to the largest cities, urban agglomerations, and metropolitan regions. On the other end of the urban-rural gradient were the regions with more 'rural' and 'natural' character and these were more concentrated in both Western Europe (Spain, Portugal, Ireland), and CEEC Europe (Hungary, Romania, Bulgaria, a part of Poland, Baltic countries).

The second strong component was the agricultural-forest gradient (see scores in Axis 2 in Table 32) confirming a geographical polarization in 'dynamic and advanced agricultural regions' (with a dominant production model based on crop intensity, mechanization and irrigation) and in more remote regions with more representation of extensive agricultural models with organic farming, woody elements, the prevalence of natural habitats over intensive large scale cropland, and a slight expansion of forest land. Examples of regions belonging to the first gradient of 'dynamic agricultural regions' are concentrated in flat and largely accessible districts of Romania, Hungary, Italy, Atlantic France, Spain, and a small part of Germany, where dynamic and intensive farming systems consolidated and possibly expanded in the last two decades. On the forest side of the gradient are Sweden and, less regularly, other Northern countries, as well as in Austria and the surrounding Alpine regions of other countries and, more sparsely, mountainous and remote districts of France (Massif Central and Alps), Italy (Alps and Apennines), Germany, Spain (Pyrenees), and Greece.

The third cluster represented a geographical gradient reflecting the East-West divide (see Axis 3 in Table 32). The typology was mostly characterized by a socioeconomic polarization in demographically dense regions, typical of Western Europe, and regions experiencing an above-average increase in per-capita income levels in the last two decades, corresponding with the countries accessing more recently to the European Union. The fourth cluster is given the title 'agroforestry vs extensive cropping systems'. On the agro-forest side we find the North and Mediterranean regions (the Iberian peninsula, France, part of Italy, Croatia, part of Denmark and, more sparsely, Sweden and Finland) having more woody landscape features in and along agricultural land, while the extensive cropping systems having the more open agricultural landscapes with low density of woody landscape elements which are mostly in Romania and

Bulgaria, and more sparsely in Germany and Poland. The fifth component confirms the geographic gradient of drylands vs humid climate divide, and the sixth geographic gradient is agricultural intensification vs solar park developments.

Trends in agricultural land use for food, feed, energy and other non-food 1990-2022

Between 1990 and 2022 the cropland (arable land + permanent cropping land) in the EU-27 remained relatively stable from 120 million hectares to 111 million hectares. Over this same period agricultural production (expressed in dry mass of main product) first increased until 2010 and then started to decline from 2010 onwards. In 1990 it amounted to 488 million ton dry mass to 510 million ton dry mass, excluding residues. The increase in production is driven by yield increases, but not so much by land increases, at least after 2000 for the whole EU-27.

The largest share of agricultural land is taken up by the production of feed in the EU-27. This land share amounts to 53% in 2022, and 60% in terms of production (in ton dry mass). In 1990 the area used for production of feed was lower at 50% and 54% in terms of production, but the total production of feed only amounted to 262 million tons dm while this became 304 million tons dm in 2022. In this same period food production in the EU-27 declined from 223 million ton dry mass to 175 million ton dry mass in 2022.

Also the volume of residues used for feed increased strongly in the whole period from 64 million ton dm in 1990 to 248 million ton dm in 2022. This use also includes residual biomass use for bedding. Still the dominant use of primary agricultural residues is livestock production in 2022 with 58% used for this purpose, while 39% is used for food (e.g. strawberries, flower bulbs, mushroom production), 2% for energy and 1% for other non-food purposes.

The decline in land used for food production between 1990 and 2010 was clearly related to competition with feed for livestock and biomass production for energy. The amount of land used for biomass production for energy increased in this period from 57 thousand hectares in 1990 to more than 5 million in 2010. The steep increase in this area is related to a strong increase in land used for production of crops for first generation biofuels and for biogas which was mostly maize based in that period. The Directive on Biofuels for Transport came into force in 2003 and led to an accelerated growth until 2009-2010, which is when the first Renewable Energy Directive (RED, 2009/28/EC) came into force. This was followed by a small dip in the agricultural area used for biofuel feedstock in 2015, with the introduction of the ILUC Directive³² which introduced a cap on food and feed based biofuel, and from then on the area used for biofuel feedstock flattens. The area used for dedicated cropping for energy is now at 6.6 million hectares. In addition, land on which the main product (grains) is purposed for food and feed production, but from which residues are harvested (mostly straw) for energy production amounts to 4.3 million hectares.

³² Directive EU 2015/1513

Competition for land between non-food uses, other than for energy, is very small, at least at EU level. In 2022 it amounts to 110 thousand hectares (<1% of UAA) with a production of 296 thousand ton dry mass and mostly involves industrial crops like cotton, flax and hemp. Recently these are experiencing an increase again, but in the period between 1990-2020 it mostly declined.

Overall it can be concluded that land for food production competed with bioenergy production most strongly in the period 2003 to 2010. After 2010 there was still a gradual increase in this land use but it was much more modest because of stricter sustainability criteria introduced in the RED from 2015 onwards. Given the dominant position of feed production in EU-27 agricultural land use, it is clear that diets, particularly in relation to animal protein consumption levels, have influenced the changes in agricultural land use since 1990.

Agricultural land take by built-up area

Farmland conversion to built-up areas (conversion of land into artificial areas) has been a dominant factor in practically all regions of the EU, although the scale of farmland loss varies strongly between countries, RALUC regions and also within RALUC regions. In absolute numbers it was highest between 1990 and 2020 in countries like Germany (310 000 ha), Spain (160 000 ha), France (360 000 ha), Poland (170 000 ha), and Italy (220 000 ha). But if expressed in relative terms, the figures between 2000 and 2018 are highest for Netherlands (2.4%), Cyprus (2.5%), Luxembourg (0.9%), Spain (0.7%), Denmark (0.7%), and Czech Republic (0.6%). RALUC regions of type 'Urbanisation' are mostly demographically dense areas as confirmed in the PCA analysis.

'Coastalization', the land take process that affects coastal areas was largest in Spain, France, Italy, and to a lesser extent, in Portugal, Denmark, Netherlands, Poland and Sweden. Within coastal regions but also outside, the growth in international tourism has also driven the transformation of agricultural land into build-up areas. This was seen in the case studies Zuidwest-Drenthe (recreation parks), Hautes-Alpes (development of second homes), and Argeş (built environment around settlements and in touristic mountain villages). The literature review mentioned demographic changes influencing land take from agriculture to urban areas in the form of population growth in urban areas and migration from rural areas, especially by young people, driven by better employment opportunities in urban settings. This went along with deteriorating access to public services in rural areas. Similar processes were noted in the case studies in Šiauliai, Siena and Albacete. Tourism has also driven urban development on agricultural land in coastal areas as in the case study in Šibenik-Knin (Croatia).

Weak normative and regulatory constraints appeared in the literature as a dominant factors for the conversion of agricultural land to urban areas. This was not mentioned in the case studies with reference to land take for conversion to urban areas (residential, industrial, commercial). However, it was mentioned for conversions from nature land into urban land in Sint-Niklaas which then had to be compensated by shifting agricultural land to protected nature in another location. It was also mentioned for the placement of windmills and solar panels on agricultural land in for example Šiauliai apskritis and Albacete.

Among the most relevant **impacts**, applicable to both agricultural lands taken by built-up areas and the specific process of coastalization, we observe the loss and further fragmentation of agricultural land, possibly leading, among other factors, to local and overall reduction of agricultural production and the competitiveness of farms.

Agricultural land to Afforestation

The literature review has shown that expansion of forest at the expense of agricultural land is one of the most prominent changes in land use in the period 1990-2018. Abandonment of agricultural land has been a dominant factor for the increase in forested area in Europe, mostly in the form of transitional woodland shrub. The literature revealed that afforestation supported by the CAP between 1992 and 2012 was also important. Therefore, a distinction needs to be made between active afforestation practices and natural revegetation after agricultural land is no longer managed. With the data available it is not always easy to make this distinction, but with LEAC land cover flow data in combination with the data collected in the case studies, estimates could be made about where each type of afforestation was most important.

Ireland, Spain, Portugal and Hungary are typically countries with active afforestation, all because CAP and national support, was important. In other EU countries, natural revegetation of abandoned farmland is likely to have been the predominant mode of afforestation. Increases in forest areas varied widely, with Hungary, Portugal, Ireland, Estonia, Poland, Lithuania, Finland, and Slovakia showing the highest values. In Ireland, Poland, Lithuania and Hungary this went together with a strong increase in the overall forest cover. There are also countries (Portugal, Estonia, Finland and Slovakia) where active afforestation did not revert the decline in overall forest area.

The share of agricultural land that has become afforested is higher in all RALUC types classified as afforestation types (A-1a, A1b, etc.). One exception is the I-3a class, in which agricultural intensification was the dominant land use change, but there is still a relatively high level of afforestation of agricultural land.

Literature review and results of case studies confirmed that **drivers** for afforestation are a complex mixture of different, often connected, factors of which unfavourable agro-ecological and socio-economic circumstances at farm level are playing a key role in combination with economic policy support or (new) market demands to make the investment in afforestation attractive. Afforestation induced by the bio-economy has also emerged from the literature as the use of domestic primary forest resources, primarily as firewood, followed by secondary wood residues, mainly for industrial processes and pellets.

This mix of drivers was also observed in the case studies in both central and eastern Europe as well as in Italy and Spain. Drivers of various types underlaid farmland abandonment and hence, natural forest regrowth, notably depopulation of rural areas, but also slow processes of land restitution in countries with formerly collectivized agricultural land under the communist Soviet regime, after their entry into the EU. Active afforestation, due to support from the CAP, was less reported in the case studies where policy influence mostly appeared in nationally promoted and financed afforestation, or where a

lack of policy led to natural revegetation after land abandonment. In the case study in Croatia, parcels overgrown by shrub vegetation and not utilized for longer periods, entered in forest management plans, and were owned by the state forest company.

Bioeconomy as a driver was only observed in the case study in Ireland and Albacete where financial support was given to the conversion of agricultural land into commercial forest plantations. However, in the Irish case study there was also some grant-funded (small-scale) planting of native tree species for biodiversity purposes, but much more in recent years.

As to the **impacts** of afforestation of agricultural lands, two factors were reviewed. On the one hand, afforestation helps building-up and/or restoring above ground biomass that contribute to carbon storage and can contribute to biodiversity restoration. On the other hand, afforestation may have adverse effects on biodiversity if it takes place on e.g., ecologically valuable permanent grasslands that rely on traditional grazing practices. Lastly, it leads to loss of farmland which may also have indirect land use effects somewhere else.

Referring to the impact of afforestation on changes in vegetation and related carbon storage, our analysis shows that afforestation of agricultural lands does contribute to building up of biomass and carbon, but that many other factors determine whether it eventually leads to a net increase at wider regional level. Countries with increases in biomass development in combination with relatively higher shares in afforestation of agricultural land are Hungary, Portugal, Slovakia, and Estonia. Ireland, with relatively large increases in both afforestation area on agricultural land and forest area, still shows an overall negative trend in vegetation productivity. For the loss of agro- biodiversity, which is monitored via a national farmland bird index, the data is only provided at a national level. There are many factors influencing farmland birds - afforestation may be one of them where birds are present that need open landscapes, such as birds of prey. Overall, it is clear that farmland birds have further declined in most EU countries since 2000, with exceptions in Cyprus and Ireland. Strongest declines in farmland birds since 2000 are seen in Lithuania and coincide with a moderate afforestation activity. Strong declines of farmland birds are also recorded in some other countries with high to moderate afforestation of agricultural land such as in Estonia, Hungary, Czech Republic, and Poland. Ireland and Portugal have among the higher afforestation shares in agricultural land but have an increasing to stable farmland bird indices.

Land Abandonment/Rewilding of agricultural lands

As seen previously, abandoned agricultural lands are described as lands that were previously used to produce an economic output (agricultural production) but are no longer used for that purpose. However, the abandonment of agricultural land in the strict sense, should not be confused with land take due to new built-up areas or active afforestation. Typically, abandoned land looks like fallow-land or non-managed pasture land. Depending on circumstances (climate, soils, slopes, socio-economic factors, etc.), there may be a transition from farmland to shrub vegetation cover to woodland shrub and, ultimately, natural recreation of a forest cover.

Unfortunately, direct data on agricultural land abandonment is practically missing both at EU, national and regional levels. The only EU wide data on land

abandonment is from Eurostat and is based on LUCAS points, however this has limited spatial resolution and time series data. Based on these data, the largest land abandonment occurred especially in post-socialist countries (namely in Bulgaria, Croatia, and the Baltic states), and led to rewilding and afforestation, with a resurgence of agricultural activities in some regions since joining the EU. The information collected in the case studies confirms that land abandonment has been widespread in many regions all over the EU and will continue to be so in the future. Abandonment of agricultural land together with an increase in forested area, mostly in the form of transitional woodland shrub, was observed in the case studies in central and eastern Europe, in Italy and Spain.

Active afforestation and agricultural land abandonment may have the same outcome, namely the forest cover, but are often driven by a different mix of **drivers**. Drivers of various types underlaid farmland abandonment, notably depopulation of rural areas, but also slow processes of land restitution in countries with formerly collectivized agricultural land under the communist Soviet regime, after their entry into the European Union. Moreover, all regions where abandonment is prominent confirm that it is mostly taking place in marginal and mountainous areas (Siena, Imathia, Albacete, Montana and Argeş). In several case studies, two processes in land use changes take place in the same region but in different landscapes. Apart from the mentioned land abandonment, taking place in hilly and mountainous low productive lands, there is also intensification of agricultural land use in the lowlands - where better soils are usually found. In countries of recent entry into the EU this also occurs, bringing formerly abandoned land back into use.

The process of land abandonment, which was especially important in the past, in some cases still continues today and coincides with a progressive decline in traditional, often semi-subsistence grazing activities. Part of agricultural land abandonment and linked afforestation trends can accompany nature creation and rewilding. Nature creation involves a process where protected nature is actively created. At RALUC region level the highest share of farmland loss is in regions in Portugal, Ireland, Estonia, Hungary, Lithuania and partly in Netherlands and Italy. There is a clear overlap with the countries and regions that are also scoring highest for afforestation of agricultural land. In most countries this involves land abandonment with revegetation but in the Netherlands it is mostly related to active allocation of protected nature areas with or without continuation of farming to improve nature area connectivity and comply with habitat Directive goals.

Impacts of land abandonment and natural re-forestation are diverse and relate mostly to carbon capture, increased risk for wildfires and biodiversity, the latter already discussed above. For several EU countries increased NDVI trends go together with high land abandonment trends, such as in Hungary, Estonia, Latvia, Netherlands, and Poland. However, for other countries, the two trends do not coincide and further explanations need to be sought. For instance, very high positive NDVI trends are found in Bulgaria, Czech Republic, Romania despite low abandonment and afforestation levels. It is likely that these are still a result of large-scale land abandonment occurred in the 1990 that created an enormous natural revegetation of former farmlands which continues to produce additional biomass. In Mediterranean countries such as Spain, Italy, Greece, where studies have indicated farmland abandonment to be quite common in the

1990s and 2020, climatic factors have likely constrained large biomass development. Overall, in all RALUC regions with high land abandonment shares, the NDVI is positive to highly positive. When it comes to wildfires, the largest burned area shares are found in Portugal, Italy, Spain, Greece, Malta, and Romania. In some countries this coincides with high abandoned land shares such as in Portugal. Overall, fires are more frequent in Mediterranean countries. As to RALUC regions, higher burned area shares are found in Afforestation types with modest to high land abandoned area shares.

Agricultural intensification

Intensification has been a very influential process of land use change in most agricultural areas in almost all regions of the EU. It was mostly concentrated in the better agricultural areas; however, also areas with more natural constraints such as because of low precipitation, have experienced strong intensification thanks to technical innovations. Faster intensification often occurred in MS who entered the EU recently, because of the opening of markets, investment opportunities and CAP support. The process, however, is not only linked to new accession into EU and to CAP payments.

The relationship with RALUC types is not always obvious. There are multiple likely reasons for this: one is that more processes occur in each RALUC type, together with the dominant one; a second is that determinants underlying proxies for intensification, such as higher yields, are more complex and not always well correlated with those of land use transformations identified through available EU data. The information derived from the case studies is therefore more informative.

A main driver for intensification has been in the past and still is the market, including through the large influence of retail that puts significant pressure on farmers to keep farm gate prices low and hence maintain competitive consumers' prices. Important also, is the reduction of the labour force in the agricultural sector and the declining rural population leading to the adoption of labour-saving agritech innovations. Especially for new MS, CAP and other EU support have been key factors for intensification of farming practices. Evidence of this is reported in literature (e.g. in Stoate et al., 2009): since the accession to the EU, agriculture on the most productive land in these countries involved, intensified. Panoutsou et al. (2022) suggested that management improvements and high yield trends observed especially in the CEEC countries, were also sustained by increasing CAP payments. Mostly to large farm enterprises. Czubak et al. (2021) observed that such farm investments were mostly sourced through CAP investment measures covered by the 2007–2013 Rural Development Program (see measure "Modernization of agricultural holdings") and the 2014–2020 Rural Development Program (see measure "Investments in physical assets"). This was also confirmed in several case studies in CEEC such as in Montana, Šiauliai, and Arges where also direct payments made resources available for farm level investments. Literature also indicates that, more recently, especially larger commercial farmers have started adhering to greening and ecosystem measures, also profiting from the dedicated CAP incentives.

The case studies confirm that this process also continues in old EU countries (like in Albacete for irrigation) and is also promoted through choices made by

national governments (Zuidwest Drenthe) as well as by investments done by financial institutions (again, the case of Zuidwest Drenthe and Siena).

The main driver for intensification is the market, including through the large influence of retail on keeping prices of agricultural products low. Important also, is the reduction of the labour force in the agricultural sector and the declining rural population leading to the adoption of labour-saving and agritech innovations. Especially for new MS, CAP and other EU support were key factors for intensification of farming practices. The case studies confirm that this process also continues in old EU countries and is still promoted through choices made by national governments (Zuidwest Drenthe) as well as investments done by financial institutions (again, the case of Zuidwest Drenthe and Siena).

Positive **impacts** of intensification is on agricultural production and food security and often also for the economic income of farmers, although this is not the case when accompanied by high investments that lead to high debts and interest payments. The development and progressive adoption of agricultural technologies has accompanied agricultural intensification across the EU, leading to increases in yields and quality of production as well as a reduction in costs. This was also reported for several case studies (Imathia, Zuidwest-Drenthe, Sint-Niklaas, Šiaulių apskritis, Argeş, Albacete). The negative impacts for biodiversity and environment have been widely reported in literature and reported for the CSs. This is related with increased use of pesticides, herbicides, fungicides, and application of large amounts of synthetic fertilisers since 1990s, mostly in croplands and even more for certain types of crops. Another strong adverse impact on biodiversity is what derives from conversion of natural habitats to agricultural lands or because of destruction of landscape elements to create larger fields for more efficient agricultural practices. This was derived from the literature review done in this study and presented in Annex 5 and from several case study results, especially the ones in countries that entered the EU more recently and for those case studies it was also reported that this process remains ongoing.

This has especially happened recently within countries that entered the EU more recently and remains ongoing. In regions with high livestock stocking densities, water pollution by nitrogen, emissions of ammonia leading to high deposition levels are a problem. The opposite is also happening where soils are depleted from nutrients, particularly potassium and carbon, because of high output and low input management seen mostly in CEEC countries rather than in Northern and western parts of the EU.

Extensification in agriculture

Although the term does not yet have a commonly agreed definition, this study defines extensification as the opposite of agricultural intensification and that reflects a process of decrease in the use inputs, usually relative to land area. Over the time frame considered, extensification trends varied across MS, without a clear geographic pattern. Countries of recent EU accession showed an intensification process from 2004 to 2006 while from 2007 to 2009 there was a clearer extensification trend, followed again by another period of intensification for most, until 2019. From the older MS, countries showing clear increases in agricultural area managed by low input farms are Belgium, Greece, Denmark,

and Finland. The opposite is seen in countries like Netherlands and Austria where the area under high input farms increased over the same period.

The literature review showed that **drivers** for extensification of agriculture since 1990 were mostly related to policy, consumer preferences and profitability at farm level. The gradual decline in extensive farming was more driven by markets and economic variables. According to the literature, growing interest among consumers for the mode of production, origin, environmental impacts, and animal welfare of their products, opened new opportunities for value addition by means of higher quality products coming from low input traditional farming systems.

This effect was observed leading to an expansion of organic farming or sustainable farming practices in several case studies (Šiaulių apskritis, Imathia, Zuidwest-Drenthe, Siena).

In the case of livestock, extensification meant a reduction in the number of animals, usually as the result of unprofitable farming or target policies. This was seen in the case studies in West-Ireland, Zuidwest-Drenthe (Netherlands) and Argeş (Romania).

One of the key drivers for extensification in eastern Europe was the breakdown of communism. This triggered a strong decline of capital- and input-intensive farming practices (e.g., lower pesticides and fertiliser applications). Intensification took place in areas highly suitable for farming, and deintensification and cropland contraction in more marginal areas.

CAP policy has supported low input, organic and HNV farming practices across the EU through the set-aside measure and subsequently through support from Pillar II (agri-environmental measures and support for green infrastructure). The **impact** of these policies was noticed in several case studies (West-Ireland, Montana, Šiaulių apskritis, Siena). For instance, in the case study in Montana, these EU policies, implying also extensification, influenced high-nature value and environmentally sustainable farming.

Scale Increase and Specialization: farm consolidation into larger units has been common across the EU, with significant reductions in mixed farming and overall negative impacts on biodiversity as was derived from several literature sources described in the literature review for this study (see Annex 5) and is also clearly reported in the Agri-environmental indicator – specialisation).

According to literature (see also Annex 5), land reform influenced agricultural land use change in post-socialist countries in Central and Eastern Europe with the transfer of land rights from state farms and cooperatives to individual farms and the reorganization of cooperatives into new private companies. The land restitution led to the creation of a mixture of small individual farms (oriented to subsistence and with a modest market integration) and large-scale commercial farms. National land-consolidation programmes led to disparities between ownership and use of land. This was the case of agricultural land managed by big entrepreneurial entities and leased out to a large group of small farmers.

Restitution of land ownership to previous owners, cooperatives and state-owned enterprises was reported for the case studies in Šiaulių apskritis and Argeş. This resulted in a shift towards either more mechanized and specialized agricultural

production and a decline of traditional farming practices in Silauiai, but also to a polarized structure of the agricultural sector in Arges (Romania), with a few big farms on one side, and many small farms on the other. Literature mentions that land consolidation occurred in several member states to reduce property fragmentation and to increase the efficiency of farming. This process was noticed in several case studies.

Drivers of scale increase in agriculture, observed in the literature, are typically stable markets, higher costs for labour or lower labour availability, land reforms, opportunities for land consolidation into larger areas and fields because smaller (and older) farmers sell their farms, and technological innovations. Investments in scale increase have been facilitated via the CAP with market and income support and direct payments.

These factors were also found in the case studies. Economic pressures and market forces were cited as the cause for an increase in the number of large farms and a decrease in the number of small farms in the case studies of Siena, Argeş and Imathia. Global markets induced a replacement of family farming structures by large cooperatives in Albacete. Another market force came from foreign investors, offering high prices for high-quality vineyards in Siena.

As to the **impacts** of scale increase, there is a relationship with impact on biodiversity, particularly as scale increases went together with land reforms and consolidation of fields which caused loss of field boundaries, landscape elements and higher input level of pesticides because of monocultures. Since scale increase also went together, or was facilitated by labour saving technologies, it is likely that it did lead to increased mechanisation which is also likely to have had adverse effects on soil health.

Impacts of scale increase and intensification do not need to be the same, as increasing scale does not necessarily need to lead to increasing input use. However, in many cases scale increase and intensification have gone together and then it is challenging to analyse the impacts of each separately. In the case studies, both processes and their drivers will occur and hopefully further information on the overlap and differences between them will result.

Renewable energy from wind and PV competing or synergizing with agricultural land use

With the introduction of the renewable energy targets, the demand for land to place wind turbines and PV panels has increased, also on agricultural lands in certain regions. This could be concluded from the relatively scarce and incomplete (spatial) data available at EU level from a JRC study (2023)³³ and Open Street Map (OSM)³⁴. The largest absolute number and highest share of windmills on agricultural lands is found in Germany with 41% of all windmills. France has the second largest number with 12% of EU capacity on agricultural land, followed by Spain with 10% of windmills, Italy (8%) and Poland (7%). A smaller country with a relatively large capacity and therefore high density of windmills is Netherlands (3% EU windmills on agricultural land). For PV, the

³³ 'Overview of the Potential and Challenges for Agri-Photovoltaics in the European Union'

³⁴ [OpenStreetMap](#)

largest absolute area on agricultural land is in Spain with 41% of the EU PV area in EU-27, followed by Germany (8%), Italy (7%) and Portugal (7%).

Agricultural area loss due to renewable energy is very small, not reaching even 0.1 % of UAA in the last 20 years. In certain regions, the land use impact can be larger of course. Even though land take is small, the perceived negative impacts on the landscape and (possibly) biodiversity need to be considered and this calls for more consideration of RES energy development in regional rural development plans. Several case studies reported an expected expansion of renewable energy infrastructure, particularly wind and solar farms, already outlined in national or regional energy strategies or development plans. Subsidies and feed-in tariffs can significantly influence the expansion of renewable energy infrastructure on agricultural land. The development of renewable energy infrastructure is reported in the case studies to possibly reduce available farmland, but also to provide additional income for farmers. In some regions, investments from farmers and land owners in solar parks are seen as a way to decrease energy costs. Agri-PV, where farming and solar energy production are synergized, was not yet taking place in any case study region, while this could be an interesting option especially in the Mediterranean region where crop growth and soil water availability can be improved by growing in the shadow of the PV panels.

Lessons learned for (past) policy instruments and land use trends

CAP has influenced land use changes in agricultural and wider rural areas in different parts of the EU. Past CAP direct payments, also in the form of coupled support, as well as investments under Pillar 2, had an overall positive impact on preventing land abandonment investments in rural development also contributed to sustaining indirectly rural communities and promoting environmental sustainability. The support of CAP helping to keep agricultural land in use also worked the opposite way where it concerned farmland that is ineligible for CAP payments (Alliance Environnement, 2019). Policy instruments on market integration and increased trade opportunities also supported farmers' income in these countries. An interesting support measure under the CAP is payment for areas facing natural and other specific constraints (ANCs). There is evidence that ANC support reduced the rate of abandonment as well as inhibited afforestation or other competing land uses, for instance in France, in Hungary and Ireland (avoided the abandonment of grassland) and in Romania (on steep slopes in mountains) (EC, 2023). One measure to stimulate continuation of farming, particularly in rural areas with ageing population and farmers, is the Young Farmers installation? support. The budget allocated to this measure has increased in recent times, but remains low in comparison to the direct payments made under Pillar 1 as was mentioned several times in several case studies. What also has become clear from the literature review in this study (see Annex 5) is that Land use impacts have been very different throughout the EU because of the non-equal distribution of CAP payments, especially in the older EU MS. Most of the funds have favoured larger farm enterprises for a long time at the expense of small holders. A non-equal distribution of CAP payments was also mentioned, which occurs throughout the EU MS: one of the main reasons indicated was that, despite several reforms, direct payments largely remained based on historic rights hence linked to production levels with regions most in need of support less likely to receive large amounts.

Measures referred to as greening under Pillar 1 and the Agricultural Environment and Climate measures (AECMs) under Pillar II in the CAP 2014-2020, indicate so far, a rather limited effect in reaching the foreseen goals on biodiversity and climate mitigation. This was largely related to underfunding and leaving too few restrictions, particularly in terms of farmers choices (Peér et al., 2017; European Court of Auditors, 2020).

Under Pillar II, for which the (relative) CAP budget has increased strongly since 2000, several support measures have a territorial dimension. These include AES, ANC, compensation payments to farmland in Natura 2000. All these support measures work differently because choices to include them in the Pillar II suite of measures and budget allocation are influenced by Member States' choices. Uptake of different measures within countries and regions can also vary strongly ((Alliance Environnement, 2019).

Important in the suite of measures are the Agri-Environment and Climate measures (AECM) under the Rural Development Programme (RDP 4.4: Support for non-productive investments linked to achievement of agri-environment-climate), effective for enhancing sustainable practices and mitigating land abandonment through providing additional income for carrying out particular management practices, including on more economically marginal farms.

Other controversial or negative impacts have been mentioned in the relevant case studies, such as limited support for extensive livestock viz a viz intensive livestock farming, with the risk of abandonment of (high biodiversity) grazing land. For the Pillar 2 Agri-Environment and Climate measures (AECM) literature showed examples in which 70% of the payments went to areas outside HNV farmland or benefitting intensive rather than extensive farming. When considering environmental goals, while organic farming received a strong boost from both Pillar I and Pillar II2, investments across case study regions regarding biodiversity and climate measures indicate that uptake and especially impact have been low. In the next section, conclusions are made regarding F2F goals and observations from this study regarding their feasibility given the carrying capacity of different regions and implementation options.

8.3. Conclusions on the future of land use for sustainable agriculture

To analyse the best way forward towards sustainable agriculture in 2050 this study developed two scenarios, business and usual (BAU) and Sustainable Agriculture (SA), for which land use change trends were modelled towards 2050 and KPIs were assessed to understand environmental impacts and socio-economic trade-offs and policy guidance needs. In the BAU scenario current trends of drivers of urban sprawl, climate change, land degradation, land abandonment, intensification, extensification diets, are expected to continue. Also recent CAP policy, Farm to Fork (F2F) and wider Green Deal policy goals are not addressed with new policy instruments. Society's interest to adopt changes in lifestyles and pay for maintenance and improvements in ecosystems

services connected to production of food does not develop further. In the SA scenario, drivers are expected to be brought in line with the Green Deal and the Farm to Fork strategy and all associated targets are expected to be met. These cover overall targets for a climate neutral agriculture sector in 2050, ensuring food security, nutrition and public health; preserving the affordability of food while generating fairer economic returns from agriculture; preserving competitiveness of the EU supply sector, and promoting fair trade. For several of these policy ambition the drivers incorporated in the scenario assessment are linked to the concrete targets set in F2F. These are: related to climate adaptation and mitigation, reach 25% organic farmland area, decrease inputs of fertilisers, pesticides and losses of nutrients, reach good soil health and zero land take, follow up the nature restoration requirements in the Nature Restoration Law and reach the renewable energy targets and contribute biomass for the bioeconomy.

Trends in future land use expected

By 2050 it can be expected that farmland area loss can be limited with active policy interventions to reach the F2F goals. However, if no active policy interventions take place, as modelled in the BAU scenario, the decline of farmland will be more than 8 Million ha. A large decline in agricultural land goes with a larger increase in urban land if no policy measures are implemented to reach zero land take by 2050 as aimed for in the Soil Monitoring and resilience Law. The amount of agricultural land converted to urban between 2020 and 2050 according to the iCLUE modelling amounts to 2.3 Million ha, while this can be 1.4 million with the implementation of the zero-land take measure through the soil monitoring and resilience law in the SA scenario.

With no policy intervention, the largest loss in agricultural land can be expected in in the Alpine zone, followed by the Mediterranean and Continental zone. The Northern region (Baltics and Scandinavia) is an exception as it will practically experience no decline in farmland in BAU. With F2F policy implementation in SA scenario losses in farmland will be much smaller, however the Mediterranean will still lose 2.3% of agricultural area, while the North and Continental zones will even show gains of 3.7% and 0.7% of the land area respectively. One factor, amongst others, causing this continuation of farmland decline in the Mediterranean and farmland increase in the North, is climate change. It leads to lower precipitation levels in the Mediterranean but also longer growing season towards the North.

The environmental zone with the largest relative forest area increase in a situation with no F2F policy implementation is the Atlantic, followed by the Mediterranean zone. If F2F policy goals are actively followed up by policy action (SA scenario) the relative largest increase in agricultural land is going to be in the North and in the Continental zone. The latter is no surprise since in the SA scenario more abandoned farmland is brought back to agricultural management in places where it became abandoned after fall of the communist system. Basically, it is a trend that was already ongoing in many former communist countries under influence of entry in the EU and introduction of the CAP. This trend of bringing back agricultural lands into production again can be expected to be stronger in the SA scenario, a situation with more active CAP policy support to F2F targets, while in the BAU this is likely to stop or even reverse.

Future land use shifts and trade-offs with food security, safe and healthy food

As to the goal of keeping agricultural land in production to ensure food security from domestic sources one can confirm that this works better in the SA scenario where more land will remain in agricultural production in the EU. Moreover, between 2020 and 2050 there will still be a considerable trend to reclaim more agricultural land and to lose less agricultural land to built-up areas and natural conversion to shrubs and forests. Also, the production of food that is sufficient, safe, and healthy will work out better in the SA scenario since a larger share of food is assumed to be produced organically, and with lower use of pesticides and artificial fertilisers.

However, impacts on food security and healthy food depend on changes in lifestyles. The KPI on total calories produced from the harvested land resource shows that the number of calories produced in SA scenario is lower than in the BAU scenario, and that both scenarios show a declining trend in calories produced compared to 2020. This has to do with an overall decrease predicted in feed production because of declining livestock numbers, but also climate change impacts on crop choices and yields. In the SA scenario this decline is bigger because expectations for larger shifts in diets towards less meat and more vegetal proteins are assumed. This together results in lower total calorie production, although this should not represent a problem if the protein transition is really going to advance. However, if people continue consuming meat at current levels, the F2F targets in relation to more organic farming and lower fertiliser and pesticide inputs will be difficult to reach. This is because higher livestock production levels also require much higher calories from crop production to feed the livestock. This can only be reached with larger production volumes of feed crops on agricultural lands or through higher imports of feed from outside the EU. Feed from outside the EU also increases the environmental footprint of EU food, particularly where it may lead to further deforestation elsewhere.

Future land use changes and environmental consequences for water, soil and GHG mitigation

Reaching the F2F goal of having a food system that should have a neutral or positive environmental impact will be challenging. On the one hand, the KPI scores confirm that in the SA scenario, the lowering of fertiliser and pesticides inputs, more organic land use, and lower livestock numbers are likely to lead to better water quality, lower ammonia emissions, considerable reduction in GHG emissions, most strongly caused by enteric fermentation (livestock based emissions) which is the largest source of GHG emissions in agriculture (EEA, 2023), but not necessarily to AFOLU based GHG emissions. In this respect the SA scenario leads to a significant improvement in environmental quality.

On the other hand, the KPI scores for soil health, namely SOC scores and soil erosion risk index, are likely to worsen in the SA scenario because more lands remain in agricultural use than in the BAU scenario. This implies that in the future more effort needs to be made to maintain SOC and decrease soil erosion through a wider uptake of soil management practices in agriculture. This effort is even more urgent given that climate change is accelerating, increasing the risk of extreme weather events leading to higher erosion risk, landslides, drought events, desertification, and wildfires. The wildfire risk will still be larger

in the BAU scenario in which more agricultural lands are abandoned increasing the area with unmanaged shrublands.

For adaptation to climate change, the SA scenario performs much better in that high water demanding crops are, to a larger extent, replaced by lower water demanding crop mixes, particularly in areas with higher climate change impacts (drought). It also widens opportunities for agricultural production in the North where growing seasons become longer, increasing crop production opportunities at higher yields. This may only happen if enough opportunities are created through markets and policy support to make investments in agriculture for adaptation.

Carrying capacity of regions and F2F policy goals

To understand the territorial differences in reaching a sustainable agriculture in the future the RALUC Nuts 3 regions were further classified in so called carrying capacity (CC) classes (see Figure 23). The CC is based on three dimensions representing (i) future climate conditions (namely climate aridity), (ii) demography (a combination of population density and expected population trends towards 2050), and (iii) the intrinsic capacity of the territories to invest in their future agriculture (current GDP).

From this CC classification it became clear that increased aridity is expected in 227 (15%) RALUC regions which cover as much as 26% of the agricultural area of EU-27. These are all located in the Mediterranean basin and particularly in the Iberian Peninsula, Southern Italy, Greece, Cyprus, but also in the Eastern regions of Continental Europe, namely in Romania and Bulgaria. Beside strong declines in effective water availability, extremes in weather events are also expected. Climate adaptation is the most urgent focus in agriculture and therefore in policy guidance, and private and public investments. More than 50% of the regions, which cover 61% of the EU farmland, have an unfavourable demographic trend which implies that they must cope with very low population density and/or a strong declining trend in population toward 2050. 15% of the regions have very low investment capacity and they cover 21% of the farmland. These regions often lack local investment capital and rely more strongly for this aspect on EU CAP support and other investment mechanisms such as the European Regional Development Fund (ERD), European Social Fund, Interreg, Just Transition Fund (JTF) and Cohesion Fund. Regions that will have the lowest CC for reaching a sustainable agricultural situation in the future are of course the ones falling in all low CC dimensions - this applies for 4% of the regions covering 7% of the EU farmland area. These regions are all located in Bulgaria, Romania and Greece. The opposite is true for 43% of the regions with 29% of the agricultural land where no threshold for CC is exceeded. These are regions with the best capacity to implement several EU policy goals and reach a sustainable agricultural status and they are mostly spread over the 'old EU' countries.

Interestingly, the 8 CC classes can also be characterised in terms of current and expected land use trends and KPI scores which are relevant to consider when developing the regional visions, plans, new policy instruments in future CAP programmes. In the next section these characteristics were considered for making the territorially specific recommendations (also summarized in the final Table 12).

Overall, in the Sustainable Agriculture (SA) scenario, in which all F2F policy goals are reached by 2050, agricultural land use will decline only marginally as compared to 2020 levels. However, this will require serious efforts in terms of policy implementation and if no active policy interventions will be in place, the decline of farmland is estimated to be more than 8 Million ha. This will be accompanied by a large increase in urban land take of agricultural soils if no policy measures are implemented to prevent this process as in BAU. In BAU, land abandonment can expand following depopulation in marginal areas, worse climate conditions for farming (warming and extreme events), and an unwanted expansion of non-managed (low-quality and often biodiversity poor) forests possibly out of the economic value chain because of an intrinsic lack in management and with limited ecosystem value, but likely advantages in terms of carbon capture. The latter contribution to ecosystem value and GHG carbon capture will very much depend on the territorial context.

In this perspective, the European space is significantly differentiated as far as land-use, economic dynamics, social structures, and ecological conditions are concerned. All these conditions intrinsically influence agricultural dynamics and drive territories to answer in a possibly different way to policy stimuli - both those impacting directly, and indirectly, the primary sector. We documented such disparities adopting a purely multidimensional perspective when delineating RALUC typologies earlier in this report. Based on a comprehensive inspection of RALUC typologies, KPIs, and additional key indicators, we introduced the concept of 'carrying capacity' to evaluate - from a territorial perspective - the different state and ability of each European region to answer policy stimuli, based on the asset of conditions and contexts available at the moment and in the future, and possibly influencing to ability to exploit policy opportunities.

8.4. Recommendations for a sustainable agriculture in all EU regions

In this section the final recommendations from this study are presented. The recommendations are structured following the different F2F goals and are made specific to the different types of regions that were classified according to carrying capacity (CC) in this study. The concept of **carrying capacity** of a given territory and its community is specifically introduced to reflect the effective capacity of RALUC regions to respond to the policies considered. The different regional profiles identified and described for CC classes in Section 7.4 are linked to specific recommendations for policies and measures in Table 12, to which reference is made in several places. The following examples are provided the policies taken from the literature review and the case studies that can be recommended. The recommendations are structured according to the different goals of the F2F to come to a more sustainable farming sector towards 2050. At the same time, Table 12 and sections in the text make specific recommendations on what policy instruments should be most strongly prioritised in every region belonging to one of the 8 CC classes.

8.4.1. General recommendations

A very important aspect, that needs to be consolidated more strongly in policy development at EU, national and regional levels, is that reaching **multiple F2F targets can be achieved through implementation of effective territorial policy instruments**. For example, a pre-requisite to restore nature in many places is to ensure the environmental quality of water, air and soil is restored. A pesticides reduction will have a very positive influence on restoring pollinating insects, will restore aquatic biodiversity but also support human health. The same applies for the reduction of nitrogen losses and fertilization application. This will prevent and diminish eutrophication processes that support restoration of several targeted habitats and species but will also help to reduce the GHG emissions.

Bringing more consistency in EU policies would here be advisable - certainly where win-wins for rural areas can be achieved. For example, it would be recommended to start subsidies for bringing land back into use or preventing land abandonment in an early stage, reducing administrative burden for 'different and novel (biomass) production practices' that are not (yet) fitting in the conventional food and feed production practices. Furthermore, much more effort could be invested in informing and educating farmers on benefits of new crops and practices that could widen their production portfolio, including for the provision of ecosystem services.

For an overview of these synergies in policy instruments to reach different goals see Table 12.

8.4.2. Climate change mitigation

Climate mitigation is an important goal of the F2F and requires both decreasing GHG emissions in land use, management, but also practices that help increase carbon capture. **Climate mitigation actions** need to be implemented **in all EU regions**, no matter to which CC class or RALUC group they belong.

Recommendations on this issue resulting from this study are the following:

- i. **Target those sectors within agriculture that are the largest sources of GHG emissions in every region.** This means that regions belonging to CC classes with a stable climate and especially 1.1.1 and 1.2.1 (see Table 12) have to take most serious action to bring their enteric GHG emissions down combined with manure management, followed by direct and indirect emissions from managed soils. Regions in CC classes coping with increased aridity problems have generally lower enteric and manure storage related GHG emissions but have to focus more on managing GHG emission losses through managed soils and AFOLU changes.
- ii. **Reduction of cattle, sheep and goat livestock numbers:** the biggest source on GHG emissions is enteric fermentation coming directly from cattle and (although to a lesser extend) from sheep and goat rearing, this needs to be addressed first through livestock reduction in all regions in which these systems are covering a large share of the agricultural production. However, this will take away an important income source from farmers and release a lot of land needed to produce feed which can then be used for other forms of agricultural production. In such a process of livestock reduction, five concrete steps need to be considered simultaneously:

- a. **Partial protein transition from animal to vegetal diets:** without it the EU will export the high GHG emissions related to livestock rearing to regions outside the EU, thereby not reducing global climate change mitigation. Also novel food entries on the EU market need to be facilitated and speeded-up to create complementary sources of proteins by promoting innovative technologies in the agri-food sector (e.g. precision fermentation, insect farming and other novel foods) as was also mentioned in the Strategic Dialogue on the future of EU agriculture³⁵.
 - b. **Prevent unwanted trade-off effects on development of organic agriculture and/or agro-biodiversity.** In regions where local organic manure sources for organic agriculture are needed to reach the 25% organic area target reductions in cattle numbers would not be advisable. In addition, regions where agro-biodiversity conservation and restoration depend on continuation/reintroduction of traditional grazing practices, livestock numbers need to be maintained.
 - c. **Stimulate measures that effectively reduce GHG emissions within existing farming systems:** through further adaptations in manure storage and application and through changes in feed diets also for pigs and poultry systems.
 - d. **Create win-wins with nature restoration and water quality problems:** regions that exceed critical nitrogen deposition levels in air (ammonia) and in ground and surface water are also the regions with high GHG emissions. Another win-win is **production of biogas and biomethane for energy** (preferably modern installations with no methane leakages): this would ensure that direct GHG emissions in agriculture are reduced by lowering fossil-based emissions in the sectors where the biogas and biomethane is consumed. This measure can create win-win situations with renewable energy production. Reduction of GHG emissions from organic soils can also be matched with restoration of organic soils following the Nature Restoration Law requirements.
- iii. **Reduce fossil based input levels:** for instance through artificial fertilisers, pesticides, mechanisation and energy provided they are not leading to significant yield reductions. Reduction levels should be addressed through stimulation of R&D in this field and measure uptake promotion to farmers through CAP measures (e.g. Pillar II support).
 - iv. **Stimulate more local R&D to increase carbon capture in agricultural soils:** research (e.g. Olsen et al., 2019; Tiefenbacher et al., 2021) shows that there are uncertainties in research results and knowledge gaps in carbon sequestration options in arable land and residue management. The differences are mostly caused by local conditions of soil and weather next to trade off effects. More R&D is needed to inform on the most effective carbon farming practices in different regional contexts and these measures will need

³⁵ [Strategic Dialogue on the Future of EU Agriculture](#)

to be promoted through information, training and farm advisory services and need to be implemented through CAP support and guidance.

- v. **Specific management on grassland and cropland on organic soils is needed:** as these soils are particularly contributing to agricultural GHG emissions in Germany, Ireland, Netherlands, Poland, Sweden, Finland, Denmark and Baltic States. In the regions measures are recommended to avoid intensive farming practices which enhance N₂O and CH₄ emissions. Win-wins can be created with nature restoration targets which also require peatland areas to be restored by 2050. Extensive grazing practices, paludicultures are alternatives which may both reduce land based GHG emissions and provide opportunities to recover semi-natural habitats and related biodiversity values.

8.4.3. Recommendations for climate adaptations (particularly increased aridity) in agriculture

The study found that 15% of the RALUC regions are expected to have to cope with increased aridity on agricultural lands as a result of climate change, while rainfall levels in many of these regions are already very low, and the impacts of aridity are already very visible. These 227 regions cover 26% of the agricultural area of EU-27. For these regions, regional, national and EU policy responses need to focus on:

1. **Improving access to water for agriculture:** missing infrastructure needs to be put in place or developed further, while ensuring efficient water resources and avoid over-exploitation of scarce water resources.
2. **Supporting the farming sector to adopt climate adaptation measures:** as the water resources will remain and become even more insufficient. The compensation can occur through increased irrigation and water buffering.
3. **Targeting policies to handle the water competition between sectors:** such as consumers, industry and nature conservation and restoration.

In principle both the CAP and the WFD provide many policy instruments to address the three recommendations mentioned above.

Regarding the improvement of access to and efficient use of water, several recommendations can be made:

1. **Improve water buffering capacity in high rainfall periods:** this can be realised by the construction of reservoirs and dams and technological developments to buffer water in the root zone of crops after rain fall. These measures should be supported by CAP and private investments.
2. **Invest in modernising existing irrigation infrastructure:** including precision irrigation technologies and through drone technologies to collect information on exact crop water needs.
3. **Invest in R&D related to water:** for water buffering, water saving technologies in agriculture, crop breeding and crop selection.
4. **Regulate water pricing and uses:** to improve access to water use realistic water prices are needed. In addition, water use needs to be better regulated, illegal (ground) water abstraction controlled, and

infringements penalized. Remote sensing and drone observations can help in the process of water use control, while good governance structures and the willingness to invest in information systems and staff are needed to realize the control.

5. **Make waste water treatment and reuse the preferred irrigation water source:** before ground water is used, certainly in the regions where natural water resources are depleted already. The CAP can finance water treatment infrastructure for the reuse of wastewater for irrigation (ECA, 2021).

For climate adaptation there are many actions to support through CAP and regional and national policies but also through investments in R&D and information and education which should focus on:

1. **Discourage large scale crop production in drought prone regions that have very high (irrigation) water requirements:** grain, maize, rice, cotton, avocado and many types of vegetables are examples of these crops. High water consumption is often not determined by crop type, but rather by cropping systems applied in these regions. The recommendation can be executed in various ways: exclude large scale crop production from CAP payments, set a maximum on irrigated area receiving CAP payment per water basin region, increase CAP payments for non-irrigated crops.
2. **More regulation in water application levels in perennial crops:** although some support that irrigation in the establishment phase of crops is necessary, continued irrigation after this phase will lower the crop resilience to droughts (limited development of the root system) and lead to a dependency on regular irrigation.
3. **Develop a high water efficient crop list:** which are resilient enough to provide economic yields at low water availability and therefore without (permanent) irrigation. Crops on such a list may also be matched with lists of crops that have high (below and/or above ground) carbon built-up capacity and or crops providing other ecosystem services (e.g. pollination, etc.). Win-wins require more attention both in research and in implementation phases and should be promoted by farm advisory systems.
4. **Further promote and support agroforestry systems development:** in which trees protect crops against direct intense sunlight, lower evapotranspiration levels and support the water holding capacity in the soils. Win-wins can be created with soil carbon built-up and improved biodiversity. Stimulation of, maintaining, and further introducing such systems is already in place in several CAP Pillar II measures - however support needs to be increased.
5. **Increase water resilient cropping systems:** for instance, crop rotation and intercropping which improve the water use efficiency and competition for water between the crop and weeds. Others include agroforestry systems, mulching which helps to lower soil temperature and maintain soil moisture, and the use of cover crops to decrease soil loss and improve the maintenance of water in the soil (see IEEP, 2021).
6. **Introduce water footprint:** in labelling and products certification so that a market bonus can be obtained for crops grown in systems with low and efficient water use.

7. **Promote R&D and support investments in agri-PV:** in regions where crop growth can benefit from the PV panel shade to lower water losses from evapotranspiration. The trade-off between yields in both crop production and electricity generation should be better studied in different climate zones to come to optimal designs of agri-PV through the EU.

8.4.4. Rural development policies to target regions with unfavourable demographic trends

The study found that 50% of the regions in the EU-27 fall in a CC class with an unfavourable demographic trend towards 2050, covering 61% of the EU farmland area. A large majority of farmland is coping with a very low population density and/or a declining rural population to 2050. Most of these regions are in CC classes 'new EU' but also in several regions in Greece. Here, a stable and sustainable farming sector can only be maintained reaching the F2F goals if the right combination of CAP guidance and investments are made, in combination with regional and national policies, to improve rural livelihoods, stop population declines, particularly where it concerns loss of young people. This is a challenge and without active rural development and population policy it is clear that at least half of the farmland areas in Europe will be confronted with a lack of active farmers and farm labourers to manage the land and an increasingly unattractive living environment because of an absence of services and young people. The following recommendations can be given:

- i. **Attract migrants towards rural areas:** from national EU or extra EU origin to work in the agricultural sector. Migrants can be attracted through the **provision of bonuses to new farm labourers and cheap housing facilities**. For **regions with low investment capacities**, several **EU funds** can help develop regional development plans and co-finance policy development and governance structures to improve livelihoods and active population policies (see Box 23 for an overview of different funds and EU support mechanisms that can be used).
- ii. **Support young farmers and small farms:** with the use of the CAP Pillar I and II (e.g. farm business development and basic service and village renewal in rural area) and increase the financial budgets for these payments as it is far too low currently, especially in the regions facing demographic challenges.
- iii. **Invest in R&D for less labour-intensive crops and labour saving technologies:** in the form of advanced and adapted forms of mechanisation, digitalisation of farm activities, introduction of sensors and IoT devices, and new forms of full automation (e.g. robotics adapted to the scale of the farm, including swarm robots) to provide additional ways to continue agricultural production in these regions (see Box 23 for an overview of different funds and EU support mechanisms that can be used).

8.4.5. Ensure fair prices and, broadly speaking, support agricultural income

One of the elements, albeit indirect, which will influence the future use of agricultural land is the economic profitability of farms and ultimately their income level. Issues to address in this respect include the following: farmer incomes in the EU are low and there is a limited bargaining power when selling agricultural products. Recommendations to ensure fair prices and support agricultural income are:

1. Promote a **level playing field on the international market** through indirect measures: as the F2F targets are expected to affect the profitability of many farms, the extent of which should be assessed by a dedicated impact study.
2. Prescribe clear **agricultural commodity standards** in relation to quality, safety, and sustainability **for all agricultural commodities** including imported products. WTO rules prescribe that no market protection is allowed but setting very clear standards for agricultural commodities may help **EU farmers not to be out-competed on a global market**.
3. Support monitoring intermediation costs the establishment of the **Agriculture and Food Chain Observatory**.
4. The former monitoring (under 3.) will help reinforcing trust and is a pre-condition for identifying mechanisms to achieve avoidance of speculative mechanisms and the creation of more sustainable affordable products
5. Support and stimulate the setting up of **labelling, certification and short supply chains** which are currently not sufficiently fostered through the CAP. The labelling and certification may also help to enhance more 'fair' conditions between the different supply chain actors (see also next section).

8.4.6. Options to improve investment capacity of a region

The capacity of a specific territory to invest in its future agricultural, and rural development at large, is the result of both public and private actors and what financial resources they can mobilize and take advantage of for promoting sustainable agriculture. The CC classification shows that investment capacity is low in 164 regions (15% of the total) and that 21% of the farmland in the EU-27 is located in these regions. Most of these regions are in the 'new EU' but also several regions in Greece belong to this group. A recommendation that flows from the current investment capacity of these regions is:

Stimulate and inform regions on funds and co-finance options from the EU: especially for the identified low investment CC regions. These funds and co-finance options aim to support further development, modernisation and environmental performance of the agricultural sector and support the viability of rural areas. For an overview of available EU funds, programmes and cofinance options see the box below. In addition to EU funding options, there are also funding possibilities exclusively based on national and regional public sources or private investments.

Box 23 Overview of fund, programmes and dedicated financial instruments to support regional governments and individuals, groups and SME to make investments in agriculture and rural development

When looking at EU funds and programmes we should first consider **initiatives of EU direct application**. The funds provided through Pillar II of the CAP, the RDP, co-funded by the **European Agricultural Fund for Rural Development (EAFRD)**, target more specifically rural areas and the agricultural sectors. The Six EU RDP priorities and 18 focus areas of EAFRD include actions that, as we have seen, can contribute strongly to promote sustainable agricultural land uses: namely farm viability (through restructuring and modernisation), support to young farmers and generation renewal, short food supply chains and local market development, rural infrastructure development, multifunctionality and organic farming. Knowledge and innovation transfer is also a cross-cutting action.

Besides RDP there are other **(non-CAP)** funding mechanisms **directly implemented by the EU** to be considered:

- The European Institute of Innovation and Technology (EIT)
- The small and medium-sized enterprise (SME) pillar of the Single Market Programme (SMP)
- the LIFE programme providing co-financing in its four sub-programmes (Nature and biodiversity, Circular economy and quality of life, Climate change mitigation and adaptation, Clean energy transition)
- Euroclusters (cross-sectoral, interdisciplinary, and trans-European strategic initiatives, specifically with reference to agri-food)
- The Connecting Europe Facility Digital programme – 5G services take up of general interest in local communities.
- Funding for research and innovation under the Horizon Europe Programme and namely under Cluster 2 (migration and mobility, reversing social, economic and political inequalities), Cluster 5 (especially on the energy and mobility sectors), and Cluster 6 (reduce environmental degradation, halt and reverse the decline of biodiversity on land, inland waters and sea, and better manage natural resources through transformative changes of the economy and society in both urban and rural areas; support the development of resilient, inclusive, healthy and green rural communities, contributing to the long-term vision for the EU's rural areas).

Secondly, we consider EU initiatives those application is done **via national or regional authorities**, including:

- The European Regional Development Fund (ERDF) for supporting rural and depressed areas from the economic point of view (mainly infrastructure and economic capital)
- The European Social Fund Plus (EFS +) that include instruments for skill implementation and construction of sustainable working communities in the primary sector;
- The Just Transition Fund (JTF) supporting regions facing serious socio-economic challenges due to the transition to a sustainable, climate-neutral economy.
- Interreg funds, which can facilitate collaboration between rural areas, promoting joint initiatives for economic development, tourism, environmental protection, and other relevant issues.
- Cohesion Fund: rural communities in countries with lower rates of economic development can benefit from the fund's support.
- The European agricultural fund for rural development (EAFRD).

Dedicated financial instruments include **InvestEU** that allocates financial resources to rural areas, supporting the improvement of the quality of social services, promoting environmental sustainability, and overall reducing territorial disparities. Examples of project funded include broadband connectivity, mobile networks, and other digital technologies, bridging the digital divide between rural and urban areas. The European Investment Bank (EIB) and other financial institutions also finance projects across the agricultural, fisheries, food, and forestry value chains.

8.4.7. Reaching the Organic farming goal of 25%

Organic farming is supported by the CAP through both direct payments (eco-schemes) and indirect payments (as one of the RDP focus areas). Depending on the region, the second case involves financing the conversion to organic and accessing agricultural investments by setting priorities or more favourable co-financing rates for organic farming. As seen in both the analysis of the KPIs and in the case studies, there are RALUC regions which are close or already achieving the organic farming target, while others are lagging behind. We observed that in regions with unfavourable climatic as well as demographic conditions combined with low investment capacity, organic farming is far away from the 25% target. There is a need for greater support in these regions, both in terms of quantity and quality of interventions.

To make organic farming sustainable in the long term, production and consumption needs to be increased, which leads to various recommendations:

1. **Encourage the development of production of organic inputs** in the form of seeds and propagation material, also considering the effects of climate change;
2. **Adapt mechanisation** to compensate for the likely increased labour demand;
3. **widening production** (not restricted to organic forage production only) with a growing share of other products such as cereals and fruits and conversion to mixed systems where cropping and livestock are combined;
4. **Increase consumption by consumer awareness raising**: willingness to pay is a precondition for the longer-term sustainability of the sector;
5. **Develop long-term programming and coherent financial commitments** by the EU.

8.4.8. Pesticide reduction goal of 50%

The objective of reaching a 50% reduction in pesticide use is a clear target of the F2F, but the question is how to reach this significant reduction in practice. Currently in the CAP, pesticide use, is addressed mostly by the first pillar, i.e. direct payments through eco-schemes including organic farming and other forms of sustainable agriculture and their requirements in the form of GAEC³⁶. Other instruments under the CAP Pillar II can also support investments in technologies to change farming practices, such as through precision farming which in turn may contribute to pesticide reduction. CAP market measures in sectors such as fruits and vegetables or wine may also finance collective actions for promoting practices such as integrated pest management or integrated production as well as organic production. Under the Farm Advisory Services, member states provide advice to farmers on issues including sustainable use of pesticides. Setting-up and use of advisory services may also be funded by the second pillar, e.g. through the EIP-AGRI.

Recommendations point to:

³⁶ See also the EC toolbox of good practices: https://agriculture.ec.europa.eu/news/using-less-chemical-pesticides-european-commission-publishes-toolbox-good-practices-2023-02-28_en

1. **Invest in R&D for innovative, integrated pest management tailored to the region's agro-ecological conditions:** including the further development and faster processing of permissions to enter EU markets for new organic products applied for plant protection.
2. **Invest and apply innovative equipment and technologies:** such as AI powered pest and disease detection systems, robotics, digital twins, data infrastructures and direct injection spraying for pesticide reduction as in the context of precision agriculture, or applications of new, non-chemical products.
3. **Disseminate the farmers' toolbox for IPM practices, techniques, and technologies:** currently developed in the different Member States. This goes together with further upscaling of visualisation tools such as the one developed by JRC as a source of the above information and advice for farmers and farmers' advisors, potentially developed as the basis of tailored digital solutions in support to the AKIS.
4. **Collect and share best practices and digital recording solutions for pesticide applications:** which can be combined with other chemicals necessary to record compliance with the CAP and other EU and national regulation to minimise administrative burden for farmers.
5. **Train farmers on ecological practices and innovative IPM technologies:** essential for building trust and confidence on their adoption, to consider them as active actors in the process of reducing pests.
6. **Strengthen extension services and technical assistance** to help farmers is seen as key for scaling the above technologies and practices. Both farmers and farm advisors should be involved in a process of co-development to ensure adoption and scaling and finding solutions for all crops. For instance, for fruit production there are already several IPM measures in place, while other crops, like seed potatoes, could face significant challenges, possibly leading to high losses in production and ultimately forcing changes in crop mixes.
7. **Change consumer preferences** and build acceptance of differently appearing products.
8. **Facilitate dialogue between farmers and consumers:** crucial in this transition process towards pest reduction.
9. **Ensure a level playing field for all EU farmers:** through dedicated financial means to innovative technologies and practices also by small scale producers with less access to resources.

8.4.9. Lower nitrogen uses and losses goal

The goals of 50% reduction in nutrient losses and of at least 20% reduction in fertiliser application on farmland with no deterioration of soil fertility are clear in the F2F, but the question is through which instruments these can be reached. Recommendations to reach the target are:

1. **Stricter nitrogen measures and incentives to reach the F2F target where it is needed:** stricter applies most strongly for the regions where high livestock production is overlapping with high critical load exceedance and overlapping with nitrate vulnerable zones;
2. In regions with very low livestock numbers, the opposite needs to be done and that is **stimulating the introduction or maintenance of**

livestock activity in order to support further transition to more organic agriculture in need of local manure resources and/or in regions where continuation of grazing is crucial to maintain biodiversity in semi-natural areas;

3. **Reduce nitrogen losses certainly where there is overlap with high GHG emission reduction needs:** this is also linked to high livestock concentrations in certain regions. The advantage is that measures addressing water quality, nature restoration and GHG mitigation are addressed simultaneously;
4. **Make CAP payments conditional on the uptake of measures to reduce nitrogen emissions:** for example through setting a maximum number of animals per hectare and maximum nitrogen application rates (already required) for crops and grasslands;
5. **Introduce mandatory nitrogen and phosphate accounting at farm and/or field level.**
6. **Introduce feeding systems that lower nitrogen excretion levels in manure;**
7. **Provide sufficient compensation for higher costs during the transition to more sustainable livestock holding and fertilisation practices:** this will also help to make conversion to organic farming more attractive among a wider group of farmers.

8.4.10. Soil health and monitoring law goals

For soil health there are no policy targets yet, although causes and performance indicators are under discussion related to avoiding soil erosion and compaction, maintaining soil carbon and other nutrients, reducing/preventing soil salinisation, and reclaiming contaminated soils. Based on this research, there are however already several recommendations that can be made:

1. **Develop CAP incentives to promote more decisively agro-ecological approaches:** including for specific measures such as cover crops, no or minimum till practices, green manures, green waste, set land aside on steep slopes. These CAP incentives should be widely implemented for example through making them part of advanced conditionality new and more ambitious Eco schemes.
2. **Support investments in appropriate farm equipment:** including lighter machinery to reduce soil compaction, for instance through robotic technology. This recommendation is especially for smaller farms.
3. **Promote conservation agriculture:** to reduce waste and pressure on the soil. Within conservation agriculture, more circular use of nutrients in compost and residual streams is needed.
4. **Develop waste policies:** to support better use of compost and other green waste streams which is often complicated by strict policies and preferences of retailers to avoid risks.
5. **Introduce soil passport:** in which soil health metrics and targets are included not only for productivity but also for soil health.

8.4.11. Zero land-take goal

For the **zero land-take** objective, policy goals are clear and consequently, policy instruments to be strengthened can be identified. In addition to approval by the EU Parliament of the proposed Soil Monitoring and Resilience Law, these are regulations that must be implemented at national and local levels. Land-take does not only involve built-up areas, but also facilities for energy generation for example. Therefore, it is recommended to invest more in planning, regulation and control.

8.4.12. Nature conservation and restoration

Agricultural activities and nature conservation have long co-existed on EU rural lands, with low-input farming systems, such as organic farming, playing a key role in supporting biodiversity in semi-natural areas. These systems, often associated with High Nature Value farmland, focus on reduced synthetic inputs and nutrient circularity, and are supported through the CAP's Pillar I payments. Non-productive landscape elements like hedges, tree lines, and ponds also enhance biodiversity, creating vital habitats and 'green veining' corridors for wildlife. Despite CAP efforts to foster synergies between agriculture and conservation, biodiversity loss has persisted, prompting the EU to introduce the Nature Restoration Law with clear restoration targets for 2030 and beyond, which will impact agricultural land use, especially in Natura 2000 areas and peatlands.

1. **Engage landowners and farmers in an early stage before rolling out the nature restoration policies and measures:** as the stakeholders in the 12 CSs have made clear that in general there is little understanding among a large group of farmers and farm advisors about how nature conservation and restoration works out for their region and how they can deal with it.
2. **Target more money to payments for ecosystems services in the future CAP:** through either already existing instruments such as Eco schemes, advanced conditionality that is clearly additional to existing practices and/or through different Pillar II RDP measures or new instruments.
 - a. **Abandon historic rights connected to direct payments:** make policy goals consistent in that only provision of ecosystems can be rewarded through public money and not for food or fibre production itself as this is paid through the markets. This will also free budget for delivery of ecosystem services that are not rewarded through the market and for income foregone because agricultural production needs to be combined with maintenance of ecosystem services.
3. **Invest in good R&D and engagement:** of local land managers and policy makers to prioritise the best services that are to be delivered by the land in a specific territorial context and how this can best be managed and supported by farming.
4. **Invest in the following strategies,** especially in CC classes where population groups are well represented with medium and higher incomes, with medium and higher education levels and with lower average age often living in more urban areas:

- a. **Incentivise and invest in convincing consumers and businesses to pay for environmental services with the agricultural commodities they buy.**
- b. **Label and certify agricultural products that are produced in extensive agricultural systems:** these labels and certificates can increase the appreciation of cultural and environmental ecosystems connected to the production of a product.
- c. **Market directly to consumers with a short (local) supply chain:** shortening the supply chain helps to increase the profitability for the producer and direct contact with consumers can further help to authenticate the product and lowers footprints because it has lower transportation, storage and processing needs.
- d. **Invest in education and information provision on environmental services** delivered through sustainable production systems in regions where population groups have lower income and education levels.
- e. **Stimulate investments in ecosystem delivery in farming.**
- f. **Stimulate agricultural land management in relation to biodiversity and ecosystem service restoration to prevent land take.**

8.4.13. Renewable energy targets and transition to a circular bioeconomy

For reaching the renewable energy targets and the transition to a circular bioeconomy, access to biomass is crucial and land will need to be used for the placement of more wind and PV and other renewable energy infrastructure. The recommendations related to this are:

1. **Explore integrated solutions that can enhance the synergies between renewable energy and agricultural practices.** There are multiple recommendations regarding this exploration:
 - a. **Develop guidelines for agri-PV to ensure that it doesn't have a negative impact on crop yield:** it is best to design systems where crops are grown in combination with agri-PV panels that support soil protection, help building up of soil carbon and/or enhance biodiversity, while providing feedstock for both food, feed and energy bioenergy. The combination of agri-PV may have more advantages for the crop in marginal circumstances, such as for crop growth on degraded and abandoned lands;
 - b. **Focus on using (under)utilised agricultural land for solar- and wind farms or bioenergy;**
 - c. **Develop clear afforestation guidelines on practices and species used:** to widen income sources and labour in rural areas, sourcing bioeconomy markets and capture carbon. This also covers **afforestation efforts with local species:** which could benefit the wider bioeconomy, including the provision of (extra or new) income and labour opportunities;
 - d. **Implement measures that successfully coordinate agriculture, the energy transition, and the bioeconomy:** this might involve better aligning the RED and associated implementing

rules with the CAP and providing financial incentives in combination with clear sustainability guidelines.

2. **Place novel crops with a potential for a wider ecosystem services delivery ability on positive crop lists:** farmers can be discouraged to change their production to novel crops for bioenergy or bioeconomy as their farmland eligibility for CAP payments may be lost.
3. **Adapt the CAP requirements to combine cover cropping with the option to harvest at the end of the growth cycle or after a minimum number of months of being on the land.** Currently cover cropping is encouraged via the CAP, via advanced conditionality, but implementation is very region-specific. In most cases cover crops are required to be ploughed back into the land. This requirement is generally beneficial to soil health, although it may also enhance additional nutrient leaching to water. However, one can also consider to harvest cover crops as biomass for bioenergy or biochemical uses. If a farmer harvests a cover crop in combination with leaving the residues on the land or returning digestate to the land with an AD/biogas system, then it is still possible to maintain or improve soil quality compared to a situation without cover cropping and have additional feedstock for bioenergy. It is therefore recommended to leave more room in the CAP to combine cover cropping with the option to harvest it at the end of the growth cycle or after a minimum number of months of being on the land.
4. **Improve consistency of EU policies :** especially when win-wins for rural areas can be achieved. For example, policy measures that would stimulate use of degraded land or that stimulate multi/intercropping, as is encouraged through the RED, are currently not in place in the CAP.
5. **Inform and educate farmers on benefits of new crops and practices that could widen their production portfolio, including for the provision of ecosystems:** agri-PV can be positive for agriculture when done correctly.

It should be realised **that fear of causing Indirect land use change (ILUC), may also lead to missing out on interesting opportunities to create alternative income sources for farmers and widen the suite of crops suitable to deliver biomass (for bioeconomy), adapt to climate change in combination with improved pollinator and soil health services.** This especially applies to Areas of Natural Constraints (ANCs) where yields of conventional food crops are generally low, and therefore the ILUC effect is limited when used for non-food crop production. In principle **new non-food crops provide many more opportunities to deliver ecosystems services than the conventional food and feed crops.** Good examples are plants that flower abundantly and for a long period to **provide nectar to pollinators** while also being a **source of harvestable biomass for energy or other industrial uses** such as Silphium Perfolatum (for biogas and feed), white melilot which provides both high biomass yields and attracts pollinators and is a nitrogen fixing plant. There are also many oil plants that have a good pollinator function and are resilient to low precipitation levels, such as camelina (can be used as cover and intermediate crop and has a very short growing cycle) and safflower. Another perennial crop is Guayule that produces rubber, oil and woody biomass

and has a good pollinator function and low input requirements. Crops that are good for improving soil health through building up carbon and preventing soil loss through erosion and often cope well with arid circumstances, are typically perennial biomass crops. Examples of these are miscanthus, switchgrass, reed canary grass, willow, poplar. Some of these may be invasive which is a risk for biodiversity, but this depends on regional context and management. For more examples of multipurpose crops which are suitable to grow on marginal soils while providing other ecosystems services simultaneously, consult Horizon Europe projects such as MAGIC³⁷, MIDAS³⁸, GRACE³⁹. A further challenge for the introduction of such crops in agricultural lands is that they are often **not included in crop lists in national and regional CAP programmes.**

³⁷ <https://magic-h2020.eu/>

³⁸ <https://www.midas-bioeconomy.eu/>

³⁹ <https://www.grace-bbi.eu/>

Table 12 : Carrying capacity of RALUC regions and examples of possible policies and measures

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
Stable or improving	Stable or improving	Medium-high	1.1.1	The region has the highest possible potential to answer any policy stimulus; any specific agricultural policy can be adopted here, good access to high income consumer markets, and therefore in good position to advancing to the targets in F2F. <u>Challenges:</u> Reduce GHG emissions, particularly from livestock activities, adapt to climate extremes, low farmers income, limited farmer's bargaining power in food chains, agricultural land take by built-up area, exceedance of nitrate critical load levels, nature conservation and restoration, reach good soil health, high pesticides and fertiliser input levels.	• Climate mitigation, particularly in livestock sectors, but also in managed soils and AFOLU • Climate adaptation to extreme weather events • Labour saving and cost reduction technologies in agriculture also through adoption of novel technologies (precision agriculture) • Increase bargaining power of farmer in food chain through labelling, short supply chains • Reduce land take by built-up area • In several region in this class livestock numbers need to be reduced for reaching targets for GHG emission reduction and bringing N losses below critical load levels • Conversion to integrated low input high output systems • Improve soil health particularly regarding SOC, soil erosion and through carbon farming • Nature based solutions creating synergies between agriculture and nature conservation • Identify opportunities to strengthen local economy through sustainable RES and bioeconomy developments
		Low	1.1.2	The region has a high potential agriculture, with relatively good access to labour and consumer markets, but investment capacity and access to higher income consumer markets is more limited and therefore not in optimal position to reach F2F targets. <u>Challenges:</u> GHG emissions and N-losses, particularly in livestock production and from agricultural soils, adapt to climate extremes, low	• Climate mitigation in all agricultural sectors and AFOLU • Climate adaptation to extreme weather events • Knowledge & education of farmers in integrated sustainable farming and organic practices & carbon farming practices • Investments in modernisation and sustainable intensification of farming • Labour saving and cost reduction technologies in agriculture also through adoption of novel technologies (precision agriculture)

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
				farmers income and low farmer's education levels, agricultural land abandonment risk and risk for unsustainable intensification also in Natura2000, no organic market & knowledge and awareness, nature conservation and restoration, reach good soil health status, low investment capacity	• Improve soil health particularly regarding SOC, soil erosion and through carbon farming • Nature based solutions creating synergies between agriculture and nature conservation • Join forces to access EU financial support funds to make investments in agriculture, set-up governance structures and R&D to find solutions for local challenges • Identify opportunities to strengthen local economy through sustainable RES and bioeconomy developments
	Worsening (Depopulation)	Medium-high	1.2.1	The region has a high potential to answer to any policy stimulus; any specific agricultural policy can be adopted here provided enough interest remains to manage farms and work in agriculture and therefore in relative position to reach F2F targets. <u>Challenges:</u> GHG emissions and N-losses, particularly in livestock production and from agricultural soils, adapt to climate extremes, low farmers income, limited farmer's bargaining power in food chains, exceedance of nitrate critical load levels, nature conservation and restoration, reach good soil health, high pesticides and fertiliser input levels, loss of population and services, high ageing levels in rural areas.	• Climate mitigation, particularly in livestock sectors, but also in managed soils and AFOLU • Climate adaptation to extreme weather events • Active migration policy to address declining population and labour market trend • Improve rural livelihoods and services • Much support towards young farmers • Labour saving and cost reduction technologies in agriculture also through adoption of novel technologies (precision agriculture) • Increase bargaining power of farmer in food chain through labelling, short supply chains • In several region in this class livestock numbers need to be reduced for reaching targets for GHG emission reduction and bringing N losses below critical load levels • Conversion to integrated low input high output systems • Improve soil health particularly regarding SOC, soil erosion and through carbon farming • Nature based solutions creating synergies between agriculture and nature conservation

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
					Identify opportunities to strengthen local economy through sustainable RES, bioeconomy and tourism developments
		Low	1.2.2	The region has a limited carrying capacity in terms of both demographic and investment potential and therefore it will need much EU support and guidance to reach F2F targets <u>Challenges:</u> GHG emissions and N-losses, particularly in from agricultural soils, adapt to climate extremes, low farmers income, very small farms and low farmer's education levels, risk for unsustainable intensification also in Natura2000, loss of traditional farming in HNV farmlands, no organic market & knowledge and awareness, nature conservation, reach good soil health status, low investment capacity, loss of population and services, high ageing and poverty levels in rural areas.	- Climate mitigation in all agricultural sectors and AFOLU - Climate adaptation to extreme weather events - Active migration policy to address declining population and labour market trend - Improve rural livelihoods and services and release rural poverty - Much support towards young farmers - Knowledge & education of farmers in integrated sustainable farming and organic practices & carbon farming practices - Investments in modernisation and sustainable intensification of farming - Labour saving and cost reduction technologies e also through adoption technologies (precision agriculture) - Improve soil health particularly regarding SOC, soil erosion and through carbon farming - Nature based solutions creating synergies between agriculture and nature conservation - Join forces to access EU financial support funds to make investments in agriculture, set-up governance structures and R&D to find solutions for local challenges - Identify opportunities to strengthen local economy through sustainable RES, bioeconomy and tourism developments
Worsening (towards increased)	Stable or improving	Medium-high	2.1.1	Regions with relatively high potential to implement the proposed policies, also based on own capital and human investment capacities. Any specific agricultural policy can be adopted here, good access	- Climate mitigation, particularly in managed soils and AFOLU - Climate adaptation particularly increased aridity

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
aridity conditions)				to higher income consumer markets, and therefore in good position to advancing to the targets in F2F. <u>Challenges:</u> Reduce GHG emissions, particularly from livestock activities, adapt to climate extremes, low farmers income, limited farmer's bargaining power in food chains, agricultural land take by built-up area, exceedance of nitrate critical load levels, nature conservation and restoration, reach good soil health, high pesticides and fertiliser input levels.	• Invest in modernisation of water infrastructure, water management, wastewater treatment and reuse, control • Invest in R&D and education to identify, test, introduce new water efficient and cost effective crops, production systems and technologies • Labour saving and cost reduction technologies in agriculture also through adoption of novel technologies (precision agriculture) • Increase bargaining power of farmer in food chain through labelling, short supply chains • Reduce land take by built-up area through improved planning and control • Conversion to integrated low input high output systems and more organic • Improve soil health particularly regarding SOC, soil erosion and through carbon farming • 2.Nature based solutions creating synergies between agriculture and nature conservation • Identify opportunities to strengthen local economy through sustainable RES, bioeconomy and tourism developments
		Low	2.1.2	Regions in this very small CC class have potential to develop agriculture, but otherwise have an atypical combination of good access to local labour force, but at the same time serious needs to adapt to climate and low investment capacity. Access to higher income consumer markets is more limited and It is not in an optimal position to reach F2F targets. <u>Challenges:</u> GHG emissions and N-losses to water, adapt to climate extremes, low farmers income, very small farms and low farmer's education levels,	• Climate mitigation in all agricultural sectors and AFOLU • Climate adaptation particularly increased aridity • Invest in modernisation of water infrastructure, water management, wastewater treatment and reuse, control • Invest in R&D and education to identify, test, introduce new water efficient and cost effective crops, production systems and technologies • Improve rural livelihoods and services and release rural poverty

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
				risk for unsustainable intensification also in Natura2000, loss of traditional farming in HNV farmlands, no organic market & knowledge and awareness, nature conservation, reach good soil health status, low investment capacity, rural poverty.	• Knowledge & education of farmers in integrated sustainable farming and organic practices & carbon farming practices • Investments in modernisation and sustainable intensification of farming • Options to develop more labour intensive agricultural activities for extra regional (high income) markets in EU • Improve soil health particularly regarding SOC, soil erosion and through carbon farming • Nature based solutions creating synergies between agriculture and nature conservation • Join forces to access EU financial support funds to make investments in agriculture, set-up governance structures and R&D to find solutions for local challenges • Identify opportunities to strengthen local economy through sustainable RES, bioeconomy and tourism developments
	Worsening (Depopulation)	Medium-high	2.2.1	Regions with relatively high investment potential to implement the proposed policies, but otherwise many challenges in relation to climate adaptation and access to local labour force due to negative demographic trends in rural areas. Access to higher income consumer markets is possible however. Overall it is not in an optimal position to reach F2F targets. <u>Challenges:</u> GHG emissions, particularly from agricultural soils, adapt to extreme weather- especially drought, low farmers income, nature conservation and restoration, reach good soil health, high pesticides and fertiliser input levels,	• Climate mitigation, particularly in managed soils and AFOLU • Climate adaptation particularly increased aridity • Invest in modernisation of water infrastructure, water management, wastewater treatment and reuse, control • Invest in R&D and education to identify, test, introduce new water efficient and cost effective crops, production systems and technologies • Active migration policy to address declining population and labour market trend • Improve rural livelihoods and services and release rural poverty • Much support towards young farmers

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
				loss of population and services, high ageing levels in rural areas.	• Labour saving and cost reduction technologies in agriculture also through adoption of novel technologies (precision agriculture) • Increase bargaining power of farmer in food chain through labelling, short supply chains • Reduce land take by built-up area through improved planning and control • Conversion to integrated low input high output systems and more organic • Improve soil health particularly regarding SOC, soil erosion and through carbon farming • Nature based solutions creating synergies between agriculture and nature conservation • Identify opportunities to strengthen local economy through sustainable RES, bioeconomy and tourism developments
		Low	2.2.2	Regions in this CC class belong to the most complicated because they have large challenges to address in relation to climate adaptation and access to local labour force due to negative demographic trends in rural areas combined with low investment capacity in government and private sectors and a local consumer market with low spending capacity. It will need much EU support and guidance to reach F2F targets. <u>Challenges:</u> GHG emissions and N-losses, particularly in from agricultural soils, adapt to climate extremes, low farmers income, small farms and low incomes and farmer's education levels, risk for unsustainable intensification also in Natura2000, loss of traditional farming in HNV farmlands, no organic market & knowledge and awareness, nature conservation, reach good soil health status, low	• Climate mitigation, particularly in managed soils and AFOLU • Climate adaptation particularly increased aridity • Invest in modernisation of water infrastructure, water management, wastewater treatment and reuse, control • Invest in R&D and education to identify, test, introduce new water efficient and cost effective crops, production systems and technologies • Active migration policy to address declining population and labour market trend • Improve rural livelihoods and services and release rural poverty • Much support towards young farmers • Labour saving and cost reduction technologies in agriculture also through adoption of novel technologies (precision agriculture)

Climate trend	Demography trend	Investment capacity	CC no.	Top opportunities and challenges of policy relevance	Top policy priorities
				investment capacity, loss of population and services, high ageing and poverty levels in rural areas.	• Knowledge & education of farmers in integrated sustainable farming, organic & carbon farming practices • Investments in modernisation and sustainable intensification of farming • Improve soil health particularly regarding SOC, soil erosion and through carbon farming • Nature based solutions creating synergies between agriculture and nature conservation • Join forces to access EU financial support funds to make investments in agriculture, set-up governance structures and R&D to find solutions for local challenges • Identify opportunities to strengthen local economy through sustainable RES, bioeconomy and tourism developments

9. References

- Achankeng, E. and Cornelis, W. (2023). Conservation tillage effects on European crop yields: A meta-analysis. *Field Crops Research*, 298, p.108967.
- Adamo, S. B., & Izazola, H. (2010). Human migration and the environment. *Population and Environment*, 32(2-3), 105-108.
- Aksoy, E, Yigini, Y., Montanarella, L (2016). Combining Soil Databases for Topsoil Organic Carbon Mapping in Europe. *PLoS ONE* 11(3): e0152098. doi:10.1371/journal.pone.0152098
- Alcantara, C., Kuemmerle, T., BAUmann, M., Bragina, E., Griffiths, P., Hostert, P., Knorn, J, Muller, D., Prishchepov A., Schierhorn, F., Sieber, A. & Radeloff, V. (2013). Mapping the extend of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data. *Environ. Res. Lett.* 8 (2013) 035035 (9pp). doi:10.1088/1748-9326/8/3/035035
- Allen, B., Kretschmer, B., Baldock, D., Menadue, H., Nanni, S., and Tucker, G. (2014). 'Space for energy crops – assessing the potential contribution to Europe's energy future.' Report produced for Birdlife Europe, European Environmental Bureau and Transport and Environment London; IEEP.
- Allen, B., Kretschmer, B., Kieve, D., Smith, C., and Baldock, D. (2013). Biofuels and ILUC – Q&A: Answers to common questions surrounding the ILUC debate. Biofuel ExChange briefing No 5, Institute for European Environmental Policy, London.
- Alliance Environment (2017). Evaluation study of the payment for agricultural practices beneficial for the climate and the environment, Final Report, European Commission, DG Agriculture - https://ec.europa.eu/agriculture/sites/agriculture/files/fullrep_en.pdf
- Alliance Environment (2017). Literature reviews on the effects of farming practices associated with the CAP greening measures on climate and the environment, carried out for the Evaluation study of the payment for agricultural practices beneficial for the climate and the environment ("greening" of direct payments), ISBN 978-92-79- 73406-9.
- Alliance Environnement (2019). Evaluation of the impact of the CAP on habitats, landscapes, biodiversity. AGRI-2018-0492. Final report. ISBN 978-92-76-11321-8, DOI: 10.2762/818843, KF-01-19-756-EN-N
- Anderson, Emily & Mammides, Christos. (2020). Changes in land-cover within high nature value farmlands inside and outside Natura 2000 sites in Europe: A preliminary assessment. *AMBIO A Journal of the Human Environment*. 10.1007/s13280-020-01330-y.
- Andersson, E., Brogaard, S., Olsson, L. (2011). The political ecology of land degradation. *Annual Review of Environment and Resources*, 36, 295-319.
- Antrop, M. (2004). Landscape change and the urbanization process in Europe. *Landscape and urban planning* 67, 9-26.
- Arabska, E, 2021. From Farm to Fork: Human Health and Well-Being through Sustainable Agri-Food Systems. *J. Life Econ.* 2021, 8, 11–27.
- Baldock, D., Beaufoy, G. Brouwer, F. & Godeschalk, F. 1996. Farming at the margins; abandonment or redeployment of agricultural land in Europe.

- Institute for European Environmental Policy (IEEP) and Agricultural Economics Research Institute (LEI). London/The Hague.
- Bański, J.(2017). The consequences of changes of ownership for agricultural land use in Central European countries following the collapse of the Eastern Bloc, *Land Use Policy*, Volume 66, 2017, Pages 120-130, ISSN 0264-8377, <https://doi.org/10.1016/j.landusepol.2017.04.045>.
<https://www.sciencedirect.com/science/article/pii/S0264837716313771>
- Barbero-Sierra, C., Marques, M.J., Ruíz-Pérez, M. (2013). The case of urban sprawl in Spain as an active and irreversible driving force for desertification. *Journal of Arid Environments* 90, 95-102.
- Barnes, A.P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Vangeyte, J., Fountas, S., van der Wal, T. and Gómez-Barbero, M. (2019). Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land use policy*, 80, pp.163-174.
- Barreiro-Hurle, J. et al. (2021). Modelling Environmental and Climate Ambition in the Agricultural Sector with the CAPRI Model: Exploring the Potential Effects of Selected Farm to Fork and Biodiversity Strategies Targets in the Framework of the 2030 Climate Targets and the post 2020 Common Agricultural Policy (Joint Research Centre, European Commission.
- Baumann, M., Kuemmerle, T, Elbakidze, M., Ozdogan, M., Radeloff, V.C., Keuler, N.S., Prishchepov, A.V., Kruhlov, I., Hostert, P. (2011). Patterns and drivers of post-socialist farmland abandonment in Western Ukraine, *Land Use Policy*, Volume 28, Issue 3, 2011, Pages 552-562, ISSN 0264-8377, <https://doi.org/10.1016/j.landusepol.2010.11.003>.
- Berkhout, P.; Achterbosch, T.; Van Berkum, S.; Dagevos, H.; Dengerink, J.; Van Duijn, A.P.; Terluin, I.J. (2018). Global implications of the European Food System – a food systems approach. Wageningen Economic Research, report 2018-051, 58 pp.
- Billen, G., Aguilera, E., Einarsson, R., Garnier, J., Gingrich, S., Grizzetti, B., Lassaletta, L., Le Noë, J. and Sanz-Cobena, A. (2021). Reshaping the European agro-food system and closing its nitrogen cycle: The potential of combining dietary change, agroecology, and circularity. *One Earth*, 4(6), pp.839-850.
- Black, R., Adger, W. N., Arnell, N. W., Dercon, S., Geddes, A., & Thomas, D. (2011). The effect of environmental change on human migration. *Global environmental change*, 21, S3-S11.
- Boix-Fayos, C.; De Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agricultural Systems* 207 (103634), <https://doi.org/10.1016/j.agry.2023.103634>.
- Borjeson, L.; Hojer, M.; Dreborg, K.; Ekvall, T.; Finnveden, G. (2006). Scenario types and techniques: towards a user's guide, *Futures*, 38(7), pp. 723-739.
- Bouma, J., Varallyay, G., & Batjes, N. H. (1998). Principal land use changes anticipated in Europe. *Agriculture, Ecosystems & Environment*, 67(2-3), 103-119.
- Bounds, A., 2022, 'EU reviews sustainable food plans as Ukraine war disrupts imports', *Financial Times* (<https://www.ft.com/content/f99d784c-0448-4552-ab8b-e77ed68ea173>) accessed 24 October 2023.

- Brady, M.; Hristov, J.; Sahrbacher, C.; Söderberg, T & Wilhelmsson, F (2017). Is Passive Farming A Problem for Agriculture in the EU? JAE vol 68, Issue 3, September 2017. P. 632-650. <https://doi.org/10.1111/1477-9552.12224>
- Brady, M.; Jordan Hristov, Sören Höjgård, Torbjörn Jansson, Helena Johansson, Cecilia Larsson, Ida Nordin, Ewa Rabinowicz (2017). Impacts of Direct Payments – Lessons for CAP post-2020 from a quantitative analysis. AgriFood Economics Centre PO Box 730 SE-220 07 Lund SWEDEN <http://www.agrifood.se> Mark
- Brady et al. Report 2017:2 Printed by Media-Tryck, Lund, 2017.
- Briassoulis, H. (2011). Governing desertification in Mediterranean Europe: the challenge of environmental policy integration in multi-level governance contexts. *Land Degradation and Development* 22(3), 313-325.
- Briassoulis, H. (2017). Policy integration for complex environmental problems: The example of Mediterranean desertification. Routledge, London.
- Briassoulis, H. (2019). Combating land degradation and desertification: The land-use planning quandary. *Land* 8(2), 27.
- Bridges, E.M. (2019). Response to land degradation. CRC Press, New York.
- CASCADE International Project (CAstastrophic Shifts in drylands: how CAN we prevent ecosystem DEgradation?) financed by European Commission, <https://esdac.jrc.ec.europa.eu/projects/cascade> (accessed October 2023).
- Brouwer, F. M., Thomas, A. J., & Chadwick, M. J. (2012). Land use changes in Europe: processes of change, environmental transformations and future patterns (Vol. 18). Springer Science & Business Media, Berlin.
- Bruegmann, R. (2005). *Sprawl: A compact history*. University of Chicago Press, Chicago, Illinois, USA.
- Buckwell, A., Nordang Uhre, A., Williams, A., Polakova, J., Blum, W.E.H., Schiefer, J., Lair, G., Heissenhuber, A., Schiebl, P., Kramer, C., Haber, W. (2014) The Sustainable Intensification of European Agriculture. Brussels: RISE Foundation <https://ieep.eu/publications/sustainable-intensification-of-european-agriculture/>
- Bundesinformationszentrum Landwirtschaft: Energie aus nachwachsenden Rohstoffen (BZL). (2022). <https://www.landwirtschaft.de/diskussion-und-dialog/umwelt/energie-aus-nachwachsenden-rohstoffen>
- Burkhard, B., Kandziora, M., Hou, Y. and Müller, F. (2014). Ecosystem service potentials, flows and demands – concepts for spatial localisation, indication and quantification. *Landscape Online*.
- Campbell, L.H. & Cooke, A.S., eds. (1997). *The indirect effects of pesticides on birds*. Joint Nature Conservation Committee, Peterborough.
- Capitanio, F., Gatto, E. and Millemaci, E. (2016) CAP payments and spatial diversity in cereal crops: An analysis of Italian farms. *Land Use Policy* No 54, 574-582.
- Carlucci, M., Grigoriadis, E., Rontos, K., & Salvati, L. (2017). Revisiting a hegemonic concept: Long-term 'Mediterranean urbanization' in between city re-polarization and metropolitan decline. *Applied Spatial Analysis and Policy* 10, 347-362.

- Ceccarelli, T., Bajocco, S., Perini, L., & Salvati, L. (2014). Urbanisation and land take of high quality agricultural soils – exploring long-term land use changes and land capability in Northern Italy. *International Journal of Environmental Research*, 8(1), 181–192.
- Ceccarelli, T., Bajocco S., Salvati S., Perini, L., 2014, Investigating syndromes of agricultural land degradation through past trajectories and future scenarios. *Soil Science and Plant Nutrition*. Taylor & Francis
- Champion, A. G. (2001). A Changing Demographic Regime and Evolving Polycentric Urban Regions: Consequences for the Size, Composition and Distribution of City Populations. *Urban Studies* 38(4), 657-677.
- Ciommi, M., Chelli, F.M., Carlucci, M., & Salvati, L. (2018). Urban growth and demographic dynamics in southern Europe: Toward a new statistical approach to regional science. *Sustainability (Switzerland)* 10(8), 2765.
- Closas, A., Molle, F. (2016). Groundwater governance in Europe. IWMI project report no. 3, 98 pp. Rep.3-Groundwater-governance-in-Europe_final_cover.pdf (iwmi.org)
- Coleman, D. (2008). New Europe, new Diversity. *Population Studies* 62 (1), 113-120.
- Corbelle-Rico, E., Butsic, V., Enríquez-García, Volker, M.J., C., Radeloff, (2015). Technology or policy? Drivers of land cover change in northwestern Spain before and after the accession to European Economic Community, *Land Use Policy*, Volume 45, 2015, Pages 18-25, ISSN 0264-8377, <https://doi.org/10.1016/j.landusepol.2015.01.004>.
(<https://www.sciencedirect.com/science/article/pii/S0264837715000071>)
- Couch, C., Petschel-Held, G. & Leontidou, L. (2008). *Urban sprawl in Europe: landscape, land-use change and policy*. Wiley, London.
- Cozma, A. C., M. V. Achim, and I. L. Safta (2022). "Economic and financial crime in the Forest industry—internationally and in Romania." 24th RSEP international conference on economics, Finance & Business. 2022.
- Czúcz, B. and I. Arany (2016). Indicators for ecosystem services. In: Potschin, M. and K. Jax (eds): *OpenNESS Ecosystem Services Reference Book*. EC FP7 Grant Agreement no. 308428. Available via: www.openness-project.eu/library/reference-book
- Dale, B. E., Sibilla, F., Fabbri, C., Pezzaglia, M., Pecorino, B., Veggia, E., Baronchelli, A., Gattoni, P., & Bozzetto, S. (2016). BiogasdonerightTM: An innovative new system is commercialized in Italy. *Biofuels, Bioproducts and Biorefining*, 10(4), 341–345. <https://doi.org/10.1002/bbb.1671>
- Dale, V., Kline, K., Wiens, J., and Fargione, J. (2010). *Biofuels: Implications for Land Use and Biodiversity*. *Biofuels and Sustainability Reports*, 1-13. <http://www.esa.org/biofuelsreports/>.
- Danube Region Strategy (2023). *Securing Drinking Water Supply – workshop*. *Securing Drinking Water Supply - workshop - PA 04* (danube-region.eu).
- Dauber, J. & Miyake, S. (2016). To integrate or to segregate food crop and energy crop cultivation at the landscape scale. *Perspectives on biodiversity conservation in agriculture in Europe*. *Energy, Sustainability and Society* (2016) 6:25

- Dauber, J., Brown, C., Fernando, A., Finnan, J., Krasuska, E., Ponitka, J., Styles, D., Trän, D., Groenigen, K., Weih, M., and Zah, R. (2012). Bioenergy from "surplus" land: environmental and socio-economic implications. *BioRisk*, 7, 5-50.
- Davin, E. L., Rechid, D., Breil, M., Cardoso, R. M., Coppola, E., Hoffmann, P. & Wulfmeyer, V. (2020). Biogeophysical impacts of forestation in Europe: first results from the LUCAS (Land Use and Climate Across Scales) regional climate model intercomparison. *Earth System Dynamics*, 11(1), 183-200.
- Davoudi, S. (2003). European briefing: Polycentricity in European spatial planning: from an analytical tool to a normative agenda. *European Planning Studies* 11, 979-999.
- Debonne, N., Bürgi, M., Diogo, V., Helfenstein, J., Herzog, F., Levers, C., Mohr, F., Swart, R., & Verburg, P. (2022). The geography of megatrends affecting European agriculture. *Global Environmental Change*, 75, 102551. <https://doi.org/10.1016/j.gloenvcha.2022.102551>
- DESERTWATCH, a project of European Space Agency entitled "Desertification Monitoring System", http://due.esrin.esa.int/page_project65.php (accessed October 2023).
- Donatelli, M., Srivastava, A. K., Duveiller, G., Niemeyer, S., & Fumagalli, D. (2015). Climate change impact and potential adaptation strategies under alternate realizations of climate scenarios for three major crops in Europe. *Environmental Research Letters*, 10(7), 075005.
- D'Odorico, P., Bhattachan, A., Davis, K.F., Ravi, S., Runyan, C.W. (2013). Global desertification: drivers and feedbacks. *Advances in Water Resources* 51, 326-344.
- Dregne, H.E. (2002). Land degradation in the drylands. *Arid land research and management*, 16(2), 99-132.
- Duvernoy, I., Zambon, I., Sateriano, A., & Salvati, L. (2018). Pictures from the other side of the fringe: Urban growth and peri-urban agriculture in a post-industrial city (Toulouse, France). *Journal of Rural Studies* 57, 25-35.
- Dwyer, J., Kubinakova, K., Lewis, N., Powell, J., Vigani, M., Fährmann, B., Gocht, A., Grajewski, R., Coto Sauras, M., Nieto Cachinero, P., Mantino, F., Berriet-Sollic, M., Pham, H. (2016). Research for AGRI Committee - Programmes implementing the 2015- 2020 Rural Development Policy. IP/B/AGRI/IC/2015-74, European Parliament, Brussels
- ECER, 2024. Expertise Center Europese Law – Dutch Ministry of Foreign Affairs (in Dutch). Dossier Water quality and management. Waterkwaliteit-en beheer | Expertisecentrum Europees Recht (minbuza.nl).
- ECMWF (2023). Climate Reanalysis. Copernicus Programme Climate Change Services. European Commission. Viewed online at 19 October 2023 at [Climate reanalysis | Copernicus](#).
- Elbersen, B., van Doorn, A & Neaff, H. (2009). Territorial distribution of CAP payments in the Netherlands in relation to present and future environmental policy targets. Wageningen. Altera-report 1900.

- Elbersen, B.S., Fritsche, U.R., Petersen, J-E, Lesschen, J-P, Böttcher, H., Overmars, K. (2013). Assessing the effect of stricter sustainability criteria on EU biomass crop potential Biofuels, Bioproducts & Biorefining (Biofpr) Journal. Article first published online: 19 MAR 2013 | DOI: 10.1002/bbb.1396.
- Elbersen, B.; Beaufoy, G., Jones, G., Noij, G-J., Doorn, A., Breman, B. & Hazeu, G. (2014). Aspects of data on diverse relationships between agriculture and the environment. Report for DG-Environment. Contract no. 07-0307/2012/633993/ETU/B1. Alterra. Wageningen, April 2014.
- Elbersen, B. Staritsky, I, Hengeveld, G., Jeurissen, L., Lesschen, JP, & Panoutsou C. (2015). Outlook of spatial biomass value chains in EU 28, September 2015, p.270.
- Elbersen, B., Eupen, van, M., Mantel, S., Verzandvoort, S. , Boogaard, H. , Mucher, S. Ceccarelli, T., Elbersen, W., Bai, Z., Iqbal, Y , Cossel, M. Ian McCallum, I, Carrasco, J., Ciria Ramos, C.d Monti, A., Scordia, D., Eleftheriadis, I. (2018). Deliverable 2.6 Methodological approaches to identify and map marginal land suitable for industrial crops in Europe. MAGIC; GA-No.: 727698
- Elbersen; Hart K; M. Koper; M. van Eupen; C. Keenleyside; S Verzandvoort; K. Kort; A. Cormont; A. Giadrossi and D. Baldock (2022). Analysis of actual land availability in the EU; trends in unused lands, abandoned and degraded (non) agricultural land use for energy and other non-food crops. Prepared for the European Commission, DG ENER, under service contract N° ENER/C2/2018-440/ SI2.806597. <https://op.europa.eu/en/publication-detail/-/publication/ac8401a8-7b6c-11ed-9887-01aa75ed71a1/language-en/format-PDF>
- ETC-SIA (2013). Elbersen, B.S.; Fritsche, U.; Overmars, K.; J.P. Lesschen, Staritsky, I; Ros, J.; Zulka, K.P.; Brodski, L.; Eerens, H.; K. Hennenberg (2013). Review of the EU bioenergy potential from a resource efficiency perspective. A follow-up to EEA report No 7/2006. ETC-SIA technical report. (July 2013)
- Eupen, M. van, Hennekens, S. & Zervas, G. (2003). Developing a high nature value indicator. Report for the European Environment Agency. Copenhagen. Further work of the EEA and JRC is documented under: <http://eea.eionet.europa.eu/Public/irc/envirowindows/hnv/library>
- Eupen, M. van; Metzger, M.J.; Pérez-Soba, M.; Verburg, P.H.; Doorn, A.M. van; Bunce, R.G.H. (2012). A rural typology for strategic European policies Land Use Policy 29 (2012)3. - ISSN 0264-8377 - p. 473 - 482.
- European biomass feedstocks. BIKE study, European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 952872
- Euronews (2022, May 31). How illegal logging is threatening Romania's unique virgin forests. Euronews. <https://www.euronews.com/2022/05/31/how-illegal-logging-is-threatening-romania-s-unique-virgin-forests>
- European Commission, DG Climate Action (nd). Land-use sector. Energy – Climate Change – Environment. Viewed online at 19 October 2023 at Land use sector (europa.eu).
- European Commission, 2018. Report from the commission to the council and the European Parliament on the implementation of Council Directive

91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2012-2015. Brussels, Belgium. 1_EN_ACT_part1_v7.docx (europa.eu).

European Commission, Directorate-General for Research and Innovation, Veerman, C., Pinto Correia, T., Bastioli, C. et al., (2020). Caring for soil is caring for life – Ensure 75% of soils are healthy by 2030 for healthy food, people, nature and climate – Interim report of the mission board for soil health and food, Publications Office, 2020, <https://data.europa.eu/doi/10.2777/918775>

European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: EU Biodiversity Strategy for 2030. Bringing nature back into our lives. COM(2020) 380 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0380>

European Commission (2020) Use of Bioenergy by sector and scenario, page 95, EC, Impact assessment, Stepping up Europe's 2030 climate ambition, SWD (2020) 176 Final, 17.9.2020

European Commission (2020). Peyraud, J., MacLeod, M., Future of EU livestock : How to contribute to a sustainable agricultural sector: final report for the Directorate-General for Agriculture and Rural Development, Publications Office, 2020, <https://data.europa.eu/doi/10.2762/3440>.

European Commission (2021). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS ON AN ACTION PLAN FOR THE DEVELOPMENT OF ORGANIC PRODUCTION. Document 52021DC0141R(01). Brussels, Belgium.

European Commission, Directorate-General for Climate Action, Arets, E., Lesschen, J., Hazeu, G., et al (2021) Study on the requirements for compliance with the regulation on Land Use, Land Use Change and Forestry (LULUCF) and associated regulations <https://data.europa.eu/doi/10.2834/757934>

European Commission – DG-Environment (2021). Current practice in flood risk management in the European Union. Directorate-General for Environment Directorate C - Quality of Life, Water & Air Unit C1 – Water, European Union 2021, 216pp. Doi:10.2779/235272.

European Commission (2021a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040. COM(2021) 345 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0345>

European Commission (2021b). Oleson et al.. Reviewing the Contribution of the Land Use, Land-use Change and Forestry Sector to the Green Deal Final

Study. Directorate-General for Climate Action LULUCF review study. doi: 10.2834/201100

European Commission (2021c). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: EU Soil Strategy for 2030: Reaping the benefits of healthy soils for people, food, nature and climate. COM/2021/699 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699>

European Commission (EC) (2021), NextGenerationEU: European Commission endorses Romania's €29.2 billion recovery and resilience plan. https://ec.europa.eu/commission/presscorner/detail/el/ip_21_4876

European Commission (2021). [Supporting evidence for the long-term vision for rural areas \(europa.eu\)](https://ec.europa.eu/rural-areas-2021) . COMMISSION STAFF WORKING DOCUMENT Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A long-term Vision for the EU's Rural Areas - Towards stronger, connected, resilient and prosperous rural areas by 2040. SWD(2021) 166 final PART 1/3

European Commission (2022). EU agricultural outlook for markets, income and environment, 2022-2032. European Commission, DG Agriculture and Rural Development, Brussels, 8 pp.

European Commission, Directorate-General for Energy (2022). Elbersen, B., Hart, K., Koper, M., et al., Analysis of actual land availability in the EU; trends in unused, abandoned and degraded (non-) agricultural land and use for energy and other non-food crops : final report, Publications Office of the European Union, 2022, <https://data.europa.eu/doi/10.2833/609071>

European Commission (2023), EU agricultural outlook for markets, 2023-2035. European Commission, DG Agriculture and Rural Development, Brussels. https://agriculture.ec.europa.eu/system/files/2024-01/agricultural-outlook-2023-report_en_0.pdf

European Commission (2024). Water Framework Directive. Water Framework Directive - European Commission (europa.eu)

European Commission (2024b). Bathing Water: EU rules to ensure clean and high-quality bathing water across Europe.

European Commission (2024c). Drinking water - Improving access to drinking water for all. Drinking water - European Commission (europa.eu).

European Commission (2024c). Urban Wastewater - Ensuring that urban wastewater is properly dealt with to protect the environment and human health. Urban wastewater - European Commission (europa.eu).

European Commission (2024). Floods - EU measures to manage the risks floods pose to human health, the environment, the economy and cultural heritage. Floods - European Commission (europa.eu).

European Commission (2024e). Nitrates – Protecting waters against pollution caused by nitrates from agricultural sources. Nitrates - European Commission (europa.eu).

European Court of Auditors, ECA (2020). EU efforts for sustainable soil management Unambitious standards and limited targeting. Special Report 2023-19. <https://www.eca.europa.eu/en/publications?ref=SR-2023-19>

European Court of Auditors (2023). Special report 19/2023: EU efforts for sustainable soil management – Unambitious standards and limited targeting (europa.eu), ECA, https://www.eea.europa.eu/ECAPublications/SR-2023-19/SR-2023-19_EN.pdf

European Court of Editors (2024). Special report 19/2024: Organic farming in the EU – Gaps and inconsistencies hamper the success of the policy. [Special report 19/2024: Organic farming in the EU | European Court of Auditors \(europa.eu\)](#).

European Environment Agency (2006). Urban sprawl in Europe – The ignored challenge. EEA Report no. 10, Copenhagen.

European Environment Agency (2010), Land in Europe: prices, taxes and use patterns. EEA Technical report No 4/2010 ISSN 1725-2237 <https://www.eea.europa.eu/publications/land-in-europe/download>

European Environment Agency (2012), European waters — assessment of status and pressures, EEA Report No 8/2012, European Environment Agency, Copenhagen.

European Environment Agency (2013). Review of the EU bioenergy potential from a resource efficiency perspective.

European Environment Agency (2015). EEA briefing on Tourism. Last modified 23 November 2020. <https://www.eea.europa.eu/soer/2015/europe/tourism>

European Environment Agency (2015a). Briefing Agriculture. Viewed online at 17 October 2023 at [Agriculture — European Environment Agency \(europa.eu\)](#).

European Environment Agency (2015b). Briefing Consumption. Viewed online at 17 October 2023 at [Consumption — European Environment Agency \(europa.eu\)](#).

European Environment Agency (2017). Land take (CSI 014/LSI 001), European Environment Agency (<https://www.eea.europa.eu/data-and-maps/indicators/land-take-2/assessment-1>) accessed 29 May 2019.

European Environment Agency (2018). Land recycling and densification (LSI 008),

European Environment Agency (<https://www.eea.europa.eu/data-and-maps/indicators/land-recycling-and-densification/assessment-1>) accessed 29 May 2019.

European Environment Agency (2019). SPECIAL REPORT N°33/2018: COMBATING DESERTIFICATION IN THE EU: A GROWING THREAT IN NEED OF MORE ACTION. <https://www.eea.europa.eu/policy-documents/special-report-ndeq33-2018-combating>

European Environment Agency (2019). Floodplains: a Natural System to preserve and restore. EEA Report No. 24/2019, 56 pp. Floodplains: a natural system to preserve and restore — European Environment Agency (europa.eu).

European Environment Agency (2019). The European environment - state and outlook 2020 (SOER 2020). Knowledge for transition to a sustainable Europe. <https://www.eea.europa.eu/soer/2020>

European Environment Agency ETC-ULS (2019). Agri-environmental Indicator – Agricultural areas under Natura 2000. Unpublished factsheet elaborated by ETC-ULS. June 2019.

European Environment Agency (2019). Land and soil in Europe. Why we need to use these vital and finite resources sustainability. Retrieved 19 February, 2021, from <https://doi.org/10.2800/779710>

European Environmental Agency (2019a). Changing menus, changing landscapes — Agriculture and food in Europe. Changing menus, changing landscapes — Agriculture and food in Europe — European Environment Agency (europa.eu)

European Environment Agency (2019b). Land and soil in Europe — Soil degradation - Environment in EU at the turn of the century (Chapter 3.6), European Environment Agency, <https://www.eea.europa.eu/publications/92-9157-202-0/page306.html>

European Environmental Agency (2019b). Climate change adaptation in the agriculture sector in Europe — 108 pp. — doi:10.2800/537176

European Environmental Agency (2019c). State of the Environment report 2019, version 2020 https://www.eea.europa.eu/publications/soer-2020/at_download/file

European Environmental Agency (2020). State of Nature report. <https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020>

European Environmental Agency, (2021). EEA/PUBL/2021/066 Annual European Union Greenhouse Gas Inventory 1990–2019 and Inventory Report 2021 Submission to the UNFCCC Secretariat. <https://www.eea.europa.eu/publications/annual-europeanunion-greenhouse-gas-inventory-2021>.

European Environment Agency (2021). Land take and land degradation in functional urban areas. EEA report 17/2021.

European Environment Agency (2021). Nature-based solutions in Europe: Policy, Knowledge and Practice for Climate Change Adaptation and Disaster Risk Reduction. EEA Report No. 01/2021, 164 pp. Nature-based solutions in Europe: Policy, knowledge and practice for climate change adaptation and disaster risk reduction — European Environment Agency (europa.eu).

European Environment Agency (2021). Annual European Union Greenhouse Gas Inventory 1990–2019 and Inventory Report 2021: Submission to the UNFCCC Secretariat (EEA/PUBL/2021/066). <https://www.eea.europa.eu/publications/annual-europeanunion-greenhouse-gas-inventory-2021>

European Environment Agency (2022). Europe's groundwater – a key resource under pressure. European Environment Agency. Europe's groundwater — a key resource under pressure — European Environment Agency (europa.eu).

European Environment Agency (2023). Agricultural area under organic farming in Europe - 8th EAP. Viewed online on 17 October 2023 at Agricultural area under organic farming in Europe - 8th EAP (europa.eu).

European Environment Agency (2023a). Annual European Union greenhouse gas inventory 1990–2021 and inventory report 2023. EEA/PUBL/2023/044. [European Union. 2023 National Inventory Report \(NIR\). | UNFCCC](#)

European Network for Rural Development (2017). RDP Analysis: Support to Environment & Climate Change. M12 – Natura 2000 & Water Framework Directive Payments. Cooperation sub-measures (europa.eu).

European Network for Rural Development (2013). RDP Summaries. RDP Summaries | The European Network for Rural Development (ENRD) (europa.eu).

European Parliament, Directorate-General for Internal Policies of the Union, Herold, A., Urrutia, C., Gores, S. 2030 climate target plan (2021): review of Land Use, Land Use Change and Forestry (LULUCF) Regulation <https://data.europa.eu/doi/10.2861/009138>

European Parliament (EP) (2023), Briefing. PETI Fact-finding visit to Romania 15 - 18 May 2023. PETI Fact-finding visit to Romania 15-18 May 2023 - On the management and protection of the brown bear population and illegal logging in Romania (europa.eu)

European Parliament Research Service (2023). Briefing on Rural tourism. [https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/751464/EPRS_BRI\(2023\)751464_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/751464/EPRS_BRI(2023)751464_EN.pdf)

European Union Joint Research Centre. (2022). *EU CropMap 2022*. <https://data.jrc.ec.europa.eu/dataset/15f86c84-eae1-4723-8e00-c1b35c8f56b9>

European Union (2006). Directive 2006/188/EC of the European Parliament and of the Council on the protection of groundwater against pollution and deterioration. Official Journal of the European Union, L.372/19, Brussels, Belgium, 13pp. LexUriServ.do (europa.eu).

European Union (2021). Strengthening the synergies between agriculture and flood risk management in the European Union. Luxembourg: Publications Office of the European Union, 2021, 31 pp. doi:10.2779/128153.

European Water Regulators (2021). Navigating the evolutions of the Drinking Water Directive. Milan, Italy. 4 - Navigating the Evolutions of the Drinking Water Directive (wareg.org).

Eurostat (2016). Agriculture, forestry and fisheries statistics. Edition 2016.

Eurostat (2018) Lucas 2018 (land use/cover area frame survey). (2018). [dataset] <https://ec.europa.eu/eurostat/en/web/lucas/data/primary-data/2018>

Eurostat (2023). Extra – EU trade in agricultural goods. Viewed online at 16 October 2023 at Extra-EU trade in agricultural goods - Statistics Explained (europa.eu).

Eurostat Data Browser (2023). Main farm land-use by NUTS 2 regions. EC Data Browser. Viewed online at 16 October 2023 at [Statistics | Eurostat \(europa.eu\)](#).

- EUR-Lex (2021). Good water quality in Europe (EU Water Framework Directive)". Water van goede kwaliteit in Europa (EU-waterrichtlijn) | EUR-Lex.
- Fachagentur Nachwachsende Rohstoffe (FNR) (2022) Statistics report. <https://www.fnr.de/ftp/pdf/berichte/22004416.pdf>
- FAO (1994). Land Degradation in South Asia: Its Severity, Causes and Effects Upon People, World Soil Resources Report, 78; FAO: Rome.
- FAO (2023). FAO's Global Information System on Water and Agriculture. Rome, Italy. Viewed online at 19 October 2023 at AQUASTAT - FAO's Global Information System on Water and Agriculture.
- Fargione, J.E., Plevin, R.J. & Hill, J.D. (2010). The Ecological Impact of Biofuels. Annual Review of Ecology, Evolution, and Systematics, 41(1), pp.351–377.
- Fayet, C., Reilly, K., Van Ham, C., Verburg, P. (2022). What is the future of abandoned agricultural lands? A systematic review of alternative trajectories in Europe. Land use Policy 112 (2022) 105833. <https://doi.org/10.1016/j.landusepol.2021.105833>
- Fazey, I., Leicester, G., G. (2022). Archetypes of system transition and transformation: Six lessons for stewarding change, Energy research & social science, 91, 102646
- Feliu E. Et al. (2013). EU-LUPA European Land Use Pattern (ESPON 2013 Programme), https://www.espon.eu/sites/default/files/attachments/DFR_Scientific_Report_EU-LUPA.pdf
- Felix, L., Houet, T., Verburg, P. (2022). Mapping biodiversity and ecosystem service trade-offs and synergies of agricultural change trajectories in Europe. Environmental Science & Policy. Volume 136, October 2022, Pages 387-399. <https://doi.org/10.1016/j.envsci.2022.07.004>
- Fernandez, R.J. (2002). Do humans create deserts? Trends in Ecology and Evolution 17, 6-7.
- Fernando, A. (2005). Fitorremediação por *Miscanthus x giganteus* de solos contaminados com metais pesados, PhD Thesis, Universidade Nova de Lisboa, Lisbon.
- Ferrara, A., Kosmas, C., Salvati, L., Padula, A., Mancino, G., Nolè, A. (2020). Updating the MEDALUS-ESA Framework for Worldwide Land Degradation and Desertification Assessment. Land Degradation and Development, <https://doi.org/10.1002/ldr.3559>.
- Filho, W.L., Mandel, M., Quasem, A., Feher A., & Chiappetta Jabbour, C. (2017) An assessment of the causes and consequences of agricultural land abandonment in Europe, International Journal of Sustainable Development & World Ecology, 24:6, 554-560, DOI: 10.1080/13504509.2016.1240113
- Fleskens, L., Stringer, L.C. (2014). Land management and policy responses to mitigate desertification and land degradation. Land Degradation and Development 25(1), 1-4.
- Frelih-Larsen, A., C. Bowyer, S. Albrecht, C. Keenleyside, M. Kemper, S. Nanni, S. Naumann, R. D. Mottershead, R. Landgrebe, E. Andersen, P. Banfi, S. Bell, I. Brémere, J. Cools, S. Herbert, A. Iles, E. Kampa, M. Kettunen, Z. Lukacova, G. Moreira, Z. Kiresiewa, J. Rouillard, J. Okx, M. Pantzar, K. Paquel,

- R. Pederson, A. Peepson, F. Pelsy, D. Petrovic, E. Psaila, B. Šarapatka, J. Sobocka, A.-C. Stan, J. Tarpey, R. Vidaurre (2016). 'Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States.' Final Report to DG Environment.
- Forest Europe (2020) State of Europe's forests 2020. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf
- Forest Europe, UNECE, FAO (2011). State of Europe's Forests 2011 — Status and Trends in Sustainable Forest Management in Europe, Ministerial Conference on the Protection of Forests in Europe. Joint report.
- Forsell, N. et al. (2016). Study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio). Final report. Project: ENV.F.1/ETU/2013/0033. Luxembourg: Publications Office of the European Union, 2016. 43 p.
- Freire, S., Santos, T., & Tenedório, J. A. (2009). Recent urbanization and land use/land cover in Portugal. The influence of coastline and coastal urban centers. *Journal of Coastal Research*, 2(SI56), 1499-1503.
- Fritsche, U., Brunori, G., Chiaramonti, D., Galanakis, C., Matthews, R., & Panoutsou, C. (2021). Future transitions for the bioeconomy towards sustainable development and a climate-neutral economy: Foresight scenarios for the EU bioeconomy in 2050. In Borzacchiello, M. T., Stoermer, E., & Avraamides, M. (Eds.), *Publications Office of the European Union*. <https://doi.org/10.2760/763277>
- Geeson, N.A., Brandt, C.J., Thornes, J.B. (2003). Mediterranean desertification: a mosaic of processes and responses. Wiley, London.
- Geist, H. (2017). The causes and progression of desertification. Routledge, London.
- Geist, H.J., Lambin, E.F. (2004). Dynamic causal patterns of desertification. *Bioscience* 54, 817–829.
- Gerbens-Leenes, P.W., Nonhebel, S. (2002). Consumption patterns and their effects on land required for food. *Ecological Economics* 42 (1-2) p. 185-199.
- GoI, 2021. An overview of Ireland's Fifth Nitrates Action Programme. Government of Ireland, 35pp. f1a6725a-6269-442b-bff1-2730fe2dc06c.pdf (www.gov.ie).
- Guastella, G., Oueslati, W., & Pareglio, S. (2019). Patterns of Urban Spatial Expansion in European Cities. *Sustainability*, 11, N/A-N/A. <https://doi.org/10.3390/su11082247>
- Gibbs, H.K., Salmon, J.M., 2015. Mapping the world's degraded lands. *Applied Geography* 57, 12-21.
- Giurca, A., Nichiforel, L., Stăncioiu, P. T., Drăgoi, M., & Dima, D. (n.d.). Unlocking Romania's Forest-Based Bioeconomy Potential: Knowledge-Action-Gaps and the Way Forward. *Land*, 11(11), 2001. <https://doi.org/10.3390/land11112001>
- Glantz, M.H. (2019). Desertification: environmental degradation in and around arid lands. CRC Press.

Goga, T.; Feranec, J.; Bucha, T.; Rusnák, M.; Sačkov, I.; Barka, I.; Kopecká, M.; Papčo, J.; Ořahel, J.; Szatmári, D.; et al. A Review of the Application of Remote Sensing Data for Abandoned Agricultural Land Identification with Focus on Central and Eastern Europe. *Remote Sens.* 2019, 11, 2759. <https://doi.org/10.3390/rs11232759>

Gonzalez-Roglich, M., Zvoleff, A., Noon, M., Liniger, H., Fleiner, R., Harari, N., Garcia, C. (2019). Synergizing global tools to monitor progress towards land degradation neutrality: Trends. *Earth and the World Overview of Conservation Approaches and Technologies sustainable land management database. Environmental Science & Policy* 93, 34-42.

Grainger, A. (2013). *The threatening desert: controlling desertification.* Routledge, London.

Graves, A.R., Morris, J., Deeks, L.K., Rickson, R.J., Kibblewhite, M.G., Harris, J.A., Truckle, I. (2015). The total costs of soil degradation in England and Wales. *Ecological Economics* 119, 399-413.

Gutman, G., & Radeloff, V. (2016). *Land-cover and land-use changes in Eastern Europe after the collapse of the Soviet Union in 1991.* Springer, Berlin.

Guyomard, H., Bureau, J.C., Chatellier, V., Détang-Dessendre, C., Dupraz, P., Jacquet, F., Reboud, X., Requillart, V., Soler, L.G. and Tysebaert, M., 2020. The Green Deal and the CAP: policy implications to adapt farming practices and to preserve the EU's natural resources [Le Pacte vert et la PAC: implications politiques pour adapter les pratiques agricoles et préserver les ressources naturelles de l'UE] (No. hal-03219169). [https://www.europarl.europa.eu/RegData/etudes/STUD/2020/629214/IPOL_STU\(2020\)629214_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2020/629214/IPOL_STU(2020)629214_EN.pdf)

Hagyo, A., Kleeschulte, S., Ruf, K., Marin, A.I., Maucha, G., Kosztra, B., Hazeu, G., Elbersen, B., Schwaiger, E., Weiss M. and Carré, A., in prep. Copernicus products for the quantification of landscape features in Agricultural Areas: An overview of past developments. ETC/DI, EEA.

Haines-Young, R. and Potschin, M., (2013). *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012.* EEA Framework Contract No EEA/IEA/09/003.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., & Townshend, J. R. G. (2013). High-resolution global maps of 21st-century forest cover change. *Science*, 342(6160), 850–853. <https://doi.org/10.1126/science.1244693>

Hart K, Allen B, Lindner M, Keenleyside C, Burgess P, Eggers J, Buckwell A (2012) *Land as an Environmental Resource*, Report Prepared for DG Environment, Contract No ENV.B.1/ETU/2011/0029, Institute for European Environmental Policy, London.

Harte, J. (2007). Human population as a dynamic factor in environmental degradation. *Population-Environment Research Network* 28, 223-236.

- Hartvigsen, M. (2013). Land Reform in Central and Eastern Europe After 1989 and Its Outcome in the Form of Farm Structures and Land Fragmentation. Land Tenure Working Paper, 24. FAO.
- Hazeu, G.W.; M.J. Metzger; C.A. Múcher; M. Perez-Soba; Ch. Renetzeder; E. Andersen (2011). European environmental stratifications and typologies: An overview, *Agriculture, Ecosystems & Environment*, Volume 142, Issues 1–2, 2011, Pages 29–39, ISSN 0167-8809, <https://doi.org/10.1016/j.agee.2010.01.009>.
- Helldén, U., Tottrup, C. (2008). Regional desertification: A global synthesis. *Global and Planetary Change* 64(3–4), 169–176.
- Henning, C., Witzke, P., Panknin, L. & Grunenberg, M. (2021), *Ökonomische und Ökologische Auswirkungen des Green Deals in der Agrarwirtschaft* (Christian-Albrechts-Universität, 2021).
- Heyl, K., Doring, T., Garske, B., Stubenrauch, J., Ekardt, F. (2020). The Common € Agricultural Policy beyond 2020: a critical review in light of global environmental goals. *RECIEL*. <https://doi.org/10.1111/reel.12351>.
- Hill, J., Stellmes, M., Udelhoven, T., Röder, A., Sommer, S. (2008). Mediterranean desertification and land degradation: mapping related land use change syndromes based on satellite observations. *Global and Planetary Change* 64(3–4), 146–157.
- Hoffmann, C.C., C. Kjaergaard, J. Uusi-Kämppe, H.C. Bruun Hansen, and B.Kronvang (2009). Phosphorus retention in riparian buffers: Review of their efficiency. *J. Environ. Qual.* 38:1942–1955. doi:10.2134/jeq2008.0087.
- ISPRA (2013), *Italian Environmental data yearbook 2012*, Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma
- Holland, J.M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, ecosystems & environment*, 103(1), pp.1–25.
- Holman, I.P.; Brown, C.; Janes, V.; Sandars, D. (2017). Can we be certain about future land use change in Europe? A multi-scenario, integrated-assessment analysis, *Agricultural Systems*, 151 (2017), p. 126–135. <https://doi.org/10.1016/j.agry.2016.12.001>.
- Hooke, J., Sandercock, P. (2017). *Combating desertification and land degradation: spatial strategies using vegetation*. Springer, Berlin.
- Le Houerou, H.N. (1993). Land degradation in Mediterranean Europe: can agroforestry be a part of the solution? A prospective review. *Agroforestry Systems* 21, 43–61.
- Hristov, J., Toreti, A., Pérez Domínguez, I., Dentener, F., Fellmann, T., Elleby C., Ceglar, A., Fumagalli, D., Niemeyer, S., Cerrani, I., Panarello, L., Bratu, M.. (2020). Analysis of climate change impacts on EU agriculture by 2050. EUR 30078 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-10617-3, doi:10.2760/121115, JRC119632.
- Hubbard, Carmen & Gorton, Matthew (2011). Placing agriculture within rural development: Evidence from EU case studies. *Environment and Planning C: Government and Policy*, 29(1), 80–95.

- IEEP, Alterra (2010). Reflecting Environmental Land Use Needs into EU Policy: Preserving and Enhancing the Environmental Benefits of "Land Services": Soil Sealing, Biodiversity Corridors, intensification/Marginalisation of Land Use and Permanent Grassland. Final Report to the European Commission, DG Environment on Contract ENVB1/ETU/2008/0030. Institute for European Environmental Policy/Alterra Wageningen UR.
- Iglesias, A.; Garrote, L.; Quiroga, S.; Moneo, M. (2012). A regional comparison of the effects of climate change on agricultural crops in European Climate Change 112 (1), 29–46.
- Imeson, A. (2012). Desertification, land degradation and sustainability. Wiley, London.
- Immerzeel, D.J. et al., (2014). Biodiversity impacts of bioenergy crop production: a state-of-the-art review. *Global Change Biology Bioenergy*, 6(3), pp.183–209. Available at: <http://doi.wiley.com/10.1111/gcbb.12067>.
- International Trade Administration (ITA) (2022). Romania - Country Commercial Guide. <https://www.trade.gov/country-commercial-guides/romania-energy>
- Ioffe, G & Nefedova, T. (2004) Marginal Farmland in European Russia, *Eurasian Geography and Economics*, 45:1, 45-59 <http://dx.doi.org/10.2747/1538-7216.45.1.45>
- IPCC (2019): Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].
- Ivits, E.; Milego, R.; Mancosu, E.; Gregor, M.; Petersen, J. E.; Büttner, G.; Löhnertz, M.; Maucha, G.; Petrik, O.; Bastrup-Birk, A.; Tafi, J.; Hazeu, G. (2020). ETC/ULS Report 02/2020: Land and ecosystem accounts for Europe. Towards geospatial environmental accounting. Technical Report 2020, ISBN: 978-3-200-07114-8.
- Jacobs, C.; Berglund, M.; Kurnik, B.; Dworak, T.; Marras, S.; Mereu, V.; Michetti, M. (2019). Climate change adaptation in the agriculture sector in Europe. Luxembourg: Publications Office of the European Union, 2019 : European Environment Agency (EEA) (EEA Report 4/2019) - ISBN 9789294800725 - 112 p.
- Johnson, D.L., Lewis, L.A. (2007). Land degradation – Creation and destruction. Rowman & Littlefield, Lanham.
- Joint Research Centre. (2023). Agrivoltaics alone could surpass EU photovoltaic 2030 goals. European Commission. <https://www.europa.eu/newsroom/content/agrivoltaics-alone-could-surpass-eu-photovoltaic-2030-goals>
- Jones, S. (2008). Political ecology and land degradation: How does the land lie 21 years after Blaikie and Brookfield's Land Degradation and Society?. *Geography Compass*, 2(3), 671-694.

- Juntti, M., Wilson, G.A. (2004). Conceptualising desertification in southern Europe: stakeholders interpretations and multiple policy agendas. *European Environment* 15, 228-249.
- Kabisch, N., & Haase, D. (2011). Diversifying European agglomerations: Evidence of urban population trends for the 21st century. *Population, Space and Place*, 17(3), 236–253.
- Kapetanaki, P., Verweij, P., Jones, L., Simoes, M., Winograd, M. (2017). [An application framework for exploring the sustainability limits: the case of climate change impacts in Brazil](#), Agile conference, Wageningen, May 2017.
- KED (2023). How is the progress of the Water Framework Directive in the Netherlands (in Dutch). Hoe staat het met de voortgang van de Kaderrichtlijn Water in Nederland? - Europa decentraal
- Keenleyside, C. and Tucker, G. M. (2010). Farmland Abandonment in the EU: an Assessment of Trends and Prospects. Report prepared for WWF. Institute for European Environmental Policy, London.
- Klijn, J.A., Vullings, L.A.E., van den Berg, M., van Meijl, H., van Lammeren, R., van Rheenen, T., Veldkamp, A., Verburg, P.H., Westhoek, H., Eickhout, B. (2005). The EURURALIS study: technical document. Alterra-rapport 1196. Alterra, Wageningen.
- Kok, K., Pedde, S., Gramberger, M., Harrison, P. A., & Holman, I. P. (2019). New European socio-economic scenarios for climate change research: operationalising concepts to extend the shared socio-economic pathways. *Regional Environmental Change*, 19, 643-654
- Kok, K., Farrow, A., Veldkamp, A., & Verburg, P. H. (2001). A method and application of multi-scale validation in spatial land use models. *Agriculture, Ecosystems & Environment*, 85(1–3), 223–238.
- Kowalska, J.; Antkowiak, M.; Sienkiewicz, P. (2022). Flower Strips and Their Ecological Multifunctionality in Agricultural Fields. *Agriculture* 2022(12), 1470. <https://doi.org/10.3390/agriculture12091470>.
- Kovats, R.S.; Valentini, R.; Bouwer, L.M.; Georgopoulou, E.; Jacob, D.; Martin, E.; Rounsevell, M.; Soussana, J.-F. (2014). Europe. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1267-1326.
- Kowalska, I., Moldoch, J., Pawelec, S., Podolska, G., Von Cossel, M., Derycke, V., Haesaert, G., Lana, M. A., Da Silva Lopes, M., Riche, A. B., Stutzel, H., Hackett, R. and Oleszek, W. (2022). Environmental and cultivar variability in composition, content and biological activity of phenolic acids and alkylresorcinols of winter wheat grains from a multi-site field trial across Europe. *Journal of Cereal Science*. 107, p. 103527. <https://doi.org/10.1016/j.jcs.2022.103527>

- Kroll, F., & Kabisch, N. (2012). The relation of diverging urban growth processes and demographic change along an urban–rural gradient. *Population, Space and Place* 18(3), 260–276.
- Kuemmerle, T., Levers, C., Erb, K., Estel, S., Jepsen, M.R., Müller, D., Plutzer, C., Stürck, J., Verkerk, P.J., Verburg, P.H. and Reenberg, A. (2016). Hotspots of land use change in Europe. *Environmental research letters*, 11(6), p.064020. DOI 10.1088/1748-9326/11/6/064020
<https://iopscience.iop.org/article/10.1088/1748-9326/11/6/064020>
- Lagarias, A. & Stratigea, A. (2023). Coastalization patterns in the Mediterranean: a spatiotemporal analysis of coastal urban sprawl in tourism destination areas. *GeoJournal* (2023) 88:2529–2552
<https://doi.org/10.1007/s10708-022-10756-8>
- Lambin, E.F., B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coome, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skånes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, J. Xu, (2001), The causes of land-use and land-cover change: moving beyond the myths *Global Environ. Change*, 11 (2001), pp. 261-269
- Langlais, A. (2023). The new Common Agricultural Policy: Reflecting an agro-ecological transition. The legal perspective. *Review of Agricultural, Food and Environmental Studies*, 104(1). <https://doi.org/10.1007/s41130-022-00183-1>
- Lasanta, T. (2002). Los sistemas de gestión en el Pirineo central español durante el siglo XX: del aprovechamiento global de los recursos a la descoordinación espacial en los usos del suelo. *Ager* 2, 173–195.
- Lasanta, T., J. Arnáez, N. Pascual, P. Ruiz-Flaño, M.P. Errea, N. Lana-Renault (2017). Space–time process and drivers of land abandonment in Europe. *CATENA*, Volume 149, Part 3, 2017. Pages 810-823. ISSN 0341-8162, <https://doi.org/10.1016/j.catena.2016.02.024>.
<http://www.sciencedirect.com/science/article/pii/S0341816216300777>.
- Leal Filho, W., Merit Mandel, Abul Quasem Al-Amin, Alexander Feher & Charbel José Chiappetta Jabbour (2017) An assessment of the causes and consequences of agricultural land abandonment in Europe, *International Journal of Sustainable Development & World Ecology*, 24:6, 554-560, DOI: 10.1080/13504509.2016.1240113.
- Lecuyer, I., Alard, D., Calla, S., B. Coolsaet, T. Fickel, K. Heinsoo, K. Henle, I. Herzon, I. Hodgson, F. Quétier, D. McCracken, B.J. McMahon, I. Melts, D. Sands, E. Skrimizea, A. Watt, R. White, Juliette Young (2021). Chapter One - Conflicts between agriculture and biodiversity conservation in Europe: Looking to the future by learning from the past. *Advances in Ecological Research*, ISSN: 0065-2504, Vol: 65, Page: 3-56 Publication Year 2021. <https://doi.org/10.1016/bs.aecr.2021.10.005>
- Levers, C., Müller, D., Erb, K., Haberl H., Rudbeck Jepsen, M., Metzger, M. J., Meyfroidt, P., Plieninger, T., Plutzer, C., Stürck, J., Verburg, P.H., Verkerk, P. J., Kuemmerle, T. (2015). Archetypical patterns and trajectories of land systems in Europe.

- Lier, H.N.. (2000). Land use planning and land consolidation in the future in Europe. *Zeitschrift fur Kulturtechnik und Landentwicklung*. 41. 138-143.
- LIFE AgriAdapt (2020). Sustainable adaptation of agricultural systems in the European Union to climate change AGRIADAPT PROJECT, Author | RADOLFZELL (Bodensee Stiftung, Fritz-Reichle-Ring 4, 78315, GERMANY): AGRIADAPT PROJECT | 2020.
- Longhi, C., & Musolesi, A. (2007). European cities in the process of economic integration: towards structural convergence. *The Annals of Regional Science* 41, 333-351.
- Lopes Barbosa, A., Lavalley, C., & Batista e Silva, F. (2015). Land allocation and suitability analysis for the production of food, feed, and energy crops in the period 2010–2050. *Joint Research Centre, Institute for Environment and Sustainability*. <https://data.europa.eu/doi/10.2788/93483>
- Louwagie G, Gay S H and Burrell A (eds.) (2009) Final report on the project 'Sustainable Agriculture and Soil Conservation (SoCo)', JRC Scientific and Technical report, Publications Office of the European Union, Luxembourg.
- Lowe, Philip (2006). European agricultural and rural development policies for the 21st century. In Jane Midgley (Ed), *A new rural agenda* (pp. 29–45). Newcastle: IPPR-North.
- Luján Soto, R., Martínez-Mena, M., Cu ´ellar Padilla, M., de Vente, J., (2021). Restoring soil quality of woody agroecosystems in Mediterranean drylands through regenerative agriculture. *Agriculture Ecosystems and Environment* 306, <https://doi.org/10.1016/j.agee.2020.107191>.
- Lutz, W., & Qiang, R. (2002). Determinants of human population growth. *Philosophical Transactions of the Royal Society B* 357(1425), 1197-1210.
- MacDonald,D., Crabtree, G Wiesinger, T Dax, N Stamou, P Fleury, J Gutierrez Lazpita, A Gibon (2000). Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response, *Journal of Environmental Management*, Volume 59, Issue 1, 2000, Pages 47-69, ISSN 0301-4797, <https://doi.org/10.1006/jema.1999.0335>. (<https://www.sciencedirect.com/science/article/pii/S0301479799903353>)
- Maes J, Teller A, Erhard M, Grizzetti B, Barredo JI, Paracchini ML, Condé S, Somma F, Orgiazzi A, Jones A, Zulian A, Vallecilo S, Petersen JE, Marquardt D, Kovacevic V, Abdul Malak D, Marin AI, Czúcz B, Mauri A, Löffler P, BastrupBirk A, Biala K, Christiansen T, Werner B (2018) Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition. Publications office of the European Union, Luxembourg.
- Mainguet, M. (2012). *Desertification: natural background and human mismanagement*. Springer Science & Business Media, Berlin.
- Manhoudt, A.G.E, de Snoo, G.R. (2003). A quantitative survey of semi-natural habitats on Dutch arable farms, *Agriculture, Ecosystems & Environment*, Volume 97, Issues 1–3, 2003, Pages 235-240, ISSN 0167-8809, [https://doi.org/10.1016/S0167-8809\(03\)00123-3](https://doi.org/10.1016/S0167-8809(03)00123-3). (<https://www.sciencedirect.com/science/article/pii/S0167880903001233>)

- Mantino, Francesco (2011). Developing a territorial approach for the CAP. MPRA Paper No. 49298, Institute for European Environmental Policy, Munich.
- Martínez-Valderrama, J., Ibáñez, J., Del Barrio, G., Sanjuán, M.E., Alcalá, F.J., Martínez-Vicente, S., Puigdefábregas, J. (2016). Present and future of desertification in Spain: Implementation of a surveillance system to prevent land degradation. *Science of the Total Environment* 563, 169-178.
- Matthews, A. (2022). Implications of the European Green Deal for agri-food trade with developing countries. Brussels, European Landowners' Organization, 75 pp.
- McBride, M. F., Lambert, K. F., Huff, E. S., Theoharides, K. A., Field, P., & Thompson, J. R. (2017). Increasing the effectiveness of participatory scenario development through codesign. *Ecology and Society*, 22(3), 16. <https://doi.org/10.5751/ES-09386-220316>
- McMorran, R., Santini, F., Guri, F., Gomez-y-Paloma, S., Price, M., Beucherie, O., Monticelli, C., Rouby, A., Vitrolles, D., & Cloye, G. (2015). A mountain food label for Europe? The role of food labelling and certification in delivering sustainable development in European mountain regions. *Journal of Alpine Research| Revue de géographie alpine*, (103-4) 0-22. <https://doi.org/10.4000/rga.2654>
- Meijninger, W, Elbersen, B., Eupen, van M., Mantel, S., Ciria, P., Parenti, A., Sanz Gallego, M., Perez Ortiz, P., Acciai, M., Monti, A. (2022). Identification of early abandonment in cropland through radar-based coherence data and application of a Random-Forest model. *GCB Bioenergy*. 2022;14:735-755. <https://doi.org/10.1111/gcbb.12939>
- Messerli, B.; Grosjeana, M.; Hofer, T.; Núñez, L.; Pfister, C.; (2000). From nature-dominated to human-dominated environmental changes. *Quantitative Science Review* 19 (1-5), 459-479.
- Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Desertification Synthesis*. World Resources Institute, Washington.
- Mittenzwei, K, Britz, W and Wieck, C (2014) Does the "green box" of the European Union distort global markets? *Bio-based and Applied Economics* No 3 (1), 1-20
- Mohammed, S., Alsafadi, K., Takács, I., & Harsányi, E. (2020). Contemporary changes of greenhouse gases emission from the agricultural sector in the EU-27. *Geology, Ecology, and Landscapes*, 4(4), 282-287
- Mucher, C. A., Klijn, J. A., Wascher, D. M. & Schaminée, J. H. J., 2010, A new European Landscape Classification (LANMAP): A transparent, flexible and user-oriented methodology to distinguish landscapes. In: *Ecological Indicators*. 10, 1, p. 87-103.
- Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. *Nature*, 463(7282), 747-756.
- Müller, Felix & Burkhard, Benjamin & Hou, Ying & Kruse, Marion & Ma, Liwei & Wangai, Peter. (2016). Indicators for ecosystem services.

- Nabuurs, G. J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M., & Ollikainen, M. (2017). By 2050, the mitigation effects of EU forests could nearly double through climate smart forestry. *Forests*, 8(12), 484. <https://doi.org/10.3390/f8120484>
- Natale, F., Kalantaryan, S., Scipioni, M., Alessandrini, A. and Pasa, A., Migration in EU Rural Areas, (2019), EUR 29779 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-08600-0 (online), doi:10.2760/544298 (online), JRC116919. <https://ec.europa.eu/migrant-integration/sites/default/files/2019-07/MigrationinEURuralAreas.pdf>
- Nieto-Romero, M., Horcea-Milcu, I., Leventon, J., Mikulcak, F., & Fischer, J. (2015). The role of scenarios in fostering collective action for sustainable development: Lessons from central Romania. *Land Use Policy*, 50, 156–168. <https://doi.org/10.1016/j.landusepol.2015.09.013>
- Nilsson, K., Pauleit, S., Bell, S., Aalbers, C., & Nielsen, T. A. S. (2013). Peri-urban futures: Scenarios and models for land use change in Europe. Springer Science & Business Media.
- Noleppa, S. ; Carlsburg, M. (2015). The agricultural trade of the European Union – consequences for virtual land trade and self-sufficiency. HFFA Research Paper 03/2015. HFFA Research GmbH, 47 pp.
- Nowak, B. (2021). Precision agriculture: Where do we stand? A review of the adoption of precision agriculture technologies on field crops farms in developed countries. *Agricultural Research*, 10(4), pp.515-522.
- Nuissl, H., & Rink, D. (2005). The 'production' of urban sprawl in eastern Germany as a phenomenon of post-socialist transformation. *Cities* 22, 123–134.
- OAP, 2021. Feeder report 2021 – Waste Water. OSPAR assessment portal. Waste water (ospar.org).
- O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, 42, 169–180.
- OPERA (2010). EU Agricultural production and trade: Can more efficiency prevent increasing 'land grabbing' outside of Europe? Humboldt University Berlin. Summary, 2 pp.
- Panagos P., Borrelli p., Meusburger K., Alewell C., Lugato E., and L. Montanarella (2015). Estimating the soil erosion cover-management factor at the European scale, *Land Use Policy*, Volume 48, 2015, Pages 38-50, ISSN 0264-8377, <https://doi.org/10.1016/j.landusepol.2015.05.021>. (<https://www.sciencedirect.com/science/article/pii/S0264837715001611>)
- Panagos, P., C. Ballabio, J. Poesen, E. Lugato, S. Scarpa, L. Montanarella, and P. Borrelli (2020). A Soil Erosion Indicator for Supporting Agricultural, Environmental and Climate Policies in the European Union, *Remote Sensing* 12, no. 9: 1365. <https://doi.org/10.3390/rs12091365>

- Panagos, P., Ballabio C., Himics, M., Scarpa, S., Matthews, F., Bogonos, M., Poesen, J., and P. Borrelli (2021). Projections of soil loss by water erosion in Europe by 2050, *Environmental Science & Policy*, Volume 124, 2021, Pages 380-392, ISSN 1462-9011, <https://doi.org/10.1016/j.envsci.2021.07.012>. (<https://www.sciencedirect.com/science/article/pii/S1462901121001970>)
- Panagos, P., Köningner, J., Ballabio, C., Liakos, L., Muntwyler, A., Borrelli, P. and Lugato, E. (2022). Improving the phosphorus budget of European agricultural soils. *Science of The Total Environment*, 853, p.158706.
- Panoutsou, C and Maniatis, K. (2021). Sustainable biomass availability in the EU, to 2050 RED II Annex IX A/B. Study for Concawe, August 2021
- Panoutsou, C., Sandford C., Malins C., Mutua K., Takacs E., Szlatenyi D., Boogaard H., Staritsky I., de Wit A., Verzandvoort S., Elbersen B., Ibrahim D., Giarola S., and Shah N. (2022). Opportunities for Low Indirect Land Use Biomass for Biofuels in Europe. *Appl. Sci.* 2022, 12(9), 4623; <https://doi.org/10.3390/app12094623>
- Papadopoulos, Apostolos G. & Liarikos, Constantinos (2007). Dissecting changing rural development policy networks: The case of Greece. *Environment and Planning C: Government and Policy*, 25(2), 291–313.
- Papadopoulos, A. (2015). The Impact of the CAP on Agriculture and Rural Areas of EU Member States. *Agrarian South: Journal of Political Economy* 4(1) 22–53 © 2015 Centre for Agrarian Research and Education for South (CARES) SAGE Publications sagepub.in/home.nav DOI: 10.1177/2277976015574054 <http://ags.sagepub.com>
- Perpiña Castillo, C, Coll Aliaga, E, Lavallo, C. & Martinez Llario, J.C. (2020). An Assessment and Spatial Modelling of Agricultural Land Abandonment in Spain (2015–2030). *Sustainability* 2020, 12(2), 560; <https://doi.org/10.3390/su12020560>
- Paracchini, M.L. ; Petersen, J.E. ; Hogeveen, Y. ; Bamps, C. ; Burfield, I. & van Swaay, C. (2008). High nature value farmland in Europe. An estimate of the distribution patterns on the basis of land cover and biodiversity data. European Commission, Joint Research Centre, Institute for Environment and Sustainability. EUR 23480 EN.
- Pebley, A. R. (1998). Demography and the environment. *Demography*, 35(4), 377-389.
- Pedroli, B., van Doorn, A., de Blust, G., Paracchini, M.L., Wascher, D., Bunce, F. (Eds.) (2007). *Europe's Living Landscapes. Essays on Exploring Our Identity in the Countryside*. LANDSCAPE EUROPE/KNNV, Wageningen.
- Pe'er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Muller, R., € Lakner, S. (2019). A greener path for the EU Common Agricultural Policy. *Science* 365 (6452), 449–451. <https://doi.org/10.1126/science.aax3146>.
- Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P.H., Hagedorn, G., Hansjurgens, € B., Herzon, I., Lomba, A^., Marquard, E. (2020). Action needed for the EU Common Agricultural Policy to address sustainability challenges. *People Nat.* 2 (2), 305–316.
- Pe'er, G., Finn, J.A., Díaz, M., Birkenstock, M., Lakner, S., Röder, N., Kazakova, Y., Šumrada, T., Bezák, P., Concepción, E.D. and Dänhardt, J. (2022). How can the European Common Agricultural Policy help halt

biodiversity loss? Recommendations by over 300 experts. *Conservation Letters*, 15(6), p.e12901.

Peeters, A., Lefebvre, O., Balogh, L., Barberi, P., Batello, C., Bellon, S., et al. (2020). A Green Deal for implementing agroecological systems. Reforming the Common Agricultural Policy of the European Union. *J. Sustain. Org. Agric. Syst.* 70 (2), 83–93.

Pérez-Soba, M., S. Petit, L. Jones, N. Bertrand, V. Briquel, L. Omodei-Zorini, C. Contini, K. Helming, J.H. Farrington, . Tinacci Mossello, D. Wascher, F. Kienast & R. de Groot (2008). Land use functions — a multifunctionality approach to assess the impact of land use changes on land use sustainability. In: Helming, K., Pérez-Soba, M., Tabbush, P. (eds) *Sustainability Impact Assessment of Land Use Changes*. Springer, Berlin, Heidelberg.

Perpiña Castillo, C., Kavalov, B., Ribeiro Barranco, R., Diogo, V., Jacobs, C., Batista E Silva, F., Baranzelli, C. and Lavalley, C., (2018a) Territorial Facts and Trends in the EU Rural Areas within 2015-2030, Joint Research Centre, JRC114016

<https://publications.jrc.ec.europa.eu/repository/handle/JRC114016>.

<https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/trends-eu-agricultural-land-within-2015-2030>

Perpiña - Castillo, C., Kavalov, B., Diogo, V., Jacobs-Crisioni, C., Batista e Silva, F., and Lavalley, C. (2018c). JRC Policy Insights – ‘Agricultural land abandonment in the EU within 2015-2030.’ Jrc113718, (October), 7. Retrieved from

[www.ec.europa.eu/jrc/en/publications%0Ahttps://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/agricultural-land-abandonment-eu-within-2015-2030%0Ahttps://ec.europa.eu/jrc/sites/jrcsh/files/jrc113718.pdf](https://ec.europa.eu/jrc/en/publications%0Ahttps://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/agricultural-land-abandonment-eu-within-2015-2030%0Ahttps://ec.europa.eu/jrc/sites/jrcsh/files/jrc113718.pdf)

Perpiña Castillo, C, Jacobs-Crisioni, C, Diogo, V. Lavalley, C. (2021). Modelling agricultural land abandonment in a fine spatial resolution multi-level land-use model: An application for the EU. *Environmental Modelling & Software*. Volume 136, February 2021, 104946.

Peyraud, J.L. and MacLeod, M. (2020). Future of EU-livestock—how to contribute to a sustainable agricultural sector. Final Report. Directorate-General for Agriculture and Rural Development (European Commission): Brussels, Belgium, p.82.

Plieninger, T., and Gaertner, M. (2011). Harnessing degraded lands for biodiversity conservation. *Journal for Nature Conservation*, 19, 18-23.

Pointereau P., Coulon F., Girard P., Lambotte M., Stuczynski T., Sánchez Ortega V., Del Rio A. (2008). Analysis of Farmland Abandonment and the Extent and Location of Agricultural Areas that are Actually Abandoned or are in Risk to be Abandoned, EUR 23411EN – 2008, Institute for Environment and Sustainability, JRC.

Poláková, J, Tucker, G, Hart, K, Dwyer, J, Rayment, M (2011). Addressing biodiversity and habitat preservation through Measures applied under the Common Agricultural Policy. Report Prepared for DG Agriculture and Rural

- Development, Contract No. 30-CE-0388497/00-44. Institute for European Environmental Policy, London.
- Potapov, P., Hansen, M. C., Pickens, A., Hernandez-Serna, A., Tyukavina, A., Turubanova, S. & Kommareddy, A. (2022). The global 2000-2020 land cover and land use change dataset derived from the Landsat archive: first results. *Frontiers in Remote Sensing*, 3, 856903.
- Potschin, M., & Haines-Young, R. (2008). Sustainability impact assessments: Limits, thresholds, and the sustainability choice space. In Helming, K., Pérez-Soba, M., & Tabbush, P. (Eds.), *Sustainability Impact Assessment of Land Use Changes* (pp. 121-144). Springer. <https://doi.org/10.1007/978-3-540-78648-1>
- Pretty J.N. (1998). *The Living Land: Agriculture, Food and Community Regeneration in Rural Europe*. Earthscan, London.
- Puigdefábregas, J. (1998). Ecological impacts of global change on drylands and their implications for desertification. *Land Degradation & Development* 9(5), 393-406.
- Purnhagen, Kai P.; Clemens, Stephan; Eriksson, Dennis; Fresco, Louise O.; Tosun, Jale; Qaim, Martin; Visser, Richard G.F.; Weber, Andreas P.M.; Wesseler, Justus H.H.; Zilberman, David (2012). Europe's Farm to Fork Strategy and Its Commitment to Biotechnology and Organic Farming : Conflicting or Complementary Goals? *Trends in Plant Science* 26 (2021)6. - ISSN 1360-1385 - p. 600 - 606 <https://doi.org/10.1016/j.tplants.2021.03.012>
- Quintas-Soriano, C., Buerkert A, Plieninger, T. (2022). Effects of land abandonment on nature contributions to people and good quality of life components in the Mediterranean region: A review, *Land Use Policy*, Volume 116, 2022, 106053, ISSN 0264-8377, <https://doi.org/10.1016/j.landusepol.2022.106053>.
- Rabbinge R.A, C.A. van Diepen (2000) Changes in agriculture and land use in Europe. *European Journal of Agronomy* 13 (2000) 85–100
- Rasmussen and Weber (2012). VOLUME I Land Use Characterization in Europe: Analysing land use patterns using typologies. Part C scientific report. Version 30 November 2012. © ESPON & TECNALIA Research & Innovation, 2012
- REACT4MED Project (Grant Agreement No. 2122), funded by PRIMA, the Partnership for Research and Innovation in the Mediterranean Area, a Programme supported by Horizon 2020, the European Union's Framework Programme for Research and Innovation, <https://react4med.eu/> (accessed October 2023).
- Renetzeder, C., van Eupen, M., Múcher, S., & Wrbka, T. (2008). Sustainability impact assessment of land use changes. In Helming, K., Pérez-Soba, M., & Tabbush, P. (Eds.), *Sustainability Impact Assessment of Land Use Changes* (pp. 293-313). Springer. https://doi.org/10.1007/978-3-540-78648-1_13
- Reynolds, J.F., Grainger, A., Stafford Smith, D.M., Bastin, G., Garcia-Barrios, L., Fernández, R.J., Verstraete, M.M. (2011). Scientific concepts for an integrated analysis of desertification. *Land Degradation & Development* 22(2), 166-183.

- Rindfuss, R. R., Entwisle, B., Walsh, S. J., Mena, C. F., Erlien, C. M., & Gray, C. L. (2007). Frontier land use change: Synthesis, challenges, and next steps. *Annals of the Association of American Geographers* 97(4), 739-754.
- Römkens, P., Rietra, R., Verzandvoort, S., Elbersen, B., Van Eupen, M. and Staritsky, I. (2023). Extent, location and contaminated land status potentially suitable for phytoremediation 2022. Deliverable 3.1 in the EU-project: Growing energy crops on contaminated land for biofuels and soil remediation. Horizon 2020 Grant Agreement Number: 101006873. Wageningen Environmental Research. 125 pp.
- Rounsevell, M. D. A., Reginster, I., Araújo, M. B., Carter, T. R., Dendoncker, N., Ewert, F. & Tuck, G. (2006). A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems & Environment*, 114(1), 57-68.
- Ruiz, I., & Sanz-Sánchez, M. J. (2020). Effects of historical land-use change in the Mediterranean environment. *Science of the Total Environment* 732, 139315.
- Salvati, L., Carlucci, M. (2010). Estimating land degradation risk for agriculture in Italy using an indirect approach. *Ecological Economics* 69(3), 511-518.
- Santini, M., Caccamo, G., Laurenti, A., Noce, S., Valentini, R. (2010). A multi-component GIS framework for desertification risk assessment by an integrated index. *Applied Geography* 30(3), 394-415.
- Sayadi, S. and Calatrava, J. (2009). Structure and productivity of Spanish mango industry: a farmers survey analysis. *Acta Horticulture* 820, p. 47-56 DOI: <https://doi.org/10.17660/ActaHortic.2009.820.2>.
- Schelhaas, M.J. , Hengeveld, G. Moriondo, G., Reinds, J., Kundzewicz, Z.W., ter Maat, H., Bindi M. (2010), Assessing risk and adaptation options to fires and windstorms in European forestry Mitig. Adapt. Strat. GL, 15 (2010), pp. 681-701
- Scherer, L.A. , P.H. Verburg, C.J.E. Schulp, (2018) Opportunities for sustainable intensification in European agriculture, *Global Environmental Change*, Volume 48, 2018, Pages 43-55, ISSN 0959-3780, <https://doi.org/10.1016/j.gloenvcha.2017.11.009>.
<https://www.sciencedirect.com/science/article/pii/S0959378017305411>
- Schils, R., J.E.Olesen, K.C.Kersebaum, B.Rijk, M.Oberforster, V.Kalyada, M.Khitrykau, A.Gobin, H.Kirchev, V.Manolova, I.Manolov, M.Trnka, P.Hlavinka, T.Paluoso, P.Peltonen-Sainio, L.Jauhiainen, J.Lorgeou, H.Marrou, N.Danalatos, S.Archontoulis, N.Fodor, J.Spink, P.P.Roggero, S.Bassu, A.Pulina, T.Seehusen, A.K.Uhlen, K.Żyłowska, A.Nieróbca, J.Kozyra, J.Vasco Silva, B. Martins Maçãs, J.Coutinho, V.Ion, J.Takáč, M. Inés Mínguez, H.Eckersten, L.Levy, J.M.Herrera, J.Hiltbrunner, O.Kryvobok, O.Kryvoshein, R.Sylvester-Bradley, D.Kindred, C.F.E.Topp, H.Boogaard, H.de Groot, J.P.Lesschen, L. van Bussel, J.Wolf, M.Zijlstra, M.P.van Loon, M.K.van Ittersum (2018). Cereal yield gaps across Europe. *European Journal of*

- Agronomy, 101, pp.109-120. Vol. 101 (November 2018), 109-120; <https://doi.org/10.1016/j.eja.2018.09.003>
- Schipper, A., Bakkenes, M., Meijer, J., Alkemade, R., & Huijbregts, M. (2016). The GLOBIO model: A technical description of version 3.5. *PBL Netherlands Environmental Assessment Agency, The Hague*. <https://www.pbl.nl/en/publications/globio-35-technical-model-description>
- Schreiber, C., Rechenburg, A., Rind, E., Kistemann, T. (2015). The impact of land use on microbial surface water pollution. *International Journal of Hygiene and Environmental Health*, Volume 218, Issue 2, Pages 181-187. <https://doi.org/10.1016/j.ijheh.2014.09.006>.
- Shucksmith, Mark, Thomson, Kenneth J. & Roberts, Deborah (2005). The CAP and the regions: The territorial impact of the Common Agricultural Policy. Wallingford: ESPON and CABI Publishing
- Schuh, B. et al. (2020), Research for AGRI Committee – The challenge of land abandonment after 2020 and options for mitigating measures, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels.
- Schulp, C. J., Levers, C., Kuemmerle, T., Tieskens, K. F., & Verburg, P. H. (2019). Mapping and modelling past and future land use change in Europe's cultural landscapes. *Land Use Policy*, 80, 332-344.
- Schwarzmüller, F. , Kastner, T. (2022). Agricultural trade and its impacts on cropland use and the global loss of species habitat. *Sustainability Science* (2022)17 p. 2363–2377.
- Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J et al. (2008). Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319 (5867), 1238-1240.
- Seely, M., Wohl, H. (2004). Connecting research to combating desertification. *Environmental Monitoring and Assessment* 99, 23-32.
- Serra, P., Vera, A., Tulla, A. F., & Salvati, L. (2014). Beyond urban-rural dichotomy: Exploring socioeconomic and land-use processes of change in Spain 1991–2011. *Applied Geography* 55, 71-81.
- Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., & Fazey, I. (2016). Three horizons: A pathways practice for transformation. *Ecology and Society*, 21(2), 47. <https://doi.org/10.5751/ES-08388-210247>
- Siauve, S., Amorsi, N., 2015. Protection of the whole catchments providing drinking water. Study of practices in Europe Part I: Cross-Analysis. Office International de l'eau, 38 pp. EU review for catchment protection from diffuse pollution.pdf (oieau.fr).
- Sica, D., Esposito, B., Supino, S., Malandrino, O., & Sessa, M. R. (2023). Biogas-based systems: An opportunity towards a post-fossil and circular economy perspective in Italy. *Energy Policy*, 182, 113719. <https://doi.org/10.1016/j.enpol.2023.113719>
- Singh, R.B. (2019). A composite method to identify desertification 'hotspots' and 'brightspots'. *Land Degradation & Development* 30(9), 1025-1039.
- Slangen, L., Heijman, W., Kroese, E, Silvis, H., Hiel, R (1996). *Economie en landbouw* (2nd edition) Houten: Stenfert-Kroese.
- Smeets, E., Lewandowski, I., and Faaij, A. (2009). The economical and environmental performance of miscanthus and switchgrass production and

supply chains in a European setting. *Renewable and Sustainable Energy Reviews*, 13, 1230-1245.

Smiraglia D., Ceccarelli T., Bajocco S., Perini L. (2015). Linking trajectories of land change, land degradation processes and ecosystem services. *ENVIRONMENTAL RESEARCH*

Sommer, S., Zucca, C., Grainger, A., Cherlet, M., Zougmore, R., Sokona, Y., Hill, J. (2011). Application of indicator systems for monitoring and assessment of desertification from national to global scales. *Land Degradation and Development* 22(2), 184-197.

Stellmes, M., Röder, A., Udelhoven, T., & Hill, J. (2013). Mapping syndromes of land change in Spain with remote sensing time series, demographic and climatic data. *Land Use Policy* 30(1), 685-702.

Stoate, C., A. Báldi, P. Beja, N.D. Boatman, I. Herzon, A. van Doorn, G.R. de Snoo, L. Rakosy, C. Ramwell, (2009). Ecological impacts of early 21st century agricultural change in Europe – A review, *Journal of Environmental Management*, Volume 91, Issue 1, 2009, Pages 22-46, ISSN 0301-4797

Stringer, L.C., Fleskens, L., Reed, M.S., de Vente, J., Zengin, M. (2014). Participatory evaluation of monitoring and modeling of sustainable land management technologies in areas prone to land degradation. *Environmental Management* 54(5), 1022-1042.

Stürck, J., Levers, C., van der Zanden, E.H., Schulp, C. & Verkerk, H., Kuemmerle, T., Helming, J.F.M., Lotze-Campen, H., Tabeau, A., Popp, A., Schrammeijer, E., Verburg, P. (2018). Simulating and delineating future land change trajectories across Europe. *Regional Environmental Change*. 18. 10.1007/s10113-015-0876-0.

Ṣumrada, T., Lovec, M., Juvancic, L., Rac, I., Erjavec, E., 2020. Fit for the task? Integration of biodiversity policy into the post-2020 Common Agricultural Policy: illustration on the case of Slovenia. *J. Nat. Conserv.* 54, 125804. <https://doi.org/10.1016/j.jnc.2020.125804>.

Swinnen, Jo (2009). Compensation payment in EU agriculture. Paper prepared for World Bank Project on 'Adjustment costs to trade', 10 September, Leuven. Available at, <https://lirias.kuleuven.be/bitstream/123456789/285432/2/Swinnen2.pdf>

Terres J.M., Anguiano E, Nisini L (2013) Assessing the risk of farmland abandonment in the EU Technical assistance to define key factors and drivers, process data sets and provide results Administrative Arrangement #AGRI-2011-0295 between DG Agriculture and Rural Development and JRC Study on farmland abandonment – Deliverable 1. JRC78131 EUR 25783 EN ISBN 978-92-79-28281-2 (pdf) ISSN 1831-9424 (online) doi: LB-NA-25783-EN-N Luxembourg: Publications Office of the European Union, 2013, European Union.

Terres, JM. Hagyo, A. Wania A. (Eds.), Confalonieri R., Jones, B. Van Diepen K., Van Oorshoven J. (2014). Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific

- constraints. Methodology and factsheets for plausible criteria combinations. JRC92686. doi: 10.2788/844501.
- Tiefenbacher, A.; Sandén, T.; Haslmayr, H.-P.; Miloczki, J.; Wenzel, W.; Spiegel, H. Optimizing Carbon Sequestration in Croplands: A Synthesis. *Agronomy* 2021, 11, 882. <https://doi.org/10.3390/agronomy11050882>
- Tittonell, P., (2014). Ecological intensification of agriculture-sustainable by nature. In: *Current Opinion in Environmental Sustainability*, vol. 8. Elsevier, pp. 53–61. <https://doi.org/10.1016/j.cosust.2014.08.006>.
- Tittonell, P., El Mujtar, V., Felix, G., Kebede, Y., Laborda, L., Lujan, Soto R., De Vente, J. (2022). Regenerative agriculture—agroecology without politics? *Front. Sustain. Food Systems* 6, 844261 <https://doi.org/10.3389/fsufs.2022.844261>.
- Toth, G, Hermann, T., Szatmari, G. & Pasztor, L. (2016). Maps of heavy metals in the soils of the European Union and proposed priority areas for detailed assessment. *Science of the Total Environment* 565 (2016) 1054–1062. <http://dx.doi.org/10.1016/j.scitotenv.2016.05.115>.
- Tuck, S., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L. and Bengtsson, J. (2013). Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. *Journal of Applied Ecology*. 51(3), p. 746–755. <https://doi.org/10.1111/1365-2664.12219>.
- UNCCD (2012). Zero Net Land Degradation A Sustainable Development Goal for Rio+20. UNCCD Secretariat policy brief. <http://www.unccd.int>
- United Nations (1977). Desertification: its causes and consequences. Pergamon Press, Oxford, UK.
- United Nations Environment Programme (2022). Spreading like Wildfire – The Rising Threat of Extraordinary Landscape Fires. A UNEP Rapid Response Assessment. Nairobi
- Uruena, S., Rodriguez, H., & Ibarra, A. (2021). Foresight and responsible innovation: Openness and closure in anticipatory heuristics. *Futures*, 124. <https://doi.org/10.1016/j.futures.2020.102632>
- USDA (2022). EU Wood Pellet Annual. <https://apps.fas.usda.gov/>
- Use of Bioenergy by sector and scenario, page 95, EC, Impact assessment, Stepping up Europe’s 2030 climate ambition, SWD (2020) 176 Final, 17.9.2020
- Valin, H., Peters, D., van den Berg, M., Frank, S., Havlik, P., Forsell, N., & Hamelinck, C. (2015). The land use change impact of biofuels consumed in the EU: Quantification of area and greenhouse gas impacts (No. BIENL13120). ECOFYS Netherlands B.V
- Van der Esch, S., ten Brink, B., Stehfest, E., Bakkenes, M., Sewell, A., Bouwman, A., Meijer, J., Westhoek, H., & van den Berg, M. (2017). Exploring future changes in land use and land condition and the impacts on food, water, climate change, and biodiversity: Scenarios for the Global Land Outlook. *PBL Netherlands Environmental Assessment Agency, The Hague*.
- Van Dijk, G., Zdanowicz, A., Blokzijl, R., (2004). Land abandonment, biodiversity and the CAP, Land abandonment and biodiversity, in relation to the 1st and 2nd pillars of the eu’s Common Agricultural Policy; outcome of an international seminar in Sigulda, Latvia, 7-8 October, 2004. Utrecht, Netherlands.

- Van Liedekerke, M., Prokop, G., Rabl-Berger, S., Kibblewhite, M., & Louwagie, G. (2014). Progress in the management of contaminated sites in Europe. *Publications Office of the European Union, Luxembourg*.
<https://doi.org/10.2788/11130>
- Van Oorschoven, J., Terres, J.-M., Toth, T. (Ed.) Jones, R., Le-Bas, C., Nachtergaele, F., Rossiter, D., Van Orshoven, J., Schulte, R., van Velthuisen, H. (2014) Updated common bio-physical criteria to define natural constraints for agriculture in Europe. Definition and scientific justification for the common biophysical criteria. JRC report EUR 26638 EN
- Van der Sluis, T., Pedroli, B., Kristensen, S.B., Cosor, G.L. and Pavlis, E. (2016). Changing land use intensity in Europe—Recent processes in selected case studies. *Land Use Policy*, 57, pp.777-785.
<https://doi.org/10.1016/j.landusepol.2014.12.005>
- Van Vliet, J., de Groot, H. L., Rietveld, P., & Verburg, P. H. (2015). Manifestations and underlying drivers of agricultural land use change in Europe. *Landscape and Urban Planning*, 133, 24-36.
- Van Vuuren, D. P., Kok, M. T. J., Girod, B., Lucas, P. L., & de Vries, B. (2012). Scenarios in global environmental assessments: Key characteristics and lessons for future use. *Global Environmental Change*, 22, 884–895.
<https://doi.org/10.1016/j.gloenvcha.2012.06.001>
- Van Zanten, E., Verburg, P., Schulp, C., Verkerk, P (2017). Trade-offs of European agricultural abandonment. *Land Use Policy* Volume 62, March 2017, Pages 290-301. <https://doi.org/10.1016/j.landusepol.2017.01.003>
- Veldkamp, A., & Fresco, L. (1996). CLUE-CR: An integrated multi-scale model to simulate land use change scenarios in Costa Rica. *Ecological Modelling*, 91(1–3), 231–248.
- Veldkamp, A., & Fresco, L. O. (1996). CLUE: A conceptual model to study the conversion of land use and its effects. *Ecological Modelling*, 85(2–3), 253–270.
- de Vente, J., Boix-Fayos, C., Pérez-Cutillas, P., Jodar-Abellan, A., and Eekhout, J.: Assessing the hillslope-channel contributions to the catchment sediment balance under climate change, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-15046
<https://doi.org/10.5194/egusphere-egu23-15046, 2023>
- Verburg, P. H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., & Mastura, S. S. (2002). Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management*, 30(3), 391–405.
<https://doi.org/10.1007/s00267-002-2630-4>
- Verburg, P. H., Schulp, C. J. E., Witte, N., & Veldkamp, A. (2006). Downscaling of land use change scenarios to assess the dynamics of European landscapes. *Agriculture, Ecosystems & Environment*, 114(1), 39–56.
- Verburg, P. H., & Overmars, K. P. (2009). Combining top-down and bottom-up dynamics in land use modeling: Exploring the future of abandoned

- farmlands in Europe with the Dyna-CLUE model. *Landscape Ecology*, 24(9), 1167–1181. <https://doi.org/10.1007/s10980-009-9355-7>
- Verburg, P. H., van Berkel, D. B., van Doorn, A. M., van Eupen, M., & van den Heiligenberg, H. A. (2010). Trajectories of land use change in Europe: a model-based exploration of rural futures. *Landscape ecology*, 25(2), 217–232. <https://doi.org/10.1007/s10980-009-9347-7>
- Verburg, P. H., Neumann, K., & Nol, L. (2011). Challenges in using land use and land cover data for global change studies. *Global change biology*, 17(2), 974–989.
- Veron, S.R., Paruelo, J.M., Oesterheld, M. (2006). Assessing desertification. *Journal of Arid Environments* 66(4), 751–763.
- Verstraete M.M., Brink A.B., Scholes R.J., Beniston M., Stafford Smith M. (2008). Climate change and desertification: Where do we stand, where should we go? *Global and Planetary Change* 64(3-4), 105–110.
- Vervoort, J., & Gupta, A. (2018). Anticipating climate futures in a 1.5 degrees Celsius era: The link between foresight and governance. *Current Opinion in Environmental Sustainability*, 31, 104–111. <https://doi.org/10.1016/j.cosust.2018.01.004>
- Verweij, P., Cormont, A., van Eupen, M., Kok, K., te Roller, J., Pérez-Soba, M., Janssen, S., Staritsky, I. (2018). Improving the applicability and transparency of land use change modelling: The iCLUE model. *Environmental Modelling & Software*, 108, 91–90. <https://doi.org/10.1016/j.envsoft.2018.07.010>
- Verweij, P., Janssen, S., Braat, L., van Eupen, M., Pérez Soba, M., Winograd, M., de Winter, W., & Cormont, A. (2016). QUICKScan as a quick and participatory methodology for problem identification and scoping in policy processes. *Environmental Science & Policy*, 66, 47–61. <https://doi.org/10.1016/j.envsci.2016.07.010>
- Verweij, P., van Haren, C., van Eupen, M., Jancovic, M., & Chayani, S. (2022). Co-developing an integrated modelling framework for the circular bioeconomy: Assessing technological, societal, and policy implications. *Wageningen Environmental Research, Report 3146*.
- Verweij, P., Student, J., Cormont, A., van Oosten, C., Lazebnik, J., & Bakker, M. (submitted). Co-designing a framework for effective stakeholder involvement in landscape processes.
- Vogt, J.V., Safriel, U., Bastin, G., Zougmore, R., von Maltitz, G., Sokona, Y., Hill, J. (2011). Monitoring and Assessment of Land Degradation and Desertification: Towards new conceptual and integrated approaches. *Land Degradation and Development* 22(2), 150–165.
- Vries, de W., Schulte-Uebbing, L., Kros, H., Voogd, J.C., Louwagie, G., (2021). Spatially explicit boundaries for agricultural nitrogen inputs in the European Union to meet air and water quality targets, *Science of The Total Environment*, Volume 786, 2021, 147283, ISSN 0048-9697, <https://doi.org/10.1016/j.scitotenv.2021.147283>. (<https://www.sciencedirect.com/science/article/pii/S0048969721023548>)
- Vu, Q.M., Le, Q.B., Frossard, E., Vlek, P.L. (2014). Socio-economic and biophysical determinants of land degradation in Vietnam: An integrated causal analysis at the national level. *Land Use Policy* 36, 605–617.

- Wang, X., Chen, F., Dong, Z. (2006). The relative role of climatic and human factors in desertification in semiarid China. *Global Environmental Change* 16, 48-57.
- The Water Forum, nd. Factsheet 1 – Water Framework Directive (WFD). Introduction to the Water Framework Directive. Water-Forum-Factsheet-1_Introduction-to-the-WFD.pdf (thewaterforum.ie).
- Wevolve (2013). Future lifestyles in Europe and the United States in 2020. A trend report for the Horizon 2020 programme. European Commission, 53 pp.
- Wilson, G., Quaranta, G., Kelly, C., & Salvia, R. (2016). Community resilience, land degradation and endogenous lock-in effects: evidence from the Alento region, Campania, Italy. *Journal of Environmental Planning and Management* 59(3), 518-537.
- Wilson, G.A., Juntti, M. (2005). Unravelling desertification: policies and actor networks in Southern Europe, Wageningen Academic Publishers, Wageningen.
- Winkler, K., Fuchs, R., Rounsevell, M., & Herold, M. (2021). Global land use changes are four times greater than previously estimated. *Nature Communications*, 12(1), 2501.
- Xie, H., Zhang, Y., Wu, Z., Lv, T. (2020). A Bibliometric Analysis on Land Degradation: Current Status, Development, and Future Directions. *Land* 9(1), 28.
- Yang, X., Liu, Y., Wang, M., Bezama, A., & Thrän, D. (2021). Identifying the Necessities of Regional-Based Analysis to Study Germany's Biogas Production Development under Energy Transition. *Land*, 10(2), 135. <https://doi.org/10.3390/land10020135>
- Zajac, Z., Gomez, O., Gelati, E., van der Velde, M., Bassu, S., Ceglar, A., Chukaliev, O., Panarello, L., Koebler, R., van den Berg, M. and Niemeyer, S. (2022). Estimation of spatial distribution of irrigated crop areas in Europe for large-scale modelling applications. *Agricultural Water Management*, 266, p.107527.
- Zakkak, S., Radovic, A., Nikolov, S., Shumka, S., Kakalis, L., Kati, V. (2015). Assessing the effect of agricultural land abandonment on bird communities in southern-eastern Europe. *Journal of Environmental Management* 164 (2015) 171e179. <http://dx.doi.org/10.1016/j.jenvman.2015.09.005>
- Zambon, I., Benedetti, A., Ferrara, C., & Salvati, L. (2018). Soil matters? A multivariate analysis of socioeconomic constraints to urban expansion in Mediterranean Europe. *Ecological Economics*, 146, 173-183.
- Zhao, M., Cai, W., Liu, T., Fu, K., MacBean, N., Zeng, Z., Zhang, Y., Shen, S. S. P., & Piao, S. (2022). Integrating satellite observations and process-based models for mapping global primary production in a data-rich era. *National Science Review*, 9(9), nwac078. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9308969/>

Study on competition for land use and sustainable farming

Final report - Annexes

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List of abbreviations

Abbreviation	Explanation
AA	Agricultural area
AE	Agro-ecology
AECM	Agri-Environment and Climate measures
AEI	Agri-environmental indicators
AECM	Agri-environment-climate Measures
AEM	Agri-environmental measures
AEI	Agri Environmental Indicators
AES	Agri-environmental scheme
AFOLU	Agriculture, Forestry and Other Land Use
Agri-PV	Agri-photovoltaics
AKIS	Agricultural Knowledge and Innovation System
ANC	Areas facing Natural Constraints
BAU	Business as usual
BISS	Basic Income Support for Sustainability
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CC	Carrying Capacity
CDDA	Nationally designated areas
CEE	Central and Eastern European
CEEC	Central and Eastern European countries
CF	Cohesion Fund
CHP	Combined heat and power
CLC	CORINE Land Cover
CO ₂	Carbon Dioxide
CS	Case Study
CSA	Climate Smart Agriculture
DA	Determined area
DG-AGRI	Directorate-General for Agriculture and Rural Development
DG-ENER	Directorate-General for Energy
EAFRD	European Agricultural Fund for Rural Development
EAGGF	European Agricultural Guidance and Guarantee Fund (EAGGF)
EASA	European Aviation Safety Agency
ECA	European Court of Auditors
EC	European Commission
EEA	European Environment Agency
EFA	Ecological Focus Areas
EIA	Environmental Impact Assessment
EIB	European Development Bank
EIP	European Innovation Partnerships
ECMWF	European Centre for Medium-Range Weather Forecasts
ENRD	European Network for Rural Development

ENZ	Environmental zone
ERDF	European Regional Development Fund
ESF	European Social Fund
ESR	Effort Sharing Regulation
ESTAT	Eurostat
ETC-SIA	European Topic Centre for Spatial information and Analysis
EU	European Union
EU28	Memberships of the European Union in the period 1 July 2013 – 31 January 2020
EU27	Memberships of the European Union in the period 1 July 2013 – 31 January 2023 (excl UK)
EU15	Memberships of the European Union from 1 January 1995 and as of December 31, 2003
EU-LUPA	European Land Use Patterns
EUR	Euro
F2F	Farm to Fork
FA	Farm area
FAA	USA Federal Aviation Administration
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization
FAOSTAT	Statistics of the Food and Agriculture Organization
FOD	Foreign Object Debris
FSS	Farm Structural Survey
GAEC	Good Agricultural and Environmental Practices
GAP	Good Agricultural Practices
GD	Green Deal
GDR	German Democratic Republic (GDR), or Communist East Germany
GDP	Gross domestic product
GHG	Greenhouse gas
GHSL	Global Human Settlement Layer
GIS	Geographic Information Systems
GLAD	Global Land Analysis & Discovery
GNSS	Global navigation satellite system
H2020	Horizon 2020
HNV	High Nature Value
IACS	Integrated Administration and Control System
ICT	Information and communications technology
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
JLS	Local self-government units (Croatian abbreviation)
KET	Key Enabling Technology
KPI	Key performance indicator
LAG	Local action groups
LAI	Leaf area index

LAU	Local Administrative Units
LCF	Land cover flows
LCOE	Levelized cost of energy
LEAC	Land and Ecosystem Accounting system
LPIS	Land Parcel Identification System
LSU	Livestock unit
LUCAS	Land Use and Coverage Area frame Survey
LULUCF	Land use, land-use change and forestry
MAGIC	Marginal Lands for Growing Industrial Crops
MEDALUS	Mediterranean desertification and land use
MS	Member State(s) of the European Union
N2000 or N2K	Natura 2000
NCFF	Natural Capital Financing Facility
NDVI	Normalized difference vegetation index
NECP	National Energy and Climate Plan
NGO	Non-governmental organization
NMR	National ... registration
NRL	Nature Restoration Law
NUAA	Unutilised agricultural area as defined by Eurostat
NUTS	Nomenclature of territorial units for statistics ranging from NUTS0 (EU country level) to 3 (most detailed regional level)
OECD	Organisation for Economic Co-operation and Development
OVAM	Public Waste Agency of Flanders
PCA	Principal component analysis
PEA	Potentially eligible area
PG	Permanent grassland
PPP	Plant Protection Products
PV	Photovoltaic
RALUC	Rural Agricultural land use changes (acronym for this study and also acronym used for referring to the typology of regions developed in this study)
RDP	Rural Development Policy (or Programme)
RED II	Revised Renewable Energy Directive 2018/2001/EU
RES	Renewable energy systems
R&D	Research and Development
R&I	Research and Innovation
SA	Sustainable agriculture
SAA	Special holding areas
SDG	Sustainable Development Goal
SAPS	Single Area Payment Scheme
SGM	Standard gross margin
SI	Sustainable Intensification
SME	Small and medium-sized enterprises
SMR	Statutory management requirement
SMRL	Soil Monitoring and Resilience Law

SOC	Soil Organic Carbon
SP	Strategic Plan
SRC	Woody perennial crops in short rotation systems
TCD	Tree cover density
UAA	Utilised agricultural area
UK	United Kingdom
UNCCD	United Nations Convention to Combat Drought and Desertification
UNECE	United Nations Economic Commission for Europe
USA	United States of America
USD	United States Dollar
USSR	Union of Soviet Socialist Republics
VCS	Voluntary Coupled Support
WA	Wooded area
WFD	Water Framework Directive
WTO	World Trade Organisation

Country codes

Abbreviation	Country
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia

Notation

Numbers:

The point symbol (.) precedes decimal places

The comma symbol (,) is used to separate thousands

Units:

Mton : megaton (1 Mton = 1,000,000 tons)

Mha : million hectares (1 Mha = 1,000,000 ha)

10. Annex 1 Definition of terms and concepts in the study

Land cover indicates the physical land type such as forest, agriculture or open water, whereas land use documents how people are using the land (the purpose). Land cover can be determined by analysing satellite and aerial imagery, amongst others. Land use cannot be determined easily (or exclusively) from satellite imagery and generally needs to be determined through additional information gathering ('ground truth'), through statistics, for example.

For the definition of the **bioeconomy** we follow the EC in the Bioeconomy Strategy (2012 and 2018): 'bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles.' According to this definition, the bioeconomy includes and interlinks:

- land and marine ecosystems and the services they provide;
- all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture);
- all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services.

We define **biobased economy (BBE)** as a sub-set of the bioeconomy, using the definition from the Netherlands Enterprise Agency⁴⁰:

'... an economy that uses crops and residual flows from agriculture, forest and waste sectors for non-food applications for the production of materials, chemicals, transport fuels and energy (electricity and heat). In the Biobased Economy, biological raw materials replace fossil raw materials. The drivers are sustainability, economic opportunities for new products, energy and raw material security and improving the economy in agriculture.'

In this study, **drivers of land use** are reviewed. For the definition of drivers we follow the definition that was derived from the DPSIR framework, which was further developed by the EEA in 1999 on indicators for monitoring the state of the environment. The DPSIR framework conceptualises a causal sequence of drivers, pressures, state, impact and response. In that scheme, a driver is a prime mover, a force which is not caused by something else (Kuhlman, 2008).

Key performance indicators (KPIs) are quantifiable indicators of progress towards intended results. In this study, KPIs are used to describe impacts of sectoral developments on land use and aspects of sustainability. KPIs are core elements of the integrated sustainability framework.

With the term **integrated sustainability framework** we designate the framework that we use in the study to organize indicators for describing impacts of sectoral developments on land use and to assess the sustainability of agriculture and other land uses within the Sustainability Choice Space. We will

⁴⁰ <https://www.rvo.nl/onderwerpen/biobased-economy>

inventory the following available frameworks of **sustainability indicators** from the literature:

- agri-environmental indicators, administered by the European Commission
- Streamlining European Biodiversity (SEBI) indicators
- Sustainable Development Goal (SDG) indicators, administered by the United Nations
- indicators for mapping and assessment of ecosystems and their services (MAES) (Maes et al., 2016)
- indicators from the Analytical framework for ex ante impact assessment of policies affecting land use (SENSOR) (Helming et al., 2008)
- the set of indicators of the environmental sustainability of agriculture developed by the World Resources Institute (WRI, 2014).

The **Sustainability Choice Space framework** describes the degree to which alternative policy outcomes are acceptable to stakeholders across a range of criteria. It allows to explore and visualise what 'room for manoeuvre' policy makers might have in the design of a specific policy. This concept is described by Potschin and Haines-Young (2008). We will use it in the study to assess the sustainability of land use combinations in regions in the EU and in the case study regions in the light of policy targets from the Farm to Fork strategy, and other EU policy targets for climate, biodiversity and energy.

Abandoned agricultural land is land that was previously used to produce economic output (agricultural production, houses for residential purposes, industrial production, etc.) and that is no longer used for that purpose. Thus, abandoned land can be reclaimed back to the original use or converted to other uses, in case demand for such uses exists.

Afforestation can be defined in this study according to the definition by FAO: "*Establishment of forest through planting and/or deliberate seeding on land that, until then, was under a different land use, implies a transformation of land use from non-forest to forest*". Given the scope of this study, the analysis will focus only on the transformation of agricultural lands to forests.

Agricultural expansion is the change from non-agricultural to agricultural land uses, with a consequent increase in the utilized agricultural area (UAA).

Agricultural land is land that is used for the allocation of arable crops, permanent crops, pastures and energy crops. In this report, it is equivalent to the Agricultural Area (AA) following the classification in Eurostat.

Energy crops are crops dedicated to production of energy. This category comprises non-food, lignocellulosic crops, belonging to the second generation feedstock. Species included are both herbaceous and woody, for instance miscanthus, switchgrass, reed canary, giant reed, cardoon, willow, poplar and eucalyptus.

Food and feed crops are used for the production of food and feed which can be grouped differently according to different classifications of these (e.g. used in FSS, FADN or CAPRI model). Note that in the REDII a definition of food and feed crops is used that is more constrained: '*crops used for the production of oil, starch or sugar crops grown as a main crop*'.

Industry/commerce/services land is land that is used for industrial activities, commerce and services is referred to as *industry, commerce and services*.

Land cover flows refer to changes in land area between different types of land cover, grouped and classified according to major land use processes (EEA Datahub⁴¹). The most recent temporal coverage is the period 2000-2018.

Land-use allocation is the spatial distribution of land over different functions, assuming that land requirements (or demands) are dictated by macro-drivers. Land use allocation is modelled by specialised sector models. The spatial allocation mechanism is based, for instance, on a binomial discrete choice method and governed by local biophysical suitability, socio-economic and neighbourhood factors, land-use transition rules and policy constraints or incentives.

Land demand, also referred to as **land claim** or **land requirement**, it is the amount of land that is demanded, claimed or required in order to satisfy assumed economic and demographic projections in a land use model simulation.

Land-take by build-up area is defined in this study as the conversion of agricultural land into urban areas. Land take in agricultural areas is a special case of land take. It is the conversion from Agricultural areas (CLC classes 2**) into Artificial surfaces (CLC classes 1**). Agricultural land is defined as land classified in CORINE Land Cover (CLC) as CLC level 1 class Agricultural areas (CLC classes 2**). It includes CORINE Land Cover classes Arable land (CLC classes 211, 212 and 213), Permanent crops (CLC classes 221, 222 and 223), Pastures (CLC class 231) and Heterogeneous agricultural areas (CLC classes 241, 242, 243 and 244). The build-up areas can be regarded artificial areas which are defined as an aggregation of land used for residences, industry, services and commercial activities (build-up area), transport infrastructure (roads, railways, airports), harbours, dumpsites and open-pit mining as well. **“Coastalization”** is a particular process of land take, which occurs especially in the coastal areas (especially but not only of the Mediterranean). This process consists of tourism development in the form of second homes, hotels, support infrastructures.

The **primary sector** is defined in this study using the European statistical classification of economic activities in the branch A – Agriculture, Forestry and Fishing⁴².

Urban land is land that is predominantly used for residential purposes, including areas hosting local services to the population, such as sport and leisure facilities, and green urban areas.

Agriculture intensification may entail an internal conversion between agricultural land uses or denote an increase in the level of inputs used by the farm per unit of production factors. Fertilizers, pesticides, other crop protection

⁴¹ <https://www.eea.europa.eu/en/datahub/datahubitem-view/bb4a1a65-fba0-4b54-bb6e-848c69728332>

⁴² <https://nacev2.com/en>

products and purchased feed are considered as agro-environmental inputs in the definition from Eurostat.

Agricultural extensification is the opposite of intensification. It is the process of decreasing the use of inputs relative to land area.

11. Annex 2 Detailed research questions, objectives, approach and methodology of the study

11.1. Research questions and sub-objectives of the study

The Commission has formulated four main objectives and research questions on land use and sustainable farming which guided the study approach and structure and required different methodological approaches.

The research questions answered through this study are:

Q1: What were the dominant factors in the evolution of land use in the last thirty years in the EU, in general and for agriculture in particular?

Q1.1 To what extent have energy use or production, urban sprawl and other forms of soil sealing and conservation of natural areas competed with or synergised with agricultural production in land use? Which have been the main drivers?

Q1.2 To what extent and where have population development, and changes in lifestyle and consumption patterns influenced agricultural production and land use? Which have been the main drivers?

Q1.3 Within agricultural land, how have food, feed, bioenergy and bioeconomy competed? Which have been the main drivers?

Q2: How have agricultural landscapes in Europe evolved, particularly with regard to crop diversity, including permanent crops and permanent grassland, concentration of livestock, plot size, high-diversity landscape features on agricultural land and high nature value agriculture? On the basis of these developments, what scenarios for the evolution of agricultural landscapes are possible?

Q3: What will be the dominant drivers of land use change, in particular agricultural land use, in the coming decades (up to 2050)? What are the different scenarios for each of the factors identified?

Q3.1 To what extent will energy use or production, urban sprawl and other forms of land sealing and conservation of natural areas compete or synergise with agricultural production in land use?

Q3.2 To what extent and where will population development, and changes in lifestyle and consumption patterns influence agricultural production and land use?

Q3.3 Within agricultural land, how will food, feed, bio-energy and bio-economy compete?

Q4: How sustainable is the current land use in Europe's rural areas for agricultural production, energy production, nature conservation and climate change? How can land use be optimised to enable the development of sustainable agriculture in the light of the Farm to Fork strategy? Which policy instruments can be mobilised to optimise land use?

Also 7 sub-objectives were formulated the term of reference for this study. These are presented in relation to the research questions in former section.

Table 1 Overview of project objectives and relation to research questions (Q). Research questions are presented in Section 1.4

Objectives	Q1	Q2	Q3	Q4
A. Identify, quantify and illustrate past and ongoing changes in land use in EU's rural areas, in particular for agricultural land, forest and natural areas;	•	•		
B. Analyse the drivers and effects of the identified trends;	•	•		•
C. Outline different scenarios for future land use change, considering impacts of climate change, changing consumption patterns, land use needs for production of food, feed, fibre, fuel or energy, land for nature conservation and biodiversity, urban sprawl and other types of soil sealing and land take in rural areas, as well as leisure with a 2050 time horizon;		•	•	•
D. Establish a balance sheet describing the different uses of biomass (food, feed, energy, bioeconomy) and their evolution over time;	•	•	•	
E. Assess the spatial connections between different land uses at the level of regional landscapes, that specifically contribute to biodiversity (landscape features, buffer strips, etc.);		•		•
F. Identify the land use requirements (quantitatively and qualitatively) to enable development of sustainable agriculture in the EU, in line with the <i>Farm to Fork Strategy</i> ;			•	•
G. Recommend possible policy instruments that can be used to enable sustainable land use (including on zoning and planning) and sustainable agriculture.			•	•

For Objectives A and B an analysis is performed of the land use changes, their main drivers and their sustainability impacts in the last 30 years, so covering a period from 1990 until 2022. The analysis is done for the whole territory of the EU-27 and also in more detail at the level of 12 regional case studies. These two objectives are reached by providing answers to research questions Q1 and Q1.1, Q1.2 and Q1.3. This part of the analysis is presented in chapters 3 to 6 and also in background documents presented in separate annexes 3 and 4.

For Objective C different scenarios for future land use change with a time horizon to 2050 were elaborated and these are presented in chapter 9 of this report. The scenarios are elaborated in a way to facilitate the answers to research questions Q2, Q3 and Q4.

Objective D requires an analysis of the evolution of different uses of biomass over food, feed, energy and other non-food bioeconomy uses such as for biomaterials, biochemicals and biopharmaceuticals. This analysis, in combination with the detailed analysis of land use changes and their drivers, provides empirical results to answer sub-questions Q1.2 and Q1.3.

Objective E requires an assessment of the spatial connections between different land uses at the level of regional landscapes that specifically contribute to biodiversity. It delivers results that help to answer specifically research question Q2, where it relates to agricultural land use types and changes in these, which influence biodiversity in agricultural and semi-natural areas. In addition, the results for this objective help to answer Q4: specifying how sustainable current land uses are in relation to biodiversity conservation and how to optimise land uses in the future to enable the development of sustainable agriculture, in the perspective of the *Farm to Fork Strategy*. The biodiversity impacts of land use changes are discussed in several places in the report particularly focussing on main land use changes and their relationships with biodiversity. In the scenario assessment and modelling of land use changes translated further into KPIs for biodiversity and connectivity effects in landscape. The scenarios are also developed in such a way that they address the nature restoration law goals for 2050. .

Objective F requires identifying what is needed in terms of land use to enable the development of sustainable agriculture in the EU, in line with the *Farm to Fork Strategy*. Reaching this objective delivers results that facilitate the answer to Q4: how land use can be optimised to enable the development of sustainable agriculture in the light of the *Farm to Fork strategy*. The outcomes are used to outline the scenarios for future land use which are required for objective C.

Objective G requires the identification of possible existing and new policy instruments that can be used to enable sustainable land use and sustainable agriculture in the future. This objective provides the answer to Q4 in finding policy instruments that enable the transition to a more optimised land use for the development of sustainable agriculture conform the *Farm to Fork Strategy*. This implies a sustainable agriculture that is competitive and provides food at affordable food prices to EU consumers. This form of sustainable agriculture should also have low climate impacts and be in balance with biodiversity conservation.

11.2. Overall approach, methods and tools

This chapter describes the methods used to answer the research questions of the study. These include:

- Literature review of land use trends, drivers and impacts (section 2.2)
- Approach to generating the typology of regions (section 2.3)
- Collection of spatial and statistical data for the analysis of drivers and trends in land use (section 2.4)

- Methods for data processing and analysis of land use trends, drivers and impacts (section 2.5)
- Methods for filling gaps in data on bioenergy driven land use demands (section 2.6)
- Assessment of balance sheets for agricultural biomass uses between 1990-2020 (section 2.7)
- Design and implementation of the case studies (section 2.8)
- Scenario construction and modelling of future land use change and development of the sustainability impact framework (section 2.9)
- Review of policy instruments for optimised land use (section 2.10)

The approach followed to develop the territorial typology of regions in the EU27 is presented in chapter 3.

11.3. Approach to literature review of (past) land use trends, drivers and impacts

A literature review is performed to give an overview of the main autonomous and political institutional drivers for land use changes and their impacts, that competed and synergized with agricultural land use. The period between 1990 and 2022 is considered.

A selection of the research questions for the study are used to design the identification, collection and review of literature (Table 2). The literature review also supports the development of the territorial typology.

Table 2 Research questions used in the literature search

Question nr	(sub-)research question
--	Develop a territorial typology to classify the EU into classes which represent the biophysical, rural and land use change diversity of Europe
Q1.1	To what extent have energy use or production, urban sprawl and other forms of soil sealing and conservation of natural areas competed with or synergized with agricultural production in land use? Which have been the main drivers?
Q1.2	To what extent and where have population development, and changes in lifestyle and consumption patterns influenced agricultural production and land use? Which have been the main drivers?
Q1.3	Within agricultural land, how have food, feed, bioenergy and bioeconomy competed? Which have been the main drivers?
Q2	How have agricultural landscapes in Europe evolved, particularly with regard to crop diversity, including permanent crops and permanent grassland, concentration of livestock, plot size, high-diversity landscape features on agricultural land and high nature value agriculture?

The literature review covers key publications on land use trends and their main drivers, on energy demand and land use, urban sprawl, soil sealing, afforestation and nature conservation in agricultural land, particularly in relation to Natura 2000 and semi-natural ecosystems in HNV farmland.

The publications are identified in the citation database Scopus. The publications that we identified focus on land use competition in rural areas in general, and specifically in agricultural land where both competition and synergy with agricultural land use occur. In the literature search, much attention is put on the relation between land use for agriculture and forest. Afforestation is a big issue in certain regions of the EU. Another aspect covered in the literature search is the abandonment of agricultural land, which is noticeable in various regions of the EU.

For research question Q2, the review involves studies with a focus on the EU and on national and regional situations. The review considers publications on the evolution of different farm types, with arable crops, livestock, horticulture, permanent crops and different levels of specialization and combinations of these types (mixed farms). The review also takes into account farm practices with attention to intensity and sustainability. Studies and publications are used, that interpret trends and explain drivers, competition and synergies.

The results of the literature review are presented in chapters 3 and 5 but the background document with the detailed literature review is presented in Annex 4.

11.4. Approach to data collection for the analysis of drivers and trends in land use

For each of the major land use change processes affecting agricultural production identified in the literature (see Annex 5) and case studies and summarized in chapter 4, a series of steps were followed:

1) The relationships found in literature and case studies between land use processes and underlying drivers and expected impacts were used as a starting point to review data sources for relevant indicators.

2) Subsequently indicators for the land use processes, drivers and impacts were identified from the data sources. For each indicator the following review was then made:

- Can the indicator be quantified or is there a proxy indicator(s) to quantify it
- The data source name (e.g. LEAC, Copernicus, Eurostat)
- The spatial resolution: grid cell resolution or NUTS level
- The spatial coverage: EU-28, FUA - EEA38, etc.
- The temporal coverage: the time series (years) included
- The level of measurement: quantitative or qualitative
- The source location (URL, etc.)
- An evaluation of the (proxy) indicator in combination with the data availability according to four considerations and scored in traffic light system:

		Good	Sufficient	Bad
1	Good and available proxy	Available and good proxy expressing indicator well	Available but weak indicator for issue	Not available
2	Temporal resolution	Covers 30 year period (1990-2020)	Covers 10 to 20 years of the 30 year period	Covers less than 10 years
3	Spatial resolution	Available at Nuts 3	Available at Nuts 2	Available at National level
4	EU27 coverage	Covers all	Covers partly but still usable	Incomplete coverage, unsuitable

The resulting overview of indicators and the data sources used are presented in Annex 6.

11.5. Methods for data processing and analysis of past land use trends, drivers and impacts

The methods used for data processing and analysis were:

- Methods and tools for the integration of data at different spatial resolutions: geo-information technologies and GIS facilities and techniques for spatial up- and downscaling;
- Statistical approaches, basically descriptive, inferential (e.g. correlation) and principle component analysis to address complexity in datasets;
- Balance sheets on the supply and use of biomass for food and non-food purposes;
- Methods to fill gaps in data on bioenergy and non-food uses;
- Methods to estimate land used and biomass produced for non-food purposes.

Analysis of drivers and trends in land use

- 1. Further investigate the relationship between detected trends and drivers and allocate integrated results to the strata of the territorial typology.** This step entails combining the outcomes of the literature review with the data analysis. The shifts in land uses for food, feed, bioenergy production and other non-food purposes, detected from the balance sheets, are connected to the outcomes of the literature review on drivers of land use changes in agricultural land. Specific drivers are matched to the locations where the land use shifts have become apparent. This requires up- and downscaling to generate main conclusions per stratum in response to research question Q1.3 (Table 1).
- 2. Integration and deeper analysis and allocation to strata of the typology.** This step implies allocation of integrated results to the strata of the typology. The analysis was done at the highest possible spatial and temporal resolution to ensure that the local context is considered as much as possible.

The following statistical methods were used to identify relations between trends and drivers:

- Descriptive statistics, simple correlation statistics;
- Geo-spatial analysis with GIS tools and analysis of spatial regimes, including the investigation of spatial autocorrelation regimes (Moran, Geary, Cliff-Ord indexes);
- Factor analysis and clustering, through principal component analysis, in order to delineate latent patterns among relevant variables over both time and space.

3. As a final step, the quantitative and qualitative **results were upscaled and downscaled to the strata of the central typology** to generate main conclusions per stratum in response to the research question Q1.1. The statistical methods mentioned above were used in this step.

11.6. Filling gaps in data on bioenergy based land use changes

As part of the Member State progress reports to the European Commission in the context of the Union Bioenergy Report, Member States need to report on estimated land use to produce crops for bioenergy purposes from 2021 onwards, if applicable. There is currently no statistical or spatial data source available that comprehensively examines agricultural land use by either renewable energy or the wider demand for biomass in the bioeconomy in Europe from 1990 to 2022. Nevertheless, it is feasible to estimate the land area necessary for bioenergy through the attributional land use change (aLUC) approach. This approach involves utilizing the existing spatial data, including the harvested area per crop and the total agricultural land, and supplementing it with statistical data such as bioenergy consumption per feedstock and the energy density of the feedstock used. Through this method, it is possible to determine the amount of land required to meet the demand for bioenergy so far from the past. The following sections will outline the data sources used to determine aLUC per type of bioenergy.

Bioliquids

It is mandatory for Member States to report on their domestic liquid biofuel production and consumption. Some also report on the type of feedstocks used in the production of liquid biofuels. This reporting requirement simplifies the process of calculating aLUC for crops used in the production of liquid biofuels, such as rapeseed and soy for biodiesel, and wheat, corn, barley, rye, and sugar beet for bioethanol.

This method has been used in published EC reports on the renewable energy progress of the EU Member States to provide an estimation of land needed to meet the EU biofuels demand. The 2023 study⁴³ replicated the methodology used in 2014 and 2018. The 2014 study reported that 62% of the biodiesel consumed in the EU in 2012 stemmed from feedstock produced in Europe, mainly from rapeseed, and 79% of the bioethanol consumed in the EU in 2012

⁴³ <https://op.europa.eu/en/publication-detail/-/publication/96d671c9-c719-11ee-95d9-01aa75ed71a1/language-en/format-PDF/source-305260384>

came from European production, mainly wheat, maize and sugar beet. The 2012 EU biofuels consumption required 7.8 Mha of agricultural land worldwide, of which 4.4 Mha in the EU. Note however, that the larger part of this is realised within the existing agriculture, via increased crop yields, supply chain efficiency improvements, and decreased consumption of other crops. When compared to the situation in 2000-2012 when biofuel consumption was negligible in the EU, in 2012 an additional 1.7 Mha was required for the EU biofuels consumption. This study was repeated for 2016, where 4.9 Mha was estimated to be required for the EU biofuel market of which 3.6 Mha in the EU, and for 2018 where 7.4 Mha was used for biofuel feedstock, of which 3.4 Mha in the EU. These studies, however, did not distinguish between Member States when looking at EU land requirements. This study will aim to fill that gap in a simplified approach. A schematic representation of the aLUC calculation for liquid biofuels is presented in the Figure below.

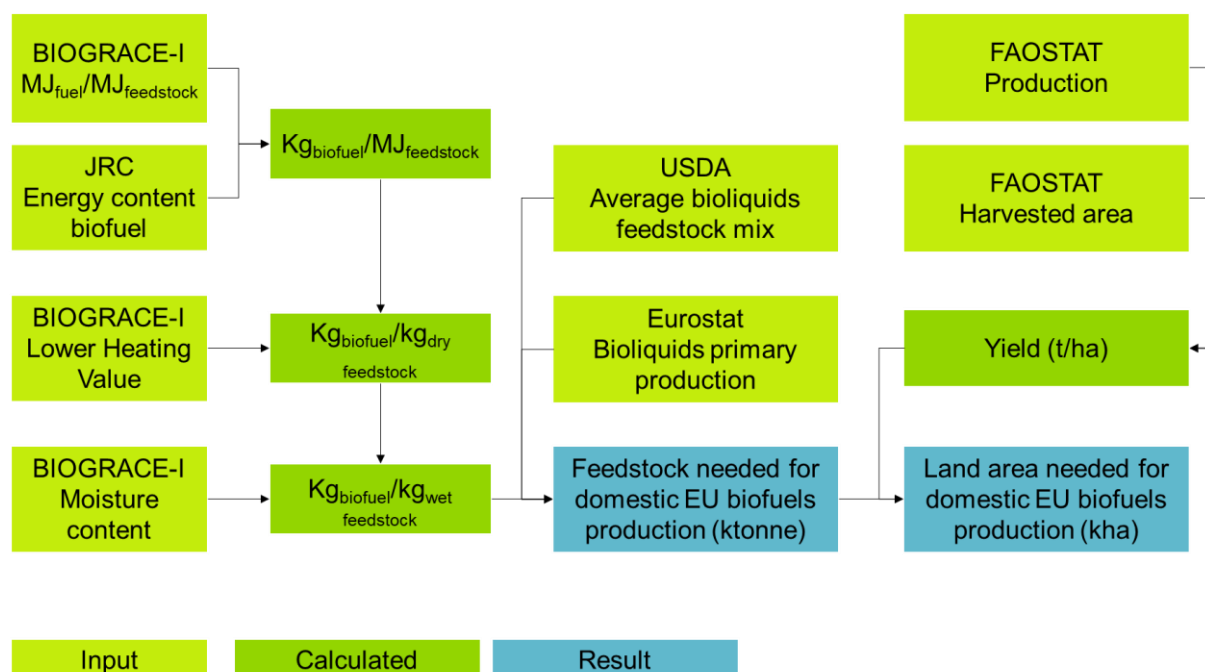


Figure 1 Methodology estimation kton and kha required for the EU domestic biofuels production

There is no EU-wide dataset covering the feedstock mix per Member State. The USDA has published annual reports since 2006 with the average feedstock mix in Europe as a whole.⁴⁴ Most of the feedstocks used in the production of biodiesel in Europe from 2006 – 2022 comes from rapeseed (52%), used cooking oil (16%), palm oil (13%) and soybeans (7%). In that same time period, bioethanol was mostly produced in Europe from sugar beet (29%), wheat (19%) and corn (14%).⁴⁵ For the key Member States in terms of biofuel production, we have supplemented the EU average with national statistics and/or literature to where possible provide a more accurate estimation. This was done for the countries with the largest production of bioliquids: the Netherlands, Germany, Spain, France, Italy and Poland.

⁴⁴ USDA Annual Biofuels Report: <https://fas.usda.gov/data/european-union-biofuels-annual-3>

⁴⁵ USDA Annual Biofuels Report: <https://fas.usda.gov/data/european-union-biofuels-annual-3>

The Netherlands reported annually since 2014 on the feedstocks used in the consumption of biofuels and the origin of these feedstocks.⁴⁶ Feedstocks that were imported were excluded from the land estimates to prevent double counting in case of another European origin.

Germany reports on estimated land use of the feedstock used in bioenergy (biodiesel, bioethanol and biogas).⁴⁷ The data is retroactively statistically allocated by combining agriculture statistics with the amounts of feedstock going to various end-uses (food and feed, material, and energy use). Their methodology of retroactively allocating hectares differs from ours, as we take the production of biodiesel and bioethanol as a starting point and then trace back to an estimated amount of hectares (as this data is available for all MSs). The German national statistics have less uncertainties in their methodology, since they take the amount of feedstock going to the production for bioliquids as a starting point. This reporting is similar to the Dutch annual reports, but the Germans take it one step further to estimate land area associated with the feedstock used.

Spain records the percentages of feedstocks used for biodiesel and bioethanol production from 2009 – 2019.⁴⁸ Unfortunately, it is not clear which feedstocks are produced domestically and which are imported. Feedstocks which are not at all produced domestically, such as palm oil sugar cane and soy, have been excluded in the land use estimates. For the remaining feedstock the assumption in this model is that they have been domestically produced.

Italy reported on the amount of feedstocks used for bioenergy in total and for 2021 Italy provided a more specific split of the feedstocks used per energy carrier.⁴⁹ This 2021 split was used to allocate the feedstocks to the production of either biodiesel or bioethanol. These individual feedstocks were then aggregated to fit the USDA labels. Like in the Spanish statistics, palm oil, sugar cane and soy were excluded. For the remaining feedstock the assumption in this model is that they have been domestically produced since no data was provided on the potential import of these feedstocks.

France reports on the feedstocks used to produce biodiesel and bioethanol, in tonnes and in percentages from 2014 to 2022.⁵⁰ These tonnes fuels produced from these feedstocks were aggregated to fit the USDA labels. Palm oil, sugar cane and soy were excluded, since it is unlikely that these crops were produced domestically. For the remaining feedstock the assumption in this model is that they have been domestically produced since no data was provided on the potential import of these feedstocks.

National statistics were not available for Poland. The USDA Biofuels Outlook for Poland states that Polish biodiesel production is nearly exclusively from

⁴⁶ Nea - Rapportage hernieuwbare energy (annual reports from 2014-2021)

⁴⁷ FNR - Anbau und Verwendung Nachwachsender Rohstoffe in Deutschland

⁴⁸ CNMC - Estadística de biocarburantes de la cnmc

⁴⁹ GSE - Energia del settore trasporti 2005 - 2021

⁵⁰ CarbuRe Statistique publique - <https://metabase.carbure.beta.gouv.fr/public/dashboard/7850c353-c225-4b51-9181-6e45f59ea3ba>

rapeseed and bioethanol is 80% corn and 20% "other grains".⁵¹ The 20% has been equally divided amongst wheat, barley, rye and triticale.

To estimate the annual feedstock mix spanning from 1990 – 2022, averages were used to fill the data gaps for the missing years. We have used the averages of the last two available years to either back-cast to 1990 or forecast to 2022. For instance, in the case of the EU average biofuel mix: the data is available from 2006 – 2022. We have used the average of 2006 and 2007 to estimate the average mix from 1990 – 2005.

The domestic biofuel production can be retrieved from the Complete Energy Balances on Eurostat. We retrieved the primary production of blended biodiesels and blended biogasoline from 1990 – 2021 per Member State.⁵² To calculate the kg biofuel per kg wet feedstock, we used the moisture content, lower heating value (LHV) and energy density of the crop as provided in the BioGrace tool.⁵³ We combined this kgbiofuel/kgwet feedstock with yield (kg/ha) data per Member State from FAOstat.⁵⁴ FAOstat data is available from 1961 – 2022.

Biogas

There is currently no EU-wide dataset where Member States report on the hectares of crops used for biogas production between 1990 – 2022. Member States do report on the amount of biogas produced. That data as presented in the Union Bioenergy report prepared by Guidehouse for DG ENER⁵⁵ shows that Germany alone makes up half of the primary production of biogas in Europe, followed by Italy (14%), France (9%), and Denmark and Czech Republic (each 4%).⁵⁶

Over time, the relative contribution of bioenergy crops to biomethane's potential is expected to increase significantly with the 35 bcm/year biomethane target by 2030. However, it is unlikely that main crops will be used for biogas and biomethane due to the restrictions under the REDIII and the push for using sequential and intermediate crops that do not drive demand for additional land. Historically Germany has been one of the larger users of main crops (maize silage) for the production of biogas. Maize cultivation in Germany began in the 1960s as a feed crop, where its prominence reached 1.5 million hectares by 1990. Maize cultivation then rapidly increased for energy use following the implementation of the RED in 2003, which in Germany's national implementation included subsidies for biogas plants. In addition, the 'Nawaro-Bonus', which was implemented in Germany in 2004, made energy-crop production more lucrative, which lead farmers to shift maize farming from abandoned land to primary agricultural land which had been previously used for food production (BZL, 2022). Between 2010 and 2017 the installed biogas production capacity rapidly rose from 50MW to 4800MW, in the same period,

⁵¹

https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Market%20Outlook%20in%20Poland%202016_Warsaw_Poland_6-29-2016.pdf

⁵² https://ec.europa.eu/eurostat/databrowser/product/view/nrg_bal_c

⁵³ <https://www.biograce.net/biograce2/>

⁵⁴ <https://www.fao.org/faostat/en/#data/QCL>

⁵⁵ [COM 2023 650 1 EN annexe autre acte part1 v7.pdf \(europa.eu\)](#)

⁵⁶ [COM 2023 650 1 EN annexe autre acte part1 v7.pdf \(europa.eu\)](#)

the area planted with maize increased by approximately 15%. In 2020, approximately one third of the planted maize was used for biogas (BZL, 2022).

The German Renewable Resource Association (FNR - Fachagentur Nachwachsende Rohstoffe) publishes annual reports on the hectares needed to produce biogas, from 2016 – 2022.⁵⁷ The other large biogas producing countries, Italy and France, do not publish such reports. In Italy, it was reported for 2018 that the majority of the biogas plants are operating on-farm using manure and agricultural residues.⁵⁸

Italy, the second largest producer of biogas in Europe, has a large focus on producing sustainable biogas through the Biogasdoneright concept. The Biogasdoneright initiative is organized by the Italian Biogas Consortium, consisting of around 600 local farmers, and aims to foster low-cost technologies to produce sustainable biogas by promoting sustainable agricultural practices (Dale et al., 2016). The strategy developed by the consortium aims to reduce risk of direct and indirect land use change by creating additional biomass on existing agricultural land rather than relying on monoculture energy crops, like maize. Growing additional biomass can be achieved through higher land efficiency through sequential cropping, e.g. using cover cropping and reducing the reliance on monocultured energy crops as input to the biogas plant. According to the IEA, in 2017 and 2018 around half of the installed capacity of biogas were using feedstocks stemming from 'agricultural activities'⁵⁹, although it is unclear how much of these crops are residues, additional biomass or main crops.

France has one of the fastest growing biomethane markets in Europe since introducing a feed-in tariff for biomethane in 2011. In 2006, 99% of the production of biogas was stemming from industrial and urban waste water treatment plants.⁶⁰ Currently approximately 90% of the feedstock used for biogas is considered to be a waste or residue.⁶¹ In August 2022, the new French Decree on biogas and biomethane stated that there is a limit of 15% on the usage of main crops as feedstock for the production of biogas or biofuels.⁶² There are no exact figures however on the feedstocks used for biogas production.

Due to the lack of data available on the feedstocks used to produce biogas, it is not possible to give insights and estimates on land use per Member State. Germany however does report on the feedstocks used to produce biogas, from 2015-2021. We have therefore focused on estimating the land used for biogas production in Germany (methodology see Figure 2). Similar to the estimation on the land area used to produce feedstock for bioliquids, German national statistics has provided estimates on land use. These estimates came to fruition by combining agricultural yield statistics with the tonnage going to biogas. To fill the datagaps between 1990 – 2014 and 2022, we have provided backcasting estimates on the amount of hectares needed based on the assumption that the main feedstock for the production of biogas is maize. Starting point of this backcasting exercise

⁵⁷ <https://factsandfigures.fnr.de/agriculture-and-forestry/agriculture>

⁵⁸ <https://www.worldbiogasassociation.org/wp-content/uploads/2018/07/Italy-International-Market-Report.pdf>

⁵⁹ IEA (2021) Task 42 - Country Report Italy

⁶⁰ Ministère de l'agriculture et de l'alimentation (2011) Faits & Tendance Production de bioénergies

⁶¹ https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2022/03/Country_Report_France_ADEME_April_2013.pdf

⁶² Décret n° 2022-1120 du 4 août 2022 relatif aux cultures utilisées pour la production de biogaz et de biocarburants

was the indigenous production of biogas from Eurostat 1990 – 2022.⁶³ We have estimated the land use needed for the whole time period in Germany, based on the average hectares per TJ in 2016 – 2022.

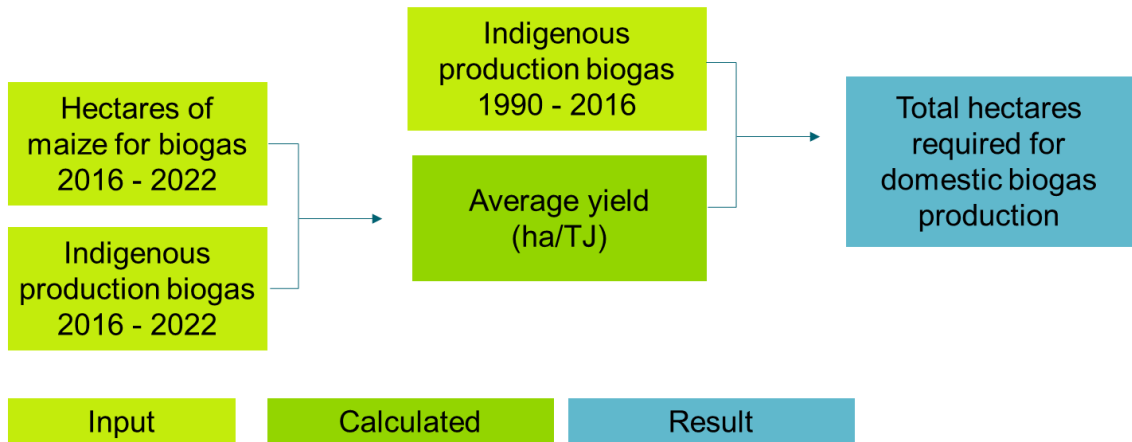


Figure 2 Methodology estimation kha required for the German biogas production

Solid/Forest biomass

From 2021 onwards, Member States are required to report biannually on the use of solid biomass for the production of bioenergy (in energy content and volume). This includes a wide range of sources within the forest biomass category, such as residues that come from industries like sawmills, as well as residues that result from forest management activities, including branches and stumps, but also primary biomass such as fuelwood.

In 2021, fuelwood accounted for nearly half (47%) of the forest biomass that was used for energy purposes in the EU.⁶⁴ This indicates that within the category of forest biomass fuelwood is a widely used source of biomass for energy production. There is no EU-wide dataset that reports on the hectares of land needed to produce this amount of fuelwood for bioenergy purposes. We will follow the methodology as visualised in Figure 3 to estimate the total hectares needed for the domestic biofuel production of fuelwood.

⁶³ https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_rw

⁶⁴ [COM 2023 650 1 EN annexe autre acte part1 v7.pdf\(europa.eu\)](#)

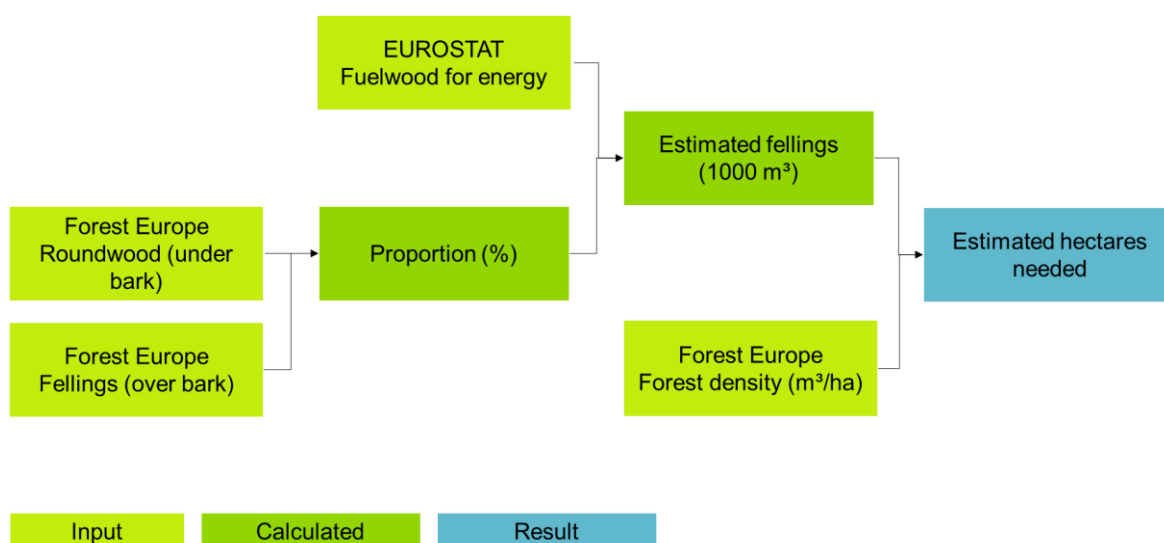


Figure 3 Methodology estimation kha required for the EU domestic production of fuelwood for energy purposes

The domestic energy production, export of fuelwood and the import of fuelwood data will all be retrieved from the Member States progress reports, as made available by Eurostat.⁶⁵ The Forest Information System for Europe made available the average fuelwood production per forest area (m^3/ha) per Member State for 2017.⁶⁶ These yield averages will be applied to the total domestic production of fuelwood for energy purposes to estimate the total hectares required.

Due to the short timeframe of the data available, it will not be possible to provide an estimation of the land use needed from 1990 – 2022. It will only be possible to provide insights for 2021. The team will look at national statistics of the top producing countries fuelwood (Poland, Germany, France, and Spain) to increase the data points available.

11.7. Assessment of balance sheets for agricultural biomass uses between 1990-2020

The balance sheets should show the evolution of agricultural land and biomass uses for food, feed, energy and other biobased products at national and EU27 wide scale between 1990 and 2020. The balance sheets, presented in Chapter 5 express total biomass production (tdm) and cropland area use together with a discussion on how different policies influenced the shifts in land use in time.

Figure 4 explains what data was used to generate the balance sheets and how it was processed. For the consecutive years from 1990-2022 data were combined on biomass production and type and uses. The balance sheets are presented for the whole EU27 in an Excel table format and in a Sankey flow showing how

⁶⁵ https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_bm/

⁶⁶ <https://forest.eea.europa.eu/topics/forest-bioeconomy/wood-uses-and-wood-flows>

agricultural biomass uses evolve from 1990 to 2022 and for a selection of intermediate years.

Approach and data sources to generate balance sheets

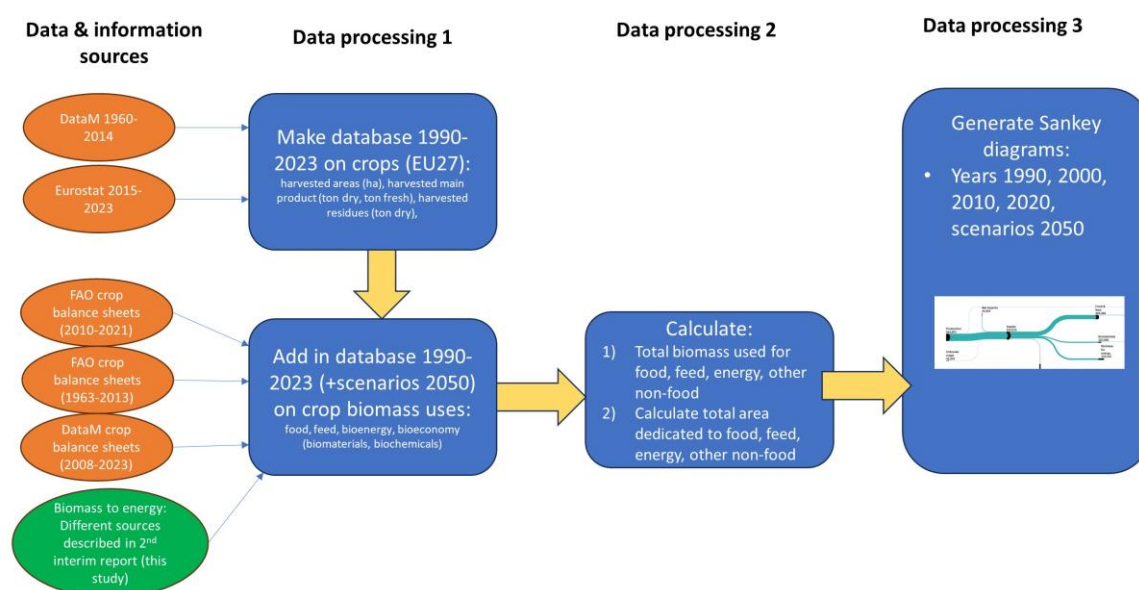


Figure 4 Steps to generate the agricultural biomass balance sheets

Main data sources that were used to generate the flows are:

- 1) DataM biomass estimates version 3: a new database to quantify biomass availability in the European Union (Ronzon, et al. ,2015)⁶⁷. The data was downloaded in March 2024. It covers the period 1990-2010.
- 2) FAOSTAT data on land use and production per crop for 2022. This data was processed in the same way as was done by Ronzon et al. (2015) for the crop and production data in DataM under point 1). It was ensured that the same conversion values were used to come from production as is to dry mass production.
- 3) Eurostat data for 2022 was also used to obtain data on fodder and forage cropland use and production. This was necessary because FAOSTAT does not provide information on forage and fodder production from cropland. Ronzon et al. (2015) also collected this information from additional data sources for the 1990-2010 period. For 2022 the Eurostat fodder and forage data were used in this study. The categories of forage and fodder that were derived from other sources concerned the following:
 - Forage and silage Alfalfa
 - Forage and silage clover
 - Forage and silage, temporary grasslands
 - Forage and silage, legumes (e.g. leguminous plants harvested green and lucerne)
 - Green maize

⁶⁷ Ronzon, T, Piotrowski, S. & Carus, M. (2015) . DataM biomass estimates version 3: a new database to quantify biomass availability in the European Union JRC96246. ISBN 978-92-79-48947-1 (PDF). ISSN 1831-9424 (online). Doi:10.2791/650215

- 4) Bioenergy land use and biomass production types and levels were assessed in this study (see chapter 5 of main report and former methodology sections)
- 5) DataM medium Outlook commodity flows for cereals, oilseeds and products⁶⁸ were also used to obtain information about the end uses going to food, feed, energy and other non-food uses.
- 6) Extra data was collected on cotton area and production from Eurostat for 1990 ([Study on the Cotton Sector in the European Union](#)) and for 2000-2022 ([Statistics | Eurostat](#)).

In Chapter 5 of the main report the detailed results are discussed and summarized. In the following an overview is given of the main input and processed data.

The Table 3 data are the Ronzon et al. (2015) data. The table displays the data for 1990. The same data for 2000 and 2010 were also used for the generation of the balance sheets. For 2022 data from Ronzon et al. (2015) were not available. Therefore data were collected from FAOSTAT for all crops available for 2022 and these were processed into the Ronzon categories, using the same conversion factors as Ronzon et al. (2015) used. Data on fodder and forage area and production were collected separately from Eurostat ([Statistics | Eurostat](#)). In the Table 4 an overview is given of the fodder and forage data used for 2022.

The final data on the balance sheet are presented in Table 5. These data are further presented and discussed in Chapter 5 of the main report.

⁶⁸ Medium-term Outlook commodity flows (europa.eu))

Table 3 Overview of data on crop balance data from Ronzon et al. (2015). The data are displayed for the year 1990 and show all crop data grown in EU27 on cropland in 1990. The same data were used for 2000 and 2010.

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Agricultural crops, total	4,401,559.5	5,701,445.7	257,313.3	4,260,676.2	1,572,232.2	2,187,976.1	615,743.9	20.1	59.4
1990	Almonds, with shell	2,505.5	3,232.9	2,383.6	2,807.5	934.1	1,037.9	103.8	1.6	3.2
1990	Anise, badian, fennel, corian.	29.6	33.8	29.3	29.2	4.2	4.6	0.5	1.2	3.0
1990	Apples	44,406.6	53,264.7	1,923.1	45,834.7	9,466.1	10,517.9	1,051.8	41.4	69.3
1990	Apricots	2,528.7	3,033.1	245.9	2,610.0	539.0	598.9	59.9	18.4	30.8
1990	Artichokes	3,569.5	4,554.2	293.1	3,564.9	1,036.4	1,151.6	115.2	22.5	36.5
1990	Asparagus	786.1	1,033.5	193.3	781.6	261.6	290.6	29.1	7.5	12.2
1990	Avocados	248.8	298.5	54.6	256.8	53.0	58.9	5.9	8.2	13.7
1990	Bananas	1,759.1	2,110.1	33.7	1,815.7	375.0	416.7	41.7	93.5	156.5
1990	Barley	551,211.1	798,325.1	47,954.6	423,196.3	290,632.3	490,271.8	199,639.5	11.7	34.5
1990	Beans, dry	1,729.1	3,279.0	973.8	2,002.1	2,174.8	2,174.8	-	2.7	5.3
1990	Beans, green	3,195.5	3,993.2	368.4	3,201.0	836.4	929.3	92.9	16.1	26.0
1990	Beets for fodder	66,438.2	66,438.2	902.5	69,326.8	-	-	-	137.6	220.8
1990	Berries Nes	41.1	59.7	9.0	41.2	20.9	23.2	2.3	7.9	13.7
1990	Blueberries	65.3	94.6	20.0	65.4	33.0	36.6	3.7	5.7	9.8
1990	Broad beans, horse beans, dry	2,982.2	5,012.1	781.2	3,453.0	2,803.2	2,803.2	-	5.8	11.5
1990	Buckwheat	591.6	914.4	141.9	423.5	391.2	639.2	248.1	4.0	12.5
1990	Cabbage for fodder	8,912.4	8,912.4	300.7	9,299.9	-	-	-	55.4	88.9
1990	Cabbages and other brassicas	19,563.4	23,815.0	698.7	19,669.5	4,429.8	4,922.0	492.2	52.2	84.0

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Canary seed	5.1	7.8	1.5	3.9	3.4	5.3	2.0	3.4	10.3
1990	Carobs	804.7	965.2	422.1	830.6	171.5	190.6	19.1	3.4	5.7
1990	Carrots and turnips	13,411.1	17,010.9	351.7	13,405.4	3,785.1	4,205.7	420.6	70.6	114.4
1990	Carrots for fodder	36.7	36.7	1.0	38.3	-	-	-	67.9	109.0
1990	Castor oil seed	8.7	17.4	16.5	7.7	8.7	9.7	1.0	0.6	1.6
1990	Cauliflowers and broccoli	6,785.4	8,516.9	399.3	6,792.8	1,816.9	2,018.8	201.9	31.5	51.0
1990	Cereals, nes	842.1	1,294.3	106.1	591.3	537.5	896.7	359.1	7.4	23.8
1990	Cherries	2,378.7	2,853.2	473.6	2,455.2	507.1	563.4	56.3	9.0	15.1
1990	Chestnuts	700.3	903.6	188.2	784.7	261.1	290.1	29.0	5.5	11.2
1990	Chick peas	382.5	803.0	240.5	442.9	595.5	595.5	-	2.4	4.8
1990	Chicory roots	1,304.2	1,470.8	11.8	1,488.7	172.5	191.6	19.2	165.9	330.7
1990	Chillies and peppers, dry	655.2	770.8	129.8	743.8	133.9	148.8	14.9	7.6	15.1
1990	Chillies and peppers, green	7,022.8	8,595.3	317.6	7,055.6	1,640.8	1,823.1	182.3	41.2	66.3
1990	Citrus fruit, nes	110.7	132.7	9.2	114.2	23.6	26.2	2.6	21.6	36.1
1990	Coffee, green	0.0	0.1		0.0	0.0	0.0	0.0		
1990	Cotton lint	1,791.2	2,030.0		2,082.1	238.8	238.8	-		
1990	Cottonseed	2,642.0	5,299.8		2,346.7	2,657.8	2,953.1	295.3		
1990	Cow peas, dry	0.4	0.8	0.3	0.5	0.6	0.6	-	2.1	4.2
1990	Cranberries	-	-	-	-	-	-	-		
1990	Cucumbers and gherkins	7,540.8	8,978.5	234.2	7,604.7	1,488.0	1,653.3	165.3	60.2	96.6
1990	Currants	1,329.4	1,878.4	188.8	1,338.8	615.1	683.4	68.3	12.3	21.1
1990	Dates	41.2	49.5	1.8	42.6	8.8	9.8	1.0	40.9	68.4

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Eggplants (aubergines)	1,930.5	2,339.5	61.5	1,942.2	425.5	472.8	47.3	58.6	94.2
1990	Fibre Crops	2,785.3	3,203.4	425.7	3,218.7	441.9	466.1	24.2	9.8	19.6
1990	Figs	922.7	1,106.7	436.5	952.3	196.7	218.5	21.9	3.8	6.3
1990	Flax fibre and tow	888.8	1,049.1	366.3	1,016.2	181.6	203.2	21.7	3.6	7.3
1990	Fodder crops	1,944,325.7	1,944,325.7	72,974.8	2,013,273.4	-	-	-	45.4	79.5
1990	Forage and silage, alfalfa	269,997.5	269,997.5	8,259.2	269,997.5	-	-	-	54.5	98.1
1990	Forage and silage, clover	123,921.0	123,921.0	3,255.4	123,921.0	-	-	-	63.4	114.2
1990	Forage and silage, grasses nes	98,946.5	98,946.5	10,610.6	98,946.5	-	-	-	15.5	28.0
1990	Forage and silage, green oilseeds	145,917.4	145,917.4	8,526.9	145,917.4	-	-	-	28.5	51.3
1990	Forage and silage, legumes	159,853.9	159,853.9	11,287.4	172,150.3	-	-	-	25.1	42.5
1990	Forage and silage, maize	654,765.5	654,765.5	17,146.6	705,132.1	-	-	-	67.6	114.6
1990	Forage and silage, rye grass	80,368.2	80,368.2	2,711.7	80,368.2	-	-	-	49.4	88.9
1990	Forage and silage, sorghum	6,148.0	6,148.0	174.2	6,620.9	-	-	-	62.4	105.9
1990	Forage products	88,496.1	88,496.1	2,797.7	88,496.1	-	-	-	57.5	94.9
1990	Fruit Fresh Nes	1,017.5	1,220.5	165.2	1,050.2	216.9	241.0	24.1	11.0	18.5
1990	Fruit, tropical fresh nes	86.2	103.4	8.4	89.0	18.4	20.4	2.0	18.4	30.8
1990	Garlic	1,336.5	1,787.3	195.8	1,325.4	477.7	530.8	53.1	12.5	20.5
1990	Gooseberries	497.3	708.0	66.2	500.2	236.4	262.7	26.3	13.1	22.5
1990	Grapefruit (inc. pomelos)	455.8	546.7	15.6	470.5	97.2	108.0	10.8	52.4	87.6
1990	Grapes	110,870.1	130,435.4	13,215.8	114,734.8	20,652.3	22,947.0	2,294.7	15.1	25.2
1990	Groundnuts, with shell	137.9	282.9	45.6	141.5	172.1	191.2	19.1	4.0	9.1

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Hazelnuts, with shell	843.6	1,088.3	322.2	945.3	314.2	349.2	34.9	3.9	7.9
1990	Hemp Tow Waste	105.3	124.2	59.3	120.4	21.5	24.1	2.6	2.6	5.3
1990	Hempseed	35.3	82.1	60.2	34.7	55.0	61.1	6.1	0.8	1.8
1990	Hops	251.8	296.2	101.5	285.8	51.5	57.2	5.7	3.7	7.4
1990	Kiwi fruit	1,509.1	1,810.2	82.1	1,557.7	321.7	357.4	35.7	33.0	55.1
1990	Leeks, other alliaceous veg	2,259.5	2,784.7	93.7	2,267.8	548.9	609.9	61.0	44.8	72.3
1990	Leguminous vegetables, nes	1,019.3	1,321.4	133.8	1,015.6	318.8	354.2	35.4	14.1	22.9
1990	Lemons and limes	5,576.2	6,688.5	289.2	5,755.5	1,188.7	1,320.7	132.1	34.6	57.8
1990	Lentils	225.7	452.0	181.7	261.3	319.3	319.3	-	1.9	3.7
1990	Lettuce and chicory	10,374.8	12,705.0	389.8	10,422.5	2,431.6	2,701.8	270.2	49.5	79.8
1990	Linseed	1,091.8	2,471.2	584.2	1,081.5	1,598.2	1,775.7	177.6	2.5	5.6
1990	Lupins	860.4	1,641.1	387.8	996.3	1,096.1	1,096.1	-	3.4	6.7
1990	Maize	236,889.9	526,847.5	23,079.0	241,290.1	329,510.6	370,861.5	41,350.9	13.9	30.8
1990	Maize, green	1,479.4	2,573.9	92.8	1,398.9	1,179.2	1,310.2	131.0	27.9	47.8
1990	Melonseed	17.6	37.4	2.1	17.7	22.1	24.6	2.5	11.3	25.1
1990	Millet	124.6	194.5	32.5	86.9	84.2	138.5	54.2	3.5	11.5
1990	Mixed grain	40,147.3	60,988.7	4,198.5	28,745.4	24,745.1	41,328.0	16,582.9	9.1	28.7
1990	Mushrooms and truffles	2,800.8	3,132.5	1.5	2,847.7	331.7	368.5	36.9	3,476.1	5,535.2
1990	Mustard seed	292.8	663.7	105.8	290.0	430.0	477.8	47.8	3.7	8.3
1990	Nuts, nes	74.9	96.6	23.9	83.9	27.9	31.0	3.1	4.6	9.4
1990	Oats	90,866.3	129,752.0	10,018.2	70,150.4	44,995.5	77,216.1	32,220.6	9.3	27.2
1990	Oilseeds, Nes	1,460.3	2,896.6	167.5	1,498.9	1,522.0	1,691.2	169.1	12.0	26.2

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Okra	4.4	5.5	0.2	4.4	1.2	1.3	0.1	35.0	56.6
1990	Olives	33,956.2	65,885.2	12,744.1	35,042.5	33,180.1	36,866.8	3,686.7	3.7	8.0
1990	Onions (inc. shallots), green	581.4	753.3	34.6	579.3	181.4	201.6	20.2	31.0	50.4
1990	Onions, dry	13,872.9	17,415.6	510.9	13,887.7	3,717.7	4,130.8	413.1	50.4	81.5
1990	Oranges	20,191.1	24,218.8	879.2	20,840.4	4,304.1	4,782.3	478.2	41.2	68.9
1990	Other crops	5,858.3	7,633.2	1,226.8	6,550.4	2,293.5	2,548.4	254.8	7.0	14.3
1990	Other melons (inc.cantaloupes)	8,001.5	10,295.9	432.4	8,177.0	2,521.8	2,802.0	280.2	32.8	55.5
1990	Peaches and nectarines	14,572.0	17,478.8	877.7	15,040.6	3,106.3	3,451.4	345.1	29.8	49.8
1990	Pears	10,408.6	12,484.9	598.2	10,743.3	2,218.8	2,465.3	246.5	30.9	52.2
1990	Peas, dry	30,190.6	44,933.2	3,733.2	34,957.5	19,819.2	19,819.2	-	12.3	24.3
1990	Peas, green	6,837.1	8,507.9	745.4	6,853.0	1,750.1	1,944.6	194.5	17.0	27.5
1990	Peppermint	13.5	15.9	0.5	15.3	2.8	3.1	0.3	39.2	78.6
1990	Persimmons	253.2	303.7	9.2	261.3	54.0	60.0	6.0	49.5	82.9
1990	Pineapples	5.5	6.6	0.6	5.7	1.2	1.3	0.1	16.5	27.6
1990	Pistachios	21.4	26.4	23.0	24.1	6.2	6.9	0.7	1.4	2.8
1990	Plums and sloes	6,073.4	7,284.9	796.5	6,268.7	1,294.6	1,438.5	143.8	13.7	22.9
1990	Poppy seed	67.5	155.0	37.4	66.6	102.2	113.6	11.4	2.4	5.4
1990	Potatoes	357,404.1	660,092.3	12,173.7	342,723.3	321,727.4	357,474.8	35,747.5	48.5	88.1
1990	Protein crops	42,357.4	66,097.2	7,683.3	49,045.4	32,309.7	32,309.7	-	8.4	16.5
1990	Pulses, nes	5,070.0	8,314.9	1,031.7	5,870.5	4,461.7	4,461.7	-	7.5	14.7
1990	Pumpkins for Fodder	182,241.7	182,241.7	5,607.2	182,241.7	-	-	-		32.5
1990	Pumpkins, squash and gourds	3,709.4	4,819.2	227.8	3,694.8	1,171.6	1,301.7	130.2	30.1	48.9

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Pyrethrum,Dried	1.2	1.3		1.4	0.1	0.2	0.0		
1990	Quinces	278.0	333.4	20.4	286.9	59.3	65.8	6.6	24.5	40.9
1990	Rapeseed	55,914.8	134,198.6	8,893.7	54,758.1	90,545.7	100,606.3	10,060.6	8.1	18.9
1990	Raspberries	442.2	644.5	87.8	443.1	227.7	252.9	25.3	8.8	15.1
1990	Rice, paddy	20,580.8	31,362.9	1,312.4	15,448.8	13,285.3	21,336.7	8,051.5	15.6	47.0
1990	Roots and Tubers, nes	43.5	81.0	2.4	42.3	40.9	45.4	4.5	28.9	54.0
1990	Rye	110,252.3	160,918.9	12,871.1	82,516.0	58,947.0	100,580.5	41,633.5	8.5	25.7
1990	Safflower seed	11.1	25.4	4.8	11.0	16.6	18.4	1.8	3.1	7.0
1990	Sesame seed	1.4	3.2	1.2	1.4	2.1	2.4	0.2	1.5	3.4
1990	Sorghum	4,556.1	6,955.8	393.0	3,384.4	2,941.3	4,750.3	1,809.0	11.4	34.8
1990	Sour cherries	1,086.5	1,303.2	195.4	1,121.4	231.6	257.3	25.7	10.0	16.7
1990	Soybeans	15,280.2	34,628.7	2,770.8	15,215.7	23,881.4	26,534.9	2,653.5	7.2	16.5
1990	Spices, nes	17.4	20.5	15.9	19.8	3.6	4.0	0.4	1.6	3.3
1990	Spinach	1,419.8	1,780.7	84.1	1,421.5	378.8	420.8	42.1	31.3	50.7
1990	Starchy Roots	357,790.0	660,813.4	12,194.9	343,098.3	322,091.5	357,879.5	35,787.9	48.5	88.0
1990	Stone fruit, nes	63.6	76.3	13.7	65.7	13.6	15.1	1.5	8.3	13.9
1990	Strawberries	3,724.6	4,999.4	353.2	3,782.0	1,415.5	1,572.8	157.3	18.6	31.6
1990	String beans	883.8	1,119.8	135.6	883.6	248.1	275.6	27.6	12.1	19.6
1990	Sugar beet	657,661.7	804,667.4	8,677.7	543,601.4	157,667.9	315,335.8	157,667.9	106.3	227.4
1990	Sugar cane	767.3	916.0	6.6	618.6	148.7	297.4	148.7	159.4	349.9
1990	Sugar crops	658,429.0	805,583.4	8,684.3	544,220.0	157,816.6	315,633.2	157,816.6	106.3	227.5
1990	Sunflower seed	41,238.0	99,465.7	11,159.7	40,352.8	67,588.6	75,098.4	7,509.8	4.7	11.1

	Sum of Value	1000 T dm	1000 T dm	1000 ha	1000 T dm	1000 T dm	1000 T dm	1000 T dm	Ton/ha dm	Ton/ha dm
Year	Row Labels	Domestic Extraction Used	Domestic Extraction, Total	Harvested Area	Production	Residues, Non-Used	Residues, Total	Residues, Used	Yield	Yield, Domestic extraction used
1990	Swedes for fodder	3,197.6	3,197.6	59.7	3,336.6	-	-	-	100.1	160.6
1990	Sweet potatoes	322.4	603.5	17.8	313.2	305.4	339.3	33.9	29.0	54.3
1990	Tangerines, mandarins, clem.	7,757.0	9,304.3	332.7	8,006.4	1,653.5	1,837.3	183.7	41.8	70.0
1990	Taro (cocoyam)	11.4	20.3	0.4	11.2	9.5	10.6	1.1	51.4	95.0
1990	Tea	1.1	1.3	0.8	1.2	0.2	0.2	0.0	1.9	3.8
1990	Tobacco, unmanufactured	3,584.3	5,022.6	937.1	3,965.2	1,924.9	2,138.8	213.9	5.6	11.5
1990	Tomatoes	53,574.3	63,465.1	1,252.4	54,065.4	10,217.5	11,352.8	1,135.3	80.0	128.3
1990	Total cereals incl. rice	2,053,488.6	3,174,363.5	175,501.0	1,644,608.8	1,320,676.1	2,018,128.1	697,452.0	12.4	35.1
1990	Total Fruits	256,624.2	307,502.4	22,558.4	264,913.9	54,338.5	60,376.1	6,037.6	20.4	34.1
1990	Total Oilseeds	118,199.3	280,227.5	23,849.4	115,824.1	188,602.5	209,558.3	20,955.8	6.4	14.9
1990	Total Vegetables	196,930.3	241,921.9	8,471.3	197,747.4	46,987.9	52,208.8	5,220.9	43.3	69.7
1990	Treenuts	5,097.3	6,575.8	3,171.2	5,711.9	1,898.4	2,109.3	210.9	2.4	4.8
1990	Triticale	35,722.4	53,688.3	3,230.2	25,959.9	21,265.6	35,631.8	14,366.2	10.6	33.2
1990	Turnips for fodder	10,021.8	10,021.8	374.2	10,457.6	-	-	-	50.1	80.3
1990	Vegetables and roots fodder	45,063.4	45,063.4	959.7	47,022.6	-	-	-	87.8	140.9
1990	Vegetables fresh nes	32,971.8	40,913.2	1,655.2	33,061.8	8,313.2	9,236.9	923.7	37.0	59.8
1990	Vetches	916.6	1,661.1	353.1	1,061.3	1,039.3	1,039.3	-	4.0	7.8
1990	Walnuts, with shell	951.6	1,227.9	230.4	1,066.3	354.8	394.2	39.4	6.1	12.4
1990	Watermelons	9,117.9	11,408.7	300.5	9,355.8	2,495.3	2,772.6	277.3	54.1	91.0
1990	Wheat	961,698.9	1,403,113.1	72,162.0	752,811.8	533,337.2	874,471.8	341,134.6	13.8	40.0
1990	Yams	8.7	16.3	0.6	8.4	8.4	9.3	0.9	24.0	44.8

Table 4 Fodder and forage area and production data derived from Eurostat ([Statistics / Eurostat](#)) for 2022

EU 27	Grain maize and corn-cob-mix	Leguminous plants harvested green	Temporary grasses and grazings	Lucerne	Clover and mixtures	Green maize	Other cereals harvested green (excluding green maize)	Other leguminous plants harvested green n.e.c.	Other plants harvested green from arable land n.e.c.
Dry mass production (1000 tdm)	45,555	26,089	39,785	13,061	-	76,380	3,731	6,721	3,669
Area (1000 ha)	8,838	4,458	7,184	1,935	0	5,851	782	1,557	1,074

Table 5 Resulting data for balance sheet with main production used for energy, food, feed and non-food in 1990, 2000, 2010 and 2022

year		MP_Energy	MPFeed	MPFood	MP_Non_food	Total
1990	Area main product (1000 ha)	57	60,416	59,306	284	120,063
2000	Area main product (1000 ha)	410	64,489	57,133	265	122,297
2010	Area main product (1000 ha)	4,812	63,625	48,741	149	117,327
2022	Area main product (1000 ha)	6,192	59,435	45,176	110	110,913
1990	Main product (Kton dm)	501	262,308	222,635	942	486,386
2000	Main product (Kton dm)	2,047	313,307	229,602	1,428	546,383
2010	Main product (Kton dm)	19,891	327,236	202,622	758	550,507
2022	Main product (Kton dm)	30,452	303,820	174,878	296	509,446
1990	Residue (residue_used Kton dm)	526	63,766	63,439	-	127,730
2000	Residue (residue_used Kton dm)	880	66,109	65,438	-	132,427
2010	Residue (residue_used Kton dm)	2,226	46,465	81,301	-	129,992
2022	Residue (residue_used Kton dm)	4,327	124,487	85,390	1,646	215,851

11.8. Methods for design and implementation of the case studies

Regional case studies (CS) are used to study the relationships between combinations of drivers and land use transitions in rural areas across Member States (MS) and regions in different parts of the EU. The case studies have multiple functions in the project:

- to enable a detailed understanding of the drivers that lead to land use change, the types of land involved and options to use land for multiple purposes;
- to provide elements for land use scenarios and to validate the sustainability assessment framework;
- to function as a reference for the project findings;
- to review national and regional policies which influence land use transitions. For this purpose, policies are considered that can be improved to optimise land use functions for sustainable agriculture at the level of regions and countries. Within the project it will not be possible to review in detail the policies already in place in all 27 Member States. However, where available, literature will be used to ensure that potential policy options are covered by the national and regional review.

11.9. Selection of case study regions

The selection of 12 case study areas is based on the territorial typology and the expertise available in the consortium. Leading principles in the selection were:

- i. distribution over all environmental zones;
- ii. selection of NUTS3 regions covering as much as possible the diversity of the different RALUC types
- iii. focus on countries where the consortium has expertise and/or connection to third parties.
- iv. suggestions for additional selection criteria provided by the Steering Group members of the project.

Additional selection criteria suggested by the Steering Group of the project were the following:

- 1) Include regions with 'traditional' and advanced bioeconomy activities. Examples of the traditional would-be activities like pruning (from permanent crops) to fuelwood, straw and wood to paper, plant residues to bedding (animals). Advanced bioeconomy activities can be straw to advanced biofuels, manure to biomethane for heating in grid, new biomass crops on abandoned or degraded lands for new non-food uses.
- 2) Include regions where afforestation is taking place for bioeconomy purposes following examples in Ireland.
- 3) Include regions where land abandonment is taking place.
- 4) Include regions where new renewable energy activities have already been developed such as windmills, agri-PV, biogas-dome-right projects.
- 5) Regions where different examples are in place of multi-functional land uses creating win-win opportunities such as high nature value farmland,

advanced climate adaptation measures, many agricultural products branded DOP, agritourism etc.

The typology and the resulting selection of case study region is further presented in chapter 3 of this report.

11.10. Approach to information collection in case study areas

For the collection of information in the case studies uniform guidelines were shared with all CS leads (see Annex 3) and a training session was organised to explain these guidelines.

The research questions central in the study presented in chapter 1 of this report were also guiding the data collection in the 12 CSs. In the CSs information was derived through four methods:

- 1 Collect and interpret for the case study region land use data and statistics on land use and farming (structure), energy (production and use) and socio-economic themes (e.g. population, labour, income, gross value added etc.) for the period 1990-2022 (or a period in this time frame).
- 2 Collect and interpret regional reports and other published information sources that demonstrate changes in land use changes, their drivers and policy instruments. The aim is to obtain information on the main land use trends and their drivers that have been competing and synergizing with agricultural land use in the period 1990-2022.
- 3 Perform interviews with local rural development organizations, local government organizations, environmental NGOs, or other stakeholders informed on the evolution of land use and policies in the region over the last 30 years and future land use changes. Statistical and spatial data on the regions is collected, processed and analysed to derive land use trends and drivers. Statistical and spatial data are retrieved from Eurostat, national and regional sources. The data are analysed in combination with the trends and related drivers from the literature review. The aim is to assess which land uses are competing and/or synergizing with agricultural land use and how.
- 4 Hold one (on-line) workshop on future land use change in the region with stakeholders and experts to identify factors most influential for the future agricultural land use and in the case study region and reflect on how policy goals can work out of the main EU policy instruments including Farm to Fork Directive, Nature restoration Law, Directives in the field of Renewable energy targets and transition to a circular bioeconomy and the Soil Monitoring and resilience Directive.

Input for land use scenarios and validation

The case studies were also used to provide input for the development of forward-looking scenarios and to validate the sustainability assessment framework in this study. This activity comprised of the following steps:

1. Review published material on sustainability assessments in the case study regions. The aim is to obtain definitions, criteria and thresholds on the research dimensions specific for the case studies and for agricultural production, energy production, nature conservation, climate and forestry. The literature review was complemented with information from stakeholders in the CSs.

2. Validate the sustainability assessment framework with relevant stakeholders in the case study regions, in order to refine the Key Performance Indicators (KPIs), and to make these more relevant at local level.

For each case study, stakeholders were selected and invited to form a 'case study panel'. Interviews with the panels were held during the CS workshops with the aim to obtain an overview of the current and future land use and sustainability issues that were regarded most relevant in every the case study.

11.11. Modelling of future land use changes and their impacts

To understand answer the central research questions on what the dominant drivers of land use change will be (Q3) and how to optimise land use change in the future to enable the development of sustainable agriculture (Q4), future land use changes are modelled. Sustainable agriculture in this study refers to a future in which all Farm to Fork strategy goals for agriculture are met.

To model the land use changes in the rural areas of the EU, two future scenarios are developed and these are then taken as the starting point to simulate future land use changes in the iCLUE model. The scenarios are designed taking input on past and future land use trends and drivers detected in literature and through the case study analysis. Policy objectives are different per scenario, see next. The scenarios are different in that they assume different policy objectives which result in different land use demands to be met. With iCLUE the different land demands are then simulated towards the future. The resulting land use change simulations from iCLUE are further assessed for trade-offs through different KPIs, brought together in a sustainability impact framework (see Figure 5).

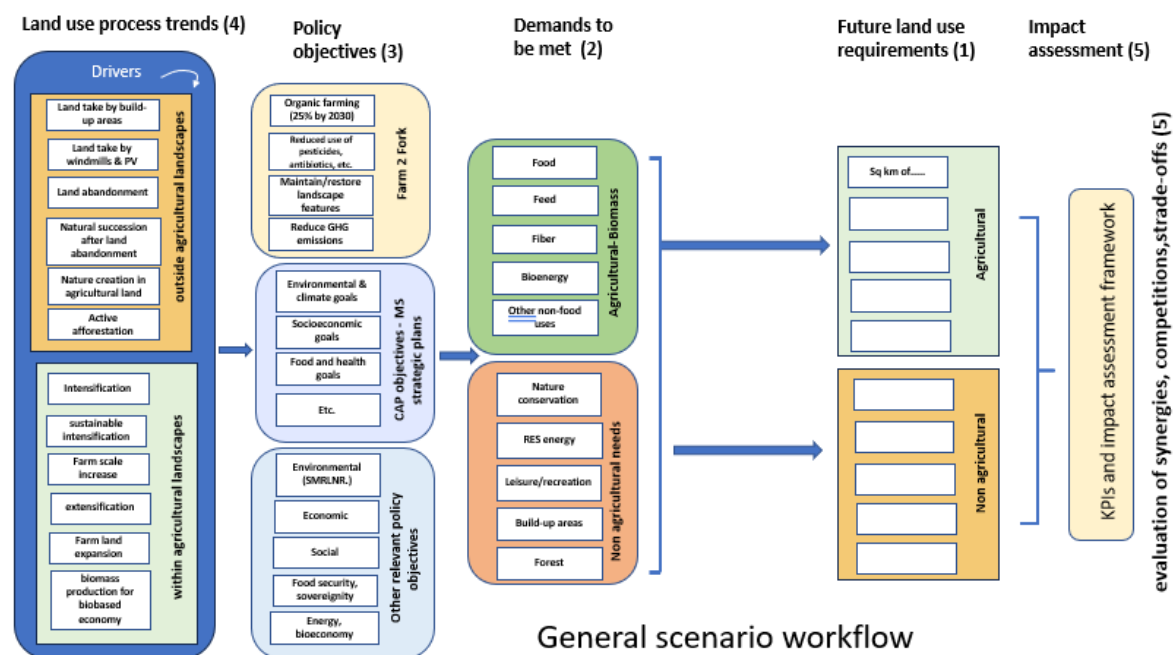


Figure 5 Approach to scenario development, future land use requirements and KPI sustainability impact framework

Scenarios

In chapter 7 of the main report the narratives of the scenarios are presented providing further details on the main drivers of land use change and their outcomes by 2050 that are foreseen through the (lack of) policy objectives implemented in every scenario.

The translation of the land use demands per scenario requires different analytical steps:

For both scenarios the starting point were the detailed land use results from the CAPRI model⁶⁹ Baseline 2015 to 2050. The CAPRI Baseline run used here was generated in 2021 and is the latest baseline run STAR 2.7⁷⁰. This baseline can be interpreted as a projection in time covering the most probable future development of the European agricultural sector under the status-quo policy, which was CAP 2014-2020) and including all future changes already foreseen in the legislation up to 2020. The Baseline model output from CAPRI was used as a starting point at the most detailed level namely crop and livestock level (1000 ha or 1000 heads) per CAPRI region (mostly NUTS 2). An example of the CAPRI Baseline information for one CAPRI region is given in Table 6.

- 1) Matching CAPRI land use 2050 into adjusted scenario specific land use demands, animal heads and yields following the detailed scenario specific policy rules and related land demands further discussed in chapter 7.

Table 6 Example of CAPRI modelled output for baseline scenario 2015-2025 (STAR 2.7) used as basis for scenario assessment in this study

CAPRI_code	Name	Capri code	Explanation CAPRI code	LEVEL 2015 (1000 ha or heads)	LEVEL 2050 (1000 ha or heads)
AT110000	Burgenland	APPL	Apples, pears and peaches	0.4	0.3
AT110000	Burgenland	BARL	Barley	7.7	12.2
AT110000	Burgenland	BULH	Bull High intensity	2.3	3.4
AT110000	Burgenland	BULL	Bull low intensity	2.3	3.4
AT110000	Burgenland	CAFF	Fattening of female calves	0.6	0.1
AT110000	Burgenland	CAFR	Raisin of female calves	19.8	27.2
AT110000	Burgenland	CAMF	Fattening of male calves	1.0	0.7
AT110000	Burgenland	CAMR	Raisin of male calves	19.3	19.5
AT110000	Burgenland	DCOW	Dairy cows	4.5	4.8
AT110000	Burgenland	DWHE	Durum wheat	2.8	1.7
AT110000	Burgenland	FALL	Fallow land	0.2	0.0
AT110000	Burgenland	FLOW	Flowers, ornamental plants, etc.	0.1	0.1
AT110000	Burgenland	FORE	Forest	119.7	109.5
AT110000	Burgenland	GRAE	Grass extensive/green fodder	10.5	8.7
AT110000	Burgenland	GRAI	Grass intensive/green fodder	10.5	8.7
AT110000	Burgenland	GRSLND	Grassland	35.7	38.1
AT110000	Burgenland	HEIH	Heifers High intensity	0.4	0.9
AT110000	Burgenland	HEIL	Heifers low intensity	0.4	0.9
AT110000	Burgenland	HEIR	Heifers fattening	1.7	2.7

⁶⁹ <https://www.capri-model.org/doku.php?id=start>

⁷⁰ <https://www.capri-model.org/lib/exe/fetch.php?media=docs:caprijan2022.pdf>

CAPRI_code	Name	Capri code	Explanation CAPRI code	LEVEL 2015 (1000 ha or heads)	LEVEL 2050 (1000 ha or heads)
AT110000	Burgenland	HENS	Laying hens	0.2	0.2
AT110000	Burgenland	MAIF	Fodder maize	4.9	4.8
AT110000	Burgenland	MAIZ	Grain Maize	19.8	3.4
AT110000	Burgenland	NECR	New energy crops	0.0	1.4
AT110000	Burgenland	NURS	Nursery plants	0.1	0.0
AT110000	Burgenland	OANI	Other animals	0.0	0.0
AT110000	Burgenland	OATS	Oats	3.1	0.7
AT110000	Burgenland	OCER	Other cereals (excl. rice)	3.0	1.7
AT110000	Burgenland	OCRO	Other final crop products	5.5	3.4
AT110000	Burgenland	OFAR	Other fodder on arable land	9.8	13.7
AT110000	Burgenland	OFRU	Other fresh fruits	0.1	0.1
AT110000	Burgenland	OOIL	Other oil seeds and oleaginous fruits	4.9	5.8
AT110000	Burgenland	OVEG	Other vegetables	3.0	4.8
AT110000	Burgenland	PIGF	Pig fattening	72.7	43.4
AT110000	Burgenland	POTA	Potatoes	0.7	3.1
AT110000	Burgenland	POUF	Poultry fattening	1.7	1.1
AT110000	Burgenland	PULS	Pulses	3.2	2.0
AT110000	Burgenland	RAPE	Rape and turnip rape	11.8	11.1
AT110000	Burgenland	RYEM	Rye	6.9	6.8
AT110000	Burgenland	SCOW	Suckler cows	2.6	1.8
AT110000	Burgenland	SETA	Set aside idling	10.0	9.8
AT110000	Burgenland	SHGF	Sheep and goat fattening	20.3	24.8
AT110000	Burgenland	SHGM	Sheep and goat for milk	20.8	24.7
AT110000	Burgenland	SOWS	Pig breeding	4.7	7.3
AT110000	Burgenland	SOYA	Soya beans	14.9	26.8
AT110000	Burgenland	SUGB	Sugar beet	2.9	5.2
AT110000	Burgenland	SUNF	Sunflower seed	3.4	0.2
AT110000	Burgenland	SWHE	Soft wheat	46.3	46.8
AT110000	Burgenland	TEXT	Textile crop	0.1	0.3
AT110000	Burgenland	TOMA	Tomatoes	0.0	0.1
AT110000	Burgenland	TWIN	Table wine	8.9	4.7
AT110000	Burgenland	UAAR	Utilised agricultural area	195.8	188.4

- 2) Give the final land demands generated in step 2) to the iCLUE model. This model simulates land use changes from 2015 to the final land use demands in 2050 using empirically quantified relations between land use and the driving factors combination (identified and discussed in chapters 4 and 5 of this report) with dynamic modelling of competition between land use types. The Capri land use codes were converted into land use classes, which could be matched with land classes originating from the combination of the Corine LandCover, EU crop map 2022, LUCAS, Forest management. Land use classes included and simulated in iCLUE: Built-up area, Maize, Cereals, Root crops, Other annual crops, Vineyards, Olive groves, Other Perennial crops, Grazed grassland & Pastures, Semi-natural & ungrazed grasslands, Managed forest, Unmanaged forest, Managed shrubland and Unmanaged

shrubland. Many natural land use classes such as Wetlands, Bare Soil, Water, Ice & Snow are left untouched.

- 3) Further process the iCLUE land use changes for the two scenarios (using the QUICKScan model) to KPIs and make an integrated sustainability or trade-off assessment for the whole EU at RALUC region level. Which KPIs are to be used is explained in the next sections. Results from QUICKScan are visualized in interactive maps, charts, trade off diagrams and a spider diagrams.

11.12. iCLUE modelling of 2050 land use changes for BAU and SA scenario

The integrated Conversion of Land Use and its Effects (iCLUE) model is the latest member of the CLUE model family (Kok et al., 2001; Veldkamp & Fresco, 1996; Verburg et al., 2002; Verburg & Overmars, 2009) and projects a future land use based on the allocation of territorial land use demands (Verweij et al., 2018). iCLUE applies a stepwise regression method to spatially project the allocation of future land use. The model needs the following inputs for the allocation procedure (see also Figure 6):

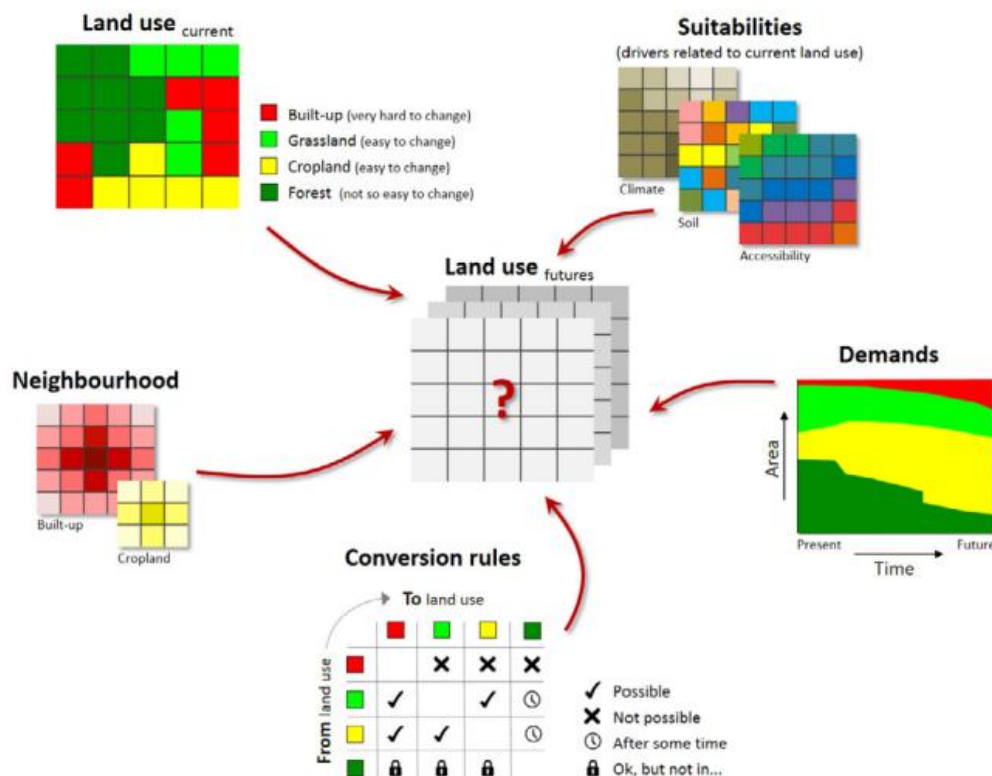


Figure 6 Inputs to iCLUE model (from Verweij et al., 2018).

- (1) **Current land use map:** For this study a land use map including a land use typology was created based on several spatial databases with agricultural land use and land management information in QUICKScan environment (Verweij et al., 2016) using knowledge rule sets. The base map was created as follows:

- (a) The start map was the Corine Land Cover (CLC) 2018 map. To specify the complex cultivation pattern classes the CLC, LUCAS, GLAD map (Zhao et al., 2022) was overlayed with the start map for the classes: annual, perennials, grassland and forest. The perennial class consists of perennials as present in the CLC 2018 map or annual crops with more than 30% tree cover as present in the Hansen et al. 2013 map. A 30% tree cover threshold was also applied to distinguish between shrubland and forest.
- (b) The previous map was then combined with the EU CropMap (European Union Joint Research Centre, 2022) to specify the agricultural land use classes towards crop type. The perennial classes were an exception to this change, as they were taken directly from the previous map.
- (c) The forest management map (Nabuurs et al., 2019) was overlayed with the created map to distinguish between managed and unmanaged forest in the base map.
- (d) With the grazing probability map of LUCAS (Eurostat, 2018) grazed grassland/pastures and semi- natural and ungrazed grassland was split up. Whereby a threshold of 60% grazing probability was seen as grazed grassland/pastures and the rest was semi- natural and ungrazed grassland. The same principle was applied to distinguish between grazed shrubland and non-managed shrubland. All these steps combined resulted in the RALUC base map with a typology as seen in Figure 7.



Figure 7 Legend of land use classes for base map 2020

It is important to remember the land use classes that iCLUE simulates. In Table 7 an overview is given of these at detailed level and a more aggregate level. The results are discussed in the following, referring either to aggregate or detailed land use levels.

Table 7 iCLUE land use type and groups modelled for 2050 in BAU and SA scenarios

Detailed iCLUE classes	Aggregate iCLUE group	Explanation
Built-up	Built-up	
Maize	Annual	Fodder and grain maize

Detailed iCLUE classes	Aggregate iCLUE group	Explanation
Cereals	Annual	Barley, wheat, oats, rice, etc.
Root crops	Annual	Potatoe, sugar beet, other root crops
Other crops	Annual	All other annuals e.g. oil crops, vegetables, nurseries, industrial annuals crops etc.
Vineyards	Perennial	Wine and table grapes
Olive groves	Perennial	Oil and table olives
Other permanent crops	Perennial	All other permanent crops e.g. citrus, apples, pears, nuts, perennial biomass crops,
Agroforestry	Agroforestry	Only located and modelled for Spain, Portugal & Italy based on CLC data.
Grazed grassland/pasture	Grazed grassland/pasture	
(semi)natural and ungrazed grasslands	(semi)natural and ungrazed grasslands	
Abandoned agriculture (unmanaged)	Abandoned agriculture (unmanaged)	becomes unmanaged (to natural) 2020-2050 - outcome of modelling
Managed forest	Managed forest	
Unmanaged forest	Unmanaged forest	
Grazed shrubland	Grazed shrubland	
non-managed shrubland	Non-managed shrubland	Abandoned agriculture goes to non-managed shrubland
Wetlands	Wetlands	
Water	Water	Remain stable
Ice & snow	Ice & snow	Remain stable

Table 8 Driver list used in iCLUE model to simulate land use changes towards 2050

Driver name	Category	Source 1	Source 2
Marginal Agricultural Land	Agricultural characteristics	Eupen et al., (2023). Europe's Maginal lands. https://storymaps.arcgis.com/stories/e57736ed9b9e4458b00356173edc00d6	
Intensive agriculture	Agricultural characteristics	Rega, C., Short, C., Pérez-Soba, M., & Paracchini, M. L. (2020). A classification of European agricultural land using an energy-based intensity indicator and detailed crop description. <i>Landscape And Urban Planning</i> , 198, 103793. https://doi.org/10.1016/j.landurbplan.2020.103793	
End of season	Agricultural characteristics	Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arsouze, T., Bergman, T., Bernardello, R., Boussetta, S., Caron, L.-P., Carver, G., Castrillo, M., Catalano, F., Cvijanovic, I., Davini, P., Dekker, E., Doblas-Reyes, F. J., Docquier, D., Echevarria, P., Fladrich, U., Fuentes-Franco, R., Gröger, M., v. Hardenberg, J., Hieronymus, J., Karami, M. P., Keskinen, J.-P., Koenigk, T., Makkonen, R., Massonnet, F., Ménégos, M., Miller, P. A., Moreno-Chamarro, E., Nieradzik, L., van Noije, T., Nolan, P., O'Donnell, D., Ollinaho, P., van den Oord, G., Ortega, P., Prims, O. T., Ramos, A., Reerink, T., Rousset, C., Ruprich-Robert, Y., Le Sager, P., Schmith, T., Schrödner, R., Serva, F., Sicardi, V., Sloth Madsen, M., Smith, B., Tian, T., Tourigny, E., Uotila, P., Vancoppenolle, M., Wang, S., Wårlind, D., Willén, U., Wyser, K., Yang, S., Yepes-Arbós, X., and Zhang, Q.: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6, <i>Geosci. Model Dev.</i> , 15, 2973–3020, https://doi.org/10.5194/gmd-15-2973-2022 , 2022.	
Fallow land	Agricultural characteristics	Eurostat. (2018). Land cover and use 2018. [data set]. https://ec.europa.eu/eurostat/web/lucas/database	
European parcel size	Agricultural characteristics	Weissteiner C, Garcia Feced C, Paracchini M. A new view on EU agricultural landscapes: Quantifying patchiness to assess farmland heterogeneity. <i>ECOLOGICAL INDICATORS</i> 61 (part 2); 2016. p. 317–327. JRC97835	
High nature value farming systems	Agricultural characteristics	European Environment Agency (n.d.). High Nature Value (HNV) farmland. [dataset] https://www.eea.europa.eu/en/datahub/datahubitem-view/1bd26e8f-8ea0-45e0-b6bf-9ed2baff5d28	
Cattle density	Agricultural characteristics	Gilbert, M., Nicolas, G., Cinardi, G. <i>et al.</i> Global distribution data for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks	

Driver name	Category	Source 1	Source 2
Goat density	Agricultural characteristics	in 2010. <i>Sci Data</i> 5 , 180227 (2018). https://doi.org/10.1038/sdata.2018.227	
Solar radiation	Climate characteristics	Global Solar Atlas. (n.d.). Solar radiation. https://globalsolaratlas.info/download	
Temperature seasonality	Climate characteristics	Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., & Kessler, M. (2017). Climatologies at high resolution for the earth's land surface areas. <i>Scientific Data</i> , 4(1), 170122. https://doi.org/10.1038/sdata.2017.122	Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., & Kessler, M. (2018). Data from: Climatologies at high resolution for the earth's land surface areas (Version 1) [dataset]. https://doi.org/10.5061/DRYAD.KD1D4
Drought index 2020	Climate characteristics	Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arsouze, T., Bergman, T., Bernardello, R., Boussetta, S., Caron, L.-P., Carver, G., Castrillo, M., Catalano, F., Cvijanovic, I., Davini, P., Dekker, E., Doblas-Reyes, F. J., Docquier, D., Echevarria, P., Fladrich, U., Fuentes-Franco, R., Gröger, M., v. Hardenberg, J., Hieronymus, J., Karami, M. P., Keskinen, J.-P., Koenigk, T., Makkonen, R., Massonnet, F., Ménégos, M., Miller, P. A., Moreno-Chamarro, E., Nieradzick, L., van Noije, T., Nolan, P., O'Donnell, D., Ollinaho, P., van den Oord, G., Ortega, P., Prims, O. T., Ramos, A., Reerink, T., Rousset, C., Ruprich-Robert, Y., Le Sager, P., Schmith, T., Schrödner, R., Serva, F., Sicardi, V., Sloth Madsen, M., Smith, B., Tian, T., Tourigny, E., Uotila, P., Vancoppenolle, M., Wang, S., Wärlind, D., Willén, U., Wyser, K., Yang, S., Yepes-Arbós, X., and Zhang, Q.: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6, <i>Geosci. Model Dev.</i> , 15, 2973–3020, https://doi.org/10.5194/gmd-15-2973-2022 , 2022.	
Drought index 2030	Climate characteristics		
Drought index 2050	Climate characteristics		
Growing season 2020	Climate characteristics		

Driver name	Category	Source 1	Source 2
Growing season 2030	Climate characteristics	Eupen et al., (2023). Europe's Maginal lands. https://storymaps.arcgis.com/stories/e57736ed9b9e4458b00356173edc00d6	
Growing season 2050	Climate characteristics		
Precipitation of driest month 2010	Climate characteristics	Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., & Kessler, M. (2017). Climatologies at high resolution for the earth's land surface areas. Scientific Data, 4(1), 170122. https://doi.org/10.1038/sdata.2017.122	Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., & Kessler, M. (2018). Data from: Climatologies at high resolution for the earth's land surface areas (Version 1) [dataset]. https://doi.org/10.5061/DRYAD.KD1D4
Precipitation of driest month 2041	Climate characteristics		
Precipitation seasonality 2010	Climate characteristics		
Precipitation seasonality 2041	Climate characteristics		
Precipitation of Driest Quarter 2010	Climate characteristics		
Precipitation of Driest Quarter 2041	Climate characteristics		
Precipitation of Warmest Quarter 2010	Climate characteristics		
Precipitation of Warmest Quarter 2041	Climate characteristics		
Precipitation of Coldest Quarter 2010	Climate characteristics		
Precipitation of Coldest Quarter 2041	Climate characteristics		
Mean Diurnal Range 2010	Climate characteristics		
Mean Diurnal Range 2041	Climate characteristics		
Isothermality 2010	Climate characteristics		
Isothermality 2041	Climate characteristics		
Temperature Seasonality 2010	Climate characteristics		
Temperature Seasonality 2041	Climate characteristics		
Temperature Annual Range 2010	Climate characteristics		

Driver name	Category	Source 1	Source 2
Temperature Annual Range 2041	Climate characteristics		
Mean Temperature of Wettest Quarter 2010	Climate characteristics		
Mean Temperature of Wettest Quarter 2041	Climate characteristics		
Mean Temperature of Driest Quarter 2010	Climate characteristics		
Mean Temperature of Driest Quarter 2041	Climate characteristics		
Frost change frequency 2010	Climate characteristics		
Frost change frequency 2041	Climate characteristics		
Precipitation of driest month Europe	Climate characteristics		
Precipitation of driest month 1ha	Climate characteristics		
Tree cover percent 2010	Forest characteristics	Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., and Townshend, J.R.G., 2013, High-Resolution Global Maps of 21st-Century Forest Cover Change: <i>Science</i> , v. 342, no. 6160, p. 850-853	
Population density 2018	Population characteristics	Eurostat. (2018). Population density. [data set] https://ec.europa.eu/eurostat/databrowser/view/tps00003/default/table	
Average eroded soil organic carbon	Soil characteristics	Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., & Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. <i>Environmental Science & Policy</i> , 54, 438–447. https://doi.org/10.1016/j.envsci.2015.08.012	
Cation exchange capacity	Soil characteristics	Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E., and Rossiter, D.: SoilGrids 2.0: producing soil information for the globe with quantified spatial uncertainty, <i>SOIL</i> , 7, 217–240, 2021.	
Grade of a sub-soil being acid e.g. having a pH < 5 and low BS	Soil characteristics		

Driver name	Category	Source 1	Source 2
Available soil water capacity (volumetric fraction) with FC = pF 2.5	Soil characteristics		
Saturated water content (volumetric fraction) θ_{res} for depth 0 cm	Soil characteristics		
Depth to bedrock (R horizon) up to 200 cm	Soil characteristics		
Probability of occurrence of R horizon	Soil characteristics		
Absolute depth to bedrock	Soil characteristics		
Cation Exchange Capacity of soil	Soil characteristics		
Weight percentage of the clay particles (<0.0002 mm)	Soil characteristics		
Volumetric percentage of coarse fragments (>2 mm)	Soil characteristics		
Histosols probability cumulative	Soil characteristics		
Soil organic carbon density	Soil characteristics		
Soil organic carbon content	Soil characteristics		
pH index measured in water solution	Soil characteristics		
Weight percentage of the silt particles (0.0002–0.05 mm)	Soil characteristics		
Texture class (USDA system)	Soil characteristics		
Global Equilibrium Water Table Depth	Soil characteristics	Fan, Y., Li, H., & Miguez-Macho, G. (2013). Global Patterns of Groundwater Table Depth. <i>Science</i> , 339(6122), 940–943. https://doi.org/10.1126/science.1229881	

Driver name	Category	Source 1	Source 2
Distance to cities	Spatial land distribution	WorldPop.org	
Distance to coast	Spatial land distribution		
Distance to rivers	Spatial land distribution		
Distance to roads	Spatial land distribution		
Distance to WPDA	Spatial land distribution		
Landscape Mosaic Percentage	Spatial land distribution	https://www.eea.europa.eu/en/datahub/datahubitem-view/a55d9224-a326-4cb1-9b9c-3a324520341a	
Digital Elevation Model (DEM)	Topography	Copernicus. (n.d.). https://doi.org/10.5270/ESA-c5d3d65	
Ruggedness	Topography		
Slope	Topography		
Lowest NDVI of the season	Vegetation characteristics	Döscher, R., Acosta, M., Alessandri, A., Anthoni, P., Arsouze, T., Bergman, T., Bernardello, R., Boussetta, S., Caron, L.-P., Carver, G., Castrillo, M., Catalano, F., Cvijanovic, I., Davini, P., Dekker, E., Doblas-Reyes, F. J., Docquier, D., Echevarria, P., Fladrich, U., Fuentes-Franco, R., Gröger, M., v. Hardenberg, J., Hieronymus, J., Karami, M. P., Keskinen, J.-P., Koenigk, T., Makkonen, R., Massonnet, F., Ménégos, M., Miller, P. A., Moreno-Chamarro, E., Nieradzick, L., van Noije, T., Nolan, P., O'Donnell, D., Ollinaho, P., van den Oord, G., Ortega, P., Prims, O. T., Ramos, A., Reerink, T., Rousset, C., Ruprich-Robert, Y., Le Sager, P., Schmith, T., Schrödner, R., Serva, F., Sicardi, V., Sloth Madsen, M., Smith, B., Tian, T., Tourigny, E., Uotila, P., Vancoppenolle, M., Wang, S., Wårlind, D., Willén, U., Wyser, K., Yang, S., Yepes-Arbós, X., and Zhang, Q.: The EC-Earth3 Earth system model for the Coupled Model Intercomparison Project 6, Geosci. Model Dev., 15, 2973–3020, https://doi.org/10.5194/gmd-15-2973-2022 , 2022.	
NDVI mean	Vegetation characteristics		
Start of the growing season	Vegetation characteristics		

Driver name	Category	Source 1	Source 2
Vegetation Height	Vegetation characteristics	P. Potapov, X. Li, A. Hernandez-Serna, A. Tyukavina, M.C. Hansen, A. Kommareddy, A. Pickens, S. Turubanova, H. Tang, C.E. Silva, J. Armston, R. Dubayah, J. B. Blair, M. Hofton (2020) Mapping and monitoring global forest canopy height through integration of GEDI and Landsat data. Remote Sensing of Environment, 112165. https://doi.org/10.1016/j.rse.2020.112165	
Inundation occurrence	Water characteristics	Dottori F; Salamon P; Alfieri L; Bianchi A; Feyen L; Hirpa F; Lorini V. Flood Hazard Maps at European and Global Scale. European Commission; 2016. JRC103765	

- (2) **Land use suitability:** Land use suitability refers to how appropriate a particular land use class is for a specific location, considering the land use drivers which indicate to area's characteristics (i.e. soil, climate, accessibility and terrain). For a full list of the used characteristics see Table 8.
- (3) **Areal demand for every land use class:** Per RALUC region the future demands of the land uses were calculated for both the BaU and the SA scenario 2050
- (4) **Conversion rules:** Conversion settings specific to each land use type affect the timing and interactions within the simulations. These settings are determined by conversion elasticities and land use transition sequences. Conversion elasticity reflects the likelihood of land use change, where a cell value of 1 permits conversion, and a value of 0 means conversion is not possible. The land use transition sequences are outlined in a conversion matrix, indicating which land use types an area can change into and which ones it cannot. The transition sequences include categories such as: conversion possible, conversion impossible, conversion possible after a specified time, and conversion (im)possible in specific areas.
- (5) **Neighbouring land use:** The allocation suitability is affected by the surrounding land use of the cell. For instance, built-up areas are more likely to expand adjacent to existing built-up areas rather than developing in new locations.

11.13. Developing the sustainability impact framework with KPIs

The project team performed an assessment of existing indicator frameworks to select the approach and the appropriate set of indicators (referred to as Key Performance Indicators - KPIs) for assessing the impact of relevant policies. The assessment of KPIs is explained in Annex 14.

To develop the sustainability impact framework and select the relevant KPIs the following activities were undertaken:

1. A review of literature on sustainability assessment frameworks, providing insights on how to operationalise the framework for a) the assessment of sustainability in the Business as Usual scenario, in terms of the agricultural production, energy production, forestry, nature conservation domains, and b) the assessment under a Sustainable Agriculture (SA) scenario reflecting realisation of all EU policies aims in the Farm to Fork strategy related to agriculture sustainability and other policy aims covered integrated under the Green Deal, i.e. the land use optimisation (in response to research question Q4.2).
2. The schematization of the relations between individual relevant policies, their targets (expressed either quantitatively or, in some cases, only qualitatively); the measures (e.g. good farming practices) expected to achieve the above objectives and targets; and finally the impacts (positive and negative) both at farm and higher, aggregated level, above

all in terms of land use but more in general in terms of social, economic, environmental effects.

3. KPIs definitions, criteria, thresholds are then formulated in the form of impact matrices to make the framework operational.

A distinction was made between:

- **Target KPIs** that correspond more directly to the relevant policy targets.
- **Condition KPIs** that reflect the necessary premises for the implementation of a policy.
- **Pressure KPIs** reflecting the impacts on the bio-physical, socio-economic, and land use spheres.

The selected KPIs and how they are calculated are further discussed in Annex 14.

In addition to the KPIs a further and final level of analysis was introduced to reflect the overall capacity of RALUC regions, and their communities to respond to policies, or in other words, a “**carrying capacity**” of a given territory. Also further explained in chapter 7 and Annex 14.

The sustainability assessment framework helps to understand synergies and trade-offs between KPIs as result of land use changes coming from implementation of the policy instruments for a sustainable agriculture in 2050. The interpretation is supported by the outcomes of the work done in RALUC on policy instruments and presented in chapter 7 and Annex 11 as well as through the interaction with the case study stakeholders, as summarized in Annex 12.

Stakeholder workshops in the 12 case studies were used to collect the views on the implementation of Farm to Fork policy goals and how they would work out in the case studies. Stakeholder were also asked in these workshops to validate land use change drivers. The stakeholder's input was used to implement of the Farm to Fork policy goals in the Sustainable Agriculture (SA) scenario and further translate in land demands given to iCLUE model to predict the final 2020-2050 land use changes.

11.14. Review of policy instruments for optimised land use

The following steps are undertaken to generate policy recommendations on how to optimize land use to comply with ambitions for sustainable agriculture in the Farm to Fork Strategy:

1. Review existing policy instruments that have driven the land use trends in rural areas and in agricultural land at EU level in the last 30 years. This is presented in chapter 7 of main report;
2. Identify the nature of trends to be reversed: the magnitude, drivers, variability and barriers to change and how pressures on agricultural land are anticipated to evolve into the future;

3. Identify the opportunities, limitations and gaps in the existing policy framework in Europe. This includes a gap analysis of policy levers and mechanisms that already exist. The gaps relate to drivers that lead to changes in land use, that are unsustainable or compete with agriculture, or to drivers that create synergies with agriculture.
4. Define future policy needs and changes or gap filling in policies and develop proposals and recommendations for policy action. These are made accessible in a decision support tool that starts from the identified gaps and intervention needs.

The outcomes of the policy review and gap analysis are integrated with the directions for optimal land use, identified in the scenario analysis and taking account of the carrying capacities of the regions. This results in needs and opportunities for policy action in regions with characteristics of the territorial typology that are represented by the case studies.

12. Annex 3 Territorial typology of regions in EU27

The territorial typology assumes a central position in the project framework (Figure 8). It is developed under the following requirements:

- reflect the key aspects of sustainable (agricultural) land use;
- be applicable in the policy domain;
- capture the land use dynamics at the regional and EU-scale.



Figure 8 Position of the rural territorial typology in the framework of the project

The typology is produced based on three dimensions: land use dynamics, environment and socio-economic characteristics. The typology is hierarchical, with at the highest level the land use dynamics and at a lower level the socio-economic dimension which is driving land use dynamics. It is an expert-based typology: by means of expert elicitation, variables (and their thresholds) representing the different dimensions of the typology are selected and classes are defined.

The typology is arranged in NUTS3-administrative regions. Data used to elaborate the typology are in grids (CLC-change data at 100 m resolution, Eurostat population density data) or polygons at NUTS3-level (Eurostat GDP or population density change data). All data are aggregated to the level of NUTS3-regions to define the typology class for each NUTS3 region.

The typology is developed for the EU27 excluding urban areas and marine water. A mask based on CLC2000 is used to extract the urban areas (CLC level 2, class 11, urban fabric) and marine waters (CLC level 2, class 52, marine waters) in the processing and definition of the different classes for the typology.

The general steps in the development of the typology are outlined in Figure 9 and explained below.

Step 1: selection of variables and data harmonization

The goal of this step is to harmonize input datasets into one spatial reference system at the highest detailed spatial resolution possible. It is expected that a spatial resolution of 1 km² is feasible given the experience within the project with the development of previous typologies. A spatial resolution of km² is also used in administrative divisions provided for policy assessments by Eurostat (countries, Local Administrative Units (LAUs) compatible with NUTS). The minimum detail of the used datasets is NUTS3 level.

The variables and drivers in the typology are selected based on magnitudes of change in land cover flows, on expertise available in the project and on a literature review. This delivered an initial selection of variables and a prioritization of variables. Variables are reviewed before Step 2 by experts from the EC. Change layers are calculated for specific variables and based on input years T1 (≥ 1990) and T2 (≥ 2018) where possible. In some cases, the 1990-2018 period is adapted to a smaller period when data is not available (e.g. harmonised CLC changes for period 2000-2018).

Step 2: cluster analysis and supervision of cluster results

A robust typology is proposed to summarize the six main usage domains of the typology (shown in Figure 8). The classification of variables is based on expert knowledge, relevance for the study and class thresholds mentioned in other studies. The main aim of the clustering of variables in strata is to show the main diversity of land use change and its drivers in Europe (step 2a, Figure 9).

Step 2b examines whether the number of dimensions in the typology can be reduced, following the approach of Van Eupen et al. (2012). The aim is to simplify the derived clustering to a maximum of three to four dimensions, for example: land use intensity, rurality, agricultural type, and biogeography. This is done by combining the dimensions in a merged dataset of the key variables. See for more details next.

Step 3: typology of land use diversity in Europe

Findings on the usability of the typology in the case studies will be used to improve the typology (see Figure 9). The data set that initially comes from step 2 (step 2b in Figure 9) is used to delineate the case study areas (step 3a). In step 3b, the outcomes of the case studies are used to improve the territorial typology of regions by feeding back into Step 2.

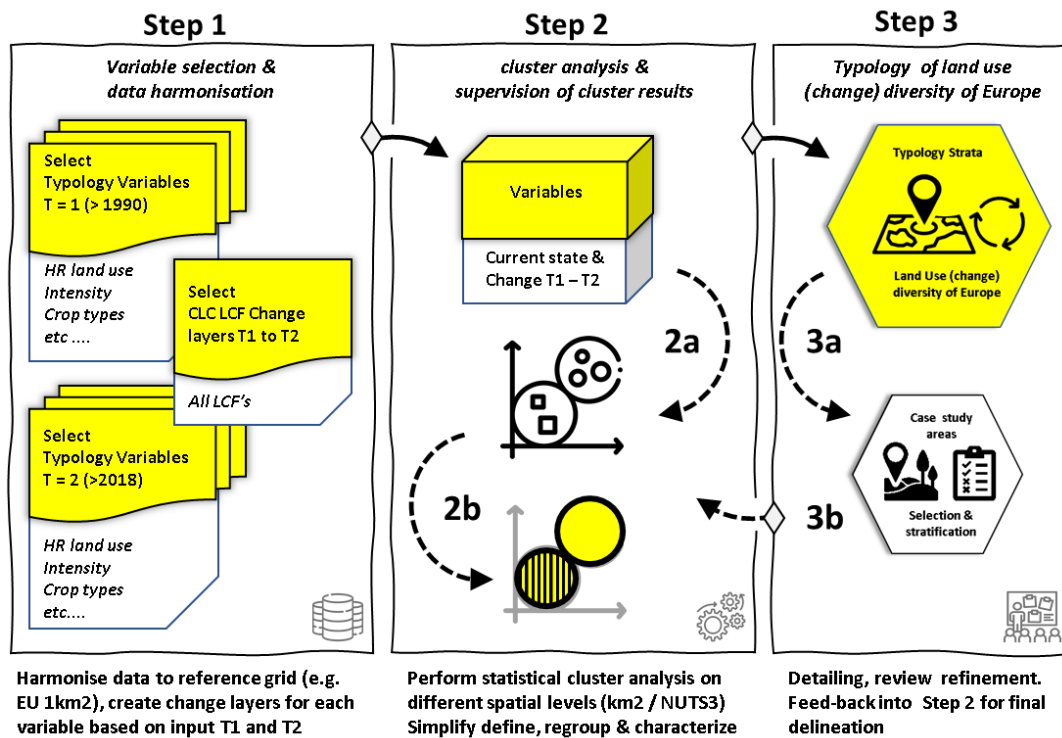


Figure 9 Methodological scheme of the development of the typology.

1. Selection of variables

The selection of variables to build the typology is along the following three dimensions: i. the land use dynamics dimension, ii. the environmental dimension and iii. the socio-economic dimension. Pre-requisites for the selection are that the data should be present at least at NUTS3-level (or more detailed) and should have as reference the 2000-2018 period.

The environmental dimension is about *where* the NUTS3-region is located in relation to biophysical or environmental variables. The land use dynamics dimension shows *what* type of processes are taking place and are relevant in relation to the agricultural domain and how dynamic the NUTS3 region is. The socio-economic dimension gives an indication *why* certain land use dynamics take place.

Environmental dimension

The dataset used for the environmental dimension is the Environmental zones 2018 - version 1.0, June 2020. This dataset is based on the Environmental Stratification of Europe (EnS) dataset (Metzger, 2018) and consists of 13 environmental zones. The environmental zones are relatively homogeneous regions regarding climate variables, elevation data and the geographical location (northing and oceanicity).

For this study, the environmental zones are aggregated to five larger zones (environmental Regions = ENZ):

- Alpine (Alpine South)
- Atlantic (Atlantic North, Central and South)
- North (Alpine North, Boreal and Nemoral)

- Continental (Continental and Pannonian)
- Mediterranean (Mediterranean Mountains, North and South).

Land use dynamics dimension

The land use dynamics dimension is defined by the degree of dynamics and the dominant land use process. CORINE Land Cover (CLC) provides harmonised European wall-to-wall land cover/use data at 6- yearly intervals. The land use dynamics for the period 2000-2018 are calculated by EEA's Land and Ecosystem Accounting system (LEAC) after harmonizing the CLC timeseries from 2000 onwards. The reason for not using the CLC1990 as starting point, is that this dataset was not taken into account in this harmonisation process (Ivits et al., 2020). The CLC changes between 2000-2018 are grouped in land cover flows (LCFs), that describe specific processes. We used the LEAC system as basis to group our land use process into the following 6 classes that are relevant for the agricultural domain:

- Land take by urban expansion
- Land take by afforestation (either from agricultural or other non-agricultural land)
- Land take by nature creation (but very small and likely not to be captured by LCFs)('rewilding')
- Extensification of agriculture; please note that this class may also cover some shifts to land abandonment
- Intensification of agricultural land
- No relevant changes

The dominant land use process is the process which occupies the largest area of the above mentioned land use processes within a NUTS3 region (Figure 10).

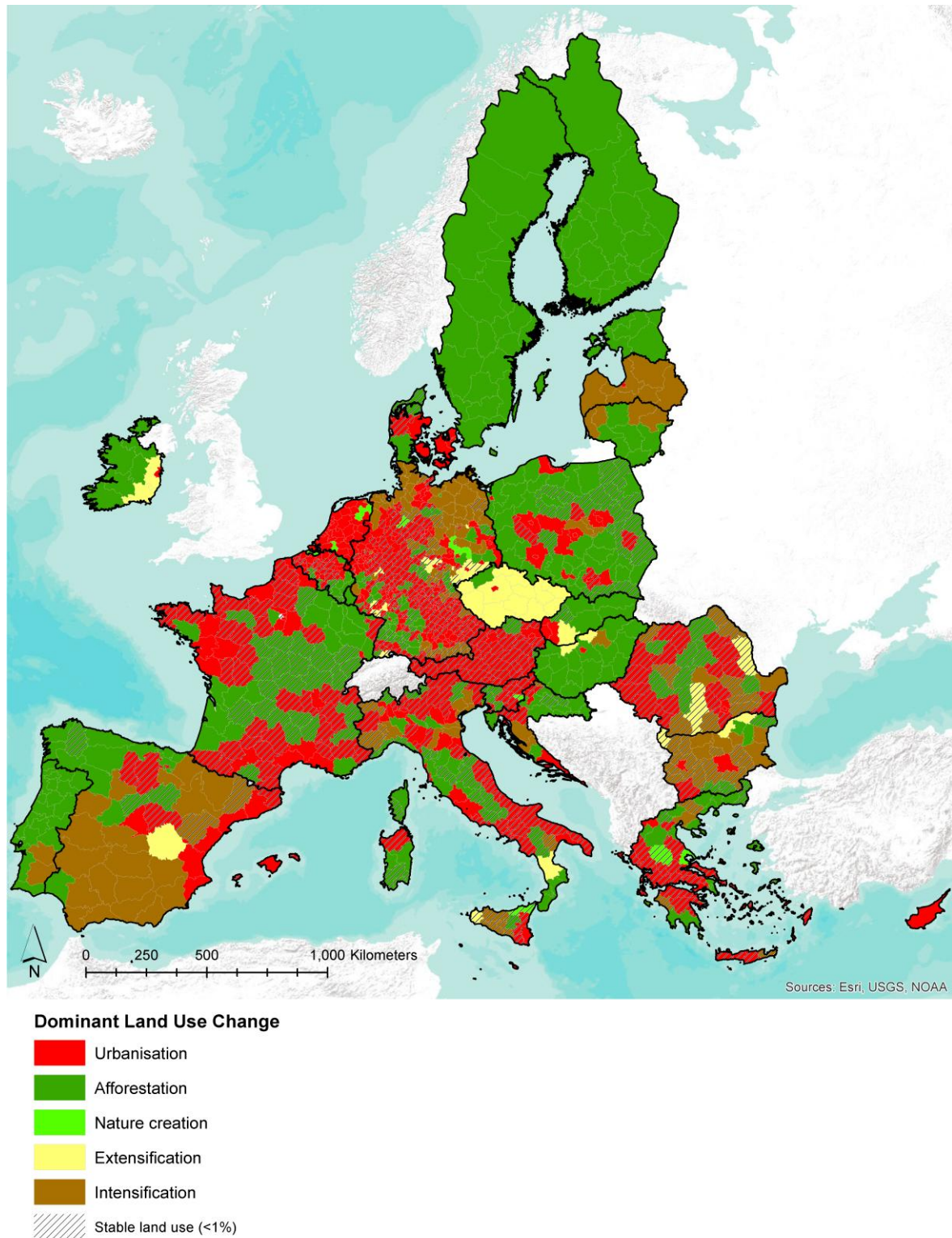


Figure 10 Dominant land use changes (based on LEAC 2000-2018)

Socio-economic dimension

To define the socio-economic dimension, we use the indicators remoteness (or accessibility), population density, population change density and GDP density.

Remoteness

The remoteness or accessibility is based on average travelling time to cities of different sizes (populations of 10.000, 50.000, 100.000, 500.000, > 1 million) and ports using data from the Malaria Atlas project (<https://data.malariaatlas.org/>). The accessibility of each NUTS3 region is classified into regions with high accessibility (less than 45 minutes travel time), moderate or low accessibility (more than 75 minutes of travel time). 45 minutes is seen as a threshold for commuting traffic.

Population density and change

The Eurostat 2000-2021 population data makes it possible to define for each NUTS3 region the population density and to indicate if the population is increasing, stable or decreasing. The population density is based on gridded 2021 population data from Eurostat. The urban areas (CLC level 2 class 11 urban fabric) and marine waters (CLC level 2 class 5 marine waters) are extracted before calculating the population density. NUTS3 regions with more than 150 persons per ha are designated as densely populated, NUTS3 regions with less than 40 inhabitants per ha are sparsely populated. The threshold of 40 inhabitants/ha is two times the threshold Eurostat uses for sparsely populated or rural areas.

Population density change is based on Eurostat NUT3-data from the period 2000-2021. The population is decreasing in our study if the percentage of change is below 0% (percentage of change per ha), while a NUTS3 region with increasing population is a region with more than 10% increase per ha.

GDP density

From the Gross Domestic Product (GDP) data of Eurostat (2000-2021), the Euro/inhabitant is used. The average over the period 2000-2021 is used. Each NUTS3 region is classified as a region with low (GDP/inhabitant < 12500 Euro), moderate or high GDP (GDP/inhabitant >25000 Euro).

Selection of classifying variables

The variables selected for the territorial typology are listed in

Table 9. The underlined layers are used for the typology. Some of the variables were not taken into consideration for the final typology as they were not adding much additional information and/or they made the typology too complex. Accessibility or remoteness (travel time) and the environmental zones were not used as classifying variables for the typology as they did not add more information as compared to population density. These variables were used in the characterization of the typology. They are calculated for each NUTS3 region in the EU-27. The classes for the selected variables are presented in Table 10.

Table 9 Variables selected for the territorial typology. Underlined variables are used as classifying variables for the typology.

Environmental dimension	
	<u>Dominant ENZ</u>
Land use dynamics dimension	
	Total area of relevant changes
	Net area of relevant changes (masked)
	<u>Dynamics class</u>
	% and area urban expansion
	% and area afforestation
	% and area nature creation
	% and area extensification agriculture
	% and area intensification agriculture
	% and area non relevant changes
	<u>Dominant process</u>
Socio-economic dimension	
	Accessibility NUTS3 region
	<u>Remoteness/accessibility class</u>
	Population 2021
	<u>Population density class</u>
	Population 2000
	Population 2021
	Population change
	Population density i.e. change/area
	<u>Population change class</u>
	GDP (Euro/inhabitant)
	<u>GDP class</u>

Table 10 Classification of variables used in the typology.

Legend typology layers	Classes
<u>Dominant ENZ</u>	ALP, ATL, NOR, CON or MED
<u>Dynamics class</u>	dynamic or stable
<u>Dominant process</u>	urbanisation, afforestation, nature creation, extensification or intensification agriculture
<u>Remoteness/accessibility class</u>	high, moderate or low
<u>Population density class</u>	sparsely, moderately and densely populated
<u>Population change/dynamic class</u>	increasing, decreasing or stable
<u>GDP class</u>	high, moderate or low

2. Definition of final typology layers and cluster analysis

The definition of the typology and the clustering has as main focus the land use dynamics in the agricultural domain. Most important for building the typology are the land use dynamics (% of land occupied by relevant land use changes) and the dominance of specific land use change processes as described above. At a second level the variables population density, population dynamics and GDP of the socio-economic dimension define the clusters.

3. Definitions of RALUC types per dominant land use change process

Urbanisation

The NUTS3 regions where urbanisation is the dominant process are grouped into 7 types (U-1a, U-1b, U-1c, U-1d, U-2a, U-2b and U-2c) on basis of the combination of population density (3 classes: dense, moderate and moderate or sparse), population change (2 classes: increase or stable and decrease) and GDP (3 classes: high, moderate or low and high, moderate or low).

U-1a: NUTS3 regions where urbanisation is dominant process with dense population density, stable or increasing population and a relatively high GDP.

U-1b: NUTS3 regions where urbanisation is dominant process with dense population density, stable or increasing population and a moderate or low GDP.

U-1c: NUTS3 regions where urbanisation is dominant process with dense population density, decreasing population and a relatively high GDP.

U-1d: NUTS3 regions where urbanisation is dominant process with dense population density, decreasing population and a moderate or low GDP.

U-2a: NUTS3 regions where urbanisation is dominant process with moderate population density, stable or increasing population and a relatively high GDP.

U-2b: NUTS3 regions where urbanisation is dominant process with moderate or sparse population density, stable or increasing population and a moderate or low GDP.

U-2c: NUTS3 regions where urbanisation is dominant process with moderate or sparse population density, decreasing population and a high, moderate or low GDP.

Afforestation

NUTS3 regions where afforestation is the dominant process are grouped into 10 types (A-1a, A-1b, A-1c, A-2a, A-2b, A-2c, A-2d, A-3a, A-3b and A-3c). The 10 types are the result of the combination of 3 population density classes (dense,

moderate and sparse), 2 population change classes (increase or stable and decrease) and 5 GDP classes (high, low, high or moderate, moderate or low and high, moderate or low).

A-1a: NUTS3 regions where afforestation is the dominant process with dense population density, stable or increasing population and a relatively high GDP.

A-1b: NUTS3 regions where afforestation is the dominant process with dense population density, stable or increasing population and a moderate or low GDP.

A-1c: NUTS3 regions where afforestation is the dominant process with dense population density, decreasing population and a high, moderate or low GDP.

A-2a: NUTS3 regions where afforestation is the dominant process with moderate population density, stable or increasing population and a relatively high GDP.

A-2b: NUTS3 regions where afforestation is the dominant process with moderate population density, stable or increasing population and a moderate or low GDP.

A-2c: NUTS3 regions where afforestation is the dominant process with moderate population density, decreasing population and a high or moderate GDP.

A-2d: NUTS3 regions where afforestation is the dominant process with moderate population density, decreasing population and a low GDP.

A-3a: NUTS3 regions where afforestation is the dominant process with sparse population density, stable or increasing population and a high, moderate or low GDP.

A-3b: NUTS3 regions where afforestation is the dominant process with sparse population density, decreasing population and a relatively high GDP.

A-3c: NUTS3 regions where afforestation is the dominant process with sparse population density, decreasing population and a moderate or low GDP.

Extensification of agriculture

Two type of NUTS3 regions are discerned where extensification of agriculture is the dominant process (E-1a and E-1b). Only population change is the discriminator between both group of regions. Population density and GDP are not having any influence/impact on the grouping of NUTS3 regions.

E-1a: NUTS3 regions where extensification of agriculture is the dominant process with dense, moderate or sparse population density, stable or increasing population and a high, moderate or low GDP.

E-1b: NUTS3 regions where extensification of agriculture is the dominant process with dense, moderate or sparse population density, decreasing population and a high, moderate or low GDP.

Intensification of agriculture

The NUTS3 regions where intensification of agriculture is the dominant process are grouped into 7 types (I-1a, I-1b, I-2a, I-2b, I-2c, I-2d and I-3a). The 7 types are the result of the combination of four population density classes (dense, moderate, sparse and moderate or sparse), 2 population change classes

(increase or stable and decrease) and four GDP classes (high, high or moderate, moderate or low and high, moderate or low).

I-1a: NUTS3 regions where intensification of agriculture is the dominant process with dense population density, stable or increasing population and a high or moderate GDP.

I-1b: NUTS3 regions where intensification of agriculture is the dominant process with dense population density, decreasing population and a relatively high GDP.

I-2a: NUTS3 regions where intensification of agriculture is dominant process with moderate or sparse population density, stable or increasing population and a relatively high GDP.

I-2b: NUTS3 regions where intensification of agriculture is dominant process with moderate or sparse population density, stable or increasing population and a moderate or low GDP.

I-2c: NUTS3 regions where intensification of agriculture is dominant process with moderate population density, decreasing population and a relatively high GDP.

I-2d: NUTS3 regions where intensification of agriculture is dominant process with moderate population density, decreasing population and a moderate or low GDP.

I-3a: NUTS3 regions where intensification of agriculture is dominant process with sparse population density, decreasing population and a high, moderate or low GDP.

Nature creation

Only there is one type of NUTS3 regions where nature creation is the dominant process (N-1). These 8 NUTS3 regions are regions where population density is classified as dense or moderate, population change as increase or decrease and GDP as high or low.

N-1: NUTS3 regions where nature creation is the dominant process with dense or moderate population density, increasing or decreasing population and a high or low GDP.

4. Selection of regions for case studies

Based on the typology and the number of RALUC types present per environmental zone, the following list of RALUC types was generated to select case study regions from:

- Alpine (4 types): stable urbanisation (U-2c) or stable afforestation types (A-2a/2c or A-3a types)
- Atlantic (6 types): dynamic urbanisation (U-1a/U-1c), dynamic afforestation (A-2a/A-2c/A3a) and dynamic nature creation (N-1)
- Continental (8 types): dynamic afforestation (A-2d), dynamic/stable intensification (I-2c resp. I-2d, I-3a), dynamic extensification (E-1b), stable urbanisation (U-2a/U-2c)

- North (5 types): dynamic afforestation (A-2a, A-3a/3b/3c), dynamic intensification (I-3a)
- Mediterranean (5 types): dynamic intensification (I-2b), stable urbanisation (U-2b/U-2c), dynamic afforestation (A-3c/A2a)

Based on the selection criteria discussed in chapter 2 and above, a final list of 12 case study regions was drawn up. The selected regions are presented in Table 11 and summarized below. Descriptions of the case study regions are given in Annex 6.

- Following the RALUC classification, the case studies (CS) were selected in 12 different EU countries.
- In the Mediterranean environmental zone (ENZ) four CSs are located, in both the Continental and Atlantic ENZ three CSs and in the both the North and the Alpine ENZ one CS is selected.
- In relation to land use change dynamics, we selected 7 dynamic and 5 stable regions.
- Since afforestation is the most frequent type in the RALUC typology, 5 of the 12 CSs are of this type, followed by 3 CS with intensification as the dominant land use change, 2 CS with urbanisation, and finally one CS in the extensification class and one in the nature creation class.
- As to population density, there are 2 CS with high population density, 5 CS with very low (sparse) population density and the remainder 5 have a moderate density. The 2 densely populated CS also have an increasing population and the remainder CS have either a stable (4) or a decreasing population (6).
- The GDP level is high in half of the selected CS, moderate in 3 and low in the remainder 3 CS.
- There are 5 CS with a remote location, so low accessibility, 5 CS are moderately accessible and 2 central, overlapping with the 2 CS with dense population.

Table 11 Selected case study regions and overview of characteristics and scoring in relation to the wish list of the Steering Group

Region name & code	Country	ENZ	Code RALUC type: code - stable/dynamic	Dominant Land use change	Population density	Population change 2000-2021)	GDP	Accessibility	Advanced bioeconomy activities	Abandonment	Biogas (done ride)	Agro-PV	Wind - mills
Arr. Sint-Niklaas	Belgium	Atlantic	U-1a dynamic	Urbanisation	dense	increase	high	high	Yes	No	Yes	Yes	Yes
Montana	Bulgaria	Continental	I-3a stable	Intensification	sparse	decrease	low	low	No	Yes	No	Yes	Yes
Wittenberg	Germany	Continental	I2c dynamic	Intensification	moderate	decrease	high	moderate	Yes	Yes	Yes	Yes	Yes
Imathia	Greece	Mediterranean	U-2c stable	Urbanisation	moderate	decrease	low	moderate	No	Yes	Yes		Yes
Albacete	Spain	Mediterranean	I-2d dynamic	Intensification	sparse	stable	moderate	low	No	Yes	Yes	Yes	Yes
Hautes Alpes	France	Alpine	A-3a stable	Afforestation	sparse	stable	high	Moderate	No	Yes	No	No	No
Šibensko-kninska županija	Croatia	Mediterranean	A-3c dynamic	Afforestation	sparse	decrease	moderate	low	No	Yes	No	Yes	Yes
West Ireland	Ireland	Atlantic	A-2a dynamic	Afforestation	Moderate	stable	high	moderate	Yes	Yes	Yes	No	Yes
Siena province	Italy	Mediterranean	A-2a stable	Afforestation	moderate	stable	high	moderate	No	Yes	Yes	Yes	No
Šiaulių Apskritis	Lithuania	North	A-3c dynamic	Afforestation	Sparse	decrease	Moderate	Low	No	Yes	No	No	No
Zuid-west-Drenthe	Netherlands	Atlantic	N1 dynamic	Nature creation	dense	increase	high	high	No	No	Yes	No	Yes
Argeș	Romania	Continental	E-1b stable	Extensification	moderate	decrease	low	low	Yes	Yes	No	Yes	No

13. Annex 4 Guidelines for case study implementation

Study on competition for land use and sustainable farming
REFERENCE: AGRI/2022/OP/0005

Guidance document for regional case studies

Version 02

January 2024

<name of organisation and responsible carrying out the case study + LOGO>

Address:

Phone:

E-mail:

Preamble

This document contains the guidance for the execution of your case study. It is also the template for reporting the results of the regional case study.

Objectives of the case study and data to be collected

This document is the template for data collection for a regional case study (sub-national) as part of an EU-wide *Study on competition for land use and sustainable farming*, commissioned by the European Commission, DG Agri (for further details see Box 1). The aim of the regional case studies is to collect detailed information at the regional level to provide a more detailed understanding of:

- relationships between drivers (or combinations of drivers) and land use transitions;
- future drivers and policy instruments to support sustainable agriculture.

Box 1: Background of the study:

A diverse range of drivers affects rural areas. That is why the European Commission announced in the action plan of the communication for a *Long-term vision for rural areas* that a study on land use linked to sustainable farming will be developed.

This study is part of the 'stronger rural areas' block of actions, which aims to support rural communities to develop integrated policy solutions which are tailored to their local area. This study will in particular examine land use competition and assess how it can further incentivise optimal land use planning and zoning.

Objectives of the study

The overall aim of the study is to provide a comprehensive analysis of the main impacts of sectoral developments (agricultural, forestry, energy, protection of natural areas, urban sprawl and infrastructure, climate action, mining, consumption patterns, etc.) on land use in the EU's rural areas and to identify recommendations for optimal land use, in particular to promote sustainable farming in light of other demands on land.

The study includes an overall analysis of the evolution of agricultural land use and how this is influenced by other, non-agricultural land use demands at the European level and at the level of case study regions. The analysis considers the historical context, current state of play and prospects for agricultural land use in the EU and case study regions.

Twelve case studies were selected in regions of twelve EU member states (see Annex I). In each of the case study regions, a regional expert is asked to perform desk research and interviews to collect the information.

The information to be collected is structured under four sections:

1. Drivers behind the evolution of land use, that have influenced agricultural land use in the period 1990-2022;
2. Evolution of agricultural landscapes;
3. Drivers of land use change up to 2050;
4. Sustainable land use in rural areas
 - a. Sustainability impacts of land use changes on environment (soil, air, water, climate), nature conservation, agricultural production, farm income and labour and sustainable energy production and consumption.
 - b. Main policy instruments for sustainable agricultural land use.

Instructions for filling the CS report

Instructions for the collection of the information are indicated in yellow as: **QUESTION #**. Information is to be collected through desk research, interviews and one workshop with stakeholders. Interviews should be held with at least 8 different stakeholders or stakeholder groups. Several questions can be combined in each interview.

Data sources must be clearly stated against the information provided. Where literature is used, please provide references at the end of the report.

We kindly ask you to provide photographs of the region that illustrate the findings in the case study, and that may be used for publication. Please mention authors and/or sources of the photographs.

Interviews can be carried out either by video call, over the phone or face to face. You must ask the interviewee's permission to refer to their organisation in the case study report. Individuals will not be identified.

The target groups for the interviews and the workshop are specified under each question. The range of target groups may include:

- Local government officials working in agriculture and rural development issues at municipal or regional level (provincial/district/county);
- Individual farms and agri-enterprises as long as they have a strong role in the local 'ecosystem' and oversee the agricultural sector, beyond their own enterprise;
- Farmers' associations (regional departments);

- Farm advisors;
- Nature protection organisations operating locally;
- Representatives from local rural development organizations that support/promote the local economic development and livelihood (e.g. LEADER, EIP-operational groups, high nature value farming, hunting and land owner groups);
- Representatives of forestry and wood processing companies, energy producers;
- Representatives of local NGOs like nature conservation organisations, environmental protection organisations, civil society organisations;
- Representatives of companies involved in carbon farming and carbon removal certification;
- Representatives of companies involved in biomass production for bioenergy and other non-food uses;
- Representatives of companies involved in organic and agro-ecological farming;
- Representatives of companies involved in ecotourism and recreation.

Please use your judgement to find the most relevant person and organisation within the target groups to speak to in order to source the information required for the purposes of this study. You may identify relevant persons to interview that do not belong to the target groups in the list above.

If you interview people you might want to record the interviews (ask permission!) as this will help you afterwards to work out the results.

Drivers influencing agricultural land use in the period 1990-2022

Objective

Research question for the study:

Q1. What were the dominant factors in the evolution of land use in the last thirty years in the case study region, in general and for agriculture in particular?

The objective of this section is to provide information to identify the main factors in the evolution of land use, that have influenced agricultural land use in the last thirty years in the region. We refer to factors with the term 'drivers'.

The topics to which the drivers relate may include:

- energy production and use
- increase of built-up area by urban sprawl and construction
- agricultural land abandonment
- nature conservation
- development of population and income
- changes in lifestyle and consumption patterns
- agricultural production markets and trade
- changes in agricultural policies (at EU level)
- land tenure and land markets
- climate change
- the bioeconomy.

Other topics may also be relevant in your region.

We ask you to do the following:

- Collect and interpret for the case study region **land use data and statistics on land use and farming (structure), energy (production and use) and socio-economic themes** (e.g. population, labour, income, gross value added etc.) for the period 1990-2022 (or a period in this time frame).

Wageningen Research will share EU (Eurostat) data on changes in land use and land cover, farming statistics and statistics on economy and population for your region (at NUTS-3 level where possible), or for the larger region at NUTS2-level, in which your region is located. Please check these data to append more detailed or accurate data that you find for your region. You may choose your own format to present and share the data.

- Collect and interpret **regional reports** that demonstrate changes in agricultural land use.

- Perform **interviews** with local rural development organizations, local government organizations, environmental NGOs, or other stakeholders informed on the evolution of land use in the region over the last 30 years.
- Review of published information sources. Preferably use regional or national reports and websites.

Questions and tables to report the information

QUESTION 1: What changes in agricultural land use over the period 1990-2022 are shown in the statistical data and reports collected?

Mention the changes that influenced agricultural land use in the region. Examples of these changes can be decrease or increase in (certain types of) agricultural land use caused by drivers like agricultural land abandonment, afforestation, urbanization.

Changes in land use (describe and illustrate with data in tables, figures and maps)

QUESTION 2: What drivers (factors) can you infer from these data, that have changed agricultural land use in the period 1990-2022? *We are searching for drivers like land abandonment (including underlying drivers like ageing farming population, low farm income etc.), urbanization (including underlying drivers*

like lack of effective spatial planning, growing urban population etc.), afforestation (incl. underlying drivers like market demand for wood) etc.

Drivers (top 6, ranked by importance)

QUESTION 3: What dominant drivers (factors) for the evolution of land use (for agriculture in particular) in the case study region can you infer from the interviews with stakeholders? Please ask respondents to mention up to 6 drivers, and to rank these based on importance.

Stakeholder (group)	Dominant factors of evolution of land use in the region in 1990-2022
local rural development organizations	
local government organizations	
environmental NGOs	
...	

Your remarks and reflections on the information obtained from statistics and reports versus the interviews. Are there differences in drivers appearing from the different sources? Can you maybe elaborate on the reasons for such discrepancies?

Evolution of agricultural landscapes in the region

Objective

Research question for the study:

Q2. How have agricultural landscapes in the case study region evolved, particularly regarding crop diversity, including permanent crops and permanent grassland, concentration of livestock, plot size, high-diversity landscape features on agricultural land and high nature value agriculture?

The objective of this section is to describe the transformation within agricultural landscapes in the region in the period 1990-2022.

The topics characterizing agricultural landscapes may include:

- cropping systems
- livestock
- landscape patterns
- agro-PV
- wind energy
- (new) crop and residue production for biobased industry
- organic farming
- High Nature Value farmland, nature inclusive farming, regenerative agriculture
- carbon farming
- 'new' farming activities (e.g. precision farming, new crops, breeds and cultivars)

We ask you to do the following:

- Collect and interpret **regional land use data and statistics on farming (structure), energy (production and use) and socio-economic themes** for the period 1990-2022 (or a period in this time frame).

Wageningen Research will provide you with data and maps on changes in land use, farming statistics and statistics on economy and population for your region (at NUTS-3 level where possible), or for the larger region at NUTS2-level, in which your region is located. Please use these data to append more detailed or accurate data that you find for your region.

- Perform **interviews** with farmers, farmers' organisations, farm advisors or other relevant stakeholders to identify changes in the agricultural landscapes in the region.

- Perform **interviews** with local rural development organisations and local government organisations to identify changes in the agricultural landscapes in the region.
- Review of published information sources. Preferably use regional or national reports and websites.

Questions and tables to report the information

QUESTION 4: What changes within agricultural landscapes over the period 1990-2022 are shown by the data on regional land use data and statistics on farming structure, energy and socio-economic themes, and by the review of published information sources (reports and websites)? Please specify your findings in the table below.

Changes in agricultural landscapes between 1990 and 2022 from land use data, statistics, reports and websites

QUESTION 5: What changes in the agricultural landscapes in the case study region can you infer from the interviews with stakeholders? Please ask respondents to mention several changes, and to rank these based on importance.

Stakeholder (group)	Changes in period 1990-2020
Farm advisors	

Local development organisations	rural	
Local government organisations		
...		

Your remarks and reflections on the information obtained from statistics and reports versus the interviews. Are there differences in changes in agricultural landscapes mentioned by the different sources? Can you maybe elaborate on the reasons for such discrepancies?

Drivers of land use change up to 2050

Objective

Research question for the study:

Q3. What will be the dominant drivers of land use change, in particular agricultural land use, in the coming decades (up to 2050)? Which trends and developments are expected in the drivers identified?

The objective of this section is to provide information to identify the drivers of land use change in the case study region over the future period until 2050.

The topics to which the drivers relate may include:

- energy production and use
- increase of built-up area by urban sprawl and construction
- agricultural land abandonment
- afforestation of agricultural land
- intensification of agriculture
- extensification of agriculture
- expansion of agriculture
- nature conservation and restoration
- development of population and income
- changes in lifestyle and consumption patterns
- agricultural production markets and trade
- changes in agricultural policies (at EU level)
- land tenure and land markets
- climate change
- the bioeconomy.

Other topics may also be relevant in your region.

We ask you to do the following:

- Collect and interpret information on expected developments in the drivers of land use change in the case study region from outlooks or visions for the case study region.
- Perform **interviews** with for example farm advisors, policy makers, civil society organisations, local rural development organisations and local government organisations.

Questions and tables to report the information

QUESTION 6: What are the dominant drivers and trends of land use change in the case study region, in particular agricultural land use, in the coming decades (up to 2050)? Please report here the findings from reports, outlooks, vision documents.

What trends and developments are expected in the drivers identified in these documents?

Drivers of land use change up to 2050	Trends and developments in drivers

QUESTION 7: What are the dominant drivers of land use change in the case study region in the coming decades (up to 2050), in particular agricultural land use, are expected by stakeholders?

What trends and developments in these drivers do stakeholders expect? Please ask respondents to mention several drivers and expected developments, and to rank these based on importance.

Stakeholder (group)	Dominant drivers of land use change in the region up to 2050 and expected developments
local rural development organizations	
local government organizations	
Farm advisors	
Policy makers	
Civil society organisations	
...	

Your remarks and reflections on the information obtained from statistics and reports versus the interviews. Are there differences in drivers of land use change up to 2050, mentioned by the different sources? Can you maybe elaborate on the reasons for such discrepancies?

Sustainable land use in rural areas

Objective

Research question for the study:

Q4a. How sustainable is the current land use in Europe's rural areas for agricultural production, energy production, nature conservation and climate change?

Q4b. How can land use be optimized to enable the development of sustainable agriculture in the light of Farm to Fork F2F (by 2050)?

The objectives of this section are to provide information on:

- a. effects of land use change on the sustainability of the environment, nature conservation, agricultural production, farm income and labour;
- b. policy instruments for sustainable agricultural land use.

We ask you to do the following:

- Perform **interviews** with managing and competent authorities (regional), policy makers, NGOs and farm advisors.
- **Review policy instruments** influencing land use in the case study region.
- Hold one **workshop on future land use change** in the region with around 8 stakeholders to evaluate scenario results for the case study region provided by Wageningen Research. The participants need not necessarily overlap with the respondents in the interviews.

This workshop will need to be held by mid-April 2024. Modelled scenarios for your case study region will be shared with you to collect reactions

from the stakeholders. We will send you a separate template to report results from the workshop(s).

The workshop is to be organised as follows:

1. Present the EU results:
 - a. the drivers and their historical and projected trends in the Business As Usual-situation, and a more disruptive scenario;
 - b. the current and projected EU land use maps based on the two scenarios;
 - c. the impact indicators of the present situation and for both scenarios.
2. Present for the case study region: the land use maps, scenario results, including the impact indicators, similarly to the EU results. Wageningen Research will prepare these materials.
Discuss with the participants whether they recognise the projected land use map and the impact indicators for the two scenarios. Can the participants imagine both scenarios of the future?
3. Reflect what the land use changes and their impacts in the scenarios mean in terms of suitable policy instruments.

Questions and tables to report the information

QUESTION 8: What were the main effects of land use changes in agricultural land in the last 30 years on the sustainability. We are looking for impacts on the environment, nature conservation, agricultural production, farm income and labour in the case study region. Can you infer the answers from reports and the interviews with stakeholders? In the interviews, please ask respondents to mention several effects of changes in land use, and to rank these based on importance.

Source report or interview	Effects on sustainability of land use changes in last 30 years

...	

Your remarks and reflections on the information obtained from statistics and reports versus the interviews. Are there differences in effects on sustainability of land use changes in agricultural land in the last 30 years, mentioned by the different sources? Can you maybe elaborate on the reasons for such discrepancies?

QUESTION 9: What were the main policy instruments influencing land use in the case study region in the last 30 years and how did these influence the land use?

Policy instrument (regional, national, EU)	How the instrument influences land use or drivers impacting land use in the region

QUESTION 10: What will be the main policy instruments influencing land use in the case study region in the coming years (until 2050) and how will these influence the land use?

Policy instrument (regional, national, EU)	How the instrument will influence land use or drivers impacting land use in the region

14. Annex 5 Literature review of past and current land use trends and their drivers and impacts at EU level

See separate document 'Annex 5 Literature review':

https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cmef/sustainability/study-competition-land-use-and-sustainable-farming_en

15. Annex 6 Overview of EU wide data collected for answering the study questions

See separate document 'Annex 6 Overview of EU wide data':

https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cmef/sustainability/study-competition-land-use-and-sustainable-farming_en

16. Annex 7 Summary Overview of drivers of land use change collected from the case studies and the literature

Table 12 Drivers for increase in build-up area identified in the literature and the case studies

Group of drivers	Source ^a	Driver
economic pressures and market forces	L	Land demand for urban use, infrastructure, industrial and commercial activities and construction sites
	CS	Economic growth and income growth Increasing demand for land for urban area, residences, infrastructure, industry, tertiary and commercial services (all case studies) Settlement development for real estate investment (Siena) urbanization in the coastal part of the country (Šibenik-Knin)
development of industry sector	L	industrial and commercial activities and construction sites
	CS	Development of the harbour of Antwerp and surrounding industry (Sint-Niklaas); expansion of industry and roads (Siena) Extension of artificial surfaces into agricultural land for the establishment of processing or industrial units (Imathia)
development of tourism sector	L	population concentration and densification of economic activities in coastal (rural) areas due to growth in international tourism development of second homes on agricultural land (Hautes-Alpes) transformation of agricultural land into built environment around settlements and touristic mountain villages (Argeş) increase of agrotourism on family farms (Šibenik-Knin)
	CS	expanding recreation parks, shift towards permanent accommodations; decrease in camping (Zuidwest-Drenthe)
demographic changes lifestyle changes	L	rapid population growth in urban areas and large-scale migration from rural areas due to better employment opportunities and preferences for better housing in urban settings; Declining rural population, deteriorating access to public services in rural areas, causing a progressive socio-economic isolation of communities involved.
	L	Lifestyle changes, e.g. detached housing preferences, contributed to urban sprawl, consuming more land per-capita than compact (dense) urbanization
	CS	Decrease of population in rural area and increase of income and employment opportunities in cities (Sialuliai, Albacete) Growth of single-person households and trend towards smaller living spaces, potentially increasing the number of housing units required (Sint-Niklaas), preferences for better housing (Argeş) City dwellers and third generation moving back and buying second homes for the summer period (Hautes-Alpes)
EU support	CS	Pre-accession funds (from PHARE and SAPARD) used for the conversion of agricultural land for tourism infrastructure (Argeş)
policy and regulation	L	Weak normative and regulatory constraints; lack of coordination and competition between local administrative units
	CS	increased selling of potential vulnerable nature land for building purposes (Sint-Niklaas) Encouragement of private investments in placing wind towers and solar panels on agricultural land by the government and legislative efforts aimed at reducing bureaucratic barriers and facilitating the expansion of renewable energy projects (Silauliai)

	CS	Restoration of ownership rights after the breakdown of the Soviet regime, with private land owners being able to repurpose land for residential, commercial or recreational purposes (Silauliai)
Renewable energy development*	L	trend in installing PV panels on agricultural lands, encouraged by the EU Solar Energy Strategy and by support from Member States in CAP Strategic Plans
	CS	replacement of crops by solar parks (Imathia, Zuidwest-Drenthe, Wittenberg, Hautes-Alpes); expansion of solar parks and wind farms on large parts of high-quality agricultural land (Silauliai)

a: L: literature; CS: case studies.

*One can argue whether construction of solar parks can be seen as 'build-up' area, but in several case studies it was categorized in this land use change class

Table 13 Drivers for afforestation and agricultural land abandonment identified in the literature and the case studies

Group of drivers	Source ^a	Driver
economic pressures and market forces	L	Adverse socio-economic conditions at farm level because of low market prices, high cost, low economic profitability
	L	Agricultural land abandonment driven by: - gradual industrialization, market orientation, and urbanization (western Europe) - collapse of socialism and subsequent institutional reforms (eastern Europe) Agricultural land abandonment, in particular of grazing practices in habitats depending on agricultural management, led to natural expansion of forests on agricultural land, mainly in the form of transitional woodland shrub Cutting of forest stands without active afforestation afterwards, leading to natural regrowth in the form of woodland shrub
	L	Decreasing financial incentives for afforestation resulted in a decrease in afforestation in member states with larger amounts of agricultural land
	CS	Marginal lands - shallow peat soils and hillsides were afforested first because of low productivity of the land (West-Ireland)
	CS	Afforestation grants gave farmers an opportunity to retain their land and plant it for a low-maintenance long-term income stream for pension purposes or to be able to move away from the land to settle in other parts of the country for better economic prospects (West-Ireland)
	CS	Natural revegetation after land abandonment due to a decline in agricultural profitability, especially in marginal land areas; abandonment of olive groves due to lack of economic viability (Siena)
demographic changes	L	Progressive rural depopulation leading to abandonment of cultivated lands and naturalization in economically depressed regions; loss of agricultural labour force ; ageing population in rural areas
	CS	Rural exodus, leading to the abandonment of marginal land, especially olive trees, which have subsequently become forested; decline in small-scale informal agriculture, lack of interest of younger generations, old farmers and lack of successors (Siena)
	CS	Depopulation, loss of young people, increasing age of farmers and consequent lack of labour for maintaining traditional small farms led to large-scale land abandonment, especially in the more marginal areas, where the land from the small farms will not be absorbed by larger farms;
		Depopulation and the lack of labour, but also changing lifestyles led to a decline in traditional pastoralism and increasing abandonment of permanent grasslands, especially in the mountainous area (Argeş)
	CS	Decline in extensive/traditional grazing activities due to a decline in the number of farmers and lack of succession by young farmers led to a reduction in livestock farming, leading to afforestation of mostly grasslands through natural revegetation (Albacete)
policy and regulation	L	Agricultural land abandonment in eastern Europe was driven by the collapse of socialism and subsequent institutional reforms
	L	Stimulation of the afforestation of agricultural land through CAP aid
	L	bioenergy targets set in EU policy
	CS	Lack of policy in agriculture and lack of legal basis for agricultural use of land resulted in a large part of arable land being fallow or abandoned; farmers could not change to market-oriented farms (Montana)

Group of drivers	Source ^a	Driver
	CS	State-promoted afforestation on agricultural land led to an increase in forest, particularly in areas less suitable for agriculture (Siauliai)
	CS	Inconsistency in legislation led to farmers not clearing vegetation from shrub pastures, and with time, these were overgrown (Šibenik-Knin)
	CS	Policy grants (Western Package Grant) for afforestation drove the afforestation of agricultural and private land, due to relatively unproductive soils and circumstances in the Western region (West-Ireland)
	CS	Decreasing number of livestock leading to abandonment of meadows and grassland, partly due to support from APIA payments that induced artificial maintenance (Argeş)
Unfavourable agro-ecological conditions	L	Water shortage, marginal land, climate change effects
renewable energy development	L	demand for forest biomass in the transition to a bioeconomy
Land restitution	CS	Slow process of restitution of the collectivised agricultural land to previous owners or heirs led to agricultural land abandonment (Montana)
Rural infrastructure	L	remote locations, lack of transport infrastructure, deteriorating access to public services
	CS	Lack of infrastructure made it impossible to build farms in the mountainous areas, suitable for grazing animals, leading to existing natural and semi-natural meadows and pastures becoming overgrown by bushes and trees and turning into forest territory (Montana)
War	CS	In the 1990s, land abandonment was a result of the war (on independence, red.). Thereafter, a large part of the County was under mines, and that land was restricted from use (Šibenik-Knin)
Land ownership (unsolved property rights)	CS	Abandonment of agricultural areas for cultivating vineyards, olives, almonds, cherries, and cereals, as well as the decline in sheep and goat farming resulted in the disappearance of characteristic agricultural landscape forms, such as dry stone walls, small rectangular fields and overgrowth of pastures and meadows into scrubland and forest, resulting in loss of landscape diversity and biodiversity (Šibenik-Knin)
Administrative reasons	CS	Slow proceeding of registration of land in the national cadastre, leading to conflicts about land and 'transitional' land abandonment, whereby farmland is temporarily under-utilised or taken out of production (Argeş)

a: L: literature; CS: case studies.

Table 14 Drivers for nature creation with or without continuation of agriculture identified in the literature and the case studies

Group of drivers	Source ^a	Driver
policy and regulation	L	Set up of the Natura 2000 network under the Bird and Habitat Directives
	CS	Designation of Natura 2000 sites in 2008-2010 leading to agricultural land becoming (protected) nature with continuation of agricultural use (Montana, Silauiai)
	CS	Increase in protected areas under Natura 2000, Bird and Habitat Directives (Albacete)
	CS	establishment of national parks, Natura 2000 sites, and enhancement of the Natuurnetwerk Nederland, leading to a transformation of parts of the agricultural landscape into natural areas (Zuidwest-Drenthe)
Societal forces	CS	growing interest among farmers to adopt nature-inclusive agricultural practices, leading to more diverse and sustainable farming approaches in the landscape (Zuidwest-Drenthe)
consumer preferences	CS	Increased demand for nature since the corona pandemic (Zuidwest-Drenthe, Sint-Niklaas)
Development of industry sector	CS	efforts to compensate and restore tidal marshes and other wetland habitats that were historically prevalent in the region but had diminished over time due to agricultural and industrial activities (development of the harbor and industry) (Sint-Niklaas)

a: L: literature; CS: case studies.

Table 15 Drivers for intensification identified in the literature and the case studies

Group of drivers	Source ^a	Driver
economic pressures and market forces	L	new market and consumers' needs at EU and global level
	L	Accession to the EU leading to new market opportunities and expansion of agricultural area
	L	Economic farm performance due to better farm gate prices or to the reduction of farming costs, enabling farmers to invest.
	CS	Market-driven incentives, including opportunities for diversification, specialization, and value-added production (e.g. luxury Italian wines, tulip bulbs, permanent crops) (Silauliai, Zuidwest-Drenthe, Siena)
demographic changes employment	L	reduction of the labor force in the agricultural sector and the declining rural population leading to the adoption of labour-saving and agritech innovations
	L	Population growth and demand by uses other than agriculture, influencing land scarcity and leading to agricultural intensification
	CS	No mention of intensification as a result of rural depopulation
CAP and other EU support	L	CAP payments contributed towards stabilized markets, provided direct income and investments support at farm level
	L	CAP measures and incentives were a strong support for the cultivation of new land
	CS	CAP payments (Siena, Imathia, West-Ireland)
	CS	Accession to the EU and the possibility to access European funds (pre-accession, funds, direct payments, RDP measures (Montana, Silauliai)
Technological advancements	L	progressive adoption of agricultural technologies: agricultural mechanization, advances in plant breeding, nutrition and protection, animal nutrition and health, plant and animal genetics, precision farming, precision livestock, precision irrigation
	CS	Technology (mechanization, precision agriculture, biotechnology, digital farming tools) increasing efficiency, productivity and farm size (Imathia, Zuidwest-Drenthe, Sint-Niklaas, Silauliai, Argeş, Albacete)
renewable energy development	L	demand for biomass in the transition to a bioeconomy: demand for land for the production of biomass and energy crops
	CS	increase in the number of farms using equipment for renewable energy production (Silauliai);
		establishment of solar energy stations in agricultural land (Imathia)
climate change & adaptation	L	Climate change impacts on agriculture through changes in precipitation, temperature, CO2 concentrations and sea level rise, affecting the suitability of land for different crops
	CS	Increase in irrigated area (Imathia, Albacete)

a: L: literature; CS: case studies.

Table 16 Drivers for scale increase identified in the literature and the case studies

Group of drivers	Source ^a	Driver
economic pressures and market forces	L	stable markets, higher costs for labour or lower labour availability
	CS	demand for land producing high quality wine, and high prices offered for the land leading to concentration of high quality vineyards in hands of foreign investors (Siena)
	CS	Economic pressures and market forces leading to increase in numbers of larger farms, decline in small farms, and overall decline in number of farms (Siena, Argeş, Imathia)
	CS	Increasing influence of global markets leading to a scale increase in agriculture; no longer the family farm structure, but large cooperatives (Albacete)
Land reform and restitution	L	Land reform in post-socialist countries in central and eastern Europe with transfer of land rights from state farms and cooperatives to individual farms, reorganization of cooperatives into new private companies
	CS	Restitution of land ownership after the restoration of independence in 1990 led to land being redistributed among private farmers, agricultural cooperatives, and state-owned enterprises; this resulted in larger farms becoming more prevalent and small-scale family farms becoming less common (Silauliai)
		... concentration of land ownership has influenced land use patterns and agricultural landscapes: shift towards more mechanized and specialized

		agricultural production and decline of traditional farming practices (Silauliai)
	CS	land reform and privatisation followed the collapse of communism, leading to dissolution of collective farms and the restitution of land to the original (or new) owners, thereby creating millions of small farms (Argeş)
Land consolidation	L	opportunities for land consolidation into larger areas and fields because smaller (and older) farmers sell their farms
	CS	concentration of large agricultural areas (as size and cultivation) in a small number of agricultural producers (Montana, West-Ireland, Hautes-Alpes)
	CS	Changes of land ownership status, leading to the increase of the utilized area per farmer (Imathia)
	CS	creation of larger plots for more efficient agriculture (Zuidwest-Drenthe, Sint-Niklaas)
CAP and other EU support	L	market and income support, direct payments and support for investments from the CAP
	CS	set-aside instrument (1988 to 2007) resulted in consolidation of farmland in hands of larger farms in the period 2000-2020 (Siena)
Technological advancements	L	Technological innovations giving opportunities for land consolidation into larger areas and fields
	CS	shift towards more mechanized and specialized agricultural production and decline of traditional farming practices, leading to larger farms becoming more prevalent and small-scale family farms becoming less common (Silauliai, Albacete)
demographic changes	CS	Increase of the size of the agricultural holdings for the plantation of arable and tree crops due to the decrease of the population which was active in agricultural sector (Imathia)

Table 17 Drivers for extensification identified in the literature and the case studies

Group of drivers	Source ^a	Driver
economic pressures and market forces	L	gradual decline in extensive farming driven by markets and economic variables: low productive farming practices at higher cost
	CS	low farm incomes because of unproductive lands and high levels of (unprofitable without subsidies) sheep farming (West-Ireland)
	CS	Economic pressures and policy changes leading to a reduction in livestock (Zuidwest-Drenthe, West-Ireland, Argeş)
	CS	growing focus on competitiveness and market demand for quality products leading to an increase in organic farming in traditional landscape settings; remaining land allocated to forage (Siena)
Policy and regulation	L	Eastern Europe: breakdown of socialism in 1989, triggering a decline of capital- and input-intensive farming practices; Subsequent land reform, reorganization of agricultural sectors and state-support for agriculture differed between countries: - intensification in areas highly suitable for farming - deintensification and cropland contraction in more marginal areas
Land reform and restitution	CS	prolonged land restitution process after intensive agriculture in the socialist period (Montana)
CAP and other EU support	L	Set-aside measure (CAP) to reduce the agricultural production on markets (until 2008) Support for low input agriculture in the CAP (Pillar 2 payments, agri-environmental measures) Support for 'non-productive' landscape elements in the CAP
	CS	Investments in nature protection and agroecological activities in Natura 2000 sites (meadows and pastures) leading to development of nature-friendly agriculture (Montana)
	CS	Increased nature-inclusive farming in response to grant schemes (AEP in CAP) (West-Ireland)
	CS	Government support and EU subsidies for organic farming leading to an increase in the area under organic farming (Silauliai, 2004-2022)
		Decoupled CAP payments and use of RDP leading to extensification (Siena)
demographic changes	CS	ageing population and young farmers not returning to the area due to the economic prospects leading to extensification of farming (West-Ireland)

Societal forces and consumer preferences	L	Stimulus of organic farming by a growing awareness of environmental concerns and consumer preferences
		Growing interest among consumers for production, origin, environmental impacts and animal welfare of products creating niche market demands
	CS	Growing consumer demand for organic products leading to an expansion of organic farming (Silauliai, Siena) or more specialized or sustainable cultivation practices (Imathia, Zuidwest-Drenthe)

a: L: literature; CS: case studies.

17. Annex 8 Multivariate analysis to further analyse land use dynamics in relation to drivers

17.1. Aims and scope

By reconnecting empirical evidence from literature review on land-use drivers and the findings from a comparative analysis of case studies (see sections 4.1 – 4.3), the results of this exercise provide a summary framework on the role a number of land-use drivers has on the main land-use change trajectories in Europe. Taken together, these results corroborate and confirm the statistical robustness and territorial reliability of the regional types described earlier in Chapter 2, and its validity when identifying homogeneous geographies of landscape transformations, and the related drivers, in the EU27. The multi-dimensional analysis proposed here is intended to associate processes of change in the main use of land to vastly different territorial (and socioeconomic) dynamics, considering – among others – the date of country's access in (and participation to) the enlarged European Community, as well as topographic gradients and reference environmental conditions.

17.2. Indicators, logical framework, model specification

After having adopted a logical framework grounded on multivariate statistics, the subsequent step in this work was model's specification, namely the selection of relevant indicators to be analyzed. Considering the exploratory analysis' results in their broadest sense (i.e. providing a comparative, aggregate, picture of European-scale and, together, local-scale land-use dynamics), we followed the main indications provided by literature review, and the empirical analysis of case studies, trying to give a summary, empirical answer to questions 1, Q1.1. and Q1.2. mentioned at the beginning of this chapter. To answer such key questions, an appropriate number of indicators were chosen to give a full picture of two basic land-use dimensions, both in time and in space, considering the 'change' dimension (mainly associated with land transformations and landscape structures/configuration) and the 'process' dimension (mainly reflecting the underlying socioeconomic and territorial functions and candidate drivers). More specifically, the selected indicators in this exercise will be directly or indirectly representative of drivers of change in land-use and agricultural landscapes considering the following five 'change' dimensions: (i) agricultural land taken by built-up area, (ii) agricultural land-use change influenced by afforestation and land abandonment, (iii) nature creation in agricultural land, (iv) scale increase in agriculture, as well as (v) agricultural extensification. These dimensions correspond with what has been earlier discussed in Chapter 4.

Indicators were selected also with the aim at delineating the following process dimensions: (a) economic pressures and market forces (including the development of industrial and/or tourism sector), (b) policy/regulation/administrative issues (including CAP and other EU support), land reform/consolidation/ownership, (c) demographic dynamics, employment, societal forces, and lifestyle changes, (d) climate change adaptation, (e) renewable energy development, (f) technological advancements and rural infrastructure, as well as (g) unfavorable agro-ecological conditions.

Based on this rationale, the indicators chosen for the analysis (see Table 18 and Table 19 for technical details) represent key processes of land-use change in the EU27 and focus on the dynamics of the primary production sector, evaluating in turn the impact of economic transformations associated with urban expansion, re-naturalization, and land abandonment in peripheral regions. Indicators were chosen to be non-uniquely associated with one dimension, likely bringing some relevant information – both directly and indirectly – to more than one dimension of change all over Europe. Moreover, considering the vast geographical differentiation across the EU27, some indicators may result to be directly or indirectly associated to the mentioned dimensions of change in specific parts of Europe. Taken together, we formed a particularly rich and informative-sound set of secondary data, based on a complete collection of variables (with no missing value) at a vastly detailed and specialized sectoral, dimensional and spatio-temporal observation scale. However, it should be noted how such indicators are clearly based on a subjective-based selection procedure driven by data availability at the desired geographical scale (NUTS-3 level).

Based on these considerations and caveats, the use of a multivariate exploratory analysis revealed to be a particularly appropriate technique aimed at identifying the geography of (apparent and latent) land-use change types in Europe, delineating in turn the role of direct and indirect drivers of change. In this perspective, the selected indicators are easily interpretable and representative of territorial contexts and socioeconomic dynamics at a regional scale. The use of additional (stratification) variables allows the land-use 'change' dimension (see above) extracted and delineated from the multivariate analysis to be identified and characterized according to specific geo-economic gradients.

Table 18 Selection of the main variables/indicators according with the identified research dimensions that represent processes of change (and the related, candidate drivers) in Europe (from (a) to (g) see above and broader details in paragraph 4.3); see also technical details of these indicators in the following Table 19.

Variable/indicator	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Year of entry in the European Union		x				x	x
Population density			x				x
Rate of change over time in population density			x				x
Per-capita income levels	x		x				
Absolute rate of change over time in per-capita income	x		x				
Travel time to cities of different sizes	x		x			x	
Coastal-inland divide		x	x				
Agricultural land-use	x		x				
Forest land-use	x		x				
Artificial land use	x		x				
Crop intensification	x			x		x	
High Nature Value farmland				x			x
Built-up surface change over time (observed)	x			x			
Built-up surface change over time (predicted)	x			x			
Utilized agricultural area, change over time	x	x		x		x	x
Organic farming area	x	x		x		x	x
Environmental risk		x		x			x
Solar parks	x	x			x	x	
Structure of small woody features				x	x		x
Small woody features as a landscape element		x		x	x		x
Change over time in area covered by trees				x	x		x
Agroforestry	x	x		x	x	x	x
Conversion from agriculture to artificial land	x			x			
Conversion from agriculture to forest land	x			x	x		x

Variable/indicator	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Long-term trend over time in forest area	x		x	x	x		x
Agricultural (plant) functionality (remotely sensed)				x			x
Wildfires			x	x	x		x

(a) economic pressures and market forces (including the development of industrial and/or tourism sector), (b) Policy/regulation/administrative issues (including CAP and other EU support), land reform/consolidation/ownership, (c) demographic dynamics, employment, societal forces, and lifestyle changes, (d) climate change adaptation, (e) renewable energy development, (f) technological advancements and rural infrastructure, as well as (g) unfavorable agro-ecological conditions.

17.3. Technicalities

Data collected on variables (and/or indicators) that are often not only correlated (namely, redundant), but also forming broad matrices, make conceptual interpretation and structural identification a particularly complex task – especially when using only standard (uni-variate or bi-variate) tools such as graphics/histograms, simple two-way tables of frequencies, descriptive statistics (means, medians, coefficients of variations) or pair-wise correlation coefficients. One of the possible approaches managing the complexity stemming from a broad data matrix composed of several columns (e.g. indicators) and rows (e.g. spatial observations) is a statistical framework based on exploratory multivariate analysis. With this perspective in mind, when indicators are fully quantitative, a possible solution is to transform the original (input) variables into a smaller number of uncorrelated (artificial) factors, with two final objectives: (i) reducing the number of variables into a smaller number of 'representative' and 'uncorrelated' factors or dimensions, as well as (ii) comparatively classifying variables and cases within a unique ('consensus') perspective based on an individual geometrical plan used to order observations and indicators within the same (comparable) space.

Stemming from the vast and generalized family of statistical techniques known as 'factor analysis', Principal Component Analysis (PCA) is one of the most applied methodologies aimed at fulfilling such objectives. Broadly speaking, the goal of a PCA is to find a lower-dimensional vector space onto which the original points (variables and/or cases) can be projected, so as to identify the underlying structure of the data. The analysis extracts the principal components and some supporting statistics, being aimed at solving large matrices. Based on standardized data, we run a PCA based on a Pearson correlation matrix, diagonalizing the symmetric matrix using correlation metrics. PCA is a particularly meaningful methodology compared with other factor analysis classes because it allows analyzing data collected on heterogeneous variables (and observational units) with respect to their respective means or with respect to their respective means and standard deviations, providing reliable and very stable results. The analysis allows selecting only few relevant components based on the visual scrutiny of the scree plot. This plot identifies the first components that concentrate the maximum amount of information, and allows discarding the remaining components that are characterized by a reduced amount of information.

All the components are orthogonal by construction, thus meaning that the information associated with a given component is not shared with any other extracted component. By retaining a few number of significant components, the analysis reaches the objective of summarizing the significant information

associated with the input matrix, managing appropriately and reducing systematically the intrinsic redundancy of any data set, especially when a large number of indicators is considered jointly. The active variables and the observational cases are projected onto the factor space using a simple graph (namely, the 'biplot'). The analysis also produces table results (i.e. the correlation coefficients between variables (indicators) and the extracted components forming the biplot) and maps (the score coefficients between observational units (geographies) and the extracted components).

In this work, the evaluation exercise was run *via* PCA applied to a dataset made up of 27 indicators (see Table 19) made available on a total of 1160 observations representative of the NUTS-3 level regions. These regions came from 27 EU countries (AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK), forming a data matrix made up of 27 columns (indicators) per 1160 rows (regional units). Additionally, 3 stratification variables (not directly involved in the PCA) were used in the subsequent tabulation plan (Country, RALUC, ENR) in order to better qualify and interpret the complex results stemming from PCA.

Table 19 List of indicators considered as input variables in the Principal Component Analysis illustrated in this report (see also Table 18 where the indicators are reported in the same order); italics indicate supplementary variables (see text for details).

Abbreviation	Explanation	Unit
Log(entry)	Year of entry in EU	Log (Year)
PopDen91	Population density 1991	inhabitants/km ²
PopDen%9123	Relative change in population density 1991-2022	%
log(GDP22)	GDP per inhabitant 2022	log(Euros)
GDP0022%	Absolute change in GDP 2000-2022	%
log(Trav)	Travel time to cities of different sizes (10.000 inhab. or more)	logarithm (min)
Inland	Non-coastal region (1), the rest (0)	Dummy
Agric%	% agricultural land use region 2018	% in total land area
For%	% forest land use region 2018	% in total land area
Artif%	% artificial land use 2018	% in total land area
Agr_int%	Crop intensification area (ha) as share of 2000 agricultural area	% change in agricultural area
HNV%	% High Nature Value farmland	% in total agricultural area
GHSL_BUA_%1990	Built-up surface change 1990-2020	% in km ²
GHSL_BUA_T50	Trend towards 2050	% in km ²
UAA%0520	Utilised agricultural area, % change 2005-2020	%
Orgf%	Organic farming area 2021 in total farmland, %	%
Aq40_BWD	Risk score between 0-5 (2-5 is medium to very high risk)	Score system
Solar_agr	Solar parks in hectares on agricultural land	Average size (ha)
SWF2018Agriha	Area covered by small woody features 2018	Average size (ha)
SWF2018Agri_mean%	Area share covered by small woody features	% agricultural area 2018
TCD2018Agri_mean%	Relative change in area covered by trees 2015-2018	% change in total area 2015
Lucas_agrof09	Lucas points with Agroforestry 2009	Density of sampling points
Agri_to_Art%	Agriculture 2000 to artificial land 2018 in N2000&CDDA	% in total reference land
Aff%0018	Agriculture 2000 to forest-afforestation N2000	% in total reference land
GLADFor0020	Trend in forest area % change 2000-2020	% change in forest area 2000

Abbreviation	Explanation	Unit
NDVIAgr0020%	Normalised weighted relative change NDVI in agricultural land	% change in NDVI2000
Burned%	Percentage burned area in forest land	% in burned area
<i>Country</i>	<i>Country code</i>	<i>Code</i>
<i>RALUC</i>	<i>RALUC dominant land use change</i>	<i>Code</i>
<i>ENR</i>	<i>Environmental region</i>	<i>Code</i>

17.4. Empirical results of the analysis

Component extraction provided highly satisfactory results, as the ‘reduction power’ of the PCA (namely the predictive capacity of the analysis) was remarkable (54% of the total variance was explained, cumulatively, by the first 6 principal components, starting from 27 input variables, with a significant reduction coefficient (2.43; an efficient PCA extraction is achieved with values greater than 2). The first two components explained respectively 14.5% and 11.3% of the overall variance of the data matrix, and thus represent the most relevant analysis dimensions in explaining the spatial variability and territorial disparities in agricultural land-use dynamics and the associated socioeconomic context, intended as a powerful driver of change when considering landscape transformations. The other four components, while being analyzed in this report, explained dimensions of less variability compared with the first two (9%, 8%, 6% and 5% respectively). For all the extracted components, we calculated loadings, i.e. the correlation coefficients between input variables and extracted principal components. This information allows us to analytically characterize the individual components and the geographical, social, economic and environmental gradients associated with them. The units (NUTS-3 regions) were also characterized in the same way, computing the component scores, i.e. the values indicating the position of individual regions on each axis extracted from the PCA. Scores identify latent characteristics and (more or less) significant associations with the geographic gradients outlined above. Component scores for each axis and European region have been depicted in specific maps.

In the following paragraphs, we briefly describe the meaning of each extracted component, considering together loadings (variables) and scores (observations). In this way, it is possible to delineate an economic geography of European (NUTS-3) regions based on dominant land-use types, and the related drivers of change, possibly in line with the regionalization scheme (i.e. RALUC regional typologies) and the evidence from literature review and the case studies. Each component was named with a specific, summary label based on the joint reading of data, tables and maps proposed in the respective paragraph.

Component 1: The urban-rural gradient

The breakdown of the indicators’ matrix (see variables’ composition above in Table 19) into specific components identified six landscape transformation processes which are in turn associated with well-defined geographical gradients and socioeconomic conditions. This was highlighted in the correlation coefficients between indicators and components illustrated analytically in

Table 20 and graphically in Figure 11. It represents the biplot projecting active variables (indicators) and cases (regions) over the factorial plane of Components 1 and 2.

Table 20 Component loadings (highly significant variables in bold)

Variable	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Log(entry)	0.57	-0.14	0.55	0.21	-0.18	0.17
PopDen91	-0.62	0.24	0.37	0.19	-0.09	-0.10
PopDen%9123	-0.22	0.17	-0.41	0.22	0.10	0.28
log(GDP22)	-0.69	0.05	-0.35	0.10	0.38	-0.11
GDP0022%	0.41	0.18	0.57	-0.15	0.30	0.21
log(Trav)	0.51	-0.45	0.15	0.06	-0.05	-0.06
Inland	-0.02	-0.13	0.26	-0.46	0.49	-0.10
Agric%	0.38	0.62	-0.34	-0.40	0.03	-0.11
For%	0.07	-0.83	0.10	0.02	0.30	0.08
Artif%	-0.77	0.33	0.37	0.13	-0.05	-0.05
Agr_int%	0.26	-0.03	0.18	0.37	-0.06	-0.50
HNv%	0.41	-0.11	0.00	0.27	0.01	0.00
GHSL_BUA_%1990	0.44	0.10	-0.36	-0.14	-0.08	0.38
GHSL_BUA_T50	0.30	0.42	-0.19	0.36	0.15	0.23
UAA%0520	0.13	0.09	0.17	0.19	0.14	-0.21
Orgf%	-0.21	-0.47	-0.31	0.05	0.24	-0.17
Aq40_BWD	0.06	0.06	-0.38	0.25	-0.71	-0.09
Solar_agr	0.27	0.13	-0.12	0.24	-0.12	-0.41
SWF2018Agriha	0.56	0.30	-0.13	0.39	0.38	0.11
SWF2018Agri_mean%	-0.31	0.02	0.20	0.54	0.14	0.37
TCD2018Agri_mean%	-0.09	-0.58	0.02	0.40	-0.19	0.11
Lucas_agrof09	0.34	0.29	-0.23	0.45	0.44	-0.13
Agri_to_Art%	-0.44	0.28	0.29	0.31	-0.04	0.20
Aff%0018	0.26	0.07	0.26	0.27	0.03	-0.35
GLADFor0020	-0.03	0.62	0.23	-0.05	0.02	-0.12
NDVIagr0020%	0.30	0.27	0.37	-0.29	-0.23	0.14
Burned%	0.03	-0.02	0.00	0.10	-0.13	0.37
Expl. Variance (%)	14.5	11.3	8.7	8.0	6.4	5.2

Component 1 highlights a clear urban-rural gradient, associated with dense settlements and wealth accumulation. In particular, the negative values of Axis 1 were associated with population density, per-capita income, the percentage of artificial areas in the landscape, and the conversion rate of agricultural areas into urban areas, understood as the main reservoir of buildable land. The regions experiencing such dynamics are those entering the European Community most early.

Table 21 Average component scores by axis and land-use RALUC class* (bold indicates significant average scores per regional type).

Class	#	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Afforestation	367	0.71	-0.66	0.12	0.36	0.14	0.07
Extensification	45	0.79	0.12	0.48	-0.70	0.27	-0.13
Intensification	162	1.00	0.15	0.11	-0.24	-0.34	-0.82
Nature creation	12	-0.08	0.63	-0.39	-0.55	-0.84	-0.26
Urbanisation	575	-0.81	0.36	-0.14	-0.10	0.00	0.20

* As far as Principal Component Analysis results in terms of RALUC classes, Axis 1 indicates a polarization in regions classified as 'urbanization' and 'intensification', while Axis 2 polarizes regions classified as 'afforestation' against those classified as 'nature creation'. Axes from 3 to 6 indicates specific regional typologies, namely pure 'extensification' (Axis 3), 'extensification' plus 'nature creation' (Axis 4), pure 'nature creation' (Axis 5) and pure 'intensification'. In line with the inherent complexity in land-use changes and landscape patterns in the EU27, combination of more than one trend in the same principal component confirms the reliability of RALUC classification in five regional typologies.

It is assumed how Component 1 reflects, in a rather clear way, the gradient from the more urbanized and demographically dense areas (negative scores) to rural districts with strong elements of natural landscape (positive scores), generally associated with countries with lower population density and more recently becoming part of the European Community. These places have also shown high anthropogenic pressure in recent years in the face of more stagnant economic growth in the 'founding' countries. Figure 12 provides a graphical illustration of the spatial distribution of European regions along Axis 1. It is more evident here how heavily urbanized regions (scores < -2 depicted in red) were mainly concentrated in Central and Western Europe, basically in Germany and, with a lesser extent, in France and Italy. Few regions were also classified with similar (negative) scores in Poland, Czech Republic, Denmark and Greece, mostly corresponding to the largest cities, urban agglomerations, and metropolitan regions.

Regions receiving high and positive (> 2) scores along Axis 1 were concentrated in both Western Europe (Spain, Portugal, as well as Ireland), and Eastern Europe (Hungary, Romania, Bulgaria, a part of Poland, Baltic countries). Despite the sparse presence of metropolitan areas (basically, capital cities) in these countries, Component 1 delineated the 'rural' and 'natural' characters of these regions, in comparison with the traditional 'founder' countries in Europe, and especially Germany, France and Italy. Intermediate territories were identified especially in France, Italy, Germany, as well as Greece, Sweden, Denmark, and Belgium, and correspond with potentially dynamic and high-density 'rural' regions positioning between strictly urban and highly natural areas. Interestingly, the most relevant variables characteristic of the positive side of Axis 1 included specific indicators of naturalness, extensive agricultural models, and remoteness from central locations.

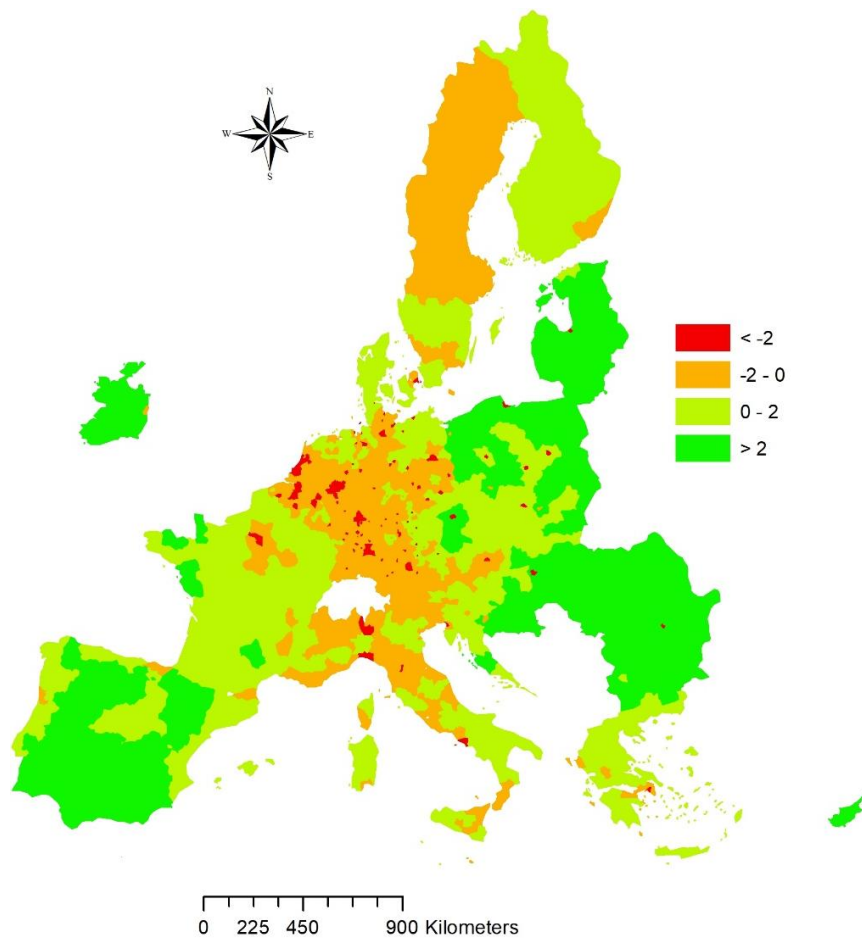


Figure 12. Map of component scores along Axis 1, by NUTS-3 region.

Concerning environmental regions, aggregated statistics on component scores (Table 22) indicated a predominance of 'Atlantic' regions along the negative side of Axis 1, and of 'North' regions (-0.84) along the positive side of Axis 1 (0.93), the other classes being more mixed and substantially less polarized along the component. At the country level, the aggregated statistics of component scores (Table 23) confirm the results outlined with the visual scrutiny of the score map (see above). The countries totalizing the highest positive scores (> 2) along Axis 1 are Bulgaria, Cyprus, Estonia, Hungary, Ireland, Lithuania, and Romania. Interestingly, no countries totalized average negative scores below -2, indicating a substantial heterogeneity of 'urbanization' trends over the continental space. These were clearly mixed to rural areas also in heavily industrialized and very dense countries in Central Europe.

Table 22 Average component scores by axis and environmental region.

Class	#	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Alpine	49	0.08	-2.30	0.37	0.41	0.61	0.57
Atlantic	335	-0.84	0.86	-0.51	0.08	0.41	0.09
Continental	464	0.22	-0.01	0.60	-0.78	0.28	0.01
Mediterranean	252	0.48	-0.11	-0.76	1.03	-1.37	-0.15
North	61	0.93	-2.36	1.01	0.95	0.78	-0.37

Table 23 Average component scores by axis and European country (international, two-digit abbreviation); bold indicates highly significant score coefficients characterizing individual countries.

Country	#	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
AT	35	-0.24	-2.13	0.02	0.01	1.16	0.56
BE	44	-1.23	1.18	-1.11	-0.71	-0.49	0.30
BG	28	2.75	-0.35	3.01	-0.94	-0.61	-0.13
CY	1	2.30	1.40	-1.68	2.15	-2.43	1.34
CZ	14	1.43	0.08	1.07	-0.04	0.97	0.57
DE	401	-1.26	-0.19	-0.24	-0.78	0.40	-0.37
DK	11	-0.62	1.82	-0.22	0.80	0.32	0.37
EE	5	2.04	-2.46	2.25	1.96	0.50	-1.97
EL	52	-0.05	-0.52	-0.41	0.68	-3.12	0.07
ES	59	1.58	0.24	-0.57	1.87	-1.04	-0.21
FI	19	0.44	-3.58	0.85	1.43	0.83	-0.85
FR	96	0.23	1.02	-1.27	1.11	1.46	0.47
HR	21	1.82	-1.05	1.64	0.62	-0.09	0.78
HU	20	2.40	1.31	2.65	-0.25	0.18	-1.02
IE	8	3.28	4.77	-0.16	5.34	4.73	-1.77
IT	107	-0.34	-0.33	-1.45	0.49	-1.20	-0.23
LT	10	2.58	0.40	2.10	-0.31	0.67	-0.72
LU	1	-1.03	0.53	-1.78	-0.28	2.00	0.77
LV	6	1.62	-0.74	2.69	0.90	0.41	-0.67
MT	2	-0.50	0.96	0.10	0.59	-2.66	-0.18
NL	40	-1.24	2.45	-0.41	-0.53	-0.03	0.19
PL	73	1.52	0.96	1.71	-0.31	-0.07	0.86
PT	25	1.95	-0.36	0.36	2.15	-1.30	0.59
RO	42	2.69	0.38	2.42	-1.73	-0.58	0.84
SE	21	-0.22	-3.29	-0.46	1.09	0.98	0.70
SI	12	0.37	-2.45	1.16	0.41	0.53	0.74
SK	8	1.55	-0.38	1.31	-0.16	0.96	0.83

Component 2: the agricultural-forest gradient

Component 2 delineates a more subtle land-use gradient based on the geographical polarization in agricultural land (associated with the positive values along Axis 2) and forest land (associated with the negative values along Axis 2). The level of remoteness was identified ($\log(\text{Trav})$) as strictly associated with a high forest cover rate of regions. By contrast, agricultural regions, likely more dynamic from the economic point of view, were predicted to experience a sudden increase in the built-up surface areas up to 2050. The percentage of organic farming in the regions was negatively associated with Axis 2 and, thus, more frequently observed in areas dominated by forests and natural habitats. The same pattern was observed for the increase in total area covered by trees over a short-term (2015-2018). However, by looking at a larger time window (2000-2020), the most dynamic agricultural regions have experienced a net expansion of total woodland (GLADFor0020), as the positive loading for this variable along Axis 2 clearly documents. In other words, Component 2 represents the geographical polarization in 'dynamic and advanced agricultural regions' (with a dominant production model based on crop intensity, mechanization and irrigation) and in more peripheral districts dominated by extensive agricultural models with organic farming, farm trees, the prevalence of natural habitats over intense cropland, and a slight expansion of forest land.

Figure 13 provides a graphical illustration of the spatial distribution of European regions along Axis 2. It is more evident here how forest regions (scores < -2 depicted in red) were mainly concentrated in Sweden and, less regularly, in other Northern countries, as well as in Austria, in the surrounding Alpine regions of other countries and, more sparsely, in mountainous and remote districts of France (Massif Central and Alps), Italy (Alps and Apennines), Germany, Spain (Pyrenees), and Greece. Regions receiving high and positive (> 2) scores along Axis 2 were mainly concentrated in flat and largely accessible districts of Romania, Hungary, Italy, Atlantic France, Spain, and a small part of Germany, where dynamic and intensive farming systems consolidated and possibly expanded in the last two decades.

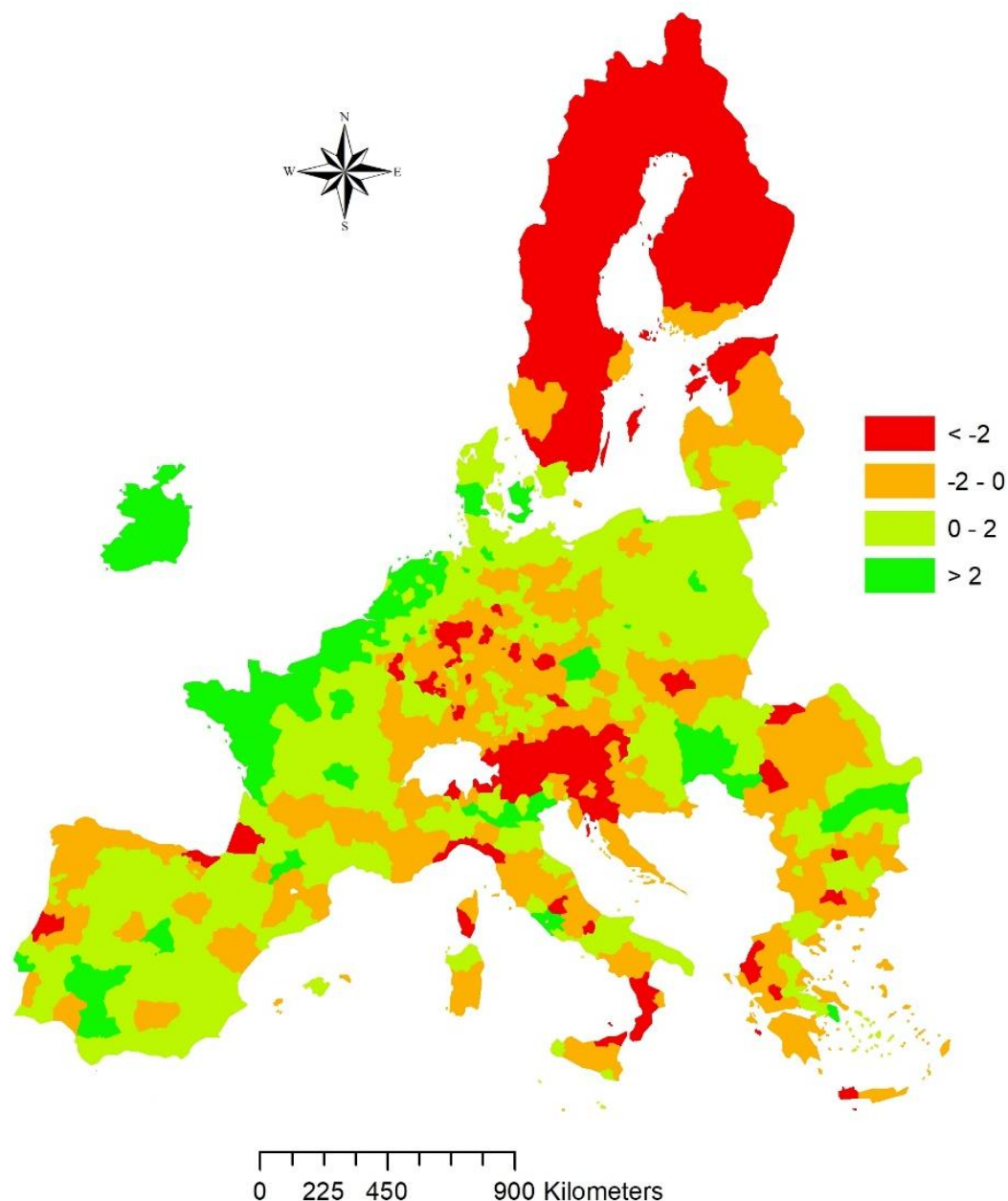


Figure 13. Map of component scores along Axis 2, by NUTS-3 region.

Figure 13 specifically reports the average score along Axis 2 as an indicator of the spatial distribution of RALUC classes in Europe. As expected, the regions

classified as experiencing 'afforestation' trends ($n = 367$) were mainly associated to negative loadings, in line with the profile of Axis 2 derived from the scrutiny of indicators' loadings. At the same time, the few regions classified as experiencing a very specific trajectory of 'natural creation' ($n = 12$) received, on average, predominantly high and positive scores on Axis 2, likely because of the small sample size and the vast heterogeneity of such land-use dynamics. However, such evidence is not in opposition with the main evidence of Axis 2 (intended as an agricultural and forest gradient), because early signs for 'natural creation' were also evident in traditional agricultural districts with intense cropping and a high production impact, possibly as a spatially point response to agro-environmental measures of the Common Agricultural Policies. These findings may confirm, all over Europe, the importance of embarking in active strategies operationally promoting (and financially supporting) the creation of natural sites and habitats and the protection of relict environments within a landscape matrix dominated by intensive cropland.

As far as environmental regions are concerned, aggregated statistics of component scores (Table 22) indicate a strong characterization of both 'North' (-2.30) and 'Alpine' (-2.36) regions on the negative side of Axis 2 (namely, the 'forest' side). In this perspective, regional districts classified along this part of the axis should not be uniquely intended as peripheral, remote and economically depressed, while being substantially anchored to a rural – and possibly dynamic – economy grounded on high-quality forestry and the related supply chain. The 'Atlantic' region, on average, was the only environmental group receiving positive loadings (0.86) along the negative side of Axis 1. At the country level, the aggregated statistics of component scores (Table 23) basically confirm the results outlined with the visual scrutiny of the score map. The countries totalizing the highest positive scores (> 2) along Axis 2 were Ireland, and the Netherlands. Austria, Estonia, Finland, Sweden and Slovenia received highly negative (< 2) scores on the same axis, on average.

Component 3: 'Old' vs 'new' Europe: the economic and demographic East-West divide

Component 3 (Figure 14) delineates a geographical gradient reflecting the East-West divide and was mostly characterized by a socioeconomic polarization in demographically dense regions, typical of Western Europe, and regions experiencing an above-than-average increase in per-capita income levels in the last two decades, corresponding with the countries accessing more recently to the European Union.

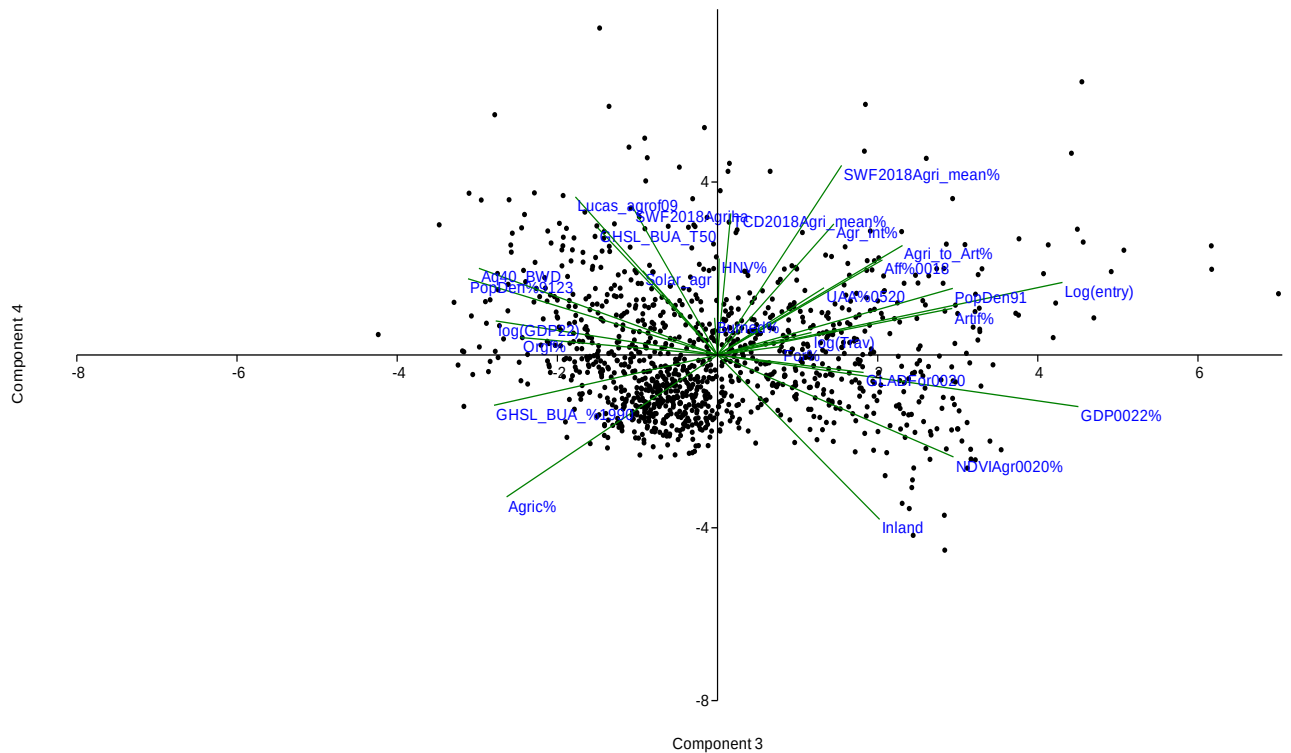


Figure 14. Biplot of Component 3 and Component 4 (see text for details).

Figure 15 provides a graphical illustration of the spatial distribution of European regions along Axis 3, confirming the results described earlier. Regions receiving high and positive (> 2) scores along Axis 3 were mainly concentrated in Eastern Europe (both in the Northern side, e.g. Baltic Republics, and in the Southern side, e.g. Romania and Bulgaria). Mediterranean-Balkan countries, such as Croatia and, in a smaller part, Slovenia, showed the same pattern. Northern countries, such as Finland and Sweden, showed intermediate patterns. Interestingly, few districts – particularly remote but growing rapidly – in Southern Portugal were the only regions classified in the same group among Western European regions. By contrast, negative scores (< -2) were assigned to remote (or less economically dynamic) regions in the 'founder' countries, such as France (including mostly the Atlantic range of the country), Italy (including all the Southern part of the country) and, more occasionally, Belgium and the Netherlands. Interestingly, similar regions were found more sparsely in remote Spain (Andalusia, Extremadura) and peripheral Greece (Crete).

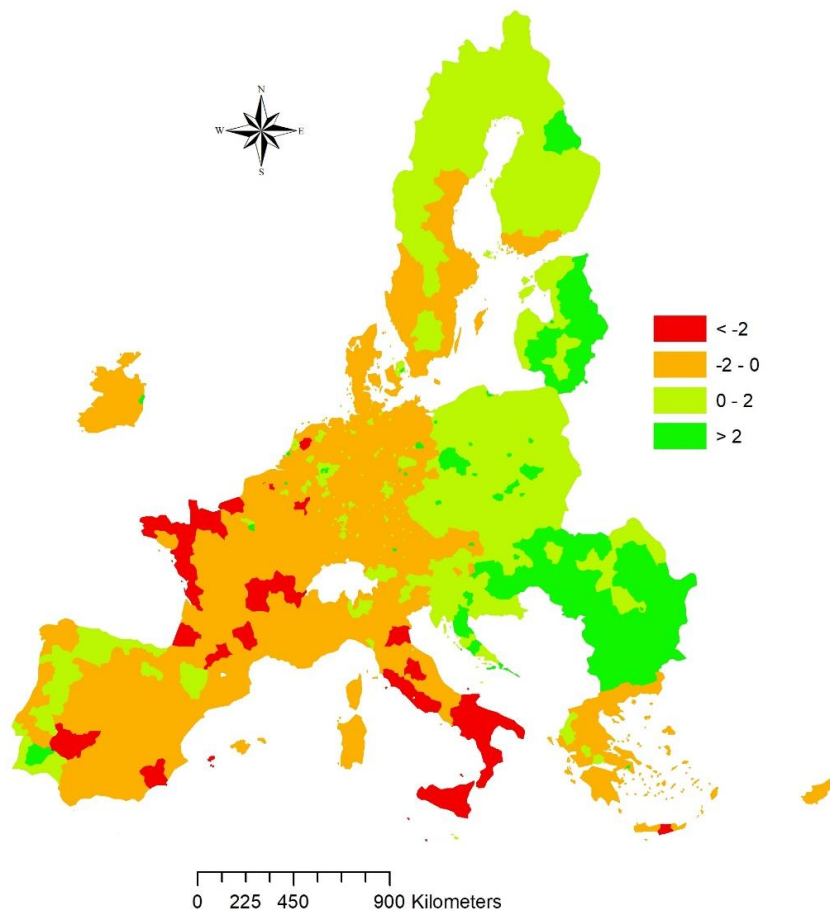


Figure 15. Map of component scores along Axis 3, by NUTS-3 region.

The average scores' distribution along Axis 3 indicates a substantially neutral relationship between this component and land-use aggregated classes. Interestingly enough, the statistical distribution of component scores confirms the outcomes of the map presented above, since 'North' and 'Continental' regions received positive values and 'Atlantic' and 'Mediterranean' regions received in turn negative scores (see Figure 15). The countries with the most evident component scores (Figure 15) were Estonia, Latvia, Lithuania, Bulgaria, and Romania (with positive values), confirming the empirical evidence derived from a visual scrutiny of the score map. The countries totalizing the highest positive scores (> 2) along Axis 2 were Bulgaria, Hungary, Latvia and Romania. There are no countries with highly negative scores (< -2) on this axis. Countries with scores between -1 and -2 are a.o. Luxembourg, Italy, Cyprus.

Component 4: Agro-forestry vs extensive cropping systems

Component 4 delineates a subtle land-use gradient with a coherent geographical divide in Western-Northern and Central-Eastern regions. Regions dominated by an above-average share of agricultural land in total landscape, mostly located inland, were associated with the negative part of this axis. Conversely, regions with a more diversified rural landscape dominated by small woody features, both in terms of average size and gross cover rate in total agricultural area, as well

as density of agro-forest points (LUCAS⁷¹ definition), were classified along the positive side of Axis 4. The average scores' distribution along Axis 4 indicates a weak association of both 'extensification' and 'nature creation' trends with the negative side of the studied component, being likely more frequent in Eastern European regions than elsewhere in the EU27. The statistical distribution of component scores (Table 23) document how 'North' and 'Mediterranean' regions received relatively high and positive scores along Component 4 being, on average, well represented by a latent expansion of agro-forest landscapes more evident than in other European regions. By contrast, 'continental' regions seem to be characterized with traditional agricultural systems lacking (or partly lacking) the 'small woody elements' matrix. The countries with the most evident positive scores along Component 4 (Figure 16) were, on average, Cyprus, Ireland, and Portugal. Confirming earlier results, Figure 16 provides a graphical illustration of the spatial distribution of European regions along Axis 4, localizing regions with high and positive (> 2) scores as mostly concentrated in the Iberian peninsula, France, part of Italy, Croatia, part of Denmark and, more sparsely, Sweden and Finland. By contrast, coastal and especially internal regions all over Romania and Bulgaria, but also more sparsely in Germany and Poland, received highly negative scores along Component 4.

⁷¹ Land use and land cover survey

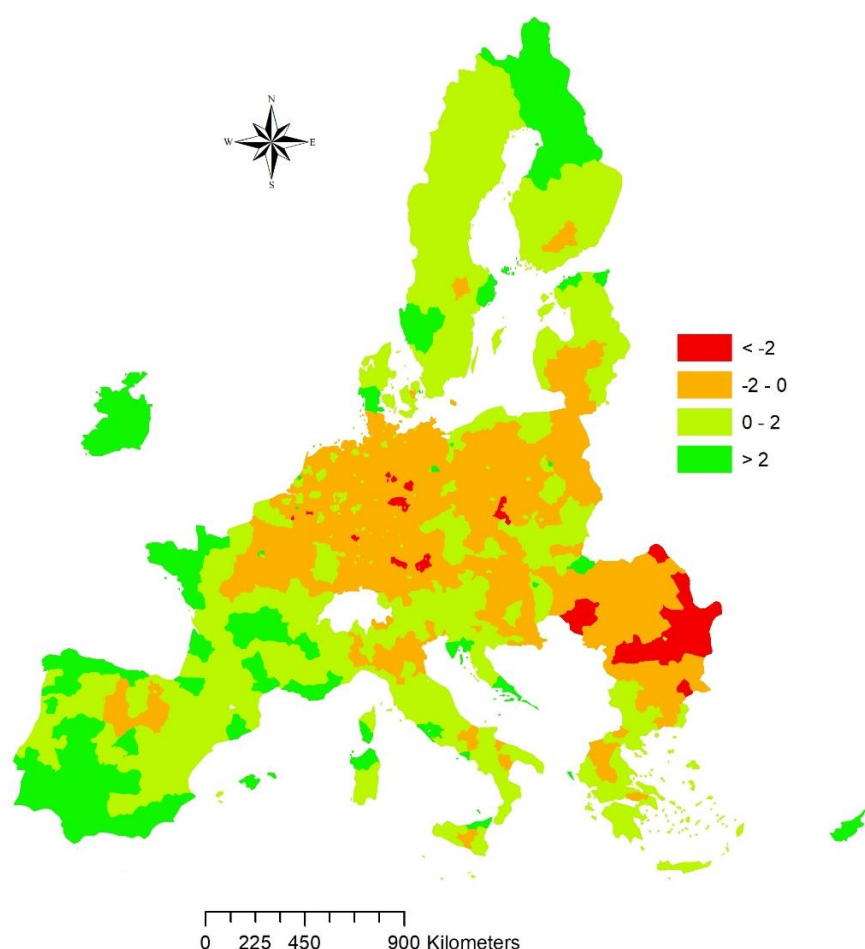


Figure 16. Map of component scores along Axis 4, by NUTS-3 region.

Component 5: Drylands vs humid climate with agro-forestry

Component 5 delineates a biophysical gradient from drylands to sub-humid lands dominated by mixed agro-forest landscapes (Figure 17). Drylands – as indicated with the 'aq40_BWD' metric of water-related risks because of climate aridity and a structural water shortage in the soils – were associated with the negative side of the axis, while density of agro-forest sites ('Lucas' definition), more frequently situated inland, received positive component loadings. Concerning RALUC typologies (Figure 17), 'nature creation' was the only trend relatively well characterized along Component 5 and basically receiving negative scores, on average. The statistical distribution of component scores (Table 22) document how the 'Mediterranean' region was the most clearly classified along the negative part of the axis, in line with the dominant climate characteristics (toward aridity and drought). Consequently, selected Southern European countries were characterized along the axis with systematically negative (average) scores (below -2), namely Cyprus, Greece, Malta. On the contrary, Hungary, Ireland and Luxembourg received positive scores.

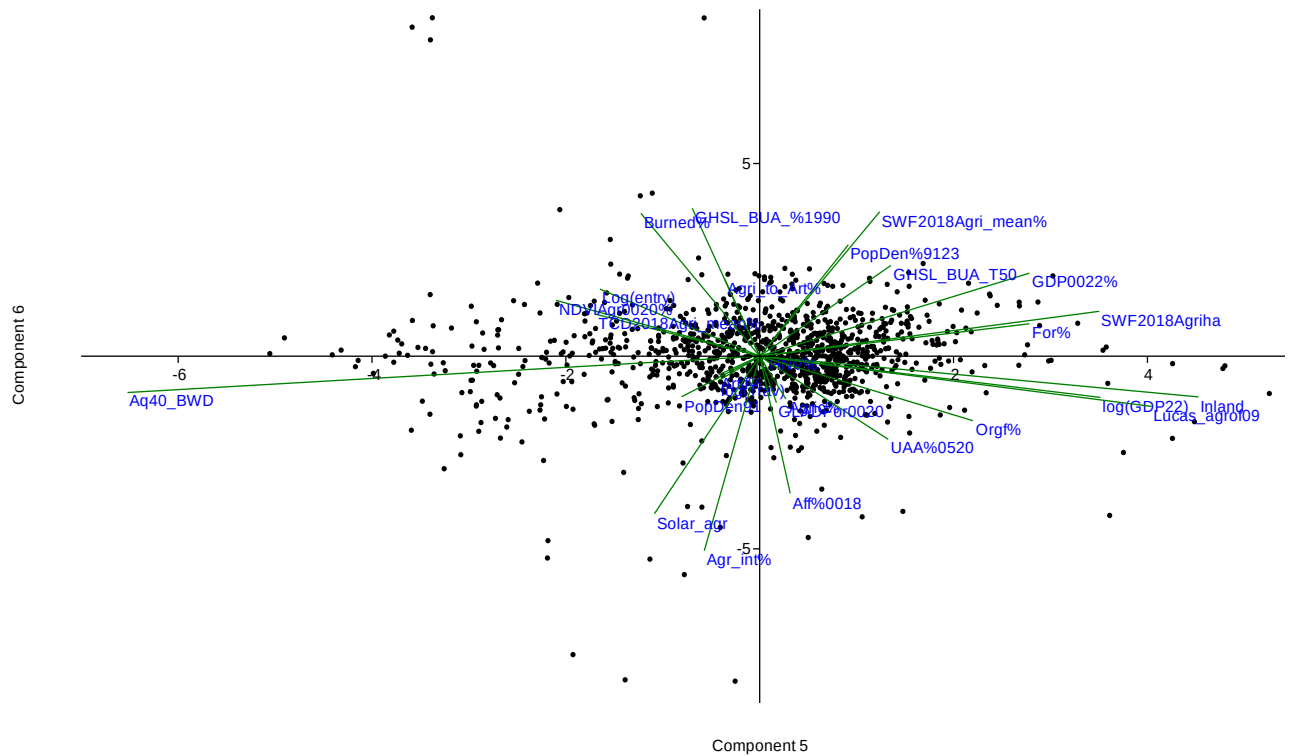


Figure 17. Biplot of Component 5 and Component 6 (see text for details).

Confirming such results, Figure 18 provides a graphical illustration of the spatial distribution of European regions along Axis 5, localizing regions with high and negative (< -2) scores along the component as basically concentrated in coastal areas along the Northern Mediterranean arc – from Spain to Greece. Regions with positive scores were found especially in France and Ireland and, more sparsely, in Germany, Austria, Sweden and, even more rarely, inland in Northern Italy and Spain. All in all, the axis reveals the traditional South-North climate polarization in semi-arid (Southern Europe) and sub-humid (Northern Europe) regions. The spatial distribution of negative scores basically reflects the geography of land degradation and early signs of desertification risk in Mediterranean Europe.

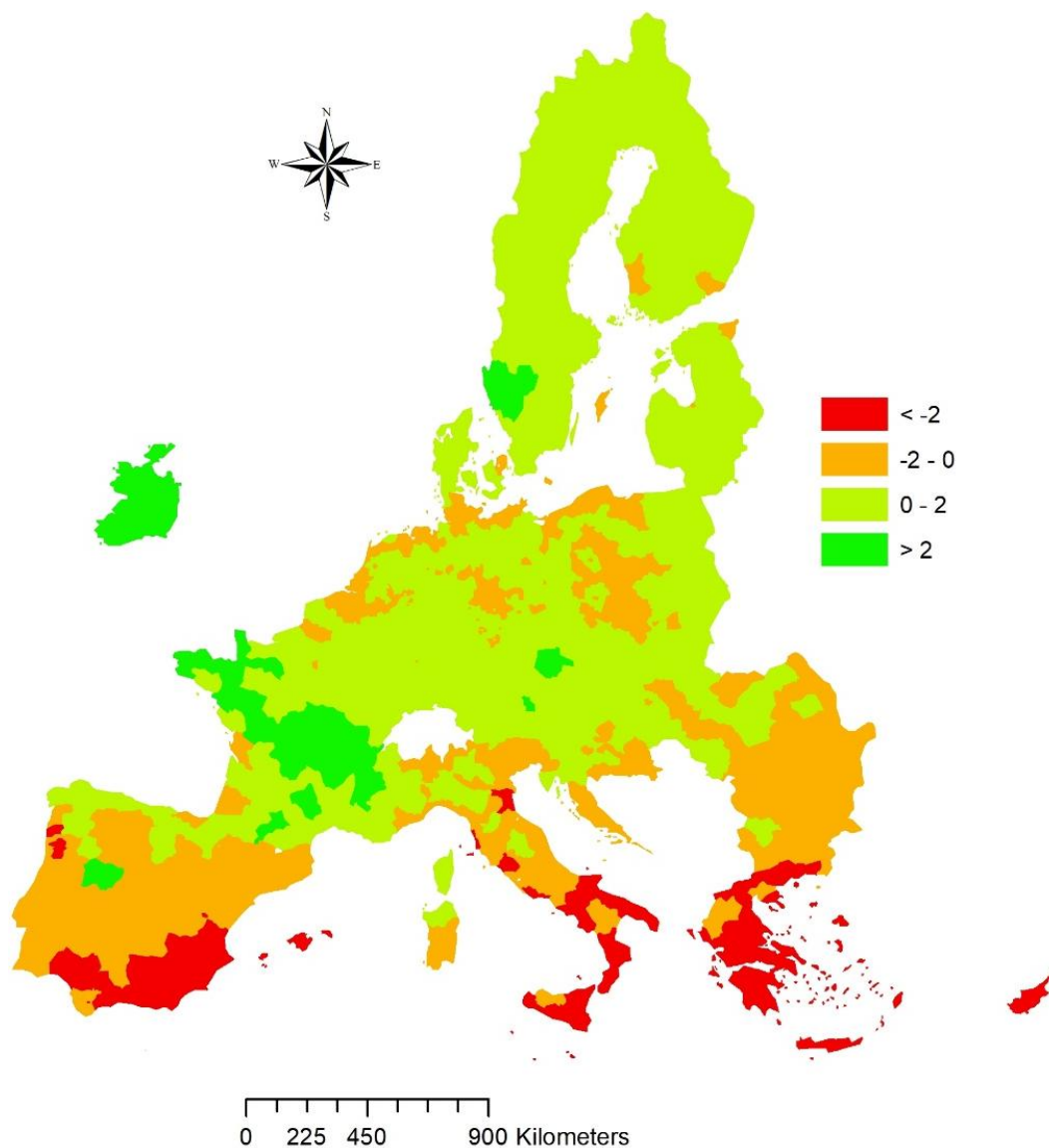


Figure 18. Map of component scores along Axis 5, by NUTS-3 region.

Component 6: Agricultural intensification and solar parks

Component 6 identifies a specific socioeconomic gradient with negative scores assigned to regions experiencing agricultural intensification and sudden expansion of solar power installations, and namely solar parks. Based on RALUC typologies (Table 21), 'intensification' was the most characteristic land-use trajectory receiving negative scores (-0.82, on average), while no environmental categories were discriminated clearly along Axis 6. Additionally, no countries (Table 23) were specifically characterized with significant values of component scores (below -2 or above 2), meaning that such gradient mainly involves point areas in the continent with a particularly evident spatial heterogeneity. This is vastly expected for territorial phenomena (like the exploitation of solar energy in agricultural fields) well connected with broader agricultural intensification processes but, at the same, extremely heterogeneous over smaller regions. Figure 19 illustrates the spatial distribution of European regions along Axis 6, localizing regions with high and negative (< -2) scores along the component as experiencing agricultural intensification and solar plant development in rural districts. Such regions were concentrated in Southern

Spain, Northern Finland, Ireland, Hungary and Estonia: Their long-term developmental path likely depends on the specific national policies leveraging investments – and possibly providing subsidies to farmers – for developing solar parks in the agricultural landscape.

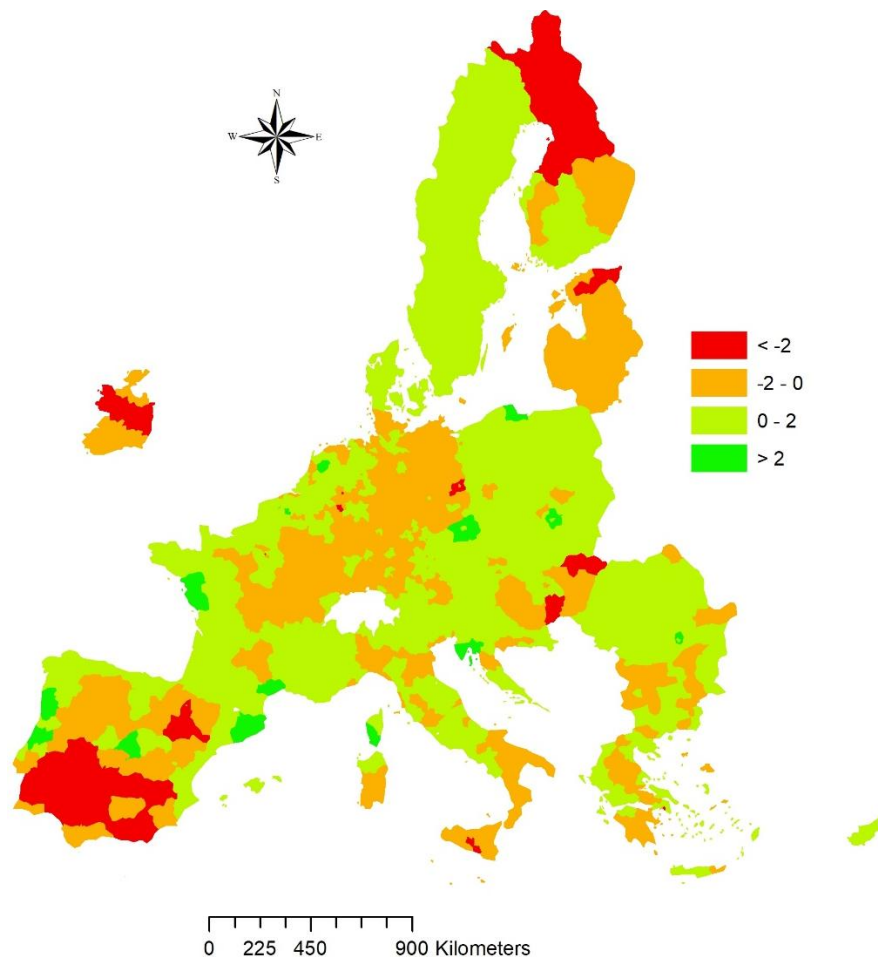


Figure 19. Map of component scores along Axis 6, by NUTS-3 region.

Conclusions of Multivariate analysis

Through a comparative scrutiny based on two-way stratification tables (land-use types, environmental classes/administrative boundaries) and maps, the multivariate analysis has outlined a particularly complex geography of landscape transformations and modification of the dominant land-use along the study period in Europe. More specifically, the analysis has identified:

- (i) the main trajectories of change over time, with particular reference to the period 2000-2022,
- (ii) how these changes impact, positively or negatively, on the rural territory, outlining processes of agricultural/productive intensification or extensification, contraction of crop surfaces, or land abandonment,

also as a functional transformation of the common agricultural model towards e.g. environmental sustainability, and

- (iii) the influence on these dynamics exerted by the main economic contexts, whether linked to demographic concentration or the economic dynamism of individual territories, and to their variation over time.

The six principal components extracted represent complex and articulated dynamics of landscape evolution, focusing in turn on the socioeconomic background context, and highlighting the close linkage between the two dimensions, as well as the importance of non-economic variables. Some of the extracted components ordered and classified the European regions according to traditional land-use gradients, highlighting the main specialization (agricultural or forestry) and the pervasiveness of urbanization phenomena.

Other components have also shown the relevance of geographical or biophysical gradients, evidencing the intense polarizations still existing between Northern and Southern Europe, and above all, between Eastern and Western Europe. Still other components have highlighted the importance of economic dynamism - which, at least in the last twenty years, has not always coincided with the demographically densest regions, having the most traditional settlement and the oldest membership in the European community. Finally, other components have highlighted important processes of rural transformation, paying attention to both extensification and intensification.

Agricultural intensification was found associated with the development of economies linked with the agro-voltaic sector. In general, the analysis' framework confirms the validity of land-use classification of the European rural space, suggesting the reliability and general representativeness of the main land-use trends identified and characterized through the elementary indicators adopted in this study. These indicators, even in a relatively small number, have proven to be crucial information sources in drawing a particularly detailed geography at the continental level, confirming the policy-supporting role of the NUTS-3 spatial domain, whose supply of official statistics on agriculture should be significantly increased.

18. Annex 9 Overview of policies that have influenced land use in the past and will continue to do in the future

In this annex an overview of how policies have affected land use is provided.

CAP and other EU policies and land uses changes in the last 30 years

With two World Wars, a serious economic crisis and regular food shortages in mind, there were strong feelings and incentives in Europe to stimulate the economy and to boost industrial and agricultural productivity. It is therefore no surprise that the CAP of the EC was focused since its establishment in 1957 on increasing agricultural productivity, ensure a fair standard of living for farmers, stabilize agricultural markets, ensure stable food supply and reasonable food prices. This policy became very successful and within 3 decades the EU became a net exporter of food and it led to productivity increases, regional and on-farm specialization and rationalization, a decline of agricultural labor, a decrease in the number of farms, shifts in land use types but also abandonment of lower productive farmland. It also went together with drastic adaptations to land and landscapes. Land re-allotment increased tremendously (Slangen et al., 1996) and plots were enlarged, ditches filled, lines of trees cleared, wet soils drained, soil profiles agronomically improved and farm buildings modernized and relocated. Low-nutrient ecosystems dominated by semi-natural vegetation were either transformed into nutrient rich farmland if possible or were abandoned. With the intensification of the land use, more and more areas were manured and drained. Specialization at farm level resulted in a large decrease in mixed farms and a scaling-up of farming in general. Farm enlargement became apparent from the rise in the numbers of livestock per farm, an increasing acreage of crops per farm, as well as from increased plot and farm size. The intensification of land use involved an increased use of inputs like concentrates, (artificial) fertilizer and pesticides (Jongeneel et al., 2007; Stoate et al., 2009; Lécuyer et al., 2021).

All these changes also put an increasing pressure on environment and resulted in strong biodiversity losses (Lécuyer et al., 2021; Stoate et al., 2009; Pretty, 1998; Campbell and Cooke, 1997; Baldock, et al. 1996). This also led to the acknowledgement that the CAP needed to be reformed and that environmental sustainability needed to be integrated into CAP policy. The McSharry reforms in 1992 resulted in implementation of the first agri-environmental measures (AEM) (EEC 2078/92) and codes of 'Good Farming Practices (GFP)', i.e., agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside were being promoted. The AEMs were introduced to stimulate extensification of certain agricultural production to support biodiversity. At that time also the Nitrates Directive 91/676/EC was approved (1991) which required Member States to identify, specify and encourage farmers to apply so-called 'Good Agricultural Practices (GAP)' for animal manure and fertilizer.

A measure that had a direct influence on food production in Europe and the area of active agricultural production was the set-aside premium. It was introduced as a response to the MacSharry reforms and addressed over production, particularly in cereals. It was first introduced as a voluntary measure in 1988

and in 1992 it became compulsory, and it lasted until 2008 following the CAP Health Check, as a response to rising prices for agricultural products. In 2008 the area under obligatory set aside amounted to 3.8 million hectares.

Set-aside was offered with a rotational scheme (in a different location every year or two) or no rotation (same location for 5-20 years) and fields could be sown with fallow crops or allowed to regenerate naturally. Some of this set-aside land could also be used for the production of energy crops to provide additional income. As mentioned in 2008 the policy was abolished, at least where it included mandatory set-aside for farmers with large production of cereals and oilseeds. It was given the possibility of being carried out even after 2008 as a voluntary set-aside while at the same time adopting agri-environmental regimes with conditionality. Rapeseed production also continued to be permitted. In some countries, e.g. Germany, France and Italy, this has led to large production of rapeseed for 1G biodiesel. In other countries it has led to a clear extensification process.

Although the amount of land set aside has varied, it affected an average of 10% of arable land per year between 1992 and 2008 and effectively reduced overproduction. After 2008 it was retained also as a soil erosion control measure that could be chosen as the GAEC standard leaving fields fallow for at least a year to control soil erosion. Besides acknowledgement of negative environmental and biodiversity impacts of agriculture under influence of intensification, rationalization and specialization, there were also other drivers that forced further reforms. These were the prospects of EU enlargement to the Central and Eastern European countries and the continuing pressure for trade liberalization. In 1996 the Cork Declaration was signed which placed sustainable rural development at the top of the EU agenda. This formed the basis for the Agenda 2000 reforms and the implementation of these into regulations such as the Rural Development Regulation (RDR) (1750/99), the so-called second pillar measures, and the Mid-Term Review proposal (Commission of the European Community, 2002). This rural development policy has been considered a legitimate formulation of a territorial policy aiming to curb sectoral interests and address socio-economic and spatial inequalities (Hubbard and Gorton 2011; Lowe 2006; Mantino 2011; Papadopoulos and Liarikos 2007). It involved a shift from Pillar 1 budget, for market, price and income support, to Pillar II rural development support.

Cross-compliance was also introduced in the EU by the Agenda 2000 CAP reform. From then on, Member States were allowed to link environmental conditions to direct payments to farmers, regardless of their production level. In June 2003 cross-compliance became an obligatory element of the CAP which is also still applied in the newest CAP cycle (2023-2027). Cross-compliance affects farmers eligible for direct payments under Pillar I single farm payments or Pillar II by deducting part of these payments in case they are detected to violate one or more statutory management requirement (SMRs) Regulations and Directives, or requirements of good agricultural and environmental (GAECs) practices. Whereas the SMRs were all based on pre-existing legislation such as the Nitrates Directive, the Habitats and Birds Directives, only the GAEC requirements included some new standards and the latter have now been extended and adapted further in the two latest CAP periods. In the post-2013 CAP reform the implementation of certain GAEC measures changed in that all

standards were made compulsory, and for each GAEC MS had to define specific management requirements. For instance, what kind of landscape elements had to be protected under GAEC 7, the minimum and maximum width of buffer strips. Therefore, the implementation of GAEC was not uniform across MS. Furthermore, the post 2013 CAP reform also introduced Greening. This led to a shift of GAECs towards Greening measures. Greening payments are an annual payment per eligible hectare and conditional on farmers respecting three simple, generalized, non-contractual and annual actions: 1) crop diversification, 2) maintenance of permanent grasslands and 3) dedicating five per cent of arable land to Ecological Focus Areas (EFAs). This implied that Member States should use part of their national ceilings for direct payments in order to grant, on top of the basic payment, an annual 'greening payment'. The compulsory practices that 'go beyond cross-compliance and that are linked to agriculture, such as crop diversification, the maintenance of permanent grassland, including traditional orchards where fruit trees are grown in low density on grassland, and the establishment of ecological focus areas'.

CAP policies as drivers for land use change

After this overview of CAP policy evolution, more detail can be provided on how CAP has influenced land use changes in agricultural and wider rural areas in different parts of the EU. There is general agreement that the direct payments under Pillar 1 as well as the Pillar 2 payments for Areas of Natural Constraints (ANCs) are key measures that have helped to maintain land under agricultural use. As concluded in the DG-Ener report (EC, 2022 or Elbersen et al, 2020) this group of support measures tend to combat the risk of land becoming abandoned primarily where it is marginally productive. They do so by increasing the viability of farming in general terms (Ecorys et al, 2016; European Commission, 2013). Brady et al, (2017) and Uthes et al. (2011) have modelled the impact of direct payments on production and showed that direct payments help to keep land in agricultural production across the EU and, while land abandonment still occurs in practice, it is likely that more land would have been abandoned had direct payments not been in place. Also, in Central and Eastern European countries it was shown that higher shares in CAP payments in farm income influenced positively the maintenance of agricultural land, while for reduced levels of support from the CAP, an extensification of farming occurred and a higher level of land abandonment was reported (Terres et al., 2013). More recently, the importance of CAP support also in the form of direct payments for maintaining agricultural practices in more remote and marginal areas was illustrated in a study by Hubbard et al. (2018) analysing the removal of CAP support in UK agriculture which suggests that typical sectors relying on exports such as sheep farmers, will suffer most.

The support of CAP helping to keep agricultural land in use also works the opposite way where it concerns farmland that is ineligible for CAP payments. It is the case, for instance, of areas that do not fit in the official definition of farmland because of presence of trees or shrubs even though it is part of agricultural management through grazing. Despite a greater flexibility in the definition of what constitutes permanent grassland since the CAP reform in 2013, hence, to be eligible for CAP support, the area of permanent grassland in receipt of CAP support decreased by 3.81 million ha between 2014 and 2015 in the EU28 (Alliance Environnement, 2019). But there were also differences seen between Member States, with an increase in the area supported of 1.5 million

ha of permanent grassland in EU-15 and a decrease of 5.3 million ha in EU-12. The declines can be attributed to Member States' different choices. Alliance Environnement (2019) indicates that there is some evidence to suggest that the way that some Member States define their eligibility criteria continue to encourage the removal of scrub and trees to enable the land to become eligible for CAP support. In relation to widening eligibility for CAP payments, the Small Farmers Scheme (SPS) in the CAP 2014-2020 was also supportive as it widened access to CAP payments in countries that have a large area of farmland managed by very small farms. This was the case in Romania, Malta and Poland where, because of this SPS, an extra 10%, 45% and 13% respectively of farmland has become eligible for direct support under both pillar I and II.

At the same time, the decoupling of payments for production, particularly in the animal sectors, have also shown that traditional grazing livestock systems were negatively affected as this caused abandonment of extensive grazing in particularly in HNV farmland areas (Stoate et al., 2009; Dwyer et al., 2006). This is therefore a reason why still in the CAP 2014-2020, Voluntary coupled support (VCSs) was maintained in all Member States to varying degrees apart from Germany. Approximately 10% of the direct payments budget was still used in the former CAP period, of which beef and veal sector received most support under VCS (40%), followed by milk and milk products (21%), and sheep and goat meat (13%) (European Commission, 2020). In 2020, 39% of bovine animals were supported through VCS and 54% of sheep and goats, the remaining 27% of support went to a variety of crops. Real evidence of whether this helped to maintain agricultural management of land is hard to get but Brady et al. (2017) concluded that VCS support for beef, sheep and goats and dairy was maintaining livestock production in areas where it would otherwise disappear. Also, Alliance Environnement (2019) gave 2 examples of VCS support that helped avoiding abandonment of terraces in mountainous areas, and extensive livestock systems which contributes to maintaining grassland systems on steep parcels slopes.

Impacts beyond land use change of CAP

Land use impacts have also been very different throughout the EU because of the non-equal distribution of CAP payments. The main reason for this is that despite the several reforms, direct payments in farming remain based on historic rights. Papadopoulos (2015) found that in 2008, the EU-15 received 91% of the funds allocated to Pillar I, against only 9 % for the EU-12. By 2013, the EU-15 has been allocated nearly 81% of the Pillar I funds, against 19% for the EU-12. Also, within size farm groups there is strong inequality in distribution of funds. In 2007 25% of the largest farms received 75% of the total support from both pillars. Swinnen (2009) showed that the payments based on historical rights also increased regional inequal distribution within countries where specialised cropping regions with most of the supported crops still receive the highest levels of payments whilst regions which are more remote and most in need of support are less likely to receive large amounts. Also Shucksmith et al. (2005) shows that richer regions with low unemployment rates and high population density benefit more from CAP support from both pillars than other regions. Elbersen et al. (2009) showed for the Netherlands for the CAP period 2000-2006 that both Pillar I and II payments were strongly targeted to intensive farming activities, particularly livestock farming, even within areas that are very sensitive to nitrate leaching and also within HNV farmland areas. This was not surprising as direct payments remained based on historic rights when payments

were still linked to production levels. For the Pillar II agri-environmental schemes (AESs) payments the conclusion of Elbersen et al. (2009) was however more surprising. They showed that 70% of the AES payments went to areas outside HNV farmland and within HNV farmlands the AES payments were targeting more strongly the intensive than the extensive farms.

Beside the historic right bases of direct payments, Papadopoulos (2015) gives three other reasons for the uneven distribution of CAP payments over EU: first, the diversity of member state priorities; second, the inadequate and uneven funding of rural development measures; and third, the cofinancing requirement, which severely restricts the implementation of especially the Pillar II measures in poorer regions of the EU.

The uneven distribution of CAP payments was noticed and because of this, a modulation was introduced in 2007-2013 and also after, which meant that the funds from Pillar I were transferred to Pillar II. This modulation also involved a reduction in direct payments to bigger farms releasing funds. Still this did not lead to a large decline in uneven distribution of CAP payments as also for the period 2014-2020 the lion-share of direct payments continued to be allocated to larger farms at the expense of the smaller ones (Heyl, 2020; Peeters, 2020).

An interesting support measure under CAP is the payment for areas facing natural and other specific constraints (ANCs), under the CAP 2014-2020 and less favoured area support under former CAPs. The aim of the ANC measure is to 'contribute to maintaining the countryside as well as to maintaining and promoting sustainable farming systems' by 'encouraging continued use of agricultural land' (Regulation (EU) 1305/2013, recital 25). ANC applies to a very large area as in 2019, 57.9% of UAA in the EU27 was designated as ANC. With very large ranges between the member States. Of this, 17.1% is designated as 'mountain' ANC, 32.6% as 'areas other than mountains facing natural constraints' and 8.1% as areas affected by other 'specific constraints'. Alliance Environment, (2019) and Louwagie et al. (2011) showed evidence that ANC support reduces the rate of abandonment as well as inhibits afforestation or other competing land uses. Evidence was found in France and avoided the abandonment of grassland in Hungary and Ireland and on steep mountain slopes in Romania. This ANC effect was also further confirmed in the 9 case studies in DG-Ener study (EC, 2022 or Elbersen et al, 2020) that highlighted the ANC measure as important for reducing the risk of abandonment. On the other hand, because there are no explicit environmental criteria attached to the ANC payments, in some cases they help maintain extensive areas of HNV and the associated environmental and climate benefits they bring. However, the payments both for ANCs but also VCSs may also provide sufficient liquidity for farmers to carry out agricultural improvements on this land and can lead to overgrazing, which can have negative environmental impacts (Elbersen et al., 2014; Alliance Environment, 2019). Direct payments may help farmers to make agricultural investments more easily that increase their production. Alliance Environnement (2019) refers to evidence of this from two studies. One from an Italian study of the impact of decoupled CAP payments on crop diversity (Capitanio, Gatto and Millemaci, 2016), which argues that the existence of stable CAP payments leads to an increase in farmers' willingness to take market risk, and that this has resulted in greater crop diversity as farmers experiment with riskier crops. The second was from studies by Mittenzwei, Britz and Wieck

(2014) and Gomez y Paloma (2011) showing that decoupled payments affect risk attitude and reduce the costs to finance investments.

In the Greening the maintenance of permanent grassland was further strengthened by requiring that the ratio of permanent grassland in relation to the total agricultural area should not decrease more than 5% in comparison to the reference year. Member states are obliged to monitor this ratio of PG at national, regional or farm level. Also, inside Natura 2000 or other Environmentally sensitive permanent grasslands (ESPG) ploughing or converting permanent grassland should be avoided. Alliance Environnement (2019) showed that the implementation of this measure at national level in all, but four Member States meant that significant losses of permanent grassland were still taking place in many regions in some Member States. However, the pre-authorization system, requiring individual farmers to make a request to local authorities before converting their grassland to another land use, put in place in six of them (DE, CY, FR, IT, LU, PT) did appear to be a disincentive to ploughing permanent grassland, especially in Germany.

Regarding this ESPG designation in 2018 affected 4.64 million ha inside Natura 2000 areas and a further 0.24 million ha outside them. This was 13% of the total permanent grassland area in the EU. Alliance Environnement (2019) concludes that the ESPG measure has in most cases improved the protection of permanent grassland on the area declared by farmers for support in the ESPG designated areas covering through better enforcement of national legislation and cross-compliance.

Greening with crop diversification and EFA areas has led to crop mix changes within arable lands. Large reductions took place in the area of protein crops in the EFA area, and this is because in the mid-term review the use of pesticides was banned which made the choice for these crops less attractive. It is also concluded by the Alliance Environnement (2019) that fallow land decline slowed down under influence of Greening.

So far however it also became clear that the so-called Greening under Pillar I and the Agricultural Environment and Climate measures (AECMs) under Pillar II in the CAP 2014-2020 have been rather limited in reaching positive effects on biodiversity and climate mitigation which were the main objectives of these measures (Peér et al., 2017; European Court of Auditors, 2020). This was largely related to underfunding, insufficient, and leaving too few restrictions particularly in terms of farmers choices. Thus, farmers choose in majority measures under Greening that were not having any additional value as compared to existing practices.

Under Pillar II, for which the (relative) CAP budget has increased strongly since 2000, several support measures have a territorial dimension these include AES, ANC, compensation payments to farmland in Natura 2000. All these support measures work out differently because choices to include them in the Pillar II suit of measures and budget allocation is also influenced by member countries' choices. For example, Natura 2000 compensation payments for restrictions attributable to the Birds and Habitats Directives were made available in the 2014-20 CAP in maintaining agricultural production on these areas. However, uptake of the measure is low, occurring in only 13 Member States and an estimated 7.9% of the total UAA in Natura 2000 areas (Alliance Environnement, 2019).

Important in this suite of measures are the Agri-Environment and Climate measures (AECM) under the Rural Development Programme (RDP 4.4: Support for non-productive investments linked to achievement of agri-environment-climate). These are effective for enhancing sustainable practices and mitigating land abandonment through providing additional income to carrying out particular management, including on more economically marginal farms (Calvo-Iglesias et al., 2009). Several examples of such support were given in the 9 case studies in the DG-Ener study (EC, 2023 or Elbersen et al, 2022; Alliance Environment, 2019). Also the Alliance Environment (2019) study showed evidence of this, although they also indicate that the area eligible for the measure and the uptake by farmers remains very small. Also the effectiveness of this measure will be different per EU country as there are differences in the design and targeting of the AECMs. The AECM are particularly relevant to the adoption of new technologies and also increasing physical output. Other relevant RDP measures include: support to training and skill acquisition; several forms of investment support; conversion to and/or maintenance of organic activities.

One measure to stimulate continuation of farming, particularly in rural areas with ageing population and farmers, is the Young Farmers support. It is support available under both CAP Pillar 1 and Pillar 2 and in several studies, it is identified as being effective to encourage young farmers to take up farming as a way of addressing one of the drivers of land abandonment, which is ageing farm population.

Policies for water management

The European Water Framework Directive (WFD) is setting out rules to halt deterioration in the status of EU water bodies and achieve good status for Europe's rivers, lakes and groundwater (European Commission, 2024). The WFD has four main objectives: i) protection of water sources from pollution and maintaining good water quality; ii) recovery and protection of ecosystems in- and around water bodies; iii) sustainable water use by communities and companies and iv) reduce effects of floods and droughts (EUR-Lex, 2021; KED, 2023). It encompasses surface water, groundwater, inland water bodies such as lakes and flowing waters on land and transitional water such as river mouths and brackish water bodies that receive fresh water sources (EUR-Lex, 2021). Implementing the WFD requires Member States to develop River Basin Management Plans (RBMPs) and Programmes of Measures (PoMs) to protect and, where necessary, restore water bodies in order to reach good status, and to prevent deterioration. Good status means both good chemical and good ecological status (European Commission, 2024). With respect to rural land-use, the European Rural Development policy is also relevant as this includes measures and targets for water management on agricultural lands to restore, preserve and enhance ecosystems in agriculture through Rural Development Plans (RDPs). Such measures include buffer strips, soil cover management, pesticide reduction, organic farming, afforestation among other measures to protect water quality and thus directly impact the agricultural land-use characteristics. In the programming period 2007-2013 RBMPs generally did not specify obligatory requirements for farmers, but with the 2014-2020 second generation of plans, it is possible to see that the sub-Measure for WFD payments is being used in more RDPs therefore strengthening the farmer's role in water management (European Network for Rural Development, 2017). An overview of percentage of agriculture land under management contracts to improve water management for the EU Member States is presented in the graph below.

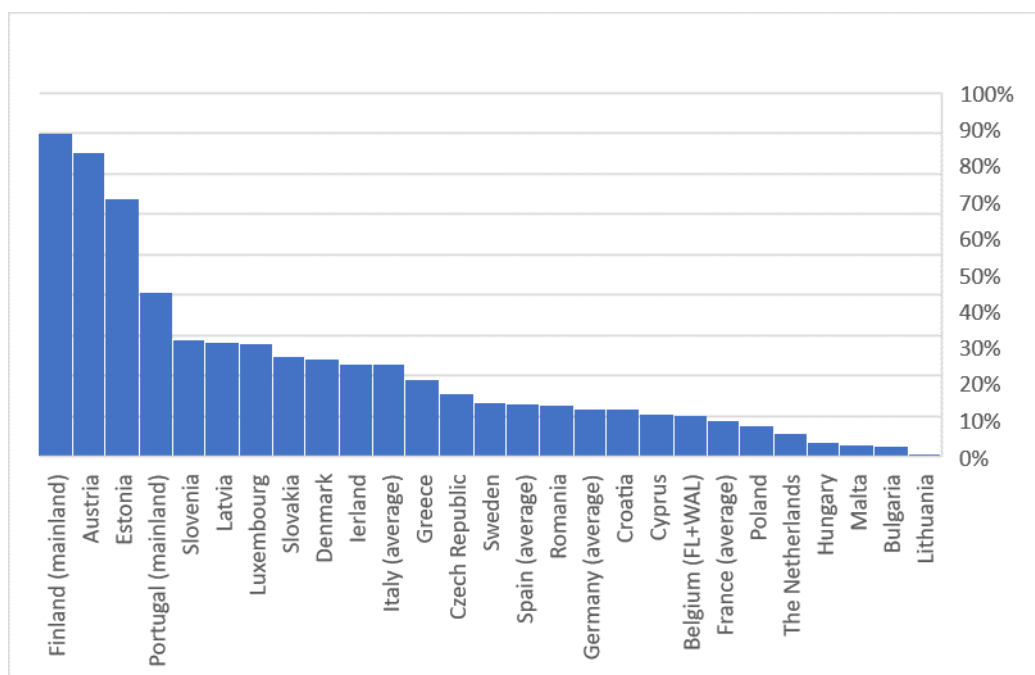


Figure 20 Percentage of agricultural land under management contracts (2014-2020) to improve water management (focus area 4B)

The Figure 20 shows a large fluctuation of agricultural lands under contract to improve water management between the EU Member States between 2014 - 2020. Most countries report improvement measures through organic farming, afforestation and agri-environmental measures (e.g. buffer zones). This implies a main shift from intensive agricultural land-use to a more extensive and nature-inclusive agricultural land-use typology. The impacts of these measures on agricultural land-use is mostly visible in Finland, Austria and Estonia. It should also be noted that severe differences within countries are observed. Germany, France, Spain and Italy report per region with differences of percentage agricultural land to improve water management fluctuating between 0.51 to even 90.05% (European Network for Rural Development, 2023). There are thus severe differences between and within countries where improved water management practices in agricultural lands are applied.

Multiple Water Directive and impacts on (agricultural) land-use

The WFD also has multiple supporting directives and guidelines that have specific impact on water quality and/or quantity issues and thus an impact on (agricultural) land-use. An overview of these water-related guidelines with their specific effect on (agricultural) land-use is presented in the Table 24.

Table 24 Overview of EU directives for water and their links to land use

EU Directive/guideline	Main objectives	Link with (agricultural) land-use
EU Drinking Water Directive (2020/2184)	Improving access to drinking water for all	Yes, with respect to (agricultural) practices in drinking water protection zones and forests
EU Bathing Water Directive (2006/7)	Sets standards to protect bathing areas under the WFD	Indirectly as it may impact agricultural management practices such as manure application around bathing water locations
EU Urban Wastewater Treatment Directive (91/271)	Urban- and industrial wastewater treatment & monitoring	Minor as main focus on securing good water quality through treatment of urban waste waters
The Floods Directive (2007/60)	Flood hazard & risk assessment and identification of adaptive measures	Yes, agricultural land-use directly affected by floods. Multiple measures are needed within agricultural domain. Main focus on Nature-based solutions
Nitrates Directive (91/767)	Monitoring, defining Nitrate Vulnerable Zones and measures to prevent nitrate pollution to water bodies	Yes, within particular buffer strips to prevent nitrogen compounds entering waterways
Groundwater Directive (2006/118)	Defining groundwater quality standards and prevent deterioration of groundwater bodies	Indirectly, as limitations on groundwater- and agrochemical use may impact agricultural landscape and/or cropping patterns

Sources: *The Water Forum, nd.; ECER, 2024.*

EU Drinking Water Directive (2020/2184)

The main purpose of the Drinking Water Directive is to provide Europeans with high quality, safe and sufficient drinking water. It aims to achieve: i) protection of human health by ensuring quality of water intended for human consumption; ii) setting good standards for drinking water quality; iii) efficient and efficient monitoring, assessment and enforcement of these standards; iv) provide the public with adequate, timely and appropriate information regarding drinking water quality and supply and v) improve access to water intended for human consumption. It therefore concerns both the quality of- and access to water intended for human consumption to protect human health (European Commission, 2024c). The Drinking Water Directive came into force in 1998 and started with particular focus on monitoring, setting of water quality standards and inform consumers and the European Commission on water quality status. In 2014, the Directive was revised and an updated version was entered into force in 2021 with additional focus on a risk-based approach. This entails assessing water pollution by looking at the whole supply chain (catchment area, abstraction, treatment, storage and distribution of water, final point of compliance) including investigating sources of pollution (European Water Regulators, 2021). From this point onwards, more attention was given to addressing sources of pollution on catchment area level in protected areas for

potable water. With respect to (agricultural) land-use this is relevant as it leads to land-based measures aiming to protect water reserves suitable for drinking purposes. In Slovakia, Serbia, Czech Republic, Croatia and Hungary the risk assessment of potable water sources are led to preventive actions such as limiting or banning certain agro-chemicals that are at risk for drinking water supply (Danube Region Strategy, 2023). This indirectly affects the type of agricultural land-use as certain agricultural practices require more pesticides compared to others and may no longer be possible in the Protection Zones for drinking water (e.g. flower cultivation). In some countries, the measures go a little further. In Germany for example, the government transformed areas near Leipzig that are suitable for potable water to organic farming areas by buying the lands and then signed contracts with farmers that apply practices aimed to protect drinking water catchments. Measures to reduce nitrogen leaching to drinking water sources include conversion of agricultural practices to sustainable and environmental agricultural practices in drinking water protection zones, afforestation among other practices (e.g. in Spain, France and Germany) (Siauve and Amorsi, 2015). Overall, the Protected Zones following from the Drinking Water Directive sets limits to the kind of (agricultural) activities and influence the (agricultural) land-use types and practices. The agricultural landscape in these zones are and have to be transformed from conventional agriculture with plentiful external agro-chemical inputs (fertilizers, pesticides) towards more environmental, nature-inclusive to even organic farming types. Although not found in literature, this could also impact the kind of agricultural activities as some cultivated crops require frequent and large amount of agrochemical input (e.g. flowers, potatoes) which may be in conflict with achieving and maintaining safe water quality standards in Protected Zones.

EU Bathing Water Directive (2006/7)

This Directive is focusing on setting monitoring standards of various faecal bacteria in bathing water. Based on the presence of these bacteria bathing water can be classified as 'excellent' as 'excellent', 'good', 'sufficient' or 'poor' (European Commission, 2024b). The objective is to provide timely information given to the public during the bathing season and requires Member States to disseminate information on bathing water quality such as notices on banning or advising against bathing. The monitoring data also provides information for water managers regarding sources of pollution to identify suitable management practices. In this context, the agricultural sector is important as run-off from the catchment is a substantial source of microbial contamination with the highest loads associated with intensive agriculture practices (Schreiber et al., 2015). The outcome of water quality monitoring data as described by this Directive may therefore lead to additional actions such as emission reduction measures or (temporary) closure of bathing water and/or manure application. But the Directive does not directly guide changes in (agricultural) land-use itself.

EU Urban Wastewater treatment (91/271)

The main objective of this Directive is to protect human health and environment from the effects of untreated urban wastewater and from certain industrial sectors. It also ensures that domestic and industrial wastewater is effectively collected, treated and discharged. The law requires that member states collect and treat wastewater in all urban areas of more than 2000 people, secondary treatment in urban areas over 2000 people or 1000 people in catchments with sensitive waters, pre-authorisation of all urban wastewater discharges, monitoring of the performance of treatment plants and receiving waters and

control of sewage disposal and reuse and treated wastewater reuse whenever appropriate (European Commission, 2024c). Recent updates of the Directive are focused on extreme weather events linked to climate change bringing heavier and more frequent rainfall in some areas, but water scarcity in others. This has an impact on storm sewers, frequency of sewage water overflows and operation of sewage water treatment plants. Also treatment of new chemicals and mixture of large variety of chemicals in low concentration have gained increasing interest (OAP, 2021). In general, the Urban Wastewater treatment Directive is focused on securing good water quality through treatment and monitoring of urban- and industrial waste water. A direct link of this Directive with (agricultural) land-use (changes) has not been found, except for the physical presence of over 23,600 urban waste water treatment plants in the EU that are covered by this Directive (OAP, 2021) .

EU Flood Directive (2007/60/EC)

Floods are the most common and mostly costly natural disasters in Europe. It is becoming a more frequent problem due to climate change and is threatening lives and multiple economic activities as well as main natural ecosystems. From an agricultural land-use perspective, an average of 6% of agricultural lands in the EU are exposed to floods by an average 100-year flood event, with significant differences between member states to even over 80% for some countries (European Union, 2021). It is for those reasons that flood risk management is a main topic in the EU (European Commission, 2024d). The Floods Directive has therefore been put in place which focuses on the assessment and management of flood risks, and includes i) assessment of all areas where significant floods could take place (hazard), ii) map flood extent and assets and humans at risk (risk assessment) and iii) taking measures to reduce flood risks (European Commission, 2024d).

The maps below show the flood risks areas in the EU (left) and the locations with potential significant flood risk (right) that have been defined based on the Floods Directive. These maps show that flood risk zones are widely spread over the European countries with over 14,000 areas at significant risk of flooding (DG-Environment, 2023; EEA, 2023).

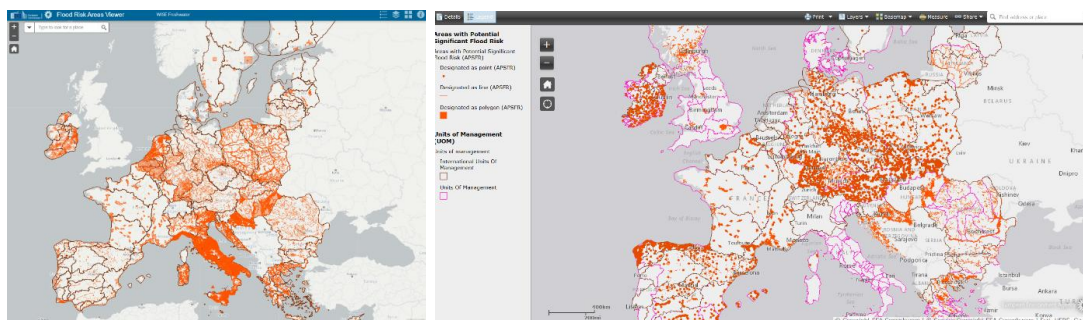


Figure 21 Flood risks areas in the EU (left) and the locations with potential significant flood risk (right) that have been defined based on the Floods Directive

Member States are required to develop flood risk management plans that include several actions related to flood risk adaptation. These action plans

impact (agricultural) land-use in Europe on various ways. Firstly, the flood risk maps developed by the Member States are used for spatial planning. Countries define different flood risk zones in which governments prohibit certain developments, mostly urban, industrial and infrastructural related. Austria, Czech Republic and Spain defined high risk flooding zones (usually flood events that occur once per one-hundred years) in which new infrastructural developments are not allowed by the government. Land-use in these areas is typically limited to agricultural and natural services. However, In Slovakia flood risk maps are used to advice municipalities but these are still allowed to build developments in flood risk zones. Belgium on the other hand applies a Water Assessment (WA) mechanism to ensure that flood risk is considered where necessary for a development. This still allows developments in flood risk zones as long as flood risk and mitigation actions are considered appropriately. Although European countries apply flood risk zones differently in their governance structure, most activities in high flood risk zones are focused on agriculture and nature and less on urban developments (European Commission – DG-Environment, 2021).

Flood management is further increasingly focused on restoring and/or developing new floodplains and river restoration based on nature-based solutions (NBS). These solutions include a large variety of measures such as channel re-profiling, sediment dredging, changing natural forms of rivers, extending floodplains, river buffers such as grass, shrubs and trees strips. Along agricultural areas, flood management measures focus on buffer strips adjacent to waterways, allowing agricultural land to be temporarily flooded during flood events and adjustments on agricultural lands such as adjusting soil management practices to low/no till, supporting agroforestry, regeneration and conservation agriculture practices (EEA, 2021, European Union, 2021).

The EU promotes these kind of interventions as they provide multiple benefits besides flood protection such as restoring habitats (relating to Habitats Directive), carbon storage (climate change mitigation), nitrate buffer zones (Nitrate Directive) among others and provide positive effects in terms of achieving the Water Framework Directive objectives (European Union, 2021). Such measures are also found to be cost-effective and an integral part of ecosystem based management and have been funded by the EU through LIFE+ and structural funds (EEA, 2019). Flood protection measures based on NBS is already ongoing in multiple EU Member States. In Hungary for example, rehabilitation of 15 major river branches and wetlands along the 124km length of the Mosoni-Danube took place as part of flood adaptation measures. In Portugal Nature-Friendly Measures were applied to address urban flooding caused by the Tamega River through removal of course woody debris from the watercourses, bank stabilisation using natural engineering techniques, floodplain restoration by creating detention basins, restoration of riparian buffer zones using native species, removal of invasive species and incorporation of swales and ponds among other traditional measures. In Spain, the Arga River Restoration consisted of a range of measures to recover the natural dynamics of the river with the combined aims of reducing flood risk and restoring water quality and habitats (European Commission – DG-Environment, 2021).

The development of NBS come with land-use transformations including in the agricultural sector (EEA, 2021). Nature-based solution usually require more space compared to grey infrastructure (such as a dike) and therefore may require (partial) transformation of agricultural land towards green infrastructure or towards agricultural land with multiple functions, e.g. crop production plus flood retention. An example of this is using agricultural areas as reservoirs for flood expansion which temporarily changes the land-use function. This practice may also impact the type of agricultural land-use as some cropping systems do not function when regularly flooded such as fruit trees. Thus agricultural land-use is also guided by presence of locations in flood risk zones.

Overall, the Flood Directive is impacting land-use in flood risk zones through restrictions of certain developments, (partial) conversion of agricultural lands for NBS and changes in agricultural land-use from conventional and intensive agriculture to alternative types such as nature-friendly and extensive agricultural practices which also allows for flood retention. In the period 2014 – 2020, over 2 billion Euro was spent for preventive actions including those addressing flood events (European Union, 2021), which shows that this process is already ongoing. Looking to future, it is expected that further actions are required within the scope of climate change which generally increases risks of (severe) flooding. While countries such as Spain and Belgium already take climate change into consideration when defining (high) risk flood zones, this is not yet applied by all EU Member States (European Commission – DG-Environment, 2021). However, this will be needed in the future and likely demand for additional areas to be defined under (high) flood risk zones. This would then entail further land-use adaptations, within particular within the agricultural domain from conventional to more environmental- and nature friendly alternatives, as being one of the main land-use types in Europe.

EU Nitrates Directive (91/767)

Nitrates and organic nitrogen compounds enter ground- and surface water particularly via agricultural practices, specifically through leaching of fertilizers and manure. High levels of nitrate in water make drinking water unsuitable and cause eutrophication in surface waters which pose a risk to aquatic ecosystems. In order to address this pollution source to water, the EU has defined the Nitrates Directive (European Commission, 2024e). The objectives of this Directive are i) monitoring of nitrate concentrations in water bodies by Member States; ii) designating nitrate vulnerable zones and iii) establishing codes of good agricultural practices and measures to prevent and reduce water pollution from nitrates (European Commission, 2024e). Nitrate Vulnerable Zones (NVZ's) are areas that drain into waters that are polluted or at risk of pollution. In such areas restrictive and/or adaptative measures have to be taken to reduce and minimize nitrate leaching to keep concentrations in waters below thresholds (50 mg/L). These zones have an impact on the land-use typology and is relevant as large portions of the EU, within particular north-west to eastern Europe, fall under NVZ's. Some Member States choose to place the entire country under NVZ's, see Figure 22 below (European Commission, 2018).

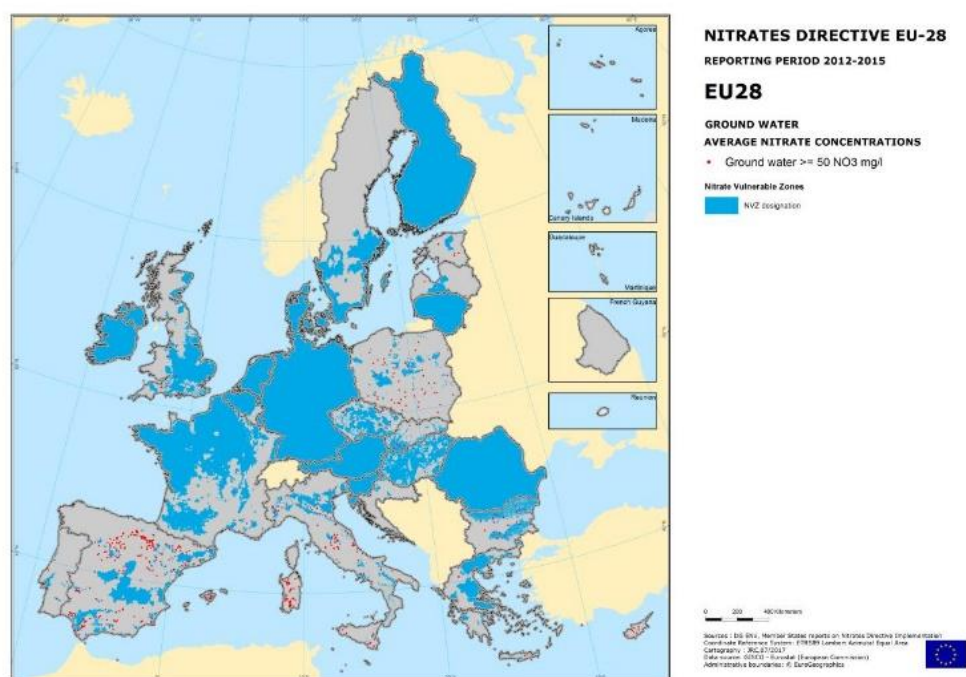


Figure 22 Nitrate Vulnerable Zones in the EU designated through the Nitrates Directive

Including the Member States that apply a whole-territory approach, the total area of NVZ has increased since 2012, from 1,951,898 km² to about 2,175,861 km² in 2015 of which approximately 61% is defined as agricultural area. The Member States are then required to adopt an action plan to address nitrogen pollution. These actions include practices within the agricultural domain such as setting maxima for nitrogen application rates, prohibiting spreading periods, maximum storage requirements for livestock, green cover in tillage lands and set-back distances from water or buffer strips (GoI, 2021). With respect to the linkage with land-use, the development of riparian buffer strips (RBS) is most relevant as these change the land-use pattern and/or type. Buffer strips act to intercept nutrients as well as other agrochemicals and thereby reducing/preventing leaching to water bodies. Buffer strips or zones can be unfertilized zones along waterways, strips with flowers or other vegetation to forested zones. In 2005, buffer strips were already mentioned in two Agri Environmental Measures related to productive land management. It mentioned the inclusion of cover strips (e.g. farmed buffer strips) as positive elements for improving water quality, increasing biodiversity and help prevent soil erosion. A new water-related GAEC buffer strips standard would be implemented by 2012, comprising mandatory establishment of dry buffer strips along water, both within and outside nitrate vulnerable zones. In the CAP 2014-2020 riparian buffer strips have also been identified as elements that can become part of 'Ecological Focus Areas' (Elbersen *et al.*, 2014). Thus further development and expansion of buffer strips within agricultural lands is expected.

The implementation of buffer strips varies between Member States. A majority of countries apply buffer strips among waterways between 5 – 20 meters including Austria, Belgium, Bulgaria, Estonia, Poland, Slovakia and Ireland. Other countries allow buffer strips that are smaller than 5 meters such as Romania and The Netherlands while other countries set standards for buffer strips over 50 meters in width like in Ireland and Latvia. There is also variation

between buffer strip width between countries based on the type of waterway such as in Malta and Estonia with different buffer strip widths requirements depending on the function of the waterway (e.g. for drains, lakes, human water supply, etc.). Hungary and Ireland have set buffer strip requirements based on the type of fertilizer applied and distinguish different widths for organic and industrial fertilizers. In the Netherlands, buffer strip widths are defined on the crop type with lowest width for cereals and grass (0.25-0.5 meters) and highest (5 meters) for fruit trees (Elbersen *et al.*, 2014).

Overall, the Nitrogen Directive is an important driver of land-use in the EU agricultural areas, within particular on the development of (riparian) buffer strips. However, the type and width of buffer strip among waterways varies significantly between Member States as stated in more detail in Elbersen *et al.* (2014).

EU Groundwater Directive (2006/188)

The Groundwater Directive objective to is establish measures in order to prevent and control groundwater pollution. A specific Directive for this water body has been defined since it is the largest freshwater resource in Europe and serving multiple crucial functions including drinking water supply (65%), securing natural ecosystems and irrigation water source for agricultural purposes (25%) (EEA, 2022). The Directive measures include in particular i) criteria for the assessment of good groundwater chemical status; and ii) criteria for the identification and reversal of significant and sustained upward trends and for the definition of starting points for trend reversals. It therefore aims to prevent the deterioration of the status of all bodies of groundwater (European Union, 2006). The Directive defined quality parameters that should be assessed in groundwater bodies. For nitrate and pesticides fixed criteria are provided. In addition, Member States need to define standards for metals, ammonium among parameters themselves (European Union, 2006). Reporting under the WFD in the second RBMP reporting cycle indicates that 24% of the total groundwater body area in the EU27 is of poor chemical status and 9% is of poor quantitative status threatening multiple services (EEA, 2022). Especially diffuse pollution from agriculture from nitrate and pesticides is the most common pressure and affects 19% of the total groundwater body area in the EU. The map below (Figure 23) shows how wide-spread the problem of poor groundwater quality is (EEA, 2022):

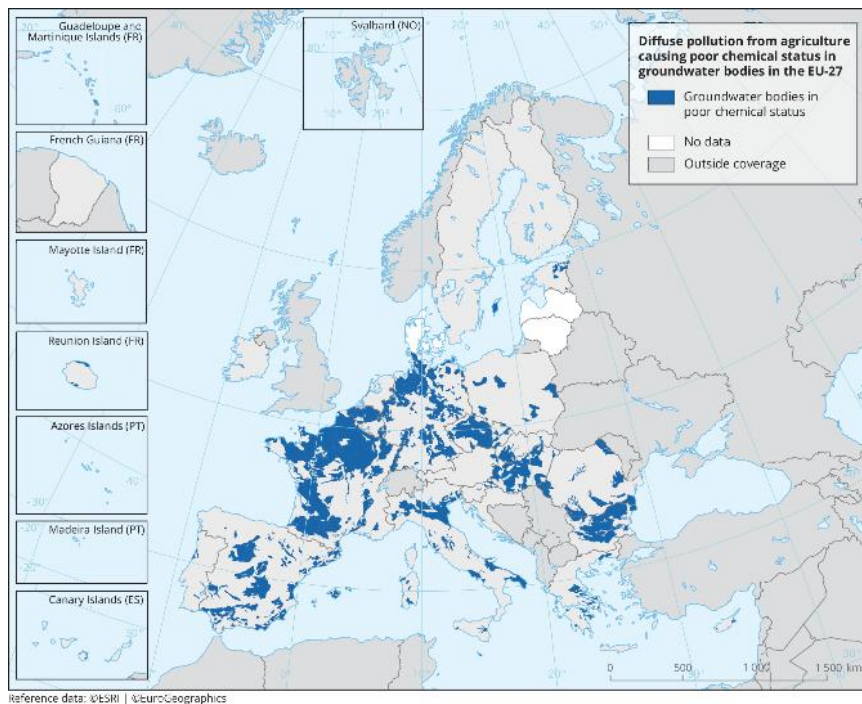


Figure 23 Chemical status ground water in EU27

In addition, water abstraction for irrigation and other agricultural activities causes less-than-good groundwater status in almost 7% of the total groundwater body area of the EU. This is most problematic in Greece, France, Hungary and southern Italy and Spain (EEA, 2022).

European legislation requires that land-use planning should consider risks to groundwater by controlling agriculture and urbanization related activities on such a way that groundwater quality and quantity is protected. Member States are thus required to set-up actions to protect groundwater. In Denmark, Spain and France there is main emphasis on controlling water abstraction from groundwater sources, e.g. through setting maximum limits and water pricing (Closas and Molle, 2016). Although implementation of such measures are unpopular to farmers, it may provide an incentive to shift cropping systems away from high water-intensive crops (e.g. maize) towards more economic and less-water intensive crop types like vegetables or certain fruits. In order to address groundwater quality deterioration, Member States also take action within the agricultural landscape with similar practices described for Nitrate- and Flood Directives. These measures are particularly focused on stimulating more environmental and nature-friendly types of agriculture such as establishment of buffer strips, agro-environmental schemes and reforestation. Also restrictions on the use pesticides and reduced use of fertilizers and manure have been set into place by Member States (Siauve and Amorsi, 2015; Closas and Molle, 2016). These restrictions could also be a driver for farmers to shift to other crops that require less agro-chemicals and thus impact the agricultural landscape.

Policies for RES energy

See Chapter 5 of main report

19. Annex 10 Overview of policy targets stemming from Green Deal and Farm to Fork

Farm to Fork (F2F) strategy is the agricultural policy core within the EU Green Deal. The strategy aims to make food systems fair, healthy, and environmentally friendly. The new CAP supports the GD and F2F goals of higher green ambitions in that all CAP strategic plans need to contribute to GD targets, 40% of the CAP budget will have to be climate-relevant and support the commitment to dedicate 10% of the EU budget to biodiversity objectives. This is done through three instruments: (mandatory) conditionality requirements, (higher environmental ambitions through) eco schemes and rural development supporting investments and farming activities that contribute to climate action and the sustainable management of natural resources. Eco-schemes under the CAP first Pillar provide a foreseen budget of minimum €48.5 billion for environmental and climate practices, including for reduction of pesticides and organic farming. Management Commitments under the CAP second Pillar (rural development) come with a foreseen EU budget of minimum €21.14 billion (supplemented by national co-financing). The CAP's second Pillar can support investments in precision farming which also contribute to pesticide reduction. CAP market measures in sectors such as fruits and vegetables or wine may finance collective actions for promoting practices such as integrated pest management or integrated production as well as organic production. Under the Farm Advisory Services, Member States must provide advice to farmers on a number of issues including sustainable use of pesticides. Setting-up and use of advice may also be funded by the CAP second Pillar, through the European Innovation Partnership (EIP-AGRI) for example.

In the following all instruments setting targets to 2030 and 2050 under the umbrella of the GD and F2F are described and how they are expected to influence land use in rural areas. This description is also used to specify the scenario assumptions used in this study.

F2F_Organic

The role of organic farming in promoting sustainable agriculture is recognized by the CAP. In 2021, an action plan was adopted to advance organic production in the EU, aiming to support both production and consumption while enhancing sustainability, aligning with the European Green Deal, the F2F strategy, and the Biodiversity Strategy. As anticipated in both strategies, the EU has set targets of reaching at least 25% of the EU's agricultural land under organic farming and significantly increasing organic aquaculture by 2030. We will focus on the former.

Good agricultural practices (GAPs) in organic farming include a range of interrelated activities dealing with nutrient supply, pest and disease control, soil management and weed control and preservation of biodiversity. At farm level this may lead to reduced crop yields. According to a review of meta-analyses commissioned by DGAGRI to the JRC⁷² crop yields in organic production are 5-30% lower than in conventional production, and the yield gap is particularly

⁷² Integrated Modelling platform for Agro-economic and resource Policy analysis, IMAP <https://wikis.ec.europa.eu/display/IMAP/>

significant for wheat. More controversial is the issue of farming costs. The same study shows that costs vary considerably across MS due to the decreased cost in the purchase of inputs as opposed to increased labor costs due to more labor-intensive operations. The land use effect caused by the above is a possible reduction in the number of farms, or an increase in medium - lower input farms, and in parallel a decline in high input farms. Positive impacts at higher level consist in increased food safety, decreased GHG emission/ha or per ton, higher crop diversity, better water and soil quality, preservation of biodiversity (both animals e.g., pollinators, and plant related). Negative impacts may include higher food prices and an overall reduced production at EU level due to the mentioned lower yields, that would in turn result in increased imports.

Links between policies, their expressed targets, possible GAPs to achieve them, impacts at farm and higher levels, are schematized in the .

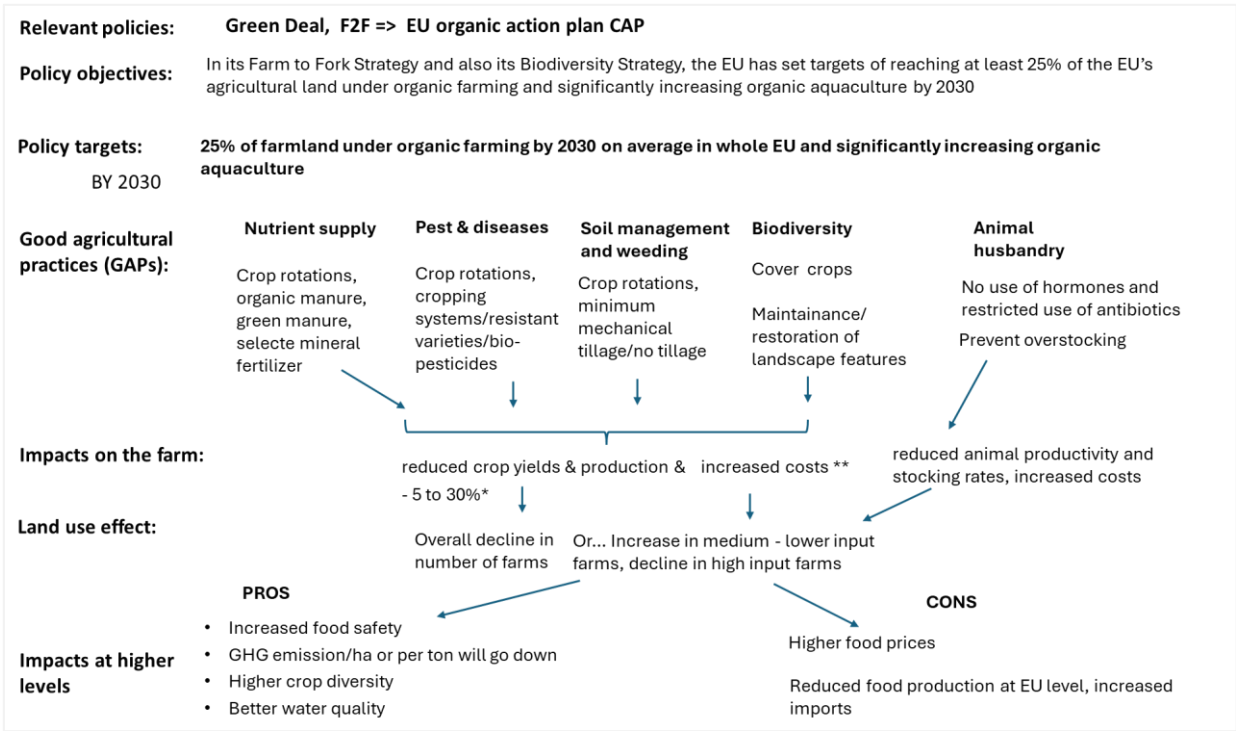


Figure 24 Links between the EU organic action plan and targets, possible GAPs to achieve them, impacts at farm and higher levels

F2F_Pesticides

One of the agriculture sustainability objectives in the F2F strategy is to reduce chemical pesticides that contribute to soil, water and air pollution, biodiversity loss and can harm non-target plants, insects, birds, mammals, and amphibians. Originally set in the proposal "Sustainable Use of Plant Protection Products" (PPP) Regulation (SUR) then withdrawn by the Commission in 2024, the targets

of PPP reduction, that are still part of the F2F and the Green Deal and to be implemented through CAP conditionality rules, are subject to rethinking and will be reformulated in a new proposal. The original targets are a reduction by 2030 of PPPs (for crop production and post-harvest protection) by 50% and in the use of more hazardous pesticides by the same percentage. These targets are followed in the implementation of the scenarios.

According to Barreiro-Hurle, et al., (2021) the adoption of the above reduction of pesticides likely implies a reduction in crop yields and production (8-12% for cereals, 11.0% for oilseeds and 10.4% for vegetables. Henning et al. (2021) estimated reductions in production of 21.4% and 20% for cereals and oilseeds, respectively. This is without considering a reduced appearance of the production that may impact on the saleability of the products. GAPs also usually lead to higher operational costs as they require more frequent treatments, more manual interventions, and care in general. In terms of product saleability, the opposite may also apply in the case of organic or IPM certified products. Higher costs may result in a decline in the overall number of farms or alternatively, in the decline of high input farms, while medium and lower input farms are advantaged. Negative effects as a consequence of farm level impacts at higher levels include higher consumer prices, increased imports, and reduced exports. Positive and mixed effects include of contribution to nature restoration, increase in organic farming, GHG emission per ton may decrease (although doubts of per ha emissions), higher crop diversity, better water quality and lower production of challenging crops (e.g., flowers, flower bulbs, cotton).

In the scheme below we connect such policy targets to farming practices which can support the policy targets, impacts at farm level and relevant land use effects as well as foreseeable impacts at higher, aggregated level.

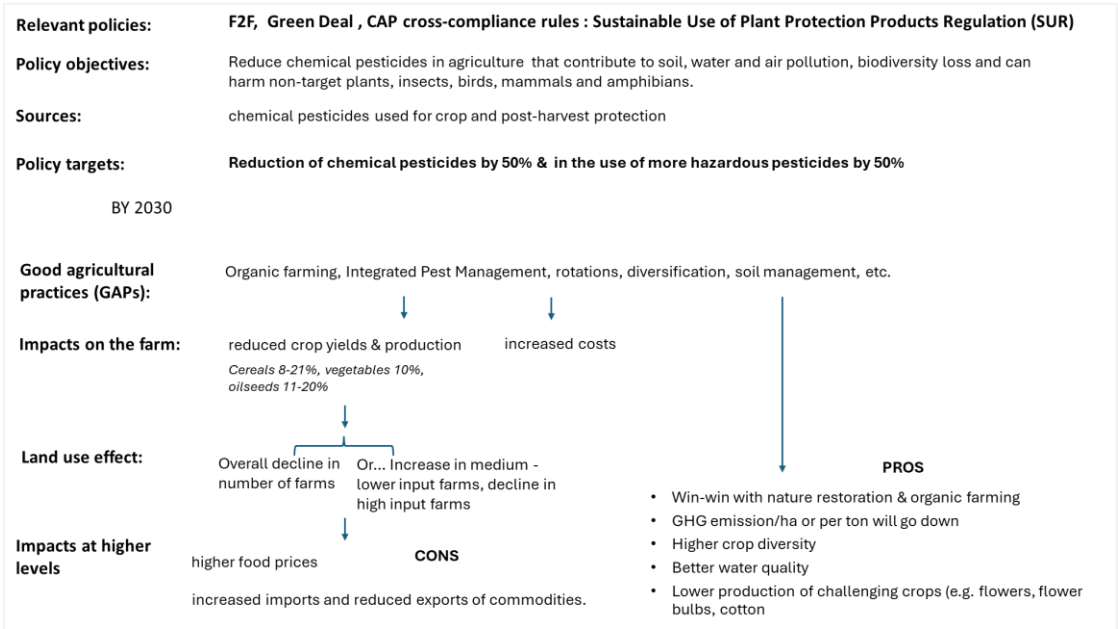


Figure 25 PPP reduction policies and targets, farming practices, impacts and land use effects

F2F-Nutrients

For nutrients the F2F sets targets of 50% reduction in nutrient losses and of at least 20% reduction in fertiliser application use on farmland with no deterioration of soil fertility.

With reference to sources of nutrient losses and ammonia emissions, there are on the one hand livestock systems and hence manure application, animal feeding, housing, and manure storage strategies. GAPs include extended grazing, managing nitrogen application at grazing, slurry/ manure amendments. The expected impact at farm level is a reduction of animal numbers, increased management requirements and costs. The foreseeable land use effect is an overall decline in the number of farms, especially small ones, or alternatively an increase in medium and lower input ones and a decline in high input farms.

On the other hand, when crop-based systems are considered sources of nitrogen losses are related to fertilizers applications, the target is to reduce fertilizer use by at least 20%. GAPs consist in nutrient management plans⁷³, reducing the use of urea, and soil incorporation. The expected impact at farm level is in the first place that of crop yield reductions (4-5%)⁷⁴. The win-wins expected from the implementation of measures to reach these goals are with nature restoration & organic farming, reductions in GHG emissions and better ground and surface water quality.

The scheme below exemplifies the possible links between policy targets and impacts:

⁷³ Possible measures for optimizing fertilizers use include those limiting the periods when nitrogen fertilisers can be applied on land to target application to periods when crops require nitrogen, measures limiting the conditions for application (on steeply sloping ground, frozen or snow-covered ground, near water courses, etc.) to prevent nitrate losses from leaching and run-off, crop rotations, soil winter cover and catch crops to prevent nitrate leaching and run-off during wet seasons.

⁷⁴ COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Ensuring availability and affordability of fertilisers, 2022 <https://secure.ipex.eu/IPEXL-WEB/download/file/082d2908838217af018461154c855a10>

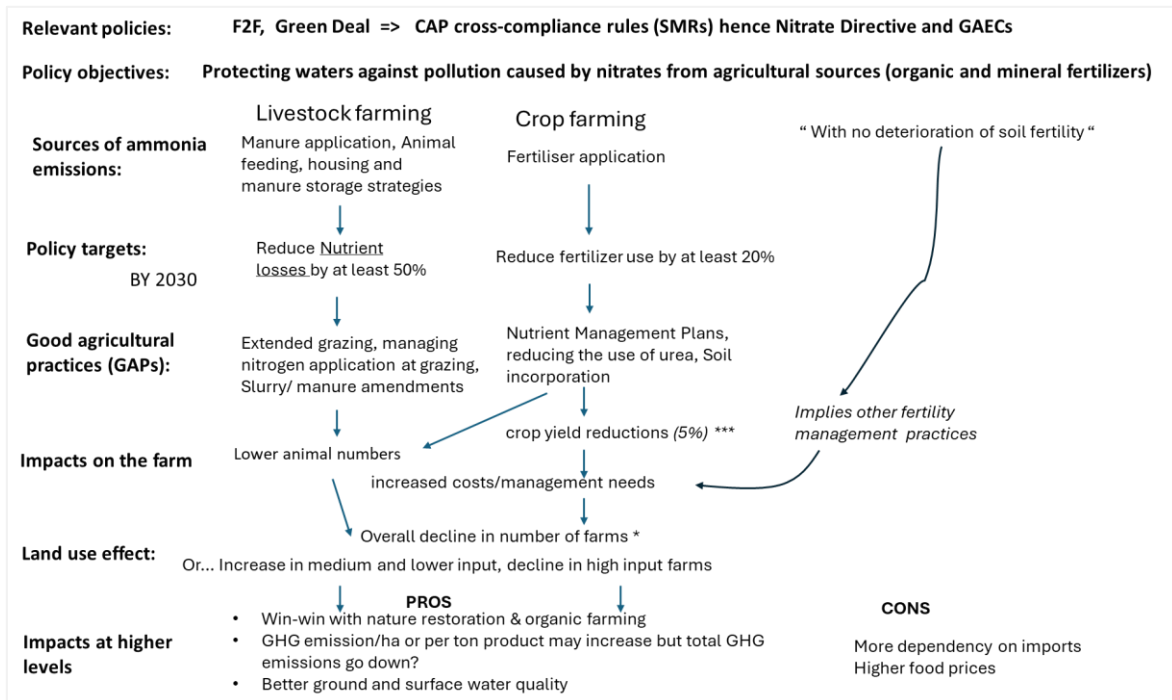


Figure 26 Nutrient reduction policies and targets, farming practices, impacts and land use effects

Nature restoration law

Under the EU Biodiversity Strategy (EC, 2020), which is part of the GD, the European Commission proposed legally binding EU nature restoration targets to restore degraded ecosystems, including those occurring in agricultural land. The EU Biodiversity Strategy for 2030 called for at least 30% of the land to be protected with the aim to preserve biodiversity. This is expected to contribute to the long-term recovery of damaged nature across the EU's land and sea areas, to achieve EU climate and biodiversity objectives and to reach the EU's international commitments, in particular the COP15 30x30 biodiversity agreement. Although these targets are in place, greenhouse gas emissions are still rising and biodiversity is declining at an "unprecedented" level according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). For agricultural land use, particular attention should also be paid to the spatial connection between agricultural areas that specifically contribute to biodiversity (landscape features, buffer strips, etc.). At the level of regional landscapes, such connections may take the form of wildlife corridors, networks of protected areas, green infrastructure preserved from anthropogenic pressures. The Strategy was finally approved in 2024 in the form of the Nature restoration Law, with the (adjusted) targets described below.

All EU MSs will have to have restoration measures in place:

- On at least 20% of EU's land and sea areas by 2030 with a focus first on Natura 2000 areas
- For all ecosystems in need of restoration by 2050
- To reverse the decline of pollinators and grassland butterflies

The key points the member states are committing to are:

- Restore at least 30% of habitats covered by the new law (from forests, grasslands and wetlands to rivers, lakes and yes, even coral beds) from a poor to a good condition by 2030, increasing to 60% by 2040, and 90% by 2050. Once in a good condition, ensure areas do not deteriorate. Give priority to Natura 2000 areas until 2030.
- Restore at least 30% of drained peatlands by 2030 (at least a quarter shall be rewetted), 40% by 2040 and 50% by 2050 (where at least one-third shall be rewetted). Rewetting will remain voluntary for farmers and private landowners.
- Improve biodiversity in agricultural ecosystems, by making progress in two of the following three indicators:

1) the grassland butterfly index;

2) the share of agricultural land with high-diversity landscape features; (hang on because there's quite the list) 'buffer strips, rotational or non-rotational fallow land, hedgerows, individual or groups of trees, tree rows, field margins, patches, ditches, streams, small wetlands, terraces, cairns, stonewalls, small ponds and cultural features'.

3) the stock of organic carbon in cropland mineral soil.

4) Take measures to increase the common farmland bird index must also be taken as birds are good indicators of the overall state of biodiversity.

5) Plant an additional three billion trees and establish a positive trend in several health indicators in forest ecosystems.

6) Restore at least 25 000 km of rivers into free-flowing rivers and ensure there is no net loss in the total national area of urban green space and of urban tree canopy cover.

The expected effects at farm level include discontinuation of agriculture on around 16 % of agricultural peatlands (per MS where peatlands in agricultural use occur) and lower irrigation/water use with a possible change in the crop mix (less annuals and more perennials).

The land use effect is a reduction of agricultural land use/land productivity through:

- Extra Natura 2000 areas on agricultural lands
- Planting 3 billion trees
- More high diversity landscape features (10% of agricultural lands): e.g. linear elements & fallow, agroforestry

Positive impacts at higher level are a win-win with organic farming, pesticides reduction, nutrient input reduction leading to:

- Reduced GHG emissions
- Better ground and surface water quality
- Less water depletion.

Negative impacts encompass higher food prices.

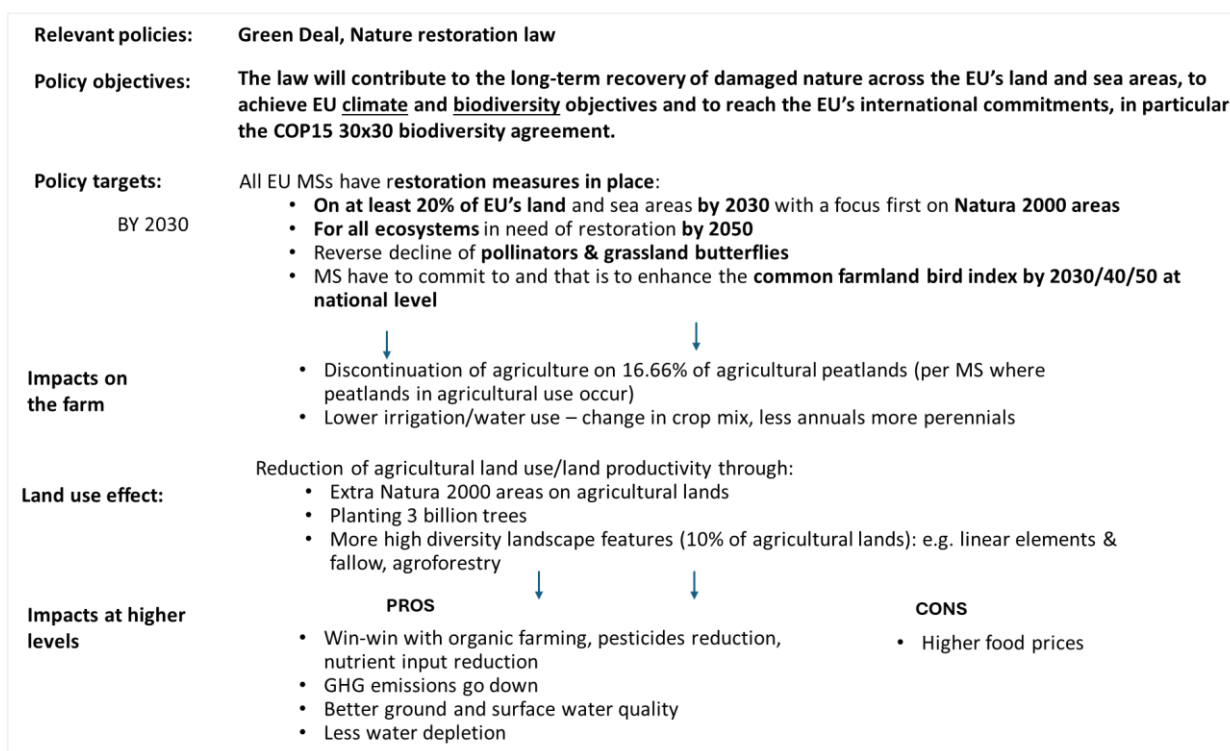


Figure 27 Links between Nature restoration law targets, impacts on farms and higher level impacts

Soil monitoring and resilience law

In 2021 the European Commission presented a new EU soil strategy for 2030, with the aim of having all EU soil ecosystems in a healthy condition by 2050. To achieve this objective, on 5 July 2023 it tabled **a proposal for a soil monitoring and resilience directive**, laying down measures for monitoring and assessing soil health, based on a common definition of what constitutes healthy soil, for managing soils sustainably, and for tackling contaminated sites. This was also in response to the European Court of Auditors that found the ambitions in this respect to be limited (ECA, 2023).

The key objective of this policy is to revert trends that led to more than 60% of European soils being unhealthy due to both degradation and pollution (ECA, 2023). 25% of the EU land was found to have erosion rates higher than the recommended sustainable threshold of 2 t/ ha/yr, and more than 6% of agricultural lands suffering from severe erosion (11 t/ ha/yr) (Panagos et al., 2021).

In the diagram below the main causes of land degradation and pollution are related to the policy targets proposed in the forthcoming directive:

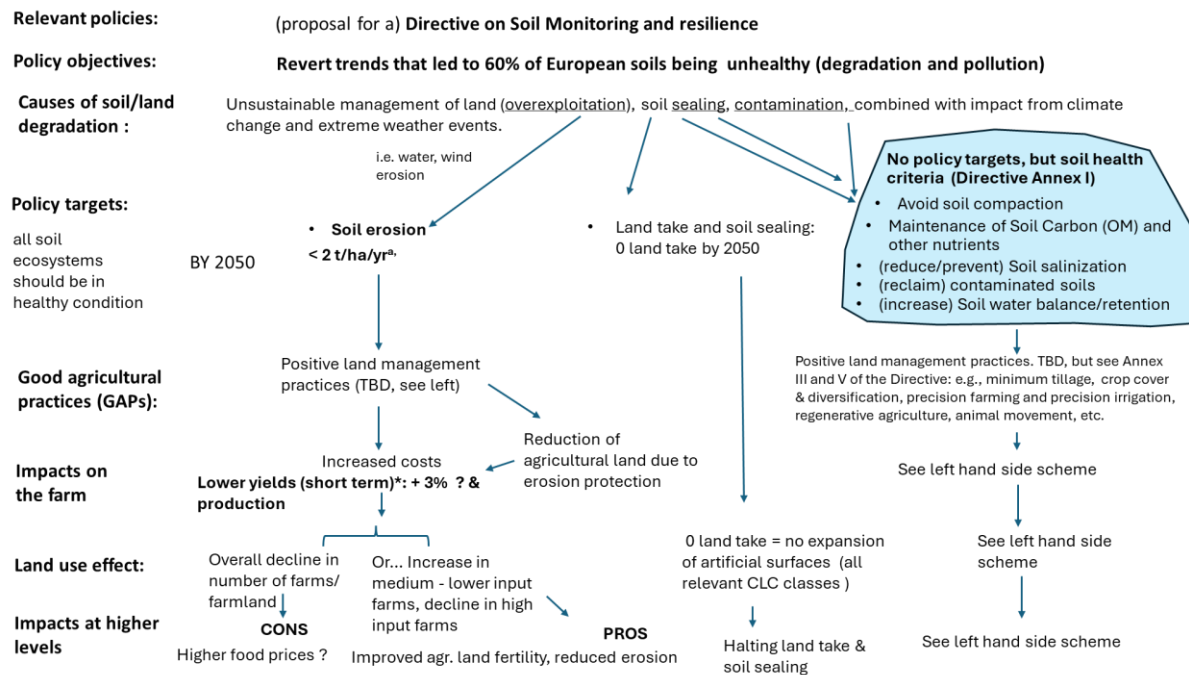
- **Overexploitation** and **poor soil management** combined with protracted aridity and extreme weather events, lead to soil erosion. The policy target set by the proposed directive is the mentioned 2 t/ ha/yr by 2050.
- A similar objective set up to reduce land degradation (Zero Net Land Degradation) at the global scale by the United Nations Convention to Combat

Desertification (UNCDD) is adopted by the EU in this proposal, hence a target of 0 **land take and soil sealing**, also by 2050. The EU soil strategy for 2030 reiterates the EU objective of reaching no net land take by 2050, calls on Member States to set land take targets for 2030, and proposes a four-step hierarchy in land planning (avoid – reuse – minimise – compensate land take)

- For other aspects of **soil health** there are no policy targets as yet, but other causes of degradation have been identified and listed in Annex I of the proposed directive together with soil descriptors and soil health criteria to be applied by Member States for monitoring and assessment purposes. Criteria are related to: avoiding soil compaction, maintaining soil carbon (OM) and other nutrients, reducing/preventing soil salinization, and reclaiming contaminated soils. Soil descriptors are split into three categories: descriptors with criteria for healthy soil condition established at EU level; descriptors with criteria set by the Member States; and descriptors without criteria. Member States would be able to adapt some of the EU-level descriptors and criteria based on specific national or local conditions. They would also have the possibility to set additional soil descriptors and land take indicators.

To contrast these main causes of land degradation and pollution, there are several GAPS which can be adopted. The CAP includes some mandatory environmental and climate conditions (good agricultural and environmental conditions – GAEC) that farmers must meet in order to receive CAP income support. Some of these conditions are linked to soil management practices, such as practices to limit soil erosion (e.g., tillage management), minimum soil cover and crop rotation. The proposed directory also identifies “Positive land management practices” (see Annex III and V): e.g., minimum tillage, crop cover & diversification, precision farming and precision irrigation, regenerative agriculture, animal movement, etc.

These practices impact at farm level. Positive ones are the expected reduction in erosion, land take and sealing of agricultural land, compaction, salinization, contamination of soils. All have the effect of improving agricultural production and yields. Negatives direct ones in that they increase costs for the farmers to implementing them, subtract in some cases parts of farmland. Indirectly these can lead the overall decline in farmland and the number of farms and hence, to reduction of farmland as a land use effect. We can also expect the decline to impact especially high input farms, while promoting medium and lower input farms. Impacts at higher levels are positive (overall restoration of soil fertility and reduced land take and soil sealing) but, in addition to the ones mentioned in relation to the increased costs at farm level, can also be negative since increased farming costs and a decline in farmland can lead to higher consumer prices.



Climate neutrality/Biobased economy/RES energy/circularity

One of the key objectives of this Bioeconomy Strategy (EC, 2018) is to manage natural resources sustainably in combination with the other four key objectives: ensuring food security; reducing dependence on non-renewable resources; mitigating and adapting to climate change; and creating jobs and maintaining EU competitiveness. At the same time it is clear that this transition to a circular bioeconomy will lead to an increasing global demand for food, feed, biomaterials and bioenergy resources. The agricultural sector can and must contribute to these new markets, but sustainable sourcing of biomass and land for other RES activities will be the main challenge for rural areas in the next decades.

For climate, RES and transition to a circular bioeconomy policy portfolio integrates essential EU energy, climate, and transport policies, along with European Commission legislative proposals within the scope of the Fit for 55 package, the REPowerEU plan.

For energy and transport the suite of policies includes the Renewable Energy Directive (REDII, and RRED III in proposal) , the EU Emissions Trading System (ETS) , the new ETS covering road transport , the Energy Taxation Directive (EU ETD) , CO2 emissions standards for cars, vans and heavy-duty vehicles , FuelEU Maritime , ReFuelEU Aviation , and the Alternative Fuel Infrastructure Regulation (AFIR) . Since the submission of the EC proposals, several have been adopted or progressed to the stage of provisional political agreement.

To stay on track for the Paris Climate Agreement and to ensure that the targets are met in the different Member States, the Governance Regulation (Regulation (EU) 2018/1999) requires Member States to submit their National Energy and Climate Plans (NECPs). These plans outline how each country intends to meet its climate and energy objectives for the coming decades. The last submission of the final NECPs was in 2019, covering mostly the period from 2021-2030. These plans must be reviewed and updated every five years. The deadline for the draft NECPs was in June 2023, Member States are expected to submit their final updated NECPs in June 2024.

RED and RES targets

The amended Renewable Energy Directive of 18 October 2023 sets targets for renewable energy sources in all European Member States. It provides targets for renewables in the heating & cooling, power and transport sectors. Biomass (in forms of biofuels, biogas and solid biomass) can be used to fulfil these targets, as long as production is in line with the set sustainability criteria and feedstock guidance. Based on the targets in the REDIII Member States have developed their National Energy and Climate Plans (NECPs) in which they indicate their targets, paths and policies applied to reach these targets. These NECPs include elements related to PV and wind that could be placed on agricultural land. In the following section we indicate the assumptions used on capacity, type of systems and type of land, which are used to estimate the share of agricultural land that will be used for these type of renewables.

We used the following assumptions for land use estimates of solar on agricultural land:

- **Projected capacity:** Most EU MSs included a 2030 target when uploading their NECPs, except Austria, Latvia, Luxembourg and Malta. For the countries missing their 2030, 2040 and 2050 NECP target, we used the ENTSO-E and ENTSGO' projections.⁷⁵ These projections include a 'high' and 'low' scenario.
- **Projected roof- and ground-mounted systems:** SolarPowerEurope estimated in their EU Market Outlook for Solar Power 2023-2027 that 62% of the total PV-power supply will be from roof-mounted systems in 2027.⁷⁶ This split was assumed to remain throughout 2030, 2040 and 2050 in this model and deducted from the projected available capacity.
- **Power density:** According to JRC's Overview of the Potential and Challenged for Agri-Photovoltaics in the European Union, traditional ground-mounted systems yield on average 2 MW/ha. This conversion factor was assumed for the BAU scenario.⁷⁷ In the same study, JRC used an estimation of 0.6 MW/ha on average for Agri-PV combined systems. This was only used for the sustainable scenario.

⁷⁵ [TYNDP 2024-Scenario-Report-Data-Figures_240522.xlsx \(live.com\)](#)

⁷⁶ [EU Market Outlook for Solar Power 2023-2027 - SolarPower Europe](#)

⁷⁷ JRC (2023) Overview of the Potential and Challenged for Agri-Photovoltaics in the European Union

- **Ground-mounted systems: Agri vs. non-agri:** No literature source could be found on the split between the solar panels in ground-mounted systems placed on agricultural land and on non-agricultural land. In the JRC study, they assume that all ground-mounted systems will come from agricultural land because they focus on agri-PV. In this study we have taken a conservative estimate of 40% of ground-mounted systems placed on agricultural land.

It is clear that in an Agri-PV combined setting there will be more hectares estimated, as more land is needed to achieve 1 MW, to allow for sufficient space between the PV-panels for the farming equipment and to ensure limited impact on the pre-existing agricultural activities. However it is important to highlight that in the case of Agri-PV the land will remain available for agricultural production and will not, like in the BAU scenario, fully be taken out of agricultural production.

If we follow the assumptions above for solar energy, the following amount of hectares are needed per scenario to meet the total solar energy demand of the EU according to the MSs NECPs. The combined function of Agri-PV would require more hectares; however those hectares are not fully occupied with the solar panels and there is an additional energy yield available of the biomass grown in synergy with the solar panels.

Table 25 Hectares needed to meet the total European solar energy targets

Scenario	2022	2030	2040	2050
Current	10,611			
BAU scenario low		34,063	36,811	46,957
BAU scenario high		35,921	73,009	108,521
Sustainable scenario low		180,471	219,386	283,031
Sustainable scenario high		186,663	380,579	584,602

In the above values we assumed that 40% of the ground-mounted systems would be placed on agricultural land. However, if we were to change this share, we obtain the estimates from Table 26 Hectares needed to meet the total European solar energy targets per share ground-mounted PV as Agri-PV. For the sustainable low and high scenarios, the amount of hectares understandably increase when the share increases as more agricultural land is shared with ground-mounted systems.

Table 26 Hectares needed to meet the total European solar energy targets per share ground-mounted PV as Agri-PV

Scenario	Share ground-mounted PV as Agri-PV	2030	2040	2050
Sustainable scenario low	20%	90,236	109,693	141,516
Sustainable scenario high	20%	93,332	190,289	292,301
Sustainable scenario low	60%	270,707	329,079	424,547
Sustainable scenario high	60%	279,995	570,868	876,903
Sustainable scenario low	80%	360,942	438,773	566,063
Sustainable scenario high	80%	373,327	761,157	1,169,204

We used the following assumptions for land use estimates of wind energy on agricultural land:

- **Projected capacity:** The countries were not required to make a differentiation between on-shore and off-shore wind when reporting their future wind energy targets. Therefore, the projections from ENTSO-E and ENTSG will be used, which do have projections on onshore wind specifically.⁷⁸ These projections are estimated in a low and high case scenario.
- **Power density:** The amount of MW/ha of a wind farm is dependent on multiple factors, such as the height of the turbines and the wind availability. WindEurope estimates a yield between 2 and 5 MW/ha⁷⁹, Denholm et al. (2009) looked at 172 windfarm projects in the US, where 80% of the farms had a minimum density of 2.5 MW/ha⁸⁰. The user is allowed to enter a different energy yield per hectare (MW/ha). If no value is entered, 2.5 MW/ha is assumed.
- **Agri vs. non-agri:** No literature source could be found on the split between windfarms on agricultural land and non-agricultural land. In literature, most is focussed on combined windfarms and agricultural land claiming that only little land use is needed and it would not significantly impact the farming area (1% of the plot would be needed). In this study we have taken a conservative estimate of 40% of onshore wind turbines placed on agricultural land.

Table 27 shows the hectares needed to reach the projections regarding wind energy in the EU countries, based on the assumptions written above. For wind there is less synergy than solar regarding combined functions with agriculture, as there will be negligible impact of land use change. This is assuming that 40% of onshore wind turbines are placed on agricultural land. Table 28 shows the amount of hectares needed to meet the total European wind projections if the share of onshore wind turbines on agricultural land would be different.

Table 27 Hectares needed to meet the total European wind energy targets

Scenario	2022	2030	2040	2050
Current	29,996			
Projection low		48,673	61,272	67,390
Projection high		60,706	100,564	129,595

Table 28 Hectares needed to meet the total European wind energy projections per share onshore wind turbines on agricultural land

Scenario	Share onshore wind turbines on agricultural land	2030	2040	2050

⁷⁸ [TYNDP 2024-Scenario-Report-Data-Figures_240522.xlsx \(live.com\)](#)

⁷⁹ <https://windeurope.org/about-wind/wind-basics/>

⁸⁰ Denholm, P. et al (2009) Land-Use Requirements of Modern Wind Power Plants in the United States [Land-Use Requirements of Modern Wind Power Plants in the United States \(nrel.gov\)](#)

Sustainable scenario low	20%	24,336	30,636	33,695
Sustainable scenario high	20%	30,353	50,282	64,798
Sustainable scenario low	60%	73,009	91,907	101,084
Sustainable scenario high	60%	91,059	150,846	194,393
Sustainable scenario low	80%	97,346	122,543	134,779
Sustainable scenario high	80%	121,412	201,129	259,191

Climate and water policies

Freshwater supplies are of extreme relevance for EU social- economic and environment wellbeing but are under threat from both quality and quantity perspective. Looking at the Drinking Water-, Nitrate- and Groundwater Directives it is clear that the agricultural sector is a main sector where actions should be taken to address these threats. Decades of intensive agricultural practices consisting of large plots usually under monoculture with large amount of external inputs, i.e. fertilizers and pesticides, aimed on maximizing crop yields came with trade-offs related to fresh water security. An ongoing trend that is already visible during last decades, is gradual transition of such intensive systems to more extensive agriculture. Multiple Member States are promoting regenerative agriculture aimed at closing the nutrient cycle, organic farming, set limits on agrochemical usage and define standards for development of buffer zones within agricultural plots, although there are still severe differences between Member States. Besides guidelines and setting limitations, countries and the EU also apply multiple subsidy or direct-payment instruments (e.g. compensation of income loss for flower strips) to achieve these transitions. These measures impact the agricultural land-use on various ways: i) shifting away for water-intensive and/or agrochemical intensive crops towards alternative cropping systems with less impact on the environment and ii) physical changes in the agricultural landscape such as flower strips and (afforested) buffer zones. It is expected that these trends will continue to achieve better water status in EU and thus further extensification of agricultural lands.

Looking at flood risks, it is expected that intensity of (peak) floods will increase within the scope of climate change. It is therefore likely that the areas defined as "high risk flood zones" is going to increase in many Member States. Currently, those areas are used for agriculture and nature purposes and will most likely continue to be used by these functions in the future. However, the agricultural landscape may change due to increasing flood risks and associated actions that Member States will apply. Water retention and assigning agricultural lands as flood retention areas may impact the agricultural landscape on several ways. Firstly, the use of heavy machinery is impossible when groundwater levels are high which makes intensive agriculture challenging. Secondly, agricultural plots that are assigned to be temporarily flooded may no longer be suitable for crops that are not resilient to be flooded (e.g., fruit trees). Another major in agricultural land-use associated with flood adaption is the increasing emphasis on Nature-Based-Solutions. Such adaptative measure require space and will lead to an agricultural land-use typology that can be described as nature-inclusive agriculture.

Overall, the EU water-related Directives and guidelines and RDPs have main impacts on (agricultural) land-use. As the agricultural sector is a main cause of water-related pressures but also functions as a solution to address those, a trend is visible from converting intensive agricultural land-use towards extensive alternatives.

20. Annex 11 Summary of finding of the 12 case studies and answers to the study questions

See separate document 'Annex 11 Summary findings case studies' for a full summary of findings reported for 12 the case studies:

https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cmef/sustainability/study-competition-land-use-and-sustainable-farming_en

21. Annex 12 Report of all modelled land use changes 2020-2050 in BAU and SA scenario

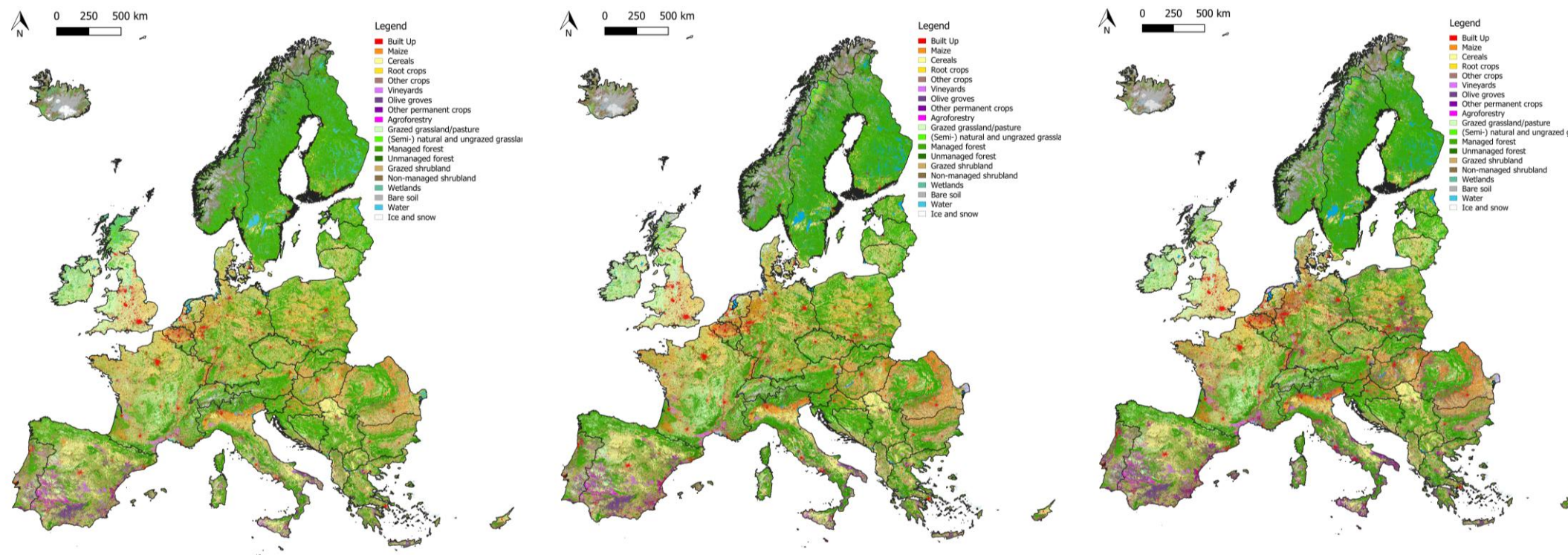


Figure 29 Land use 2020 (first map left) and land use 2050 in BAU (centre map) and in SA scenario (right map)

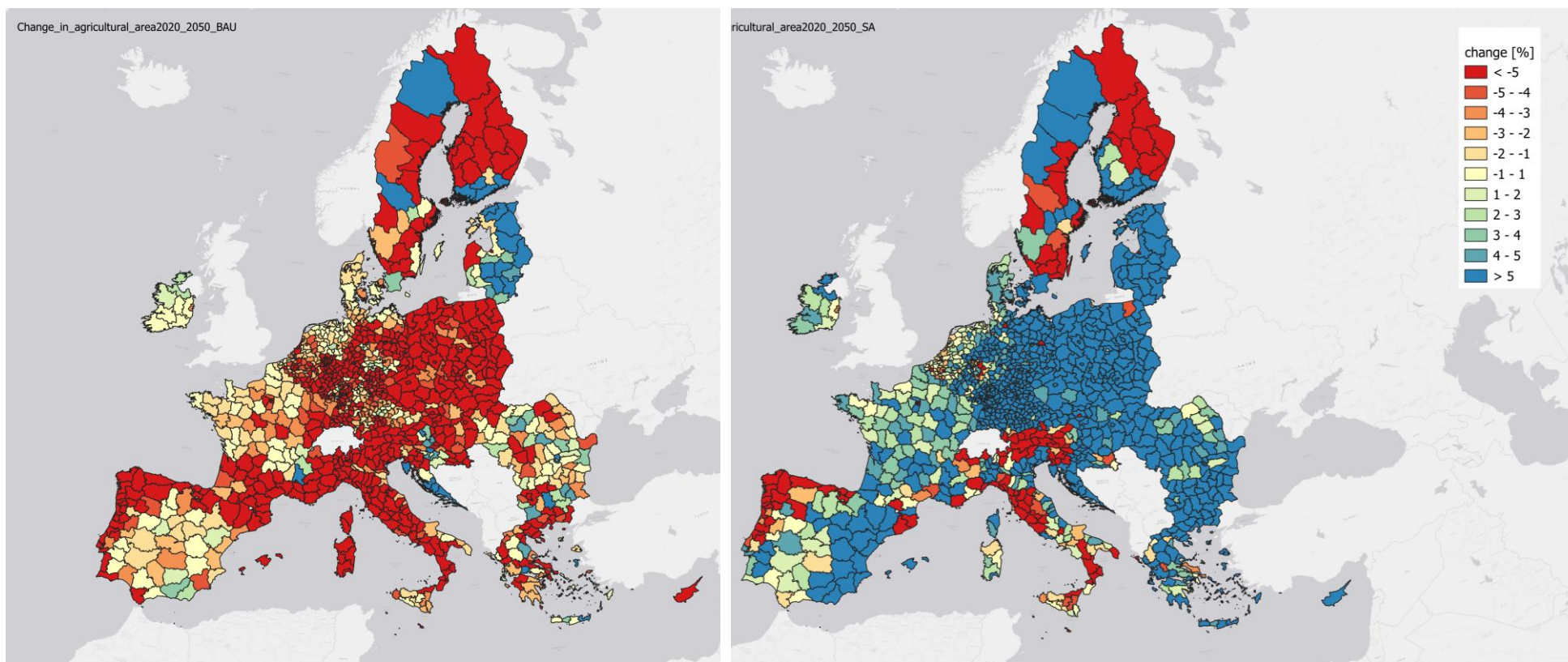


Figure 30 Agricultural area change in BAU (left) and SA scenario between 2020 and 2050

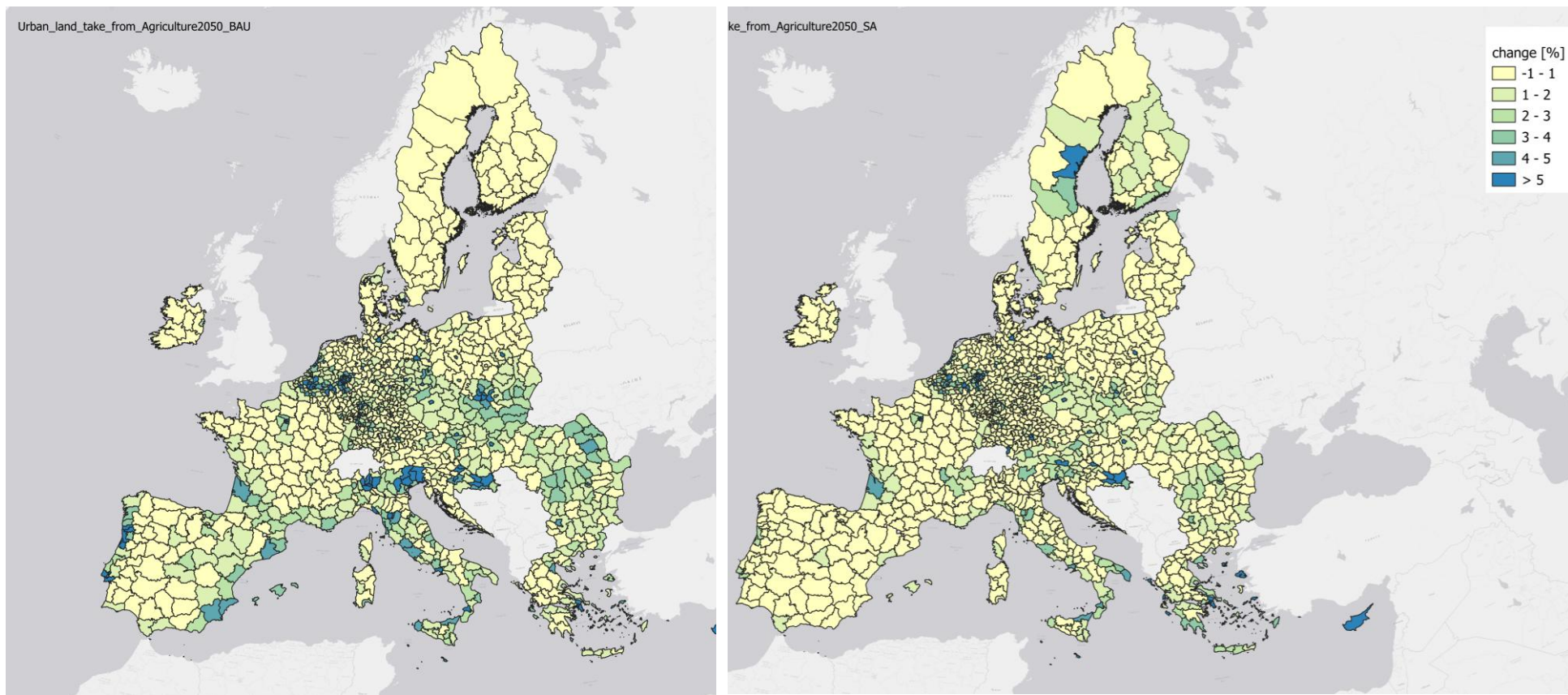


Figure 31 Build-up land take from agriculture between 2020 and 2050 BAU (left) and SA scenario (right). This is also a KPI1 'Land take from agriculture by built-up area' expressed in % land take of agricultural area 2020

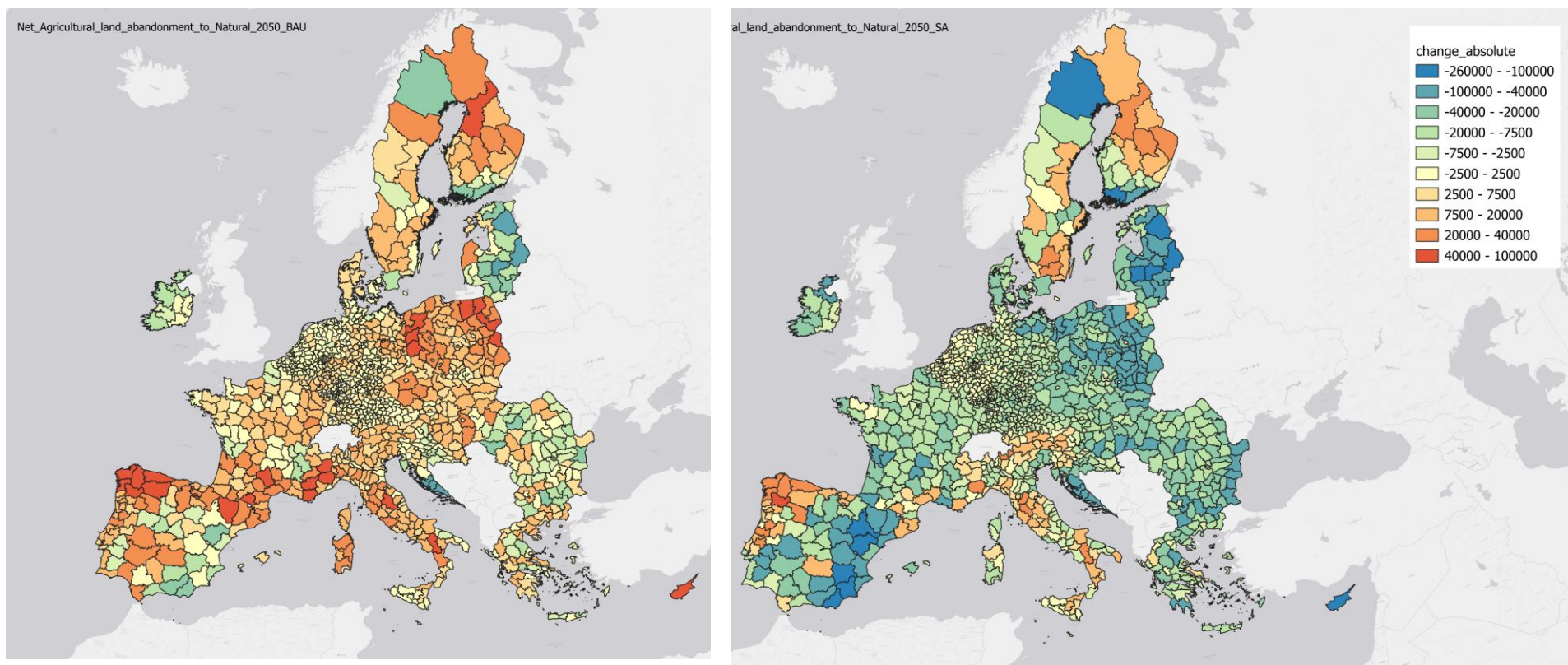


Figure 32 Net agricultural land abandonment between 2020 and 2050 in BAU (left) and SA scenario (right). Net implies that the loss of land is corrected for an agricultural land gain, where land is also brought back into agricultural use. This is also a KPI2 'Agriculture land abandonment' expressed by calculating the net percentage change in agricultural land through abandonment to non-managed land and agricultural land reclaim between 2020-2050 for BAU (left map) and SA (right map) scenario.

Table 29 Land use 2020 and in 2050 in SA scenario and BAU scenario (Hectares) per country

Ha	Land area	Built-up 2020	Built-up SA 2050	Built-up SA 2050	Agricultural area 2020	Agricultural area SA 2050	Agricultural area BAU 2050	Forest 2020	Forest SA 2050	Forest BAU 2050	Other 2020	Other SA 2050	Other BAU 2050
AT	8.337.700	460.300	509.200	536.200	3.375.600	3.361.000	3.222.900	4.021.400	3.978.500	4.077.700	480.400	489.000	500.900
BE	3.050.500	641.400	678.800	706.500	1.636.700	1.610.300	1.547.900	757.900	753.800	785.900	14.500	7.600	10.200
BG	11.036.200	516.400	565.600	627.000	5.879.900	5.977.400	5.623.700	4.524.300	4.394.900	4.671.600	115.600	98.300	113.900
CY	923.300	89.100	89.200	89.900	428.800	428.900	424.700	216.400	215.500	217.400	189.000	189.700	191.300
CZ	7.839.600	511.200	567.600	628.000	4.238.400	4.239.000	3.940.300	3.035.600	3.003.800	3.232.100	54.400	29.200	39.200
DE	35.417.700	3.280.400	3.448.100	3.616.900	19.550.900	19.820.900	18.448.700	12.238.900	11.911.900	13.011.700	347.500	236.800	340.400
DK	4.256.200	337.500	356.000	372.300	3.069.200	3.086.700	3.048.600	743.800	743.800	737.800	105.700	69.700	97.500
EE	4.329.200	97.100	104.000	117.800	1.281.300	1.407.300	1.273.100	2.667.900	2.638.800	2.712.400	282.900	179.100	225.900
EL	13.022.200	447.500	538.000	592.100	7.116.200	6.926.600	6.974.300	4.894.000	4.993.100	4.897.500	564.500	564.500	558.300
ES	49.637.100	1.262.200	1.554.400	1.842.700	30.597.300	29.876.400	29.368.700	15.970.600	16.399.300	16.610.600	1.807.000	1.807.000	1.815.100
FI	30.839.800	448.400	473.800	493.000	3.259.300	2.990.100	2.975.100	23.404.700	24.218.100	24.009.400	3.727.400	3.157.800	3.362.300
FR	54.594.100	3.236.400	3.593.300	3.741.800	32.449.200	32.404.100	30.989.000	17.975.200	17.766.000	18.943.900	933.300	830.700	919.400
HR	5.607.000	216.400	255.400	233.500	2.410.500	2.438.600	2.286.300	2.716.100	2.649.000	2.878.100	264.000	264.000	209.100
HU	9.178.400	593.900	641.100	695.100	6.153.400	6.092.300	5.925.900	2.166.200	2.109.800	2.141.100	264.900	335.200	416.300
IE	6.893.700	162.000	165.300	169.600	4.991.800	5.045.800	5.067.900	1.208.700	1.205.200	1.145.900	531.200	477.400	510.300
IT	29.822.900	1.673.700	1.920.600	2.112.700	16.073.900	15.407.100	14.596.900	11.064.300	11.466.000	12.094.800	1.011.000	1.029.200	1.018.500
LT	6.400.600	208.700	219.300	240.900	3.634.700	4.090.500	3.665.200	2.431.500	2.050.300	2.428.900	125.700	40.500	65.600
LU	259.400	26.200	27.200	27.600	136.500	136.500	120.000	96.500	95.400	111.600	200	300	200
LV	6.354.100	121.000	127.200	148.300	2.296.600	2.660.900	2.318.500	3.668.800	3.446.800	3.704.800	267.700	119.200	182.500
MT	31.400	9.800	19.600	22.200	18.700	8.900	8.100	1.900	1.900	200	1.000	1.000	900
NL	3.459.800	512.800	547.700	555.900	2.407.000	2.390.600	2.368.100	474.500	474.100	477.200	65.500	47.400	58.600
PL	30.844.400	1.896.900	2.020.300	2.124.200	16.945.400	17.291.300	16.289.500	11.060.100	10.751.900	11.329.900	942.000	780.900	1.100.800
PT	8.817.300	344.600	391.400	457.300	5.355.100	5.212.900	4.999.800	2.967.600	3.063.000	3.199.400	150.000	150.000	160.800
RO	23.576.500	1.321.800	1.507.900	1.694.000	13.703.400	13.628.000	13.271.900	8.145.900	7.999.600	8.128.800	405.400	441.000	481.800
SE	41.572.900	593.000	626.100	649.900	5.595.400	5.494.100	5.836.200	29.180.600	30.646.200	29.799.800	6.203.900	4.806.500	5.287.000

Ha	Land area	Built-up 2020	Built-up SA 2050	Built-up SA 2050	Agricultural area 2020	Agricultural area SA 2050	Agricultural area BAU 2050	Forest 2020	Forest SA 2050	Forest BAU 2050	Other 2020	Other SA 2050	Other BAU 2050
SI	2.023.500	66.500	75.500	79.000	608.900	542.900	591.200	1.317.900	1.376.700	1.328.400	30.200	28.400	24.900
SK	4.876.900	293.700	323.600	354.400	2.157.600	2.167.900	2.023.300	2.387.600	2.356.500	2.463.700	38.000	28.900	35.500
EU2 7	403.002.400	19.368.900	21.346.200	22.928.800	195.371.700	194.737.000	187.205.800	169.338.900	170.709.900	175.140.600	18.922.900	16.209.300	17.727.200

Table 30 Land use 2020 and in 2050 in SA scenario and BAU scenario (% OF TOTAL LAND AREA) per country

HA	Land area	Built-up 2020	Built-up SA 2050	Built-up SA 2050	Agricultural area 2020	Agricultural area SA 2050	Agricultural area BAU 2050	Forest 2020	Forest SA 2050	Forest BAU 2050	Other 2020	Other SA 2050	Other BAU 2050
AT	100%	6%	6%	6%	40%	40%	39%	48%	48%	49%	6%	6%	6%
BE	100%	21%	22%	23%	54%	53%	51%	25%	25%	26%	0%	0%	0%
BG	100%	5%	5%	6%	53%	54%	51%	41%	40%	42%	1%	1%	1%
CY	100%	10%	10%	10%	46%	46%	46%	23%	23%	24%	20%	21%	21%
CZ	100%	7%	7%	8%	54%	54%	50%	39%	38%	41%	1%	0%	1%
DE	100%	9%	10%	10%	55%	56%	52%	35%	34%	37%	1%	1%	1%
DK	100%	8%	8%	9%	72%	73%	72%	17%	17%	17%	2%	2%	2%
EE	100%	2%	2%	3%	30%	33%	29%	62%	61%	63%	7%	4%	5%
EL	100%	3%	4%	5%	55%	53%	54%	38%	38%	38%	4%	4%	4%
ES	100%	3%	3%	4%	62%	60%	59%	32%	33%	33%	4%	4%	4%
FI	100%	1%	2%	2%	11%	10%	10%	76%	79%	78%	12%	10%	11%
FR	100%	6%	7%	7%	59%	59%	57%	33%	33%	35%	2%	2%	2%
HR	100%	4%	5%	4%	43%	43%	41%	48%	47%	51%	5%	5%	4%
HU	100%	6%	7%	8%	67%	66%	65%	24%	23%	23%	3%	4%	5%
IE	100%	2%	2%	2%	72%	73%	74%	18%	17%	17%	8%	7%	7%
IT	100%	6%	6%	7%	54%	52%	49%	37%	38%	41%	3%	3%	3%
LT	100%	3%	3%	4%	57%	64%	57%	38%	32%	38%	2%	1%	1%
LU	100%	10%	10%	11%	53%	53%	46%	37%	37%	43%	0%	0%	0%
LV	100%	2%	2%	2%	36%	42%	36%	58%	54%	58%	4%	2%	3%
MT	100%	31%	62%	71%	60%	28%	26%	6%	6%	1%	3%	3%	3%
NL	100%	15%	16%	16%	70%	69%	68%	14%	14%	14%	2%	1%	2%
PL	100%	6%	7%	7%	55%	56%	53%	36%	35%	37%	3%	3%	4%
PT	100%	4%	4%	5%	61%	59%	57%	34%	35%	36%	2%	2%	2%
RO	100%	6%	6%	7%	58%	58%	56%	35%	34%	34%	2%	2%	2%
SE	100%	1%	2%	2%	13%	13%	14%	70%	74%	72%	15%	12%	13%

SI	100%	3%	4%	4%	30%	27%	29%	65%	68%	66%	1%	1%	1%
SK	100%	6%	7%	7%	44%	44%	41%	49%	48%	51%	1%	1%	1%
EU27	100%	5%	5%	6%	48%	48%	46%	42%	42%	43%	5%	4%	4%

Table 31 Land use 2020 and in 2050 in SA scenario and BAU scenario (HA) per RALUC type in EU 27

HA	Land area	Built-up 2020	Built-up SA 2050	Built-up SA 2050	Agricultural area 2020	Agricultural area SA 2050	Agricultural area BAU 2050	Forest 2020	Forest SA 2050	Forest BAU 2050	Other 2020	Other SA 2050	Other BAU 2050
A-1a	9.493.900	989.100	1.094.100	1.130.900	4.009.300	3.931.500	3.607.500	4.360.700	4.372.200	4.641.500	134.800	96.100	114.000
A-1b	3.732.900	414.700	454.500	491.400	1.812.000	1.752.300	1.627.400	1.420.800	1.438.400	1.509.800	85.400	87.700	104.300
A-1c	3.366.700	323.500	357.900	390.000	1.470.900	1.448.800	1.323.100	1.509.300	1.510.600	1.596.000	63.000	49.400	57.600
A-2a	28.238.500	1.157.000	1.306.600	1.337.700	13.581.300	13.548.600	13.035.800	12.731.600	12.845.500	13.170.100	768.600	537.800	694.900
A-2b	19.062.600	734.800	821.800	865.300	9.481.700	9.394.500	8.867.900	8.383.800	8.407.600	8.843.000	462.300	438.700	486.400
A-2c	21.812.400	898.100	962.400	1.054.700	11.131.000	11.086.300	10.349.200	9.449.700	9.480.300	10.097.100	333.600	283.400	311.400
A-2d	24.941.800	1.248.800	1.347.000	1.458.300	14.375.500	14.495.300	13.819.700	8.635.400	8.421.400	8.771.800	682.100	678.100	892.000
A-3a	46.117.500	482.200	522.500	531.500	7.556.200	7.455.900	7.666.700	31.014.600	32.473.600	31.831.300	7.064.500	5.665.500	6.088.000
A-3b	26.030.000	256.900	275.200	287.900	4.319.900	4.025.200	4.027.600	18.235.900	18.942.300	18.744.700	3.217.300	2.787.300	2.969.800
A-3c	19.043.300	359.800	398.100	448.900	9.952.700	10.135.500	9.602.400	8.144.700	8.050.700	8.478.700	586.100	459.000	513.300
E-1a	8.242.000	349.800	387.900	434.400	5.009.400	4.992.200	4.782.000	2.692.000	2.691.600	2.845.600	190.800	170.300	180.000
E-1b	8.706.600	604.900	675.000	758.600	5.095.800	5.080.400	4.826.800	2.930.400	2.886.000	3.043.100	75.500	65.200	78.100
I-1a	3.404.300	266.900	306.200	321.400	2.190.100	2.146.900	2.112.200	871.300	881.400	902.500	76.000	69.800	68.200
I-1b	1.467.800	127.100	140.500	155.600	1.020.400	1.007.500	978.500	306.900	308.400	320.700	13.400	11.400	13.000
I-2a	11.852.900	364.800	411.800	467.500	6.906.800	6.837.800	6.589.700	3.863.700	3.903.700	4.080.900	717.600	699.600	714.800
I-2b	15.726.400	404.100	518.100	623.100	10.773.000	10.673.200	10.619.800	4.102.500	4.114.900	4.045.400	446.800	420.200	438.100
I-2c	4.718.700	222.800	236.100	256.900	2.969.100	3.010.900	2.846.000	1.463.500	1.416.200	1.538.500	63.300	55.500	77.300
I-2d	14.279.500	654.300	737.000	834.700	9.355.700	9.384.800	9.099.900	4.113.300	4.012.300	4.168.000	156.200	145.400	176.900
I-3a	17.988.000	329.700	370.000	435.800	9.617.000	10.088.300	9.506.200	7.244.600	6.845.800	7.306.800	796.700	683.900	739.200
N-1	2.187.900	118.500	129.300	140.100	1.262.300	1.247.300	1.220.200	757.500	768.000	780.300	49.600	43.300	47.300
U-1a	30.468.600	4.355.200	4.733.200	4.913.300	16.853.400	16.518.600	15.869.500	8.592.600	8.615.300	9.033.400	667.400	601.500	652.400
U-1b	6.757.300	652.300	722.000	791.900	4.209.900	4.174.100	4.060.500	1.736.100	1.720.500	1.738.900	159.000	140.700	166.000

U-1c	3.332.500	547.000	580.500	594.800	1.739.100	1.738.000	1.634.200	1.001.700	978.000	1.061.400	44.700	36.000	42.100
U-1d	3.639.800	368.100	410.200	438.500	2.119.300	2.100.900	2.026.300	1.101.600	1.087.800	1.117.500	50.800	40.900	57.500
U-2a	26.906.500	1.459.900	1.573.300	1.687.600	16.114.300	16.176.100	15.599.700	8.566.900	8.430.400	8.856.500	765.400	726.700	762.700
U-2b	7.484.400	343.300	378.500	420.500	4.432.700	4.387.100	4.254.800	2.448.200	2.477.100	2.542.200	260.200	241.700	266.900
U-2c	33.999.600	1.335.300	1.496.500	1.657.500	18.012.900	17.899.000	17.252.200	13.659.600	13.629.900	14.074.900	991.800	974.200	1.015.000
EU27	403.002.400	19.368.900	21.346.200	22.928.800	195.371.700	194.737.000	187.205.800	169.338.900	170.709.900	175.140.600	18.922.900	16.209.300	17.727.200

Table 32 Land use 2020 and in 2050 in SA scenario and BAU scenario (% OF TOTAL LAND AREA) per RALUC type in EU27

%	Land area	Built-up 2020	Built-up SA 2050	Built-up SA 2050	Agricultural area 2020	Agricultural area SA 2050	Agricultural area BAU 2050	Forest 2020	Forest SA 2050	Forest BAU 2050	Other 2020	Other SA 2050	Other BAU 2050
A-1a	100%	10%	12%	12%	42%	41%	38%	46%	46%	49%	1%	1%	1%
A-1b	100%	11%	12%	13%	49%	47%	44%	38%	39%	40%	2%	2%	3%
A-1c	100%	10%	11%	12%	44%	43%	39%	45%	45%	47%	2%	1%	2%
A-2a	100%	4%	5%	5%	48%	48%	46%	45%	45%	47%	3%	2%	2%
A-2b	100%	4%	4%	5%	50%	49%	47%	44%	44%	46%	2%	2%	3%
A-2c	100%	4%	4%	5%	51%	51%	47%	43%	43%	46%	2%	1%	1%
A-2d	100%	5%	5%	6%	58%	58%	55%	35%	34%	35%	3%	3%	4%
A-3a	100%	1%	1%	1%	16%	16%	17%	67%	70%	69%	15%	12%	13%
A-3b	100%	1%	1%	1%	17%	15%	15%	70%	73%	72%	12%	11%	11%
A-3c	100%	2%	2%	2%	52%	53%	50%	43%	42%	45%	3%	2%	3%
E-1a	100%	4%	5%	5%	61%	61%	58%	33%	33%	35%	2%	2%	2%
E-1b	100%	7%	8%	9%	59%	58%	55%	34%	33%	35%	1%	1%	1%
I-1a	100%	8%	9%	9%	64%	63%	62%	26%	26%	27%	2%	2%	2%
I-1b	100%	9%	10%	11%	70%	69%	67%	21%	21%	22%	1%	1%	1%
I-2a	100%	3%	3%	4%	58%	58%	56%	33%	33%	34%	6%	6%	6%
I-2b	100%	3%	3%	4%	69%	68%	68%	26%	26%	26%	3%	3%	3%
I-2c	100%	5%	5%	5%	63%	64%	60%	31%	30%	33%	1%	1%	2%
I-2d	100%	5%	5%	6%	66%	66%	64%	29%	28%	29%	1%	1%	1%
I-3a	100%	2%	2%	2%	53%	56%	53%	40%	38%	41%	4%	4%	4%
N-1	100%	5%	6%	6%	58%	57%	56%	35%	35%	36%	2%	2%	2%
U-1a	100%	14%	16%	16%	55%	54%	52%	28%	28%	30%	2%	2%	2%
U-1b	100%	10%	11%	12%	62%	62%	60%	26%	25%	26%	2%	2%	2%
U-1c	100%	16%	17%	18%	52%	52%	49%	30%	29%	32%	1%	1%	1%
U-1d	100%	10%	11%	12%	58%	58%	56%	30%	30%	31%	1%	1%	2%
U-2a	100%	5%	6%	6%	60%	60%	58%	32%	31%	33%	3%	3%	3%

U-2b	100%	5%	5%	6%	59%	59%	57%	33%	33%	34%	3%	3%	4%
U-2c	100%	4%	4%	5%	53%	53%	51%	40%	40%	41%	3%	3%	3%
EU27	100%	5%	5%	6%	48%	48%	46%	42%	42%	43%	5%	4%	4%

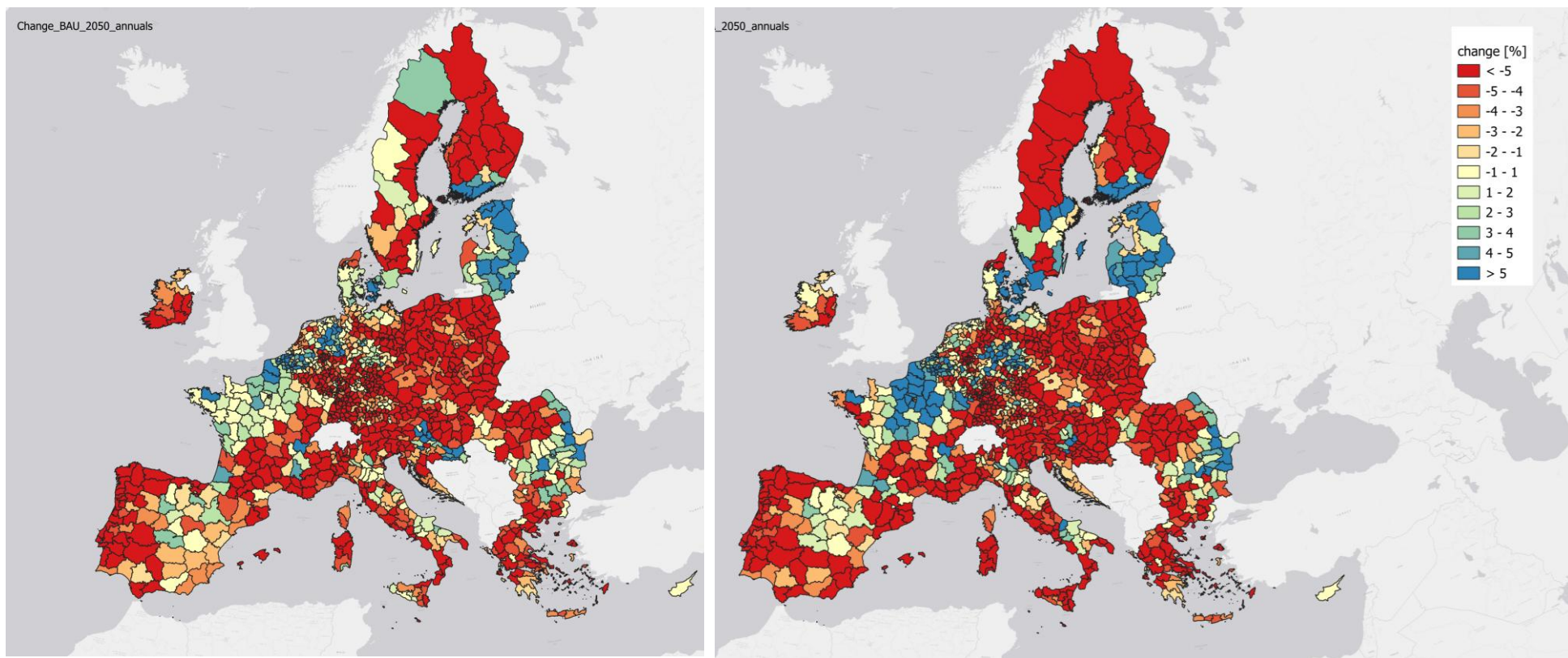


Figure 33 Shifts in annuals between 2020 and 2050 in BAU (left) and SA scenario (right).

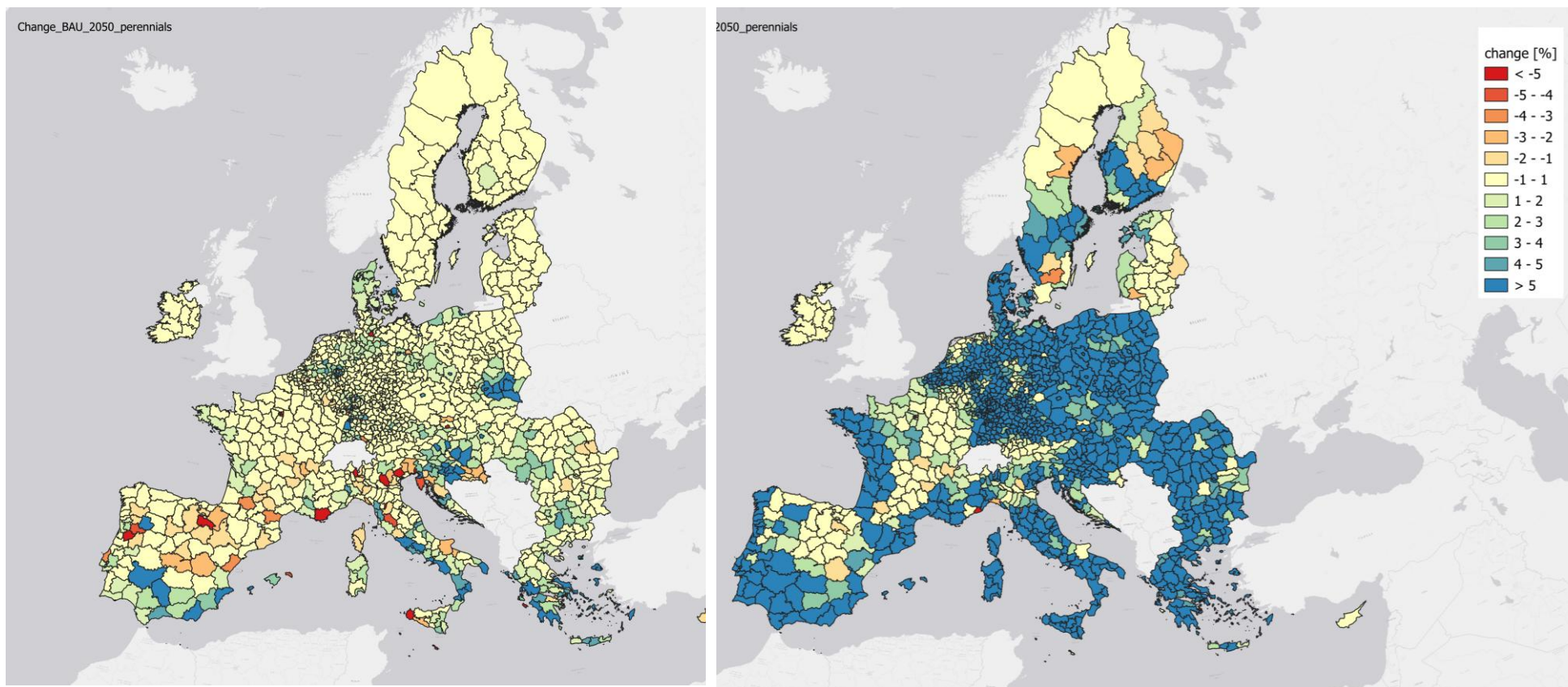


Figure 34 Shifts in perennials between 2020 and 2050 in BAU (left) and SA scenario (right).

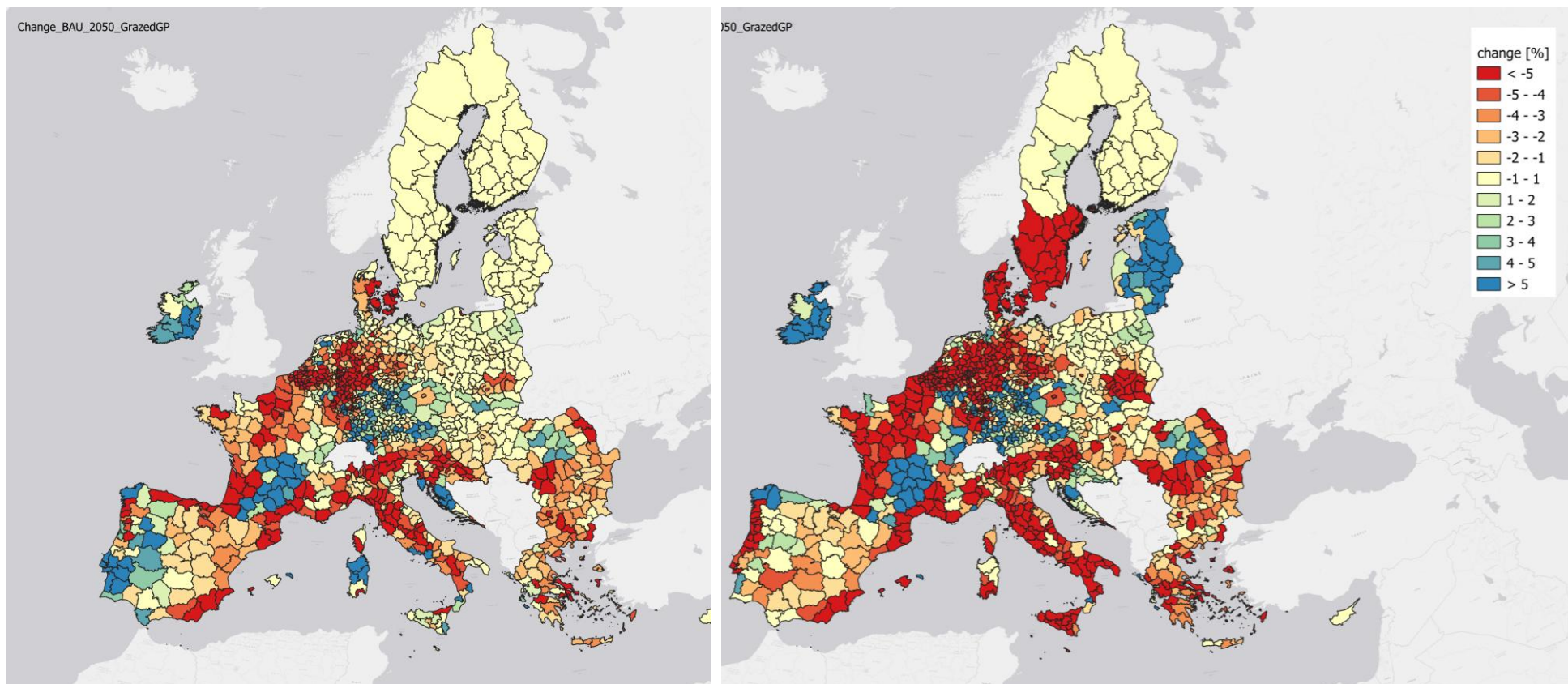


Figure 35 Shifts in grazed grasslands and pastures between 2020 and 2050 in BAU (left) and SA scenario (right).

Table 33 Land use within agricultural land in 2020 and 2050 for SA scenario and BAU scenario (Hectares) in EU 27

HA	Agri land 2020	Agri land SA 2050	Agri land BAU 2050	Annuaals land 2020	Annuaals SA 2050	Anuaals BAU 2050	Perennials 2020	Perennials SA 2050	Perennials BAU 2050	Grazed grassland 2020	Grazed grassland SA 2050	Grazed grassland BAU 2050	Other* 2020
AT	3.375.600	3.361.000	3.222.900	1.398.500	1.064.500	1.136.800	127.200	376.100	154.300	841.300	855.200	868.000	1.008.600
BE	1.636.700	1.610.300	1.547.900	864.900	917.000	895.600	66.000	172.100	67.500	606.000	452.000	510.600	99.800
BG	5.879.900	5.977.400	5.623.700	3.481.100	3.371.500	3.416.500	258.800	794.100	311.000	976.900	821.400	830.300	1.163.100
CY	428.800	428.900	424.700	270.900	269.400	269.500	89.900	89.100	84.400	2.600	2.900	2.700	65.400
CZ	4.238.400	4.239.000	3.940.300	2.560.300	2.368.800	2.307.300	142.800	417.200	145.600	951.400	965.300	990.100	583.900
DE	19.550.900	19.820.900	18.448.700	12.236.700	11.311.700	11.385.700	685.500	2.790.800	823.300	4.577.200	4.141.400	4.399.400	2.051.500
DK	3.069.200	3.086.700	3.048.600	2.058.100	2.154.500	2.099.100	99.400	410.800	155.500	614.300	305.600	486.900	297.400
EE	1.281.300	1.407.300	1.273.100	598.500	693.100	696.100	44.700	62.900	44.900	132.200	231.700	132.200	505.900
EL	7.116.200	6.926.600	6.974.300	1.613.400	1.159.100	1.208.500	1.222.400	1.947.300	1.420.200	1.097.100	801.800	913.500	3.183.300
ES	30.597.300	29.876.400	29.368.700	10.791.300	9.263.400	9.702.700	5.389.100	7.207.800	5.601.700	4.924.200	4.204.500	4.550.300	9.492.700
FI	3.259.300	2.990.100	2.975.100	1.279.800	1.158.100	1.075.000	129.800	205.000	138.200	7.400	7.100	7.400	1.842.300
FR	32.449.200	32.404.100	30.989.000	16.038.100	15.907.200	15.380.300	1.860.700	3.102.100	1.838.200	11.189.300	10.521.400	10.809.500	3.361.100
HR	2.410.500	2.438.600	2.286.300	1.019.500	826.300	1.000.200	147.000	300.700	178.700	414.600	441.600	414.400	829.400
HU	6.153.400	6.092.300	5.925.900	4.470.000	3.985.500	4.109.800	274.600	1.055.800	354.200	533.400	426.600	501.700	875.400
IE	4.991.800	5.045.800	5.067.900	446.800	251.900	167.800	20.600	14.600	13.300	4.005.400	4.324.200	4.235.500	519.000
IT	16.073.900	15.407.100	14.596.900	7.019.100	6.020.300	6.283.900	2.998.000	4.847.300	3.086.100	3.141.600	2.128.100	2.808.700	2.915.200
LT	3.634.700	4.090.500	3.665.200	2.159.200	2.483.000	2.333.700	104.300	100.300	104.800	798.200	1.066.400	798.200	573.000
LU	136.500	136.500	120.000	50.700	51.700	44.300	6.000	7.900	4.600	71.200	68.900	64.700	8.600
LV	2.296.600	2.660.900	2.318.500	1.120.300	1.241.600	1.182.700	60.700	57.400	61.100	387.000	630.500	387.000	728.600
MT	18.700	8.900	8.100	7.100	1.100	800	2.400	2.900	200	2.800	1.500	2.700	6.400
NL	2.407.000	2.390.600	2.368.100	1.047.600	1.032.800	1.034.500	63.700	238.000	88.900	1.151.500	1.002.600	1.098.500	144.200
PL	16.945.400	17.291.300	16.289.500	11.342.300	9.602.400	9.887.400	624.000	3.105.700	788.600	1.374.000	1.164.300	1.362.000	3.605.100
PT	5.355.100	5.212.900	4.999.800	596.900	130.000	178.000	1.061.300	1.594.900	1.078.900	1.302.800	1.215.500	1.523.500	2.394.100
RO	13.703.400	13.628.000	13.271.900	8.417.300	8.019.000	8.268.000	607.400	1.859.000	693.700	2.985.000	2.523.700	2.735.700	1.693.700
SE	5.595.400	5.494.100	5.836.200	1.960.000	1.843.700	1.862.300	158.500	311.100	167.300	792.700	363.600	792.700	2.684.200

SI	608.900	542.900	591.200	207.100	219.400	218.600	54.000	112.100	68.500	182.000	104.700	142.700	165.800
SK	2.157.600	2.167.900	2.023.300	1.309.700	1.136.800	1.169.900	69.200	271.300	75.600	384.400	396.600	402.000	394.300
EU27	195.371.700	194.737.000	187.205.800	94.365.200	86.483.800	87.315.000	16.368.000	31.454.300	17.549.300	43.446.500	39.169.100	41.770.900	41.192.000

Table 34 Land use within agricultural land in 2020 and 2050 for SA scenario and BAU scenario (% of total agricultural area) in EU27

%	Agri land 2020	Agri land SA 2050	Agri land BAU 2050	Annuals land 2020	Annuals SA 2050	Annuals BAU 2050	Perennials 2020	Perennials SA 2050	Perennials BAU 2050	Grazed grassland 2020	Grazed grassland SA 2050	Grazed grassland BAU 2050	Other* 2020	Other* SA 2050	Other* BAU 2050
AT	100%	100%	100%	41%	32%	35%	4%	11%	5%	25%	25%	27%	30%	32%	33%
BE	100%	100%	100%	53%	57%	58%	4%	11%	4%	37%	28%	33%	6%	4%	5%
BG	100%	100%	100%	59%	56%	61%	4%	13%	6%	17%	14%	15%	20%	17%	19%
CY	100%	100%	100%	63%	63%	63%	21%	21%	20%	1%	1%	1%	15%	16%	16%
CZ	100%	100%	100%	60%	56%	59%	3%	10%	4%	22%	23%	25%	14%	12%	13%
DE	100%	100%	100%	63%	57%	62%	4%	14%	4%	23%	21%	24%	10%	8%	10%
DK	100%	100%	100%	67%	70%	69%	3%	13%	5%	20%	10%	16%	10%	7%	10%
EE	100%	100%	100%	47%	49%	55%	3%	4%	4%	10%	16%	10%	39%	30%	31%
EL	100%	100%	100%	23%	17%	17%	17%	28%	20%	15%	12%	13%	45%	44%	49%
ES	100%	100%	100%	35%	31%	33%	18%	24%	19%	16%	14%	15%	31%	31%	32%
FI	100%	100%	100%	39%	39%	36%	4%	7%	5%	0%	0%	0%	57%	54%	59%
FR	100%	100%	100%	49%	49%	50%	6%	10%	6%	34%	32%	35%	10%	9%	10%
HR	100%	100%	100%	42%	34%	44%	6%	12%	8%	17%	18%	18%	34%	36%	30%
HU	100%	100%	100%	73%	65%	69%	4%	17%	6%	9%	7%	8%	14%	10%	16%
IE	100%	100%	100%	9%	5%	3%	0%	0%	0%	80%	86%	84%	10%	9%	13%
IT	100%	100%	100%	44%	39%	43%	19%	31%	21%	20%	14%	19%	18%	16%	17%
LT	100%	100%	100%	59%	61%	64%	3%	2%	3%	22%	26%	22%	16%	11%	12%
LU	100%	100%	100%	37%	38%	37%	4%	6%	4%	52%	50%	54%	6%	6%	5%
LV	100%	100%	100%	49%	47%	51%	3%	2%	3%	17%	24%	17%	32%	27%	30%
MT	100%	100%	100%	38%	12%	10%	13%	33%	2%	15%	17%	33%	34%	38%	54%
NL	100%	100%	100%	44%	43%	44%	3%	10%	4%	48%	42%	46%	6%	5%	6%
PL	100%	100%	100%	67%	56%	61%	4%	18%	5%	8%	7%	8%	21%	20%	26%
PT	100%	100%	100%	11%	2%	4%	20%	31%	22%	24%	23%	30%	45%	44%	44%
RO	100%	100%	100%	61%	59%	62%	4%	14%	5%	22%	19%	21%	12%	9%	12%

SE	100%	100%	100%	35%	34%	32%	3%	6%	3%	14%	7%	14%	48%	54%	52%
SI	100%	100%	100%	34%	40%	37%	9%	21%	12%	30%	19%	24%	27%	20%	27%
SK	100%	100%	100%	61%	52%	58%	3%	13%	4%	18%	18%	20%	18%	17%	19%
EU27	100%	100%	100%	48%	44%	47%	8%	16%	9%	22%	20%	22%	21%	19%	22%

Table 35 Land use within agricultural land in 2020 and 2050 for SA scenario and BAU scenario (Hectares) per RALUC class in EU 27

HA	Agri land 2020	Agri land SA 2050	Agri land BAU 2050	Annuals land 2020	Annuals SA 2050	Anuals BAU 2050	Perennials 2020	Perennials SA 2050	Perennials BAU 2050	Grazed grassland 2020	Grazed grassland SA 2050	Grazed grassland BAU 2050	Other* 2020
A-1a	4.009.300	3.931.500	3.607.500	1.839.700	1.701.000	1.671.300	461.500	827.100	465.800	1.076.600	858.500	945.700	631.500
A-1b	1.812.000	1.752.300	1.627.400	799.800	585.500	624.100	222.300	583.300	247.700	364.400	243.100	344.300	425.500
A-1c	1.470.900	1.448.800	1.323.100	628.000	526.800	532.200	216.400	415.100	231.800	279.700	237.500	261.100	346.800
A-2a	13.581.300	13.548.600	13.035.800	6.133.400	6.117.600	5.757.300	581.700	1.280.300	617.100	4.919.700	4.444.900	4.822.600	1.946.500
A-2b	9.481.700	9.394.500	8.867.900	4.165.000	3.209.700	3.396.800	609.000	1.540.100	681.200	2.311.500	2.250.100	2.272.900	2.396.200
A-2c	11.131.000	11.086.300	10.349.200	5.133.000	4.659.300	4.605.900	855.300	1.622.400	888.300	3.011.400	2.922.800	2.935.600	2.131.300
A-2d	14.375.500	14.495.300	13.819.700	9.519.300	8.385.700	8.591.800	551.900	2.333.900	707.400	1.670.900	1.479.000	1.605.600	2.633.400
A-3a	7.556.200	7.455.900	7.666.700	1.845.700	1.390.100	1.578.200	183.600	292.300	187.000	2.205.900	2.199.200	2.200.100	3.321.000
A-3b	4.319.900	4.025.200	4.027.600	1.539.600	1.308.700	1.269.000	119.100	163.300	111.100	985.900	1.076.500	1.049.700	1.675.300
A-3c	9.952.700	10.135.500	9.602.400	3.814.400	3.669.800	3.535.600	661.600	1.088.200	717.200	2.395.100	2.527.900	2.507.600	3.081.600
E-1a	5.009.400	4.992.200	4.782.000	2.591.300	2.349.300	2.298.500	252.400	440.300	231.000	1.428.100	1.515.600	1.536.800	737.600
E-1b	5.095.800	5.080.400	4.826.800	3.232.100	3.110.500	3.126.300	444.000	837.400	455.000	814.600	708.100	769.800	605.100
I-1a	2.190.100	2.146.900	2.112.200	1.034.500	881.500	934.300	341.500	538.400	360.200	385.100	344.800	380.300	429.000
I-1b	1.020.400	1.007.500	978.500	521.900	492.900	514.700	144.000	260.600	148.100	238.400	165.800	214.300	116.100
I-2a	6.906.800	6.837.800	6.589.700	3.997.600	3.783.200	3.889.000	572.700	934.300	541.200	1.093.300	934.200	950.800	1.243.200
I-2b	10.773.000	10.673.200	10.619.800	3.664.100	2.946.800	3.295.700	2.572.000	3.668.100	2.811.400	1.259.100	886.300	1.089.000	3.277.800
I-2c	2.969.100	3.010.900	2.846.000	1.912.800	1.785.900	1.774.700	73.500	357.800	85.300	663.600	607.000	654.900	319.200
I-2d	9.355.700	9.384.800	9.099.900	5.444.700	5.304.400	5.399.200	1.191.000	1.935.200	1.264.900	1.363.000	1.058.500	1.186.900	1.357.000
I-3a	9.617.000	10.088.300	9.506.200	3.693.400	3.566.700	3.508.300	558.500	1.032.500	582.200	2.372.300	2.640.700	2.553.200	2.992.800

N-1	1.262.300	1.247.300	1.220.200	633.200	574.200	604.200	101.600	249.200	116.000	271.000	200.000	232.200	256.500
U-1a	16.853.400	16.518.600	15.869.500	8.884.400	8.505.200	8.588.600	1.248.500	2.782.700	1.320.300	4.466.100	3.462.100	3.965.200	2.254.400
U-1b	4.209.900	4.174.100	4.060.500	1.722.000	1.463.500	1.596.200	919.100	1.543.900	1.020.100	560.600	282.000	450.400	1.008.200
U-1c	1.739.100	1.738.000	1.634.200	903.200	881.000	860.600	95.700	288.200	113.300	540.100	409.200	479.400	200.100
U-1d	2.119.300	2.100.900	2.026.300	876.100	677.100	771.100	656.800	1.053.200	720.600	307.000	164.400	282.400	279.400
U-2a	16.114.300	16.176.100	15.599.700	8.949.500	8.812.600	8.795.200	1.022.500	1.948.700	1.064.900	4.130.600	3.620.900	3.833.900	2.011.700
U-2b	4.432.700	4.387.100	4.254.800	2.034.600	1.776.200	1.783.300	599.200	997.300	632.500	630.400	534.000	640.900	1.168.500
U-2c	18.012.900	17.899.000	17.252.200	8.851.900	8.018.600	8.012.900	1.112.600	2.440.500	1.227.700	3.702.100	3.396.000	3.605.300	4.346.300
EU27	195.371.700	194.737.000	187.205.800	94.365.200	86.483.800	87.315.000	16.368.000	31.454.300	17.549.300	43.446.500	39.169.100	41.770.900	41.192.000

Table 36 Land use within agricultural land in 2020 and 2050 for SA scenario and BAU scenario (% of total agricultural area) in EU27

%	Agri land 2020	Agri land SA 2050	Agri land BAU 2050	Annuals land 2020	Annuals SA 2050	Anuals BAU 2050	Perennials 2020	Perennials SA 2050	Perennials BAU 2050	Grazed grassland 2020	Grazed grassland SA 2050	Grazed grassland BAU 2050	Other* 2020	Other* SA 2050	Other* BAU 2050
A-1a	100%	100%	100%	46%	43%	46%	12%	21%	13%	27%	22%	26%	16%	14%	11%
A-1b	100%	100%	100%	44%	33%	38%	12%	33%	15%	20%	14%	21%	23%	19%	23%
A-1c	100%	100%	100%	43%	36%	40%	15%	29%	18%	19%	16%	20%	24%	19%	23%
A-2a	100%	100%	100%	45%	45%	44%	4%	9%	5%	36%	33%	37%	14%	13%	14%
A-2b	100%	100%	100%	44%	34%	38%	6%	16%	8%	24%	24%	26%	25%	25%	28%
A-2c	100%	100%	100%	46%	42%	45%	8%	15%	9%	27%	26%	28%	19%	17%	19%
A-2d	100%	100%	100%	66%	58%	62%	4%	16%	5%	12%	10%	12%	18%	16%	21%
A-3a	100%	100%	100%	24%	19%	21%	2%	4%	2%	29%	29%	29%	44%	48%	44%
A-3b	100%	100%	100%	36%	33%	32%	3%	4%	3%	23%	27%	26%	39%	37%	40%
A-3c	100%	100%	100%	38%	36%	37%	7%	11%	7%	24%	25%	26%	31%	28%	30%
E-1a	100%	100%	100%	52%	47%	48%	5%	9%	5%	29%	30%	32%	15%	14%	15%
E-1b	100%	100%	100%	63%	61%	65%	9%	16%	9%	16%	14%	16%	12%	8%	10%
I-1a	100%	100%	100%	47%	41%	44%	16%	25%	17%	18%	16%	18%	20%	18%	21%
I-1b	100%	100%	100%	51%	49%	53%	14%	26%	15%	23%	16%	22%	11%	9%	10%
I-2a	100%	100%	100%	58%	55%	59%	8%	14%	8%	16%	14%	14%	18%	17%	18%
I-2b	100%	100%	100%	34%	28%	31%	24%	34%	26%	12%	8%	10%	30%	30%	33%
I-2c	100%	100%	100%	64%	59%	62%	2%	12%	3%	22%	20%	23%	11%	9%	11%
I-2d	100%	100%	100%	58%	57%	59%	13%	21%	14%	15%	11%	13%	15%	12%	14%
I-3a	100%	100%	100%	38%	35%	37%	6%	10%	6%	25%	26%	27%	31%	28%	30%
N-1	100%	100%	100%	50%	46%	50%	8%	20%	10%	21%	16%	19%	20%	18%	23%
U-1a	100%	100%	100%	53%	51%	54%	7%	17%	8%	26%	21%	25%	13%	11%	13%
U-1b	100%	100%	100%	41%	35%	39%	22%	37%	25%	13%	7%	11%	24%	21%	24%
U-1c	100%	100%	100%	52%	51%	53%	6%	17%	7%	31%	24%	29%	12%	9%	11%
U-1d	100%	100%	100%	41%	32%	38%	31%	50%	36%	14%	8%	14%	13%	10%	13%

U-2a	100%	100%	100%	56%	54%	56%	6%	12%	7%	26%	22%	25%	12%	11%	1
U-2b	100%	100%	100%	46%	40%	42%	14%	23%	15%	14%	12%	15%	26%	25%	2
U-2c	100%	100%	100%	49%	45%	46%	6%	14%	7%	21%	19%	21%	24%	23%	2
EU27	100%	100%	100%	48%	44%	47%	8%	16%	9%	22%	20%	22%	21%	19%	2

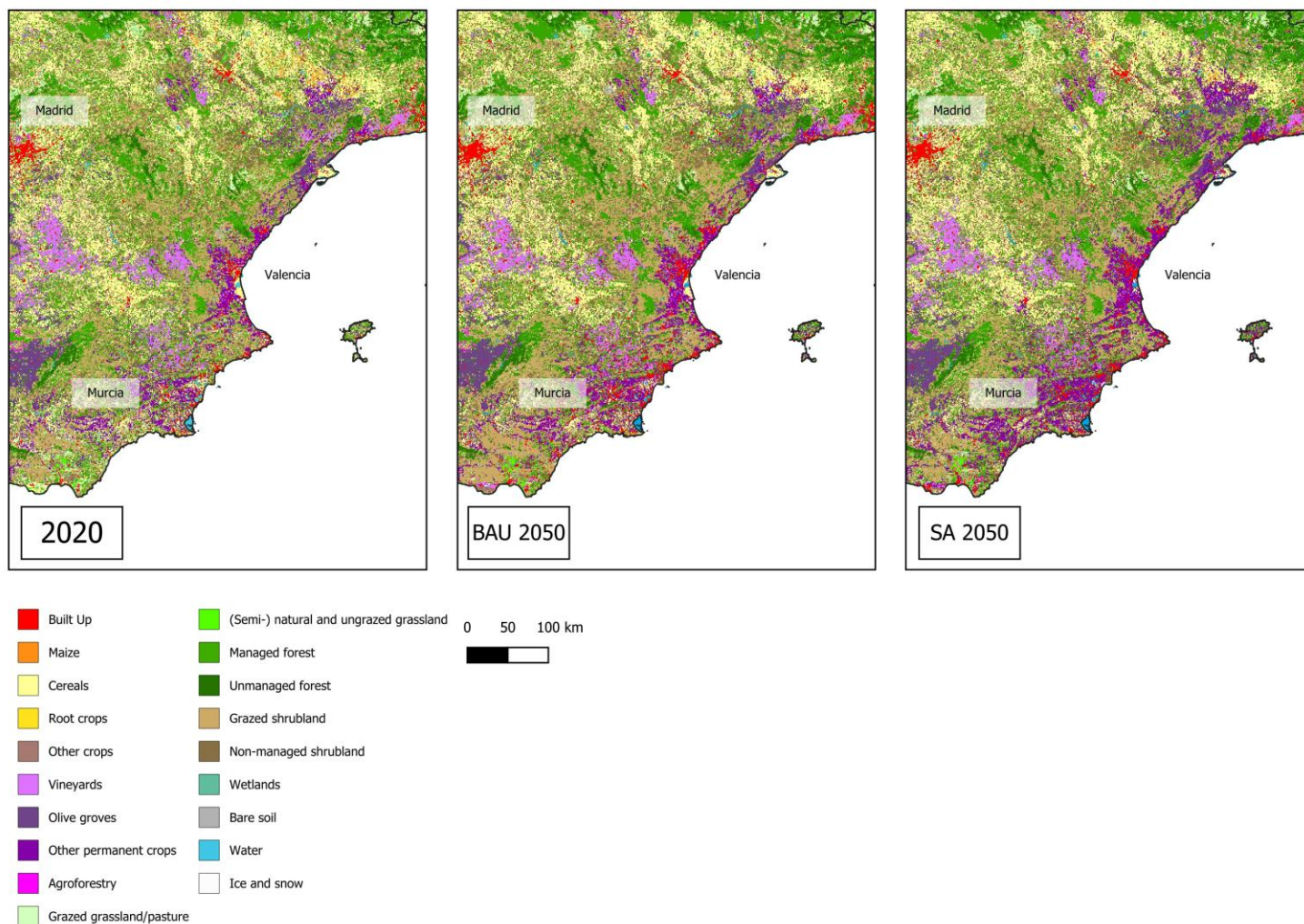


Figure 36 Comparison of Eastern Spain from the current situation (left) with Business-As-Usual (middle) and Sustainable Agriculture (right).

In both the Business-As-Usual and the Sustainable Agricultural scenario the built-up area (in red) around already existing cities will expand. Furthermore, the sustainable agricultural scenario sees an increase in perennial crops (in purple and pink, e.g. see east of Murcia) while the Business-As-Usual scenario will also experience land abandonment of agricultural fields Southwest of Murcia.

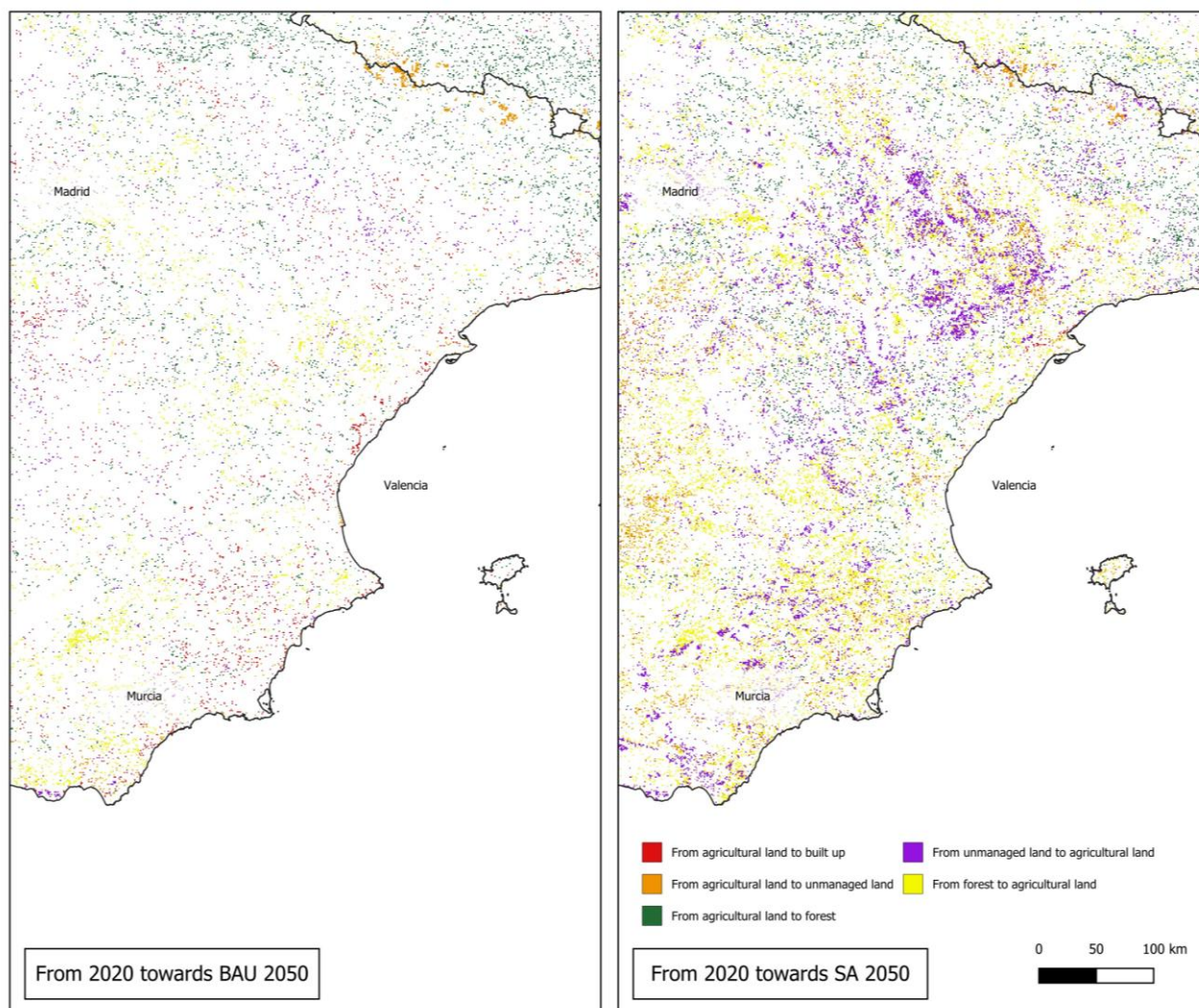


Figure 37 Agricultural land use transitions from 2020 towards BAU 2050 (left) and SA 2050 (right).

For BAU in Northern Poland densifying of the forest will take place, close to Gdansk indicating land abandonment (see Figure 38). In the SA scenario, the region southern of Warsaw will experience an increase in perennials to create space for the production of energy crops. In addition, in the SA scenario grassland will disappear to make way for perennials and maize. Both transitions indicate reclamation of formerly abandoned lands; an opposite direction of the BAU scenario.

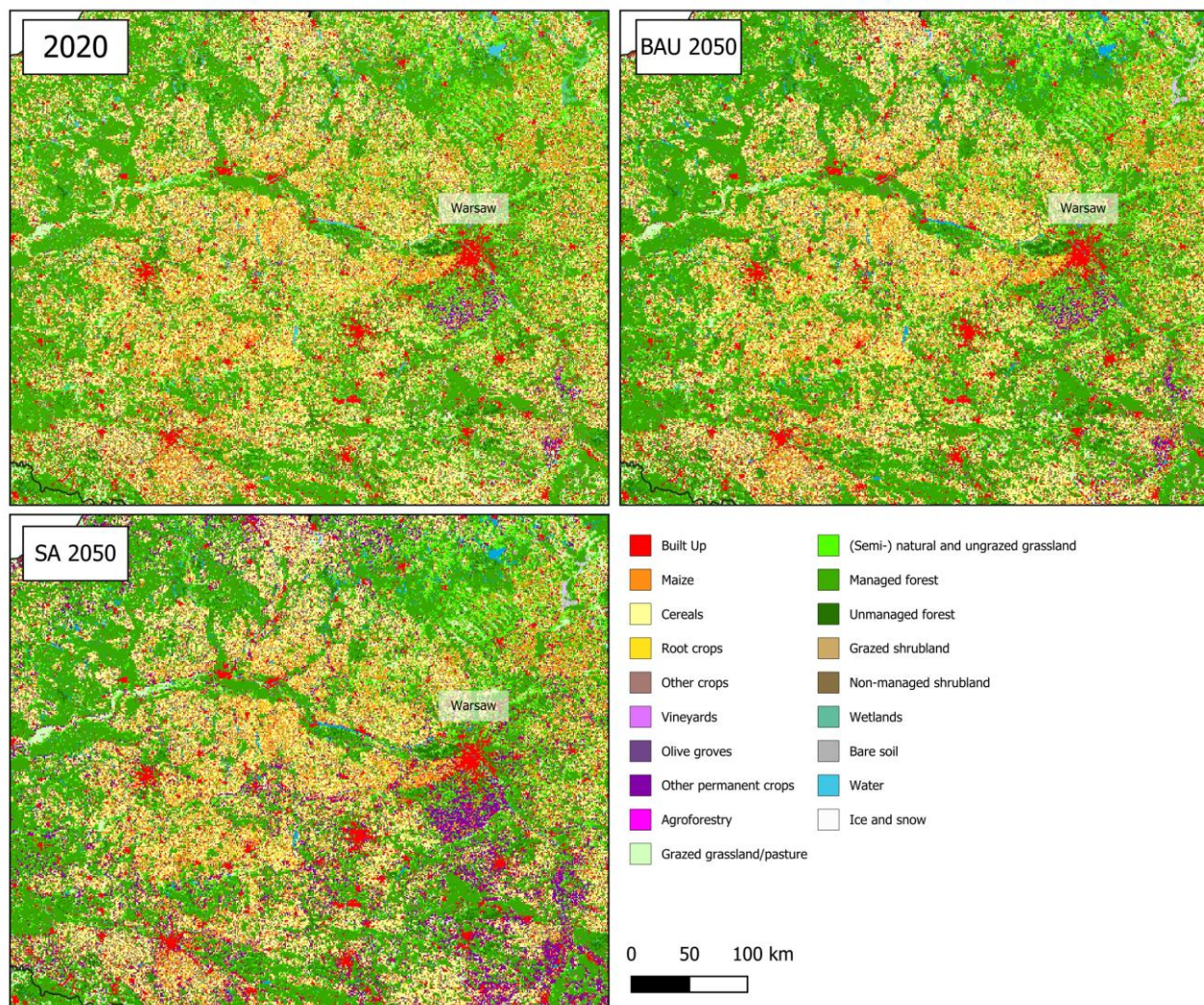


Figure 38 Comparison of Northern Poland from the current situation (top left) with Business-As-Usual (top right) and Sustainable Agriculture (left bottom).

Table 37 Land use flows BAU 2020 to 2050 (Hectares) at Nuts 3 level for EU27

See excel file 'Annex 15 tables land use'

Table 38 Land use flows SA 2020 to 2050 (Hectares) at Nuts 3 level for EU27

See excel file 'Annex 15 tables land use'

Table 39 Land use flows within agricultural lands in BAU 2020 to 2050 (Hectares) at Nuts 3 level for EU27

See excel file 'Annex 15 tables land use'

Table 40 Land use flows within agricultural lands in SA 2020 to 2050 (Hectares) at Nuts 3 level for EU27

See excel file 'Annex 15 tables land use'

22. Annex 13 KPI scores overview

Table 41 Overview of all KPIs

Number	Issue	KPI definition	Type of KPI	Type of KPI
KPI1	Land take - soil sealing	Urban land take from agriculture (%/2020 UAA)	T	P
KPI2	Agricultural land use	% Change in agricultural land abandoned to nonmanaged land 2020-2050 total and in Natura 2000	T	P
KPI3	Agri production & food security	% Change in production of food (Change in calories) 2020-2051	P	
KPI4	Organic farming	Distance to 25% organic farming share in UAA (% of UAA)	T	C
KPI5	Pesticide use	Change Pesticide use (average Kg Active Substances/ha) 2020-2050	T	C
KPI5	Pesticide use	Change is total Kg Active Substances 2020-2050	T	C
KPI6	Fertilizer use	Agri area >=20% reduction fertilizer use (%/UAA) between 2020-2050	T	T
KPI7	Livestock density	% change LU/ha UAA 2020-2050	P	C
KPI8	Organic matter	% SOM (% of the fraction of SOC change) 2020-2050 (total region)	C	
KPI9	Soil health	% soil erosion risk change (cover factor Russle eq. ONLY for land cover!) Total region!@)	C	
KPI10	GHG reduction	GHG emission AFOLU change 2020-2050 (MtonnesCO ₂ -eq)	T	P
KPI11	GHG reduction	GHG emission land use + agrmanagement change 2020-2050 (MtonnesCO ₂ -eq)	T	P
KPI12	Nature restoration	Change in Flora and nesting suitability index 2020-2050	C	
KPI13	Landscape quality	% change in Shanon landscape evenness index 2020-2050	C	
KPI14	Nitrogen losses to water	Distance to critical load exceedance for Nitrogen concentration in surface and groundwater	C	
KPI15	Ammonia emissions	Distance to critical load exceedance for ammonia emissions (affects sensitive nature area - Habitat Directive)	C	
KPI16	Agricultural land use	Perc_Agricultural area change 2020_2050	T	P
KPI-CC1	Climate	Aridity index 2050	CC	P
KPI-CC2	Demography	Population density and trend towards 2050	CC	P

KPI-CC3	Economic resilience	GDP/head	CC	P
T	Target (policy) indicator	T		
C	Condition indicator	C		
P	Pressure indicator	P		
CC	Carrying Capacity indicator	CC		

Table 42 Scores KPI1 land take, KPI2 Land abandonment, KPI3 calories produced at country level for BAU and SA scenario

	KPI1 Land take BAU	KPI1 land take SA	KPI2 Agri abandonment BAU	KPI2 Agri abandonment SA	KPI3 - Total calories BAU	Total calories SA
AT	1.3%	1.2%	5.9%	-3.5%	-13%	-21%
BE	2.6%	1.8%	2.2%	-3.3%	40%	53%
BG	1.2%	0.9%	-0.8%	-16.8%	9%	18%
CY	24.5%	35.2%	11.0%	-47.7%	-31%	-15%
CZ	2.1%	1.3%	4.4%	-8.9%	-1%	-10%
DE	1.2%	0.7%	4.3%	-13.2%	1%	2%
DK	0.6%	0.3%	0.8%	-4.8%	2%	-14%
EE	0.0%	0.6%	-12.4%	-29.4%	-10%	46%
EL	1.2%	1.3%	2.3%	-9.9%	-50%	-29%
ES	1.2%	0.3%	2.2%	-5.5%	-6%	11%
FI	0.1%	1.1%	13.8%	-5.2%	-56%	-3%
FR	0.9%	0.6%	3.1%	-4.4%	5%	-1%
HR	3.4%	1.7%	-8.7%	-21.0%	0%	-9%
HU	1.2%	0.6%	4.4%	-9.6%	1%	9%
IE	0.1%	0.0%	-0.9%	-3.1%	-64%	-85%
IT	2.1%	0.9%	8.0%	-0.1%	-38%	-12%
LT	0.0%	0.2%	-5.6%	-20.5%	-25%	17%
LU	0.7%	0.5%	10.2%	-8.0%	-13%	-9%
LV	0.0%	0.4%	-3.9%	-18.5%	-34%	13%
MT	58.6%	42.9%	8.3%	-12.8%	-94%	-100%
NL	1.2%	0.9%	1.0%	-1.9%	4%	5%
PL	1.0%	0.5%	9.0%	-18.5%	-2%	-8%
PT	1.2%	0.3%	5.2%	-1.2%	-63%	-35%
RO	2.0%	1.2%	-1.2%	-7.2%	44%	53%
SE	0.0%	0.7%	2.9%	-5.6%	67%	-4%
SI	0.4%	1.3%	1.0%	-0.3%	22%	34%
SK	2.4%	1.3%	4.2%	-10.8%	-14%	-24%

Table 43 Scores KPI1 land take, KPI2 Land abandonment, KPI3 calories produced at RALUC type level for BAU and SA scenario

RALUC type	KPI1 Land take BAU	KPI1 land take SA	KPI2 Agri abandonment BAU	KPI2 Agri abandonment SA	Total calories BAU	Total calories SA
A-1a	2.3%	1.5%	7%	-7%	-9%	-1%
A-1b	3.5%	1.1%	10%	-7%	-6%	13%
A-1c	3.2%	1.6%	7%	-12%	-3%	-1%
A-2a	0.7%	0.5%	3%	-5%	-7%	-10%
A-2b	1.4%	0.8%	8%	-7%	-14%	-12%
A-2c	0.8%	0.4%	6%	-5%	-4%	-3%
A-2d	1.1%	0.6%	6%	-14%	1%	1%
A-3a	0.8%	0.6%	5%	-6%	82%	-14%
A-3b	0.3%	0.2%	7%	-4%	-5%	20%
A-3c	0.4%	0.3%	1%	-8%	-27%	-7%
E-1a	1.2%	0.6%	3%	-6%	-5%	-10%
E-1b	2.2%	1.5%	1%	-9%	13%	13%
I-1a	1.9%	0.6%	3%	-7%	-3%	14%
I-1b	2.1%	1.1%	2%	-3%	9%	24%
I-2a	1.0%	0.1%	4%	-9%	-10%	0%
I-2b	1.2%	0.5%	0%	-8%	13%	29%
I-2c	0.8%	0.4%	5%	-11%	1%	4%
I-2d	1.3%	0.9%	-1%	-10%	21%	30%
I-3a	0.5%	0.3%	-1%	-15%	-12%	12%
N-1	1.2%	1.0%	2%	-6%	4%	4%
U-1a	2.1%	1.2%	4%	-6%	8%	9%
U-1b	2.2%	1.0%	1%	-11%	12%	8%
U-1c	1.9%	1.3%	5%	-7%	0%	1%
U-1d	2.3%	2.2%	2%	-7%	-3%	11%
U-2a	1.4%	1.3%	2%	-7%	2%	-4%
U-2b	1.3%	0.8%	4%	-8%	-2%	-4%
U-2c	1.2%	0.7%	2%	-8%	1%	7%

Table 44 Scores KPI1 land take, KPI2 Land abandonment, KPI3 calories produced at ENR level for BAU and SA scenario

	KPI1 Land take BAU	KPI1 land take SA	KPI2 Agri abandonment BAU	KPI2 Agri abandonment SA	Total calories BAU	Total calories SA
Alpine	1.2%	1.0%	7.5%	-3.2%	-25%	-21%
Atlantic	1.0%	0.6%	3.0%	-3.3%	8%	5%
Continental	1.5%	0.9%	3.4%	-13.1%	5%	3%
Mediterranean	1.5%	0.8%	3.1%	-6.0%	-20%	2%
North	0.1%	0.5%	0.9%	-14.1%	12%	4%
EU27	1.3%	0.8%	3.2%	-8.0%	2%	3%

Table 45 Scores KPI4 to KPI7 at country level for BAU and SA scenario

RALUC type	KPI4 - Distance to 25% organic farming target BAU	KPI4 - Distance to 25% organic farming target SA	KPI5 - Change in pesticides used BAU	KPI5 - Change in pesticides used SA	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 BAU	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 SA	KPI7- LU density (LU/ha UAA)% change 2020-2050 BAU	KPI7 -LU density (LU/ha UAA)% change 2020-2050 BAU
A-1a	5%	-4%	-46%	0%	20%	100%	-9%	-25%
A-1b	21%	0%	-35%	9%	4%	100%	-6%	-8%
A-1c	25%	0%	-41%	2%	0%	100%	-35%	-45%
A-2a	22%	0%	-34%	-1%	3%	100%	23%	-43%
A-2b	10%	-4%	-44%	0%	13%	100%	-36%	-26%
A-2c	15%	0%	-40%	2%	9%	100%	6%	-41%
A-2d	15%	0%	-44%	1%	10%	100%	-1%	-23%
A-3a	5%	0%	-49%	-3%	20%	100%	-11%	-15%
A-3b	21%	0%	-35%	8%	4%	100%	-1%	-14%
A-3c	21%	0%	-42%	2%	4%	100%	10%	-43%
E-1a	11%	-1%	-43%	7%	12%	100%	2%	0%
E-1b	16%	0%	-47%	-1%	7%	100%	-1%	-8%
I-1a	20%	0%	-41%	-1%	5%	100%	12%	-50%
I-1b	23%	0%	-39%	2%	2%	100%	-25%	-35%
I-2a	24%	0%	-52%	-4%	1%	100%	-32%	-47%
I-2b	15%	-2%	-40%	2%	12%	100%	-7%	-16%
I-2c	17%	0%	-49%	-2%	8%	100%	-8%	-21%
I-2d	21%	0%	-47%	-2%	4%	100%	-8%	-21%
I-3a	14%	0%	-46%	-1%	11%	100%	-13%	-23%
N-1	24%	0%	-36%	-20%	1%	100%	-20%	-40%
U-1a	21%	0%	-41%	4%	4%	100%	-6%	-22%
U-1b	23%	0%	-37%	2%	2%	100%	6%	-14%

RALUC type	KPI4 - Distance to 25% organic farming target BAU	KPI4 - Distance to 25% organic farming target SA	KPI5 - Change in pesticides used BAU	KPI5 - Change in pesticides used SA	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 BAU	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 SA	KPI7- LU density (LU/ha UAA)% change 2020-2050 BAU	KPI7 -LU density (LU/ha UAA)% change 2020-2050 BAU
U-1c	20%	0%	-40%	2%	4%	100%	-3%	-9%
U-1d	24%	0%	-42%	1%	1%	100%	23%	7%
U-2a	7%	-2%	-42%	7%	16%	100%	-11%	-14%
U-2b	16%	0%	-37%	9%	9%	100%	-3%	-26%
U-2c	15%	0%	-44%	-2%	9%	100%	-32%	-40%

Table 46 Scores KPI4 to KPI7 at RALUC type level for BAU and SA scenario

RALUC type	KPI4 - Distance to 25% organic farming target BAU	KPI4 - Distance to 25% organic farming target SA	KPI5 - Change in pesticides used BAU	KPI5 - Change in pesticides used SA	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 BAU	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 SA	KPI6- LU density (LU/ha UAA)% change 2020-2050 BAU	KPI6 -LU density (LU/ha UAA)% change 2020-2050 BAU
A-1a	15%	0%	-40%	2%	9%	100%	-3%	-28%
A-1b	21%	0%	-34%	6%	3%	100%	-11%	-26%
A-1c	15%	-2%	-36%	10%	15%	100%	-6%	-29%
A-2a	14%	0%	-45%	-1%	8%	100%	-3%	-18%
A-2b	19%	0%	-41%	0%	6%	100%	-4%	-24%
A-2c	15%	-2%	-42%	1%	8%	100%	-4%	-26%
A-2d	23%	0%	-40%	1%	2%	100%	-3%	-19%
A-3a	12%	-2%	-43%	5%	8%	100%	-3%	-13%
A-3b	14%	-1%	-44%	8%	5%	100%	4%	-2%
A-3c	18%	0%	-44%	0%	6%	100%	-4%	-17%
E-1a	16%	0%	-43%	-1%	6%	100%	-19%	-36%
E-1b	16%	-2%	-44%	1%	8%	100%	8%	-38%
I-1a	19%	0%	-40%	2%	5%	100%	-12%	-38%
I-1b	18%	-1%	-42%	0%	11%	100%	19%	-41%
I-2a	18%	0%	-43%	0%	4%	100%	-1%	-38%
I-2b	17%	0%	-39%	4%	6%	100%	-12%	-37%
I-2c	15%	0%	-42%	1%	11%	100%	-15%	-39%
I-2d	20%	-1%	-43%	1%	4%	100%	-4%	-23%
I-3a	20%	0%	-42%	0%	5%	100%	15%	-24%
N-1	19%	-1%	-40%	5%	6%	100%	6%	-29%
U-1a	17%	0%	-39%	3%	7%	100%	1%	-30%

RALUC type	KPI4 - Distance to 25% organic farming target BAU	KPI4 - Distance to 25% organic farming target SA	KPI5 - Change in pesticides used BAU	KPI5 - Change in pesticides used SA	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 BAU	KPI6 - Agri area with >=20% reduction in art fertilizers in 2050 compared to 2020 SA	KPI6- LU density (LU/ha UAA)% change 2020-2050 BAU	KPI6 -LU density (LU/ha UAA)% change 2020-2050 BAU
U-1b	18%	0%	-38%	5%	7%	100%	-5%	-33%
U-1c	17%	0%	-39%	3%	7%	100%	20%	-42%
U-1d	17%	0%	-37%	2%	11%	100%	12%	-31%
U-2a	15%	0%	-44%	1%	8%	100%	-8%	-28%
U-2b	19%	0%	-42%	4%	6%	100%	5%	-23%
U-2c	17%	-1%	-41%	2%	5%	100%	-4%	-27%

Table 47 Scores KPI4 to KPI7 at ENR level for BAU and SA scenario

RALUC type	KPI4 - Distance to 25% organic farming target BAU	KPI4 - Distance to 25% organic farming target SA	KPI5 - Change in pesticides used BAU	KPI5 - Change in pesticides used SA	KPI6 - Agri area with $\geq 20\%$ reduction in art fertilizers in 2050 compared to 2020 BAU	KPI6 - Agri area with $\geq 20\%$ reduction in art fertilizers in 2050 compared to 2020 SA	KPI7- LU density (LU/ha UAA)% change 2020-2050 BAU	KPI7 -LU density (LU/ha UAA)% change 2020-2050 BAU
Alpine	14%	-2%	-44%	0%	9%	100%	-5%	-19%
Atlantic	19%	0%	-41%	3%	5%	100%	10%	-34%
Continental	17%	0%	-41%	1%	5%	100%	-11%	-30%
Mediterranean	17%	-1%	-39%	3%	6%	100%	2%	-25%
North	11%	-1%	-44%	4%	12%	100%	-5%	-9%
EU27	17.1%	-0.4%	-41%	2%	6%	100%	2%	-31%

Table 48 Scores KPI8 to KPI9 at national level for BAU and SA scenario

	KPI8 % change in SOC BAU	KPI8 % change in SOC SA	KPI9 % change in Soil erosion risk fraction BAU	KPI9 % change in Soil erosion risk fraction BAU
AT	3%	0%	-10%	-3%
BE	-4%	-10%	8%	15%
BG	0%	-7%	0%	18%
CY	15%	-1%	-25%	19%
CZ	2%	-6%	-6%	7%
DE	1%	-11%	-3%	15%
DK	-4%	-14%	1%	13%
EE	-2%	-4%	4%	24%
EL	2%	-7%	-6%	15%
ES	2%	-6%	-7%	7%
FI	0%	-1%	-11%	3%
FR	1%	-5%	-4%	6%
HR	5%	-2%	-1%	15%
HU	4%	-10%	-3%	10%
IE	3%	1%	-9%	-3%
IT	2%	-4%	-10%	4%
LT	-3%	-8%	2%	18%
LU	4%	-6%	-12%	13%
LV	-1%	-3%	-2%	15%
MT	39%	-4%	-37%	5%
NL	0%	-5%	2%	8%
PL	4%	-11%	-7%	15%
PT	4%	-7%	-17%	0%
RO	-1%	-8%	5%	15%
SE	0%	-2%	-7%	5%
SI	-1%	-3%	7%	11%
SK	2%	-4%	-6%	7%

Table 49 Scores KPI8 to KPI9 at RALUC type level for BAU and SA scenario

RALUC type	KPI8 % change in SOC BAU	KPI8 % change in SOC SA	KPI9 % change in Soil erosion risk fraction BAU	KPI9 % change in Soil erosion risk fraction BAU
A-1a	2%	-7%	-9%	12%
A-1b	4%	-7%	-12%	7%
A-1c	2%	-8%	-10%	14%
A-2a	1%	-3%	-7%	5%
A-2b	4%	-3%	-10%	6%
A-2c	3%	-4%	-11%	4%
A-2d	3%	-9%	-4%	13%
A-3a	1%	-1%	-12%	4%
A-3b	1%	-2%	-10%	6%
A-3c	1%	-6%	-6%	9%
E-1a	4%	-5%	-9%	1%
E-1b	1%	-7%	-2%	9%
I-1a	0%	-9%	3%	17%
I-1b	1%	-9%	-4%	15%
I-2a	1%	-7%	-3%	10%
I-2b	2%	-9%	-2%	13%
I-2c	3%	-8%	-8%	7%
I-2d	0%	-8%	1%	12%
I-3a	1%	-7%	-2%	18%
N-1	-1%	-7%	2%	8%
U-1a	0%	-11%	0%	15%
U-1b	1%	-11%	-1%	13%
U-1c	1%	-11%	-4%	15%
U-1d	1%	-6%	-3%	11%
U-2a	1%	-7%	-1%	10%
U-2b	2%	-5%	-6%	8%

U-2c	2%	-6%	-6%	9%

Table 50 Scores KPI8 to KPI9 at ENR level for BAU and SA scenario

RALUC type	KPI8 % change in SOC BAU	KPI8 % change in SOC SA	KPI9 % change in Soil erosion risk fraction BAU	KPI9 % change in Soil erosion risk fraction BAU
Alpine	2%	0%	-15%	-4%
Atlantic	0%	-8%	0%	11%
Continental	2%	-10%	-4%	14%
Mediterranean	2%	-6%	-8%	8%
North	0%	-3%	-5%	11%
EU27	1%	-7%	-3%	11%

Table 51 Scores KPI10 to KPI11 at national level for BAU and SA scenario

	KPI10 - GHG emission change through AFOLU change BAU	KPI10 - GHG emission change through AFOLU change BAU	KPI11 - GHG emission change through AFOLU + management change BAU	KPI11 - GHG emission change through AFOLU + management change SA
AT	-0.9	-0.6	-0.9	-0.6
BE	-0.1	0.1	-0.1	0.1
BG	-0.2	2.5	-0.2	2.2
CY	5.6	6.1	5.6	6.4
CZ	0.9	3.8	0.9	3.7
DE	-1.1	-0.2	-1.1	-0.3
DK	-0.2	-0.4	-0.2	-0.4
EE	-2.4	1.4	-2.4	1.0
EL	1.4	1.8	1.4	1.7
ES	3.4	1.4	3.4	1.3
FI	-16.4	-15.5	-16.4	-15.8
FR	-2.2	-0.2	-2.2	-0.5
HR	1.4	1.2	1.4	1.2
HU	-0.6	0.0	-0.6	-0.1
IE	0.3	1.2	0.3	1.2
IT	-2.2	-1.2	-2.2	-1.4
LT	-7.2	-1.8	-7.2	-2.3
LU	-4.3	-1.3	-4.3	-1.5
LV	-4.7	-2.6	-4.7	-2.7
MT	0.3	0.2	0.3	0.2
NL	-0.4	-0.2	-0.4	-0.2
PL	-2.5	1.1	-2.5	0.8
PT	-2.0	-1.7	-2.0	-1.8
RO	-3.0	-3.0	-3.0	-3.1
SE	-8.7	-6.1	-8.7	-6.5
SI	-1.6	-1.4	-1.6	-1.4
SK	-8.3	-5.9	-8.3	-5.8

Table 52 Scores KPI10 to KPI11 at RALUC region level for BAU and SA scenario

	KPI10 - GHG emission change through AFOLU change BAU	KPI10 - GHG emission change through AFOLU change BAU	KPI11 - GHG emission change through AFOLU + management change BAU	KPI11 - GHG emission change through AFOLU + management change SA
A-1a	0.0	-0.1	-1.7	-0.6
A-1b	0.0	-0.2	-1.3	-0.3
A-1c	-0.1	-0.1	-1.2	-0.6
A-2a	0.0	0.0	-3.8	-1.3
A-2b	0.0	-0.1	-3.1	-0.8
A-2c	0.0	-0.1	-3.3	-1.8
A-2d	0.0	-0.1	-2.6	0.4
A-3a	0.0	0.0	-6.6	-5.8
A-3b	0.0	0.0	-13.8	-13.1
A-3c	0.0	0.0	-1.7	0.3
E-1a	0.0	0.0	1.3	2.6
E-1b	0.0	0.0	-1.1	-0.1
I-1a	0.0	-0.1	-0.2	0.2
I-1b	0.0	0.0	-0.2	0.0
I-2a	0.0	-0.1	-1.1	-0.8
I-2b	0.0	-0.1	4.5	4.5
I-2c	0.0	-0.1	-1.9	0.0
I-2d	-0.1	-0.1	-0.6	0.7
I-3a	0.0	0.0	-1.4	0.7
N-1	0.0	0.0	-0.5	0.2
U-1a	0.0	0.0	-0.6	-0.2
U-1b	0.0	-0.1	0.4	0.9
U-1c	0.0	0.0	-0.6	-0.2
U-1d	0.0	-0.1	-0.7	0.4
U-2a	0.0	-0.1	-1.4	-0.2

U-2b	0.0	-0.1	0.1	1.2
U-2c	0.0	-0.1	-1.0	-0.3

Table 53 Scores KPI10 to KPI11 at ENR level for BAU and SA scenario

RALUC type	KPI10 - GHG emission change through AFOLU change BAU	KPI10 - GHG emission change through AFOLU change BAU	KPI11 - GHG emission change through AFOLU + management change BAU	KPI11 - GHG emission change through AFOLU + management change SA
Alpine	-2.5	-1.6	-2.5	-1.7
Atlantic	-1.2	-0.5	-1.2	-0.6
Continental	-1.5	-0.1	-1.5	-0.2
Mediterranean	0.5	0.8	0.5	0.6
North	-9.9	-7.1	-9.9	-7.5

Table 54 Scores KPI12 to KPI13 at National level for BAU and SA scenario

	KPI12 - % change flora & nesting factor BUA	KPI12 - % change flora & nesting factor SA	KPI13 - Evenness %Change BAU	KPI13 - Evenness %Change SA
AT	1%	-1%	-1%	0%
BE	-2%	-5%	-3%	0%
BG	-1%	-7%	-2%	0%
CY	-1%	-17%	-3%	-2%
CZ	0%	-7%	-3%	0%
DE	1%	-9%	-3%	-1%
DK	-2%	-8%	-3%	-4%
EE	-3%	-4%	-2%	-1%
EL	2%	-3%	-2%	0%
ES	2%	-3%	-3%	-1%
FI	0%	-1%	-2%	-4%
FR	0%	-5%	-3%	-2%
HR	0%	-3%	-6%	1%
HU	3%	-8%	0%	1%
IE	2%	-3%	-2%	-4%
IT	2%	1%	-4%	-2%
LT	-4%	-10%	-2%	-3%
LU	5%	-5%	-3%	1%
LV	-2%	-2%	-1%	0%
MT	-35%	-31%	-25%	-19%
NL	-1%	-4%	-2%	1%
PL	4%	-9%	-1%	1%
PT	2%	0%	-3%	0%
RO	-2%	-6%	-2%	-1%
SE	0%	0%	-2%	-8%
SI	0%	-1%	-2%	-9%
SK	1%	-4%	-1%	2%

Table 55 Scores KPI12 to KPI13 at RALUC type level for BAU and SA scenario

RALUC type	KPI12 - % change flora & nesting factor BUA	KPI12 - % change flora & nesting factor SA	KPI13 - Evenness %Change BAU	KPI13 - Evenness %Change SA
A-1a	1%	-5%	70%	72%
A-1b	2%	-2%	70%	71%
A-1c	1%	-6%	67%	69%
A-2a	1%	-2%	65%	66%
A-2b	3%	-2%	69%	71%
A-2c	2%	-3%	69%	71%
A-2d	3%	-7%	73%	74%
A-3a	1%	-1%	56%	55%
A-3b	0%	-3%	54%	53%
A-3c	0%	-5%	68%	69%
E-1a	2%	-4%	71%	73%
E-1b	-1%	-7%	73%	74%
I-1a	0%	-7%	74%	76%
I-1b	-1%	-7%	69%	71%
I-2a	2%	-6%	71%	73%
I-2b	2%	-3%	74%	75%
I-2c	3%	-7%	73%	75%
I-2d	-1%	-6%	73%	73%
I-3a	-1%	-6%	70%	71%
N-1	1%	-3%	76%	76%
U-1a	-2%	-8%	72%	74%
U-1b	-1%	-6%	76%	76%
U-1c	0%	-7%	70%	72%
U-1d	-1%	-2%	70%	70%

U-2a	1%	-6%	74%	76%
U-2b	2%	-3%	72%	73%
U-2c	2%	-4%	71%	72%

Table 56 Scores KPI12 to KPI13 at ENR level for BAU and SA scenario

	KPI12 - % change flora & nesting factor BUA	KPI12 - % change flora & nesting factor SA	KPI13 - Evenness %Change BAU	KPI13 - Evenness %Change SA
Alpine	2%	0%	-1%	-2%
Atlantic	0%	-5%	-4%	-1%
Continental	1%	-9%	-2%	0%
Mediterranean	1%	-2%	-3%	-2%
North	-1%	-2%	-2%	-4%
EU27	1%	-5%	-3%	-1%

Table 57 Scores KPI14 to KPI15 at National level for BAU and SA scenario

	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) -2020	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - BAU	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - SA	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - 2020	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - BAU	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - SA
AT	-5.8	-5.7	-10.8	1.92	1.92	-3.04
BE	12.5	12.2	-2.3	14.62	14.37	-10.42
BG	2.2	2.0	-2.9	-1.88	-1.76	-4.76
CY	2.0	1.9	0.4	0.00	0.00	0.00
CZ	3.9	3.6	-6.6	1.73	1.61	-6.21
DE	4.0	3.6	-10.7	7.78	7.20	-7.04
DK	0.7	0.7	-1.7	8.08	7.99	3.67
EE	-0.2	-0.2	-1.0	0.91	0.77	-0.45
EL	1.3	1.3	-1.6	1.67	1.76	-1.16
ES	-0.1	0.0	-4.8	3.08	2.55	-2.18
FI	-2.4	-2.5	-3.1	32.29	40.46	23.51
FR	3.2	5.2	-29.1	6.08	5.92	0.39
HR	0.0	0.0	-0.1	0.01	0.01	-0.01
HU	4.7	4.6	-4.0	4.18	4.10	-2.04
IE	-8.4	-8.5	-9.2	11.62	11.63	8.34
IT	1.3	1.3	-2.0	10.19	9.57	2.19
LT	-2.2	-1.9	-6.5	4.16	3.76	-0.96
LU	0.1	0.1	-10.9	14.40	12.66	5.58
LV	-3.4	-3.0	-4.4	-0.04	-0.03	-1.44
MT	-234.4	-467.7	-859.4	0.00	0.00	0.00
NL	8.3	8.4	-3.0	30.85	30.63	3.28
PL	5.0	4.7	0.1	6.12	5.79	-2.51

	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) -2020	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - BAU	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - SA	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - 2020	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - BAU	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - SA
PT	-2.1	-1.9	-7.6	7.40	6.30	0.70
RO	1.0	1.0	-4.0	0.59	0.56	-4.35
SE	-2.1	-2.5	-3.7	15.93	20.94	8.68
SI	-8.1	-10.4	-12.2	14.10	16.97	3.34
SK	0.9	0.9	-7.3	2.53	2.39	-3.10

Table 58 Scores KPI14 to KPI15 at RALUC type level for BAU and SA scenario

RALUC type	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) -2020	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - BAU	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - SA	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - 2020	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - BAU	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - SA
A-1a	2.7	2.4	-8.2	4.7	4.4	-7.0
A-1b	2.6	2.7	-5.0	11.9	10.7	1.8
A-1c	2.9	2.5	-6.9	5.7	5.2	-3.2
A-2a	-0.9	-0.9	-5.9	6.8	6.6	1.4
A-2b	1.1	1.0	-2.0	2.5	2.3	-1.2
A-2c	0.8	0.7	-6.6	4.6	4.2	-2.7
A-2d	4.4	4.1	-2.0	4.3	4.1	-3.0
A-3a	-3.0	-3.2	-3.9	11.9	15.6	6.9
A-3b	-1.3	-1.7	-4.0	33.9	42.9	23.9

RALUC type	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) -2020	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - BAU	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - SA	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - 2020	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - BAU	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - SA
A-3c	-0.3	-0.3	-4.7	1.4	1.2	-2.4
E-1a	1.7	1.6	-6.6	3.4	3.3	-3.5
E-1b	4.2	4.0	-7.4	2.5	2.2	-4.4
I-1a	0.0	-0.1	-7.1	14.0	14.0	-3.9
I-1b	3.9	3.9	-6.4	12.5	11.0	1.2
I-2a	-2.0	-1.9	-8.6	7.2	7.0	-5.4
I-2b	1.2	1.1	-3.1	1.4	1.3	-3.3
I-2c	3.5	3.2	-7.9	6.5	6.1	-4.9
I-2d	2.6	2.5	-4.4	-0.3	-0.2	-5.4
I-3a	-0.3	-0.2	-3.8	-0.1	-0.1	-3.4
N-1	3.5	3.4	-5.5	14.9	14.6	-2.0
U-1a	5.4	5.5	-17.5	12.8	12.5	-4.3
U-1b	-5.5	-14.9	-38.5	7.5	7.1	-0.3
U-1c	4.9	4.5	-10.3	13.5	11.8	-4.5
U-1d	3.6	3.4	-2.1	11.2	10.5	4.1
U-2a	2.0	1.9	-8.9	10.0	9.6	-2.0
U-2b	0.5	0.0	-2.8	4.0	4.1	-0.8
U-2c	1.4	1.1	-6.8	1.3	1.4	-5.3

Table 59 Scores KPI14 to KPI15 at ENR level for BAU and SA scenario

RALUC type	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) -2020	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - BAU	KPI14 – Distance to critical load exceedance for nitrogen in water (Kg/ha) negative=below critical load) - SA	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - 2020	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - BAU	KPI15 - Distance to critical load exceedance for ammonia (NH3) (Kg/ha) negative=below critical load) - SA
Alpine	-5.1	-5.5	-8.5	5.0	4.9	1.1
Atlantic	5.0	5.4	-14.8	15.0	14.4	-2.6
Continental	3.3	3.0	-7.1	3.4	3.2	-6.0
Mediterranean	-1.0	-2.9	-9.1	5.0	4.8	-0.2
North	-1.9	-2.0	-3.6	16.2	20.4	9.7
EU27	2.3	1.8	-9.6	7.9	7.8	-2.6

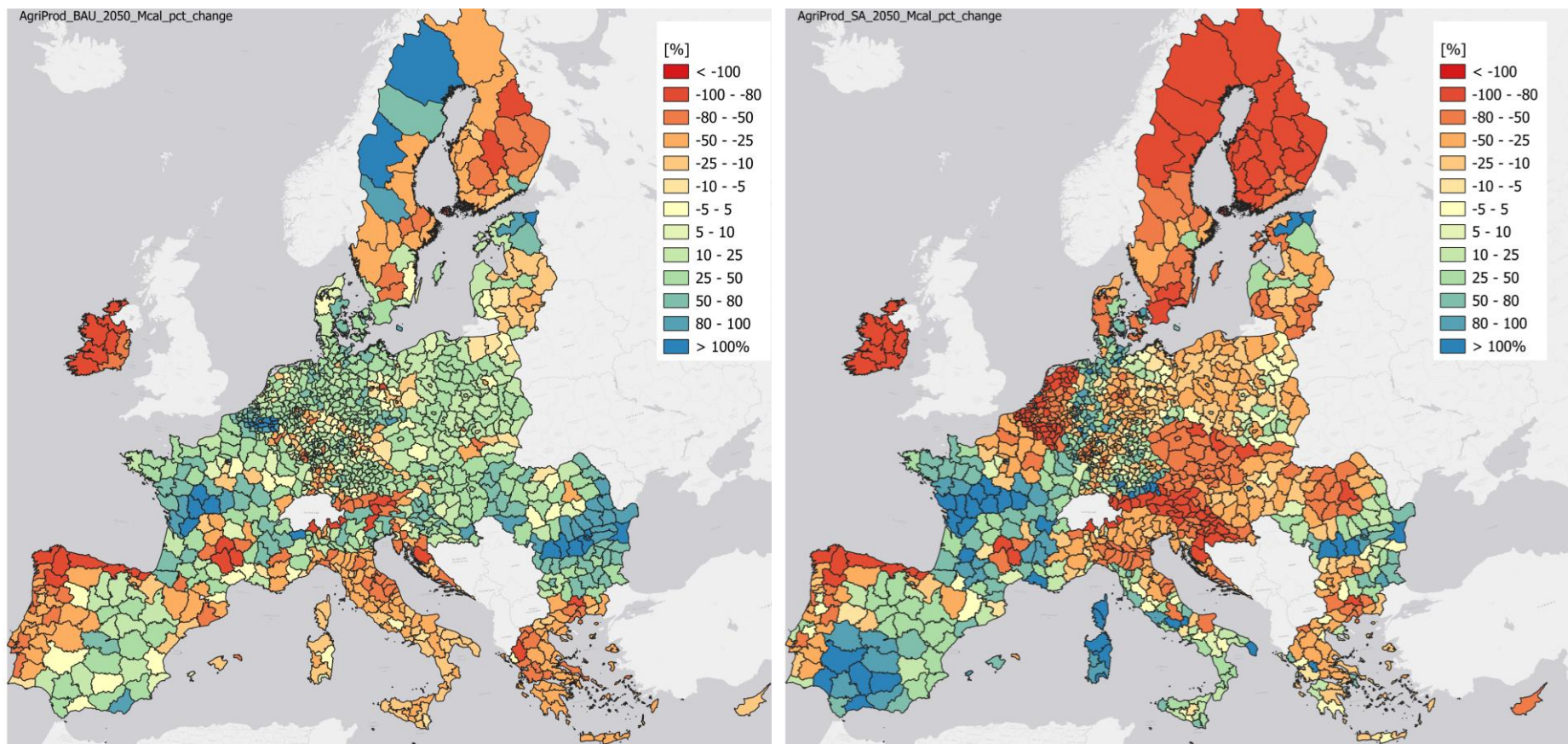


Figure 39 KPI scores for KPI3 'Relative change in production of food expressed as relative change in calories produced on agricultural lands in EU27 between 2020-2050 for BAU (left map) and SA (right map) scenario.

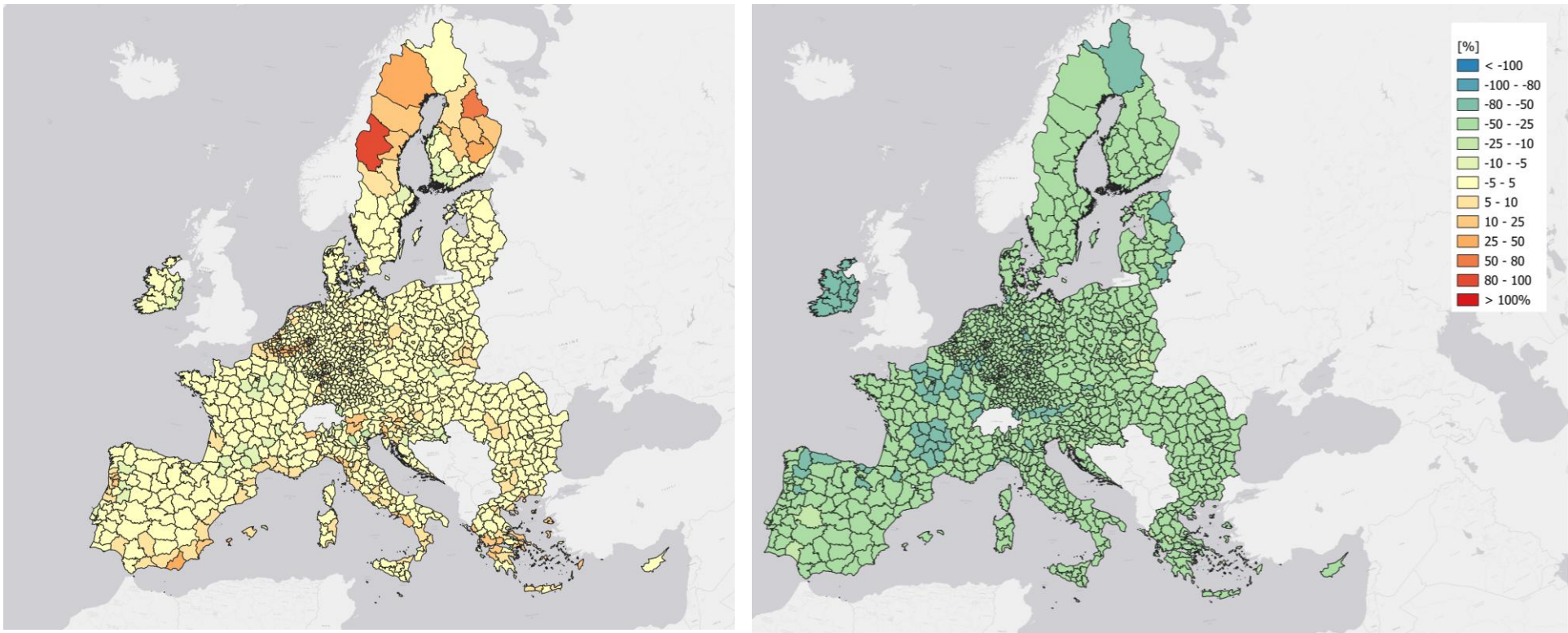


Figure 40 KPI5 'Relative change in pesticides used in kg of active substances/ha between 2020-2050 for BAU (left map) and SA (right map) scenario.

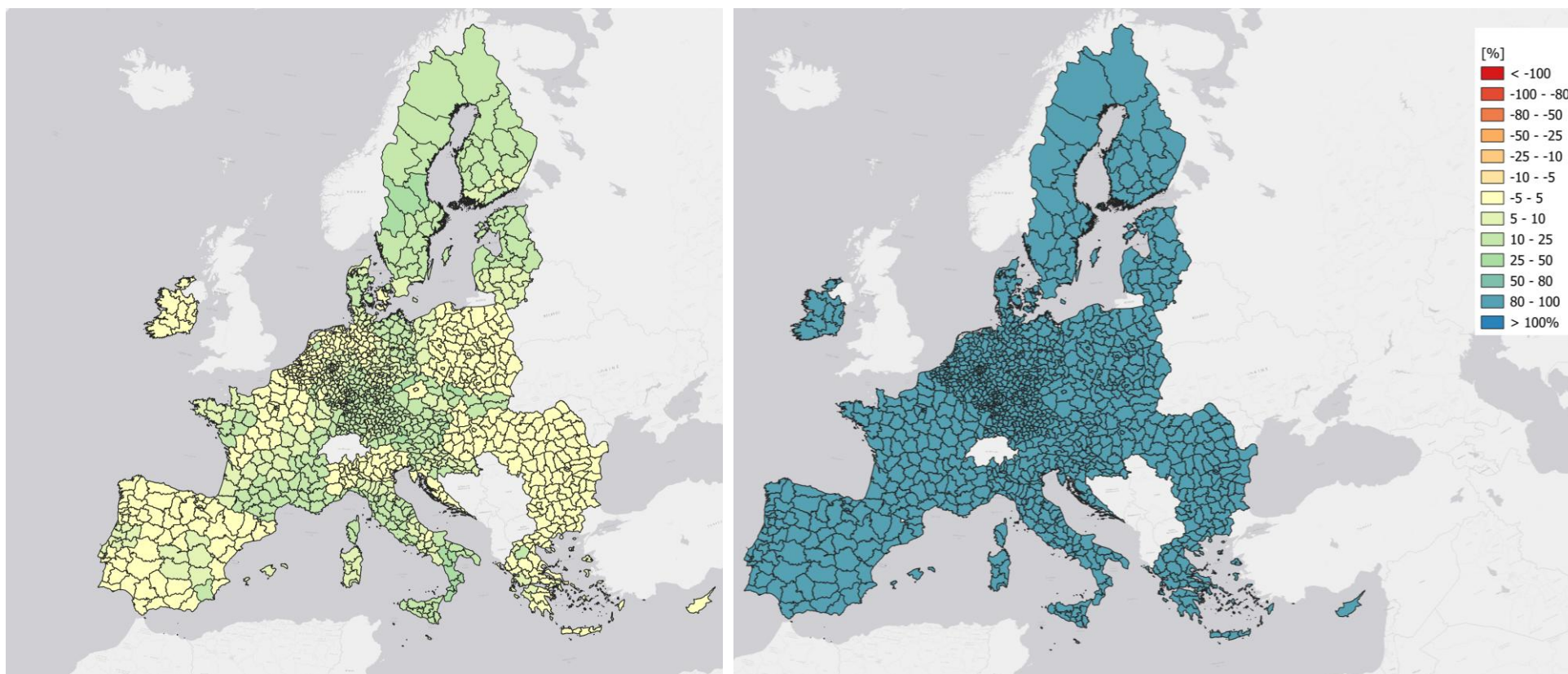


Figure 41 KPI6 agricultural area share (%/UAA) with $\geq 20\%$ reduction in artificial fertilizers in 2050 as compared to 2020 for BAU (left map) and SA (right map) scenario.

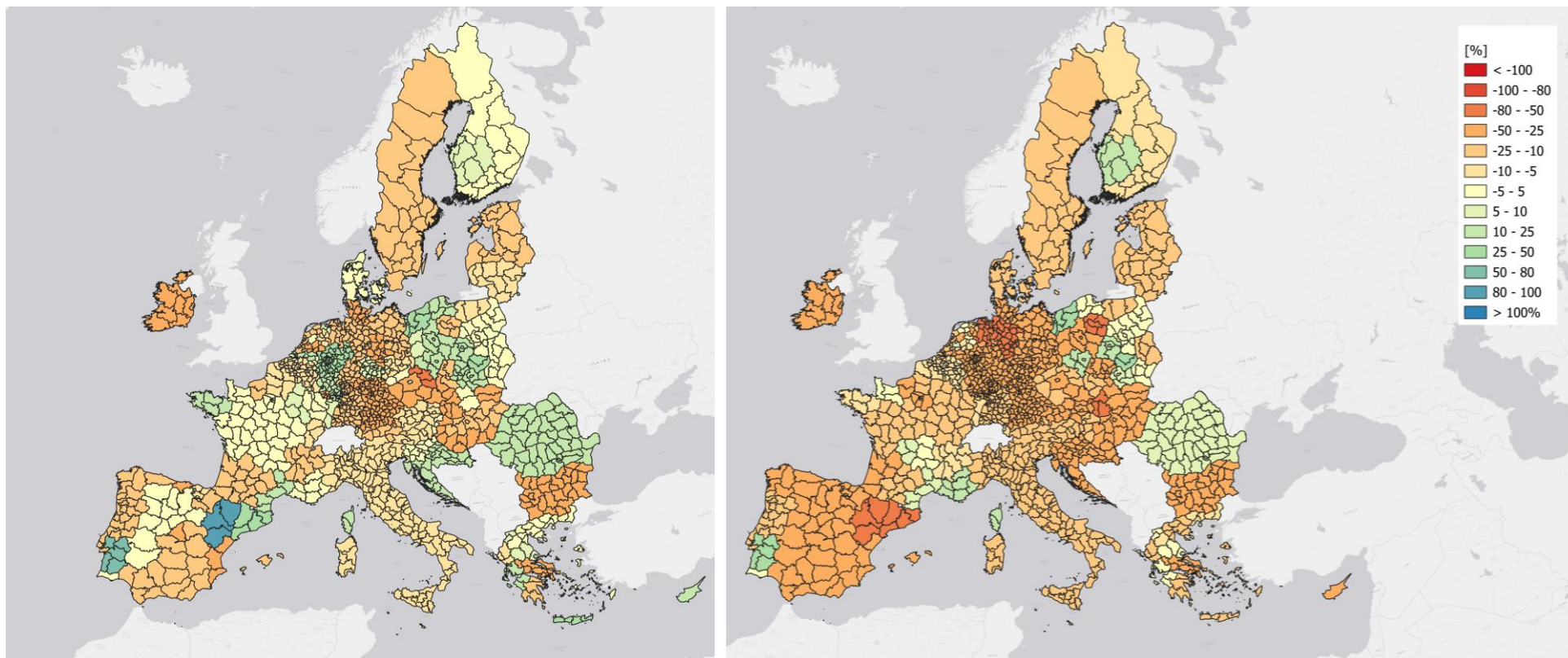


Figure 42 KPI7 LU density (LU/ha UAA)% change 2020-2050 for BAU (left map) and SA (right map) scenario.

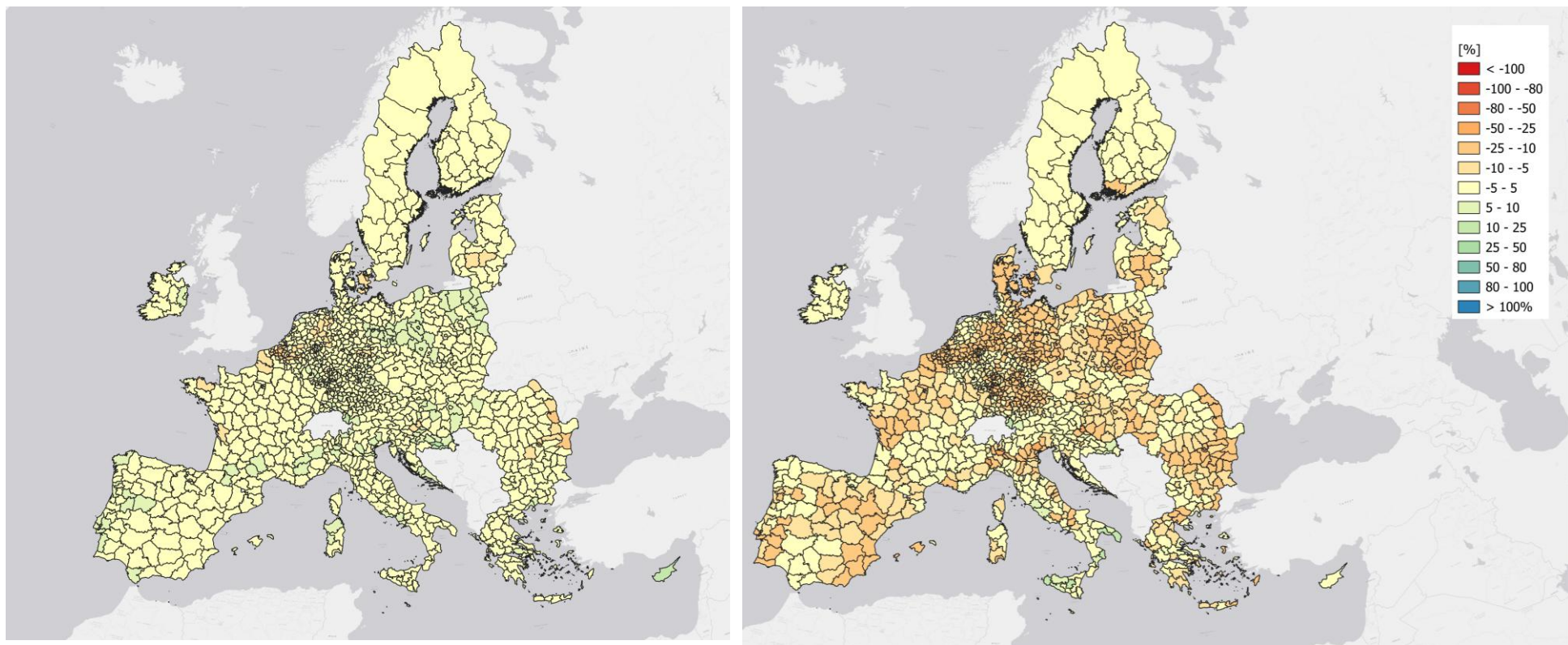


Figure 43 KPI8 % change 2020-2050 in average SOC status because of land use changes expected for BAU (left map) and SA (right map) scenario.

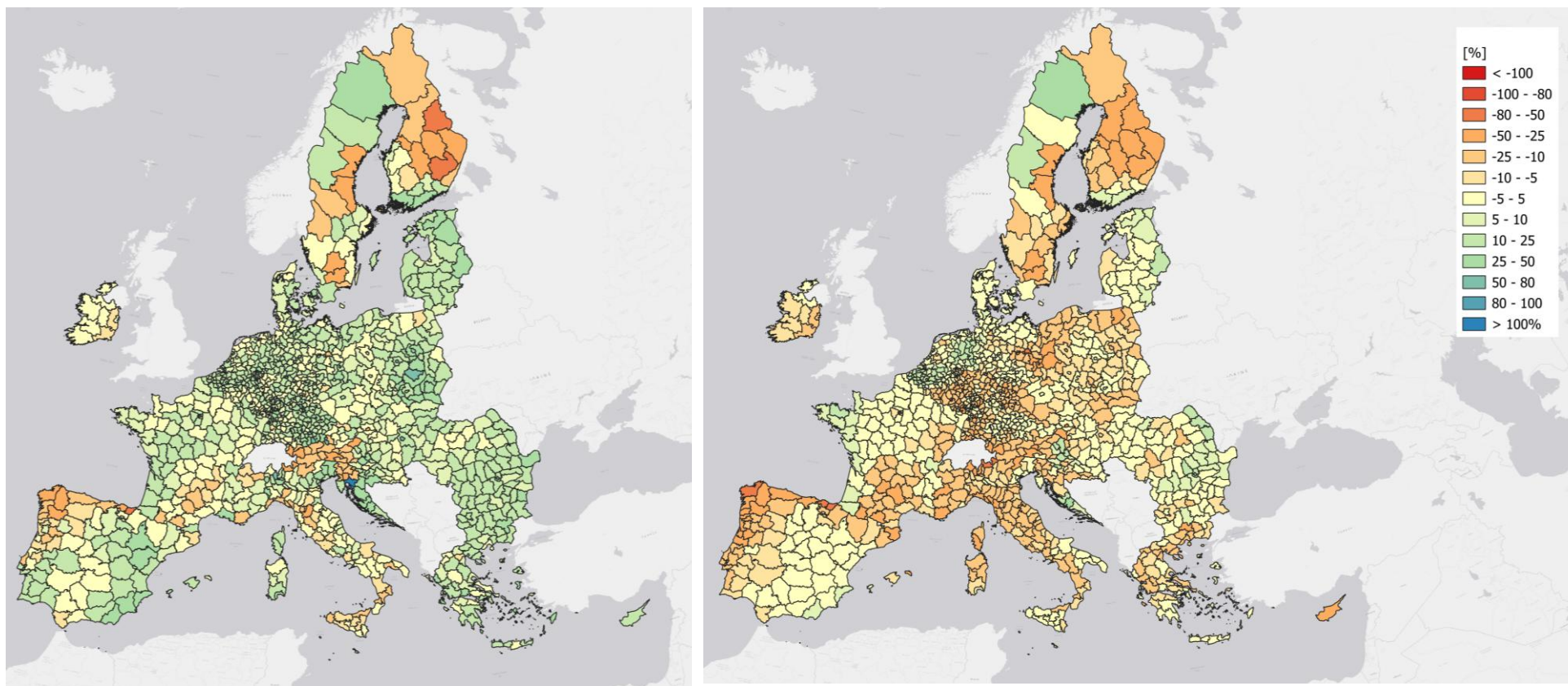


Figure 44 KPI9 % change 2020-2050 in average soil erosion risk factor because of land use changes expected for BAU (left map) and SA (right map) scenario.

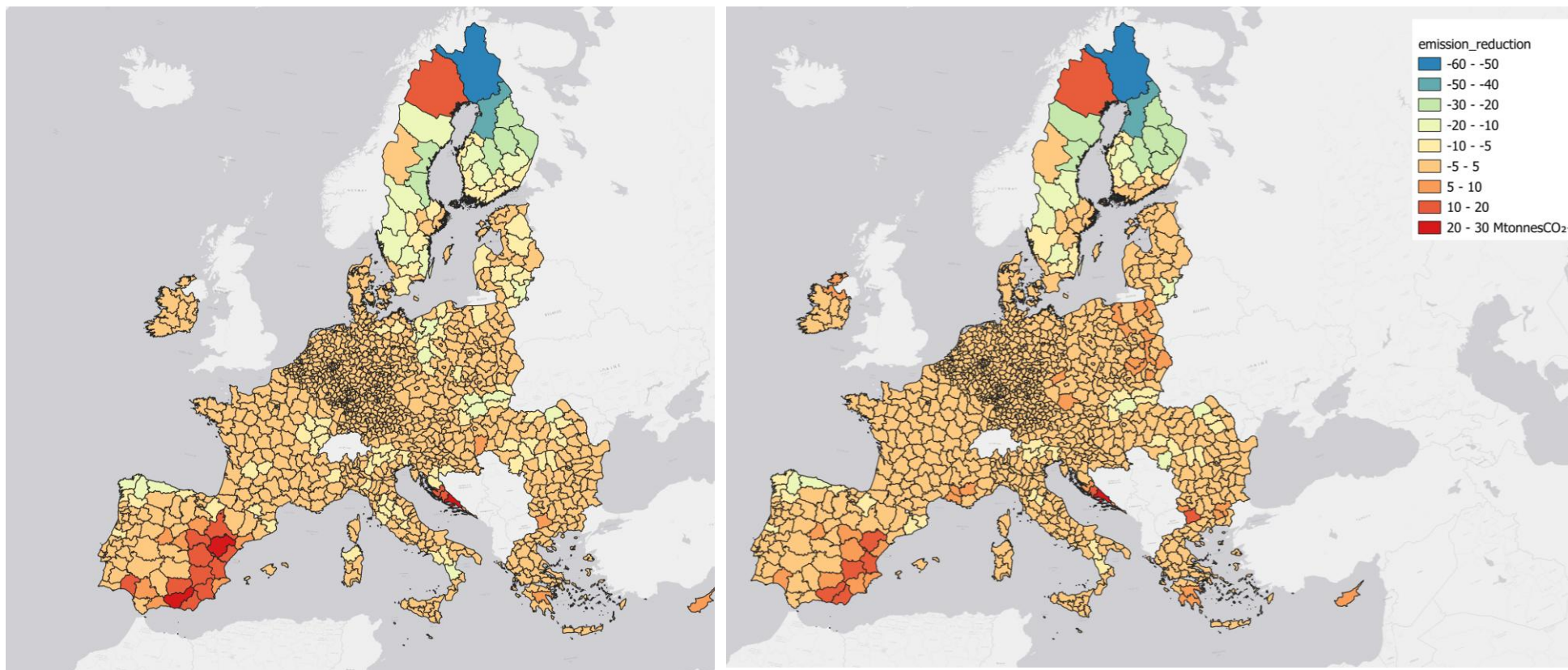


Figure 45 KPI10 Change in GHG emissions related to changes in AFOLU (Agriculture, Forest and Other land use) in million tonnes (Mtonnes) CO₂-eq for BAU (left map) and SA (right map) scenario.

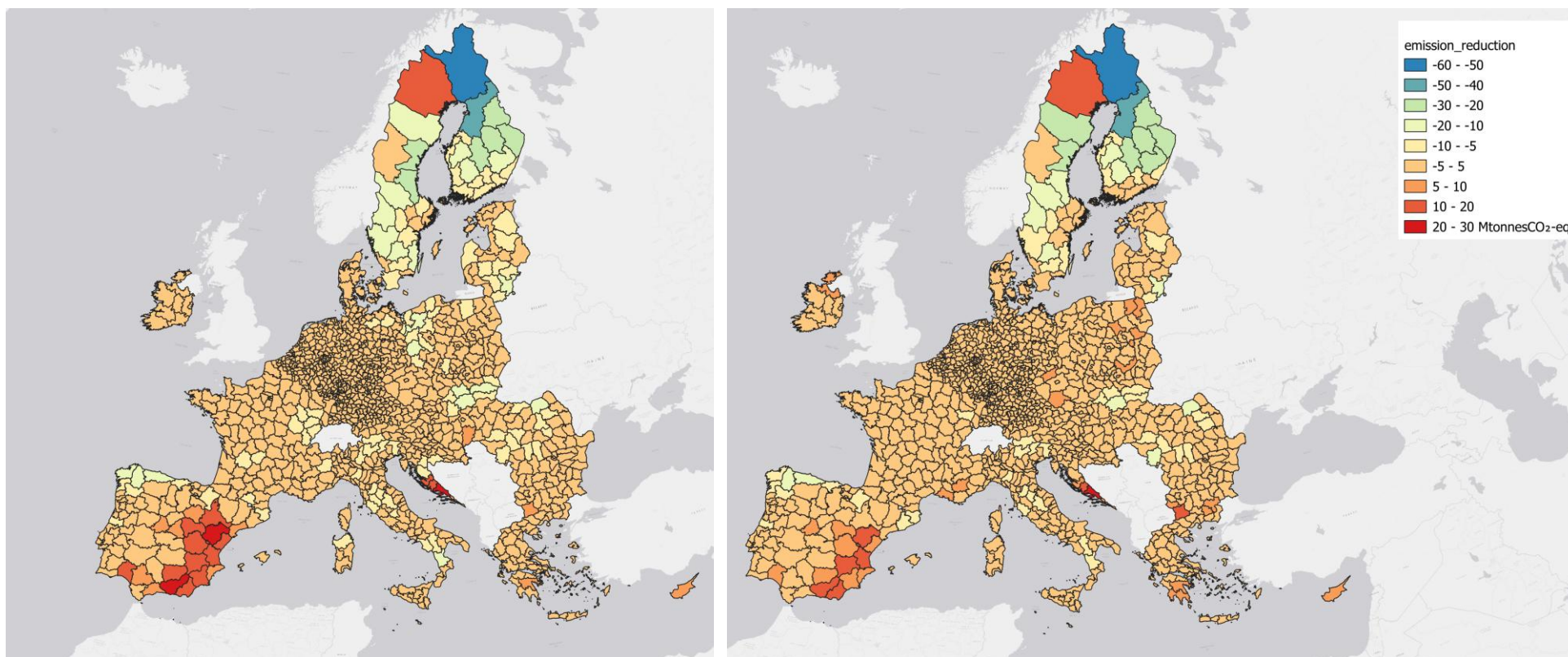


Figure 46 KPI11 Change in GHG emissions related to changes in AFOLU (Agriculture, Forest and Other land use) and changes in management (20% reduction in cropland in SA scenario) in million tonnes (Mtonnes) CO₂-eq for BAU (left map) and SA (right map) scenario.

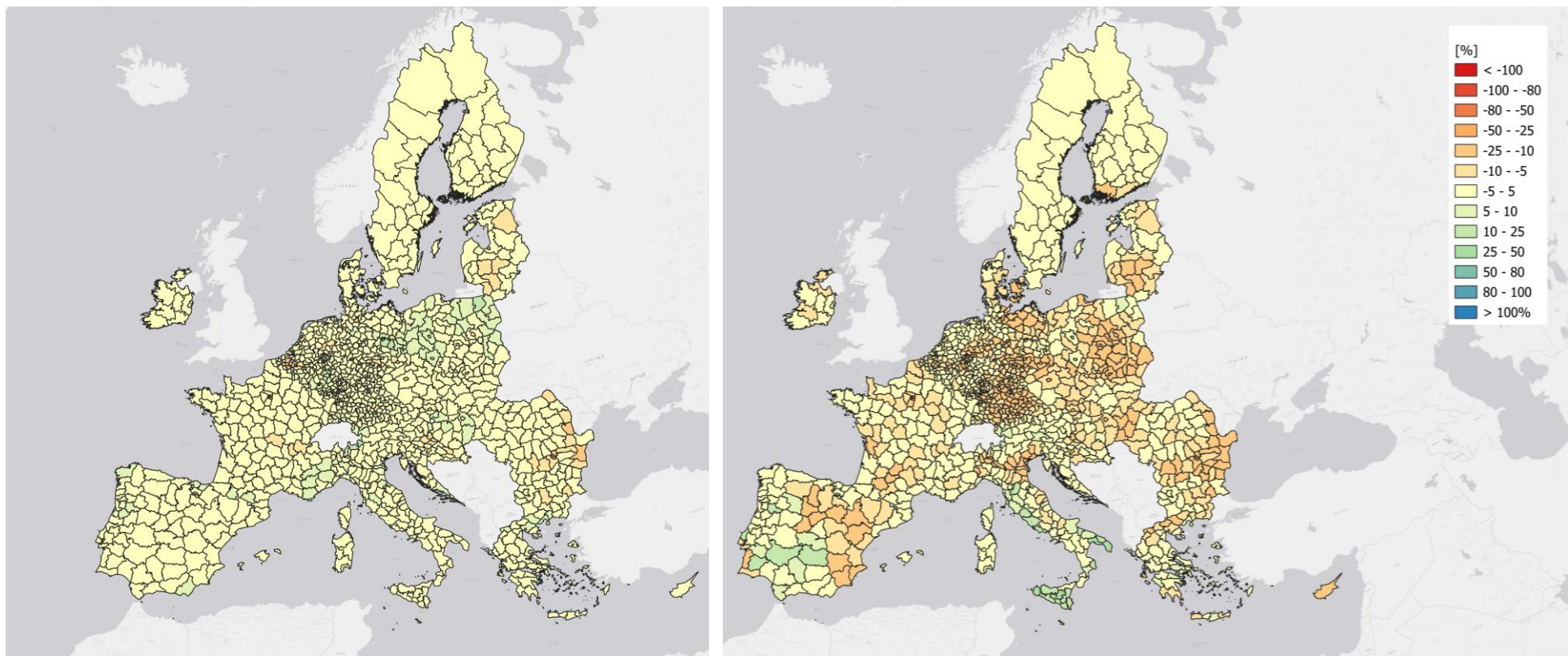


Figure 47 KPI12 Change in flora & nesting factor because of 2020-2050 land use changes in BAU (left map) and SA (right map) scenario.

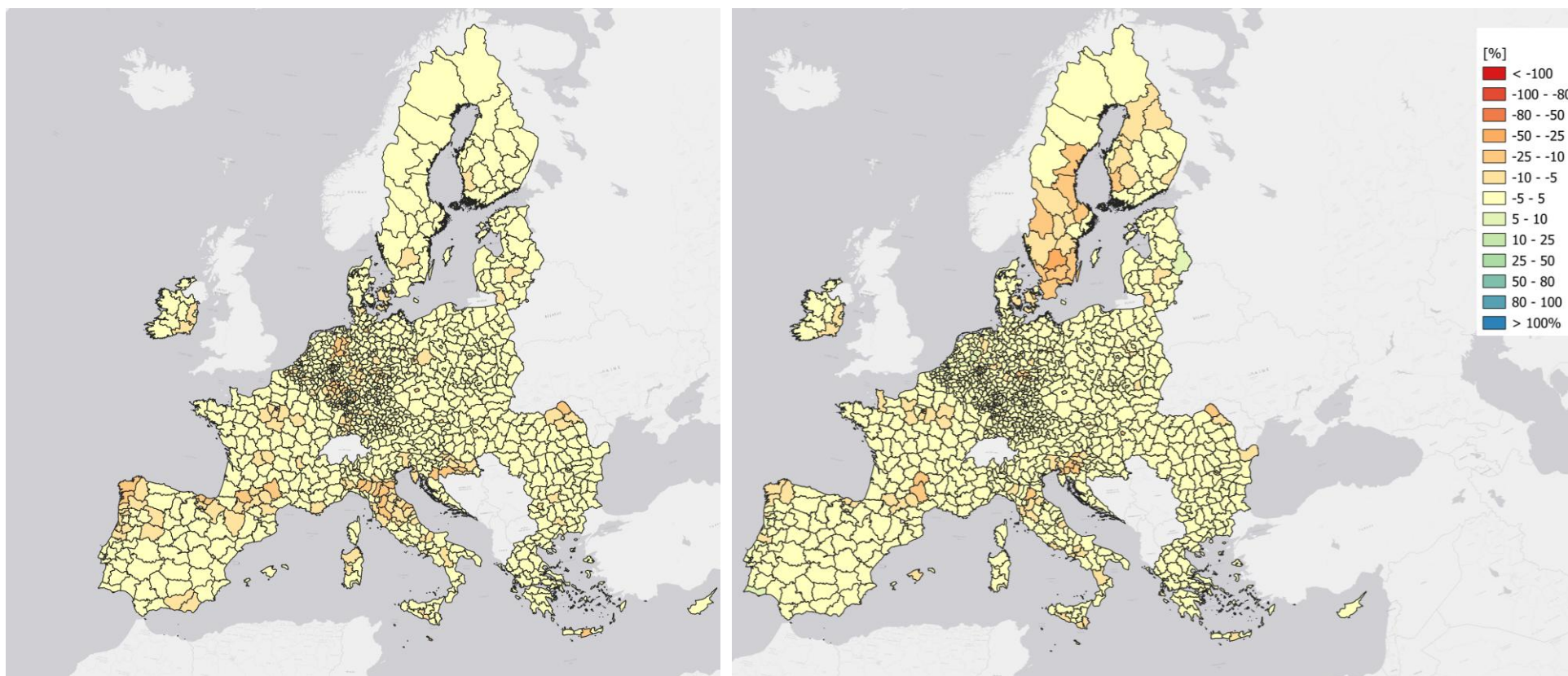


Figure 48 KPI13 Change in landscape evenness factor because of 2020-2050 land use changes in BAU (left map) and SA (right map) scenario.

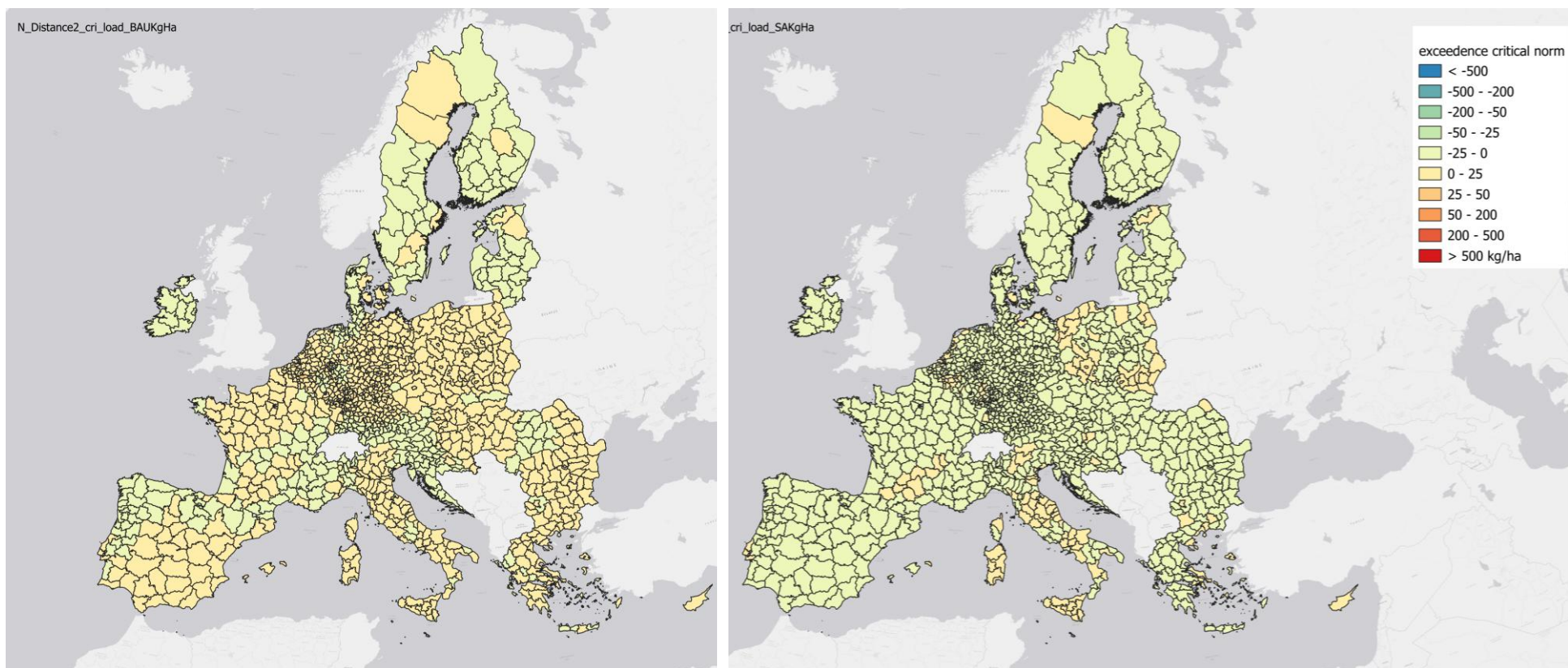


Figure 49 KPI14 Exceedance in critical Nitrogen load in surface and/or ground water in BAU (left map) and SA (right map) scenario.

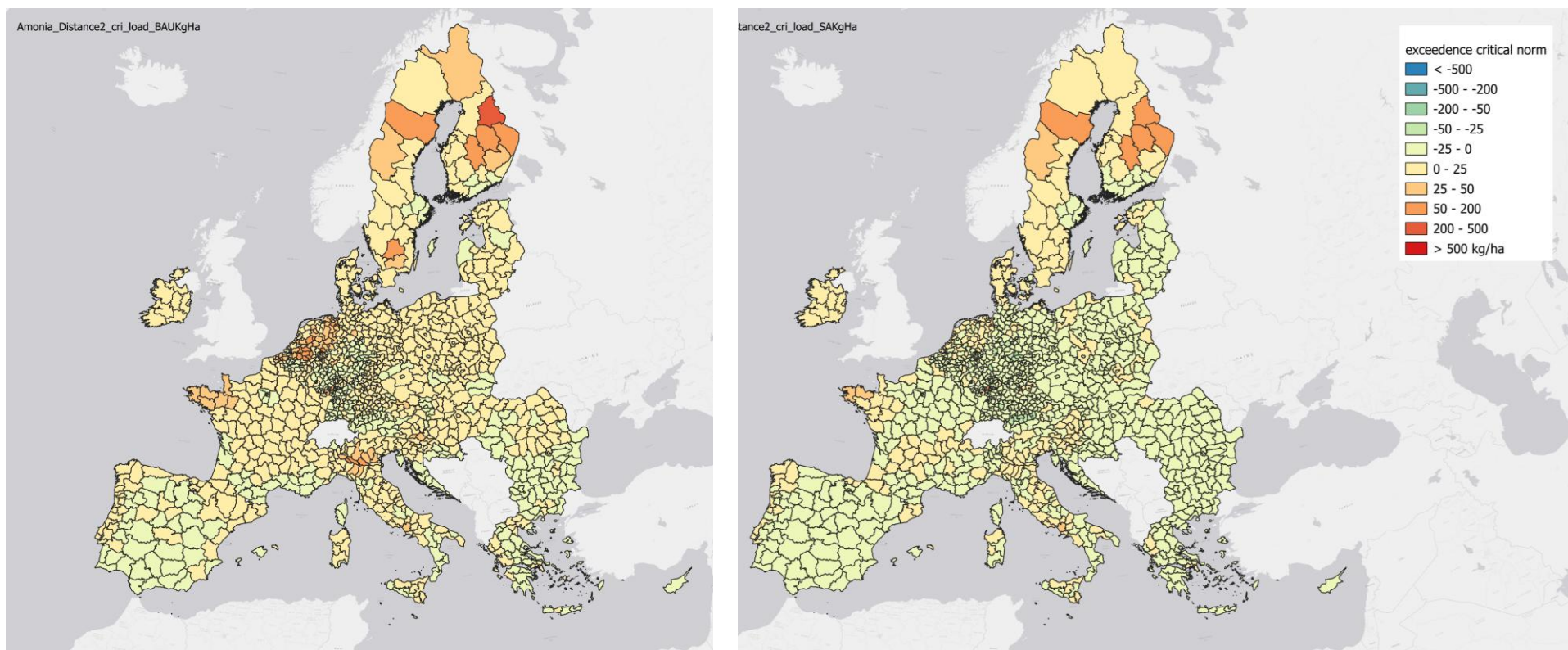


Figure 50 KPI15 Exceedance in critical nitrogen (ammonia – NH₃) deposition levels in BAU (left map) and SA (right map) scenario.

23. Annex 14 KPI matrix and explanation of KPI assessment approach

A sustainability assessment framework was developed in the form of a matrix, where KPIs of different nature were selected. KPIs included:

- **Target KPIs** reflecting relevant policy targets.
- **Condition KPIs** expressing necessary pre-conditions for the implementation of a given policy.
- **Pressure KPIs** which reflect the impacts according to different dimensions (bio-physical, socio-economic, and land use).
- **“Carrying capacity” KPIs** reflecting the potential of a given territory and of their communities to respond to the relevant policies.

In the assessment matrix, a “long list” of KPIs was developed first, covering on the one hand specific policies and on the other hand proxy indicators for different domains such as agricultural production, energy production, forestry, nature conservation, etc.

This “long list” was further scrutinized on the basis of available data. In each cell the nature of the KPI is specified. This “short list” includes the following KPIs:

KPI1 Land take - soil sealing

Depending on the policies this can be a target (Soil monitoring and resilience law, zero land take) or a pressure indicator (Bioeconomy and RED RES targets, national targets for wind). It expresses the relative share of farmland in 2020 (%/2020 UAA) that is expected to be lost to built-up area in 2050 in the BAU and SA scenarios. The calculation approach is based on iCLUE land use flows from agriculture to built-up area for the period 2020-2050 divided by UAA 2020.

KPI2 Agricultural land use

This indicator is defined as the relative change in agricultural land abandoned to non-managed land 2020-2050 (in total and in Natura 2000). This indicator is generated from the iCLUE modelling output presented in annex 12 and 13.

KPI3 Agri production and food security

It is defined as relative change in production of food (expressed in calories) 2020-2050. In this study this indicator is regarded as a pressure KPI for several policies: F2F organic, pesticides and fertilizers reduction, Nature restoration law. It is expressed as the energy produced by all agriculture products derived from the total cropping land and their change is computed over the period 2020-2050 for the 2 scenarios. Conversions to energy (initially expressed as Kcal per grams) are performed from the crop and livestock items in the list outputted by the iClue model. Conversion factors are based on sources such as the USDA National Nutrient Database⁸¹, the Food and Agriculture Organization (FAO)⁸² databases (see Table 60).

⁸¹ <https://fdc.nal.usda.gov/fdc-app.html#/food-search?query=&type=Foundation>

⁸² <https://www.fao.org/4/Y5022E/y5022e04.htm>

The total production (in ton product) per crop item per region is multiplied with the energy units. This results in a total number of calories produced per region on agricultural land in 2020 and 2050 for BAU and SA scenario.

Table 60 Overview of Kcal per gram used for the calculation

Crop	iCLUE groups	Tot energy (Kcal/gr)
Apples, pears and peaches	PER3	0.5
Barley	ANN2	0.35
Cauliflowers	ANN4	0.25
Citrus fruits	PER3	0.5
Durum wheat	ANN2	3.4
Fallow land	ANN2	
Flax and hemp *** (faser) ***	ANN4	5.4
Flowers, ornamental plants, etc.	ANN4	0.2
Grass extensive/green fodder	GRASS_E	0.3
Grass intensive/green fodder	GRASS_I	0.3
Fodder maize	ANN1	0.1
Grain Maize	ANN1	3.65
New energy crops	NECR	4.5
Oats	ANN2	3.89
Other cereals (excl. rice)	ANN2	3.6
Other final crop products	ANN4	
Other fodder on arable land	ANN1	0.1
Other fresh fruits	PER3	0.5
Other industrial crops	ANN4	0.7
Olives for oil	PER2	1.6
Other oil seeds and oleaginous fruits	ANN4	5.5
Other root crops	ANN3	0.5
Other vegetables	ANN4	
Other wine	PER1	0.7
Paddy rice	ANN2	3.6
Potatoes	ANN3	6
Pulses	ANN2	3.5
Rape and turnip rape	ANN4	4.2
Fodder Root crops	ANN1	0.6
Rye	ANN2	3.5
Silage	ANN1	0.3
Soya beans	ANN4	4.2
Sugar beet	ANN3	0.7
Sunflower seed	ANN4	5.5
Soft wheat	ANN2	3.5
Table olives	PER2	1.6
Table grapes	PER1	0.7
Textile crop	ANN4	
Tobacco, unmanufactured, incl. dried	ANN4	

Tomatoes	ANN4	0.2
Table wine	PER1	0.7

KPI4 Organic farming (% of UAA or hectares)

Regarded as the target indicator for the F2F organic farming policy, this KPI is calculated as the distance to the 25% policy objective expressed either as share in UAA (% of UAA) or in hectares. Positive values express the distance to the target of 25% in the relative agricultural area share. Negative values mean that more than 25% of the organic farming area is reached.

It is also a condition indicator for several policies such as F2F reduction in Pesticides and Nutrients, Nature restoration law, Soil monitoring and resilience law. Negative value means that more than the 25% organic farming area is reached. Positive value expresses the distance in relative agricultural area share to the target of 25%.

As for many of the other policy targets it is originally set for 2030 but assumed to be also valid by the year 2050.

The score is calculated based on the RALUC scenario assumptions.

KPI5 Pesticide use

It is regarded as a target (for the F2F pesticide reduction policy) or a condition indicator (e.g. the F2F organic farming policy). It indicates the total pesticide use in Kg and average kg/ha per Nuts 3 area in 2020 and in 2050 in the BAU and SA scenarios. The land areas per crop in 2020 and 2050 are multiplied for both scenarios by the average pesticides use (kg/ha) per crop type, as registered by Eurostat (2007). From this the total pesticide application level in kg and in kg/ha can be calculated for the two reference years.

Literature and data references used: Eurostat (2007). Pesticide Use in European Agriculture: Estimation and Sensitivity Analysis (DOI: 10.1016/j.scitotenv.2017.12.005).

KPI6 Fertilizer use

It is at the same time a policy target (for the F2F nutrients reduction policy) and a condition indicator (for the F2F organic farming policy and the soil monitoring and resilience law, good soil health in 2050). It indicates the share of total agricultural area (% of UAA) per Nuts 3 that has a fertiliser use level 20% lower than the average fertiliser application per hectare and per region, in 2020. Since it can be assumed that in the SA scenario the 20% fertilizer application reduction level is reached in the totality of the agricultural area, the SA level is set at 100% in 2050. In the BAU scenario it is assumed that no changes in management will take place between 2020 and 2050. This implies that this 20% reduction level in fertilizer is only reached in the area that is covered by organic farming in 2020. This share in 2020 is assumed to remain stable between 2020 and 2050 in the BAU scenario.

KPI7 Livestock density

In this study the livestock density factor is regarded as a Condition indicator for F2F Organic farming and a pressure one for F2F reduction of Nutrients. It is expressed as the average number of Livestock Units (LSU) per hectare of UAA in the region in 2020 and 2050, computed for both scenarios. To calculate this factor the number of heads per livestock type are multiplied with the LSU factors

for every animal type, as specified by Eurostat (2020). This results in a total number of LSU per region, and these are then divided by the total number of hectares of the UAA in the different years and scenarios.

The KPI scores are calculated from CAPRI figures in both the BAU and the SA scenarios although in the latter we consider lower livestock densities as it assumes a reduction in the ammonia emissions.

EUROSTAT conversion factors are used, provided in: [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_\(LSU\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU))

KPI8 Organic matter

It can be regarded as a condition indicator for the Soil monitoring and resilience law, as well as a pressure indicator for several policies (i.e. F2F organic and F2F nutrients reduction). It is expressed as organic matter (SOM) change between 2020-2050 and based on the per land cover class average figures documented in Aksoy et al. (2016). In this study the Soil Organic Content (SOC) in percentage is calculated per main land cover class as shown in the table below, based on the combination of 3 databases, LUCAS, the BioSoil Project and "Soil Transformations in European Catchments" (SoilTrEC) Project (samples from local soil data coming from six different critical zone observatories (CZOs) in Europe).

Table A10-1

Land cover class	SOC (%)
Arable land	1.98
Permanent crops	1.8
Pastures	5.28
Heterogeneous agricultural areas	3.03
Forests	6.75
Scrub/herbaceous	7.49
Open spaces with little/no vegetation	6.37
Wetlands	10.48

KPI9 Soil health

It can be regarded as a target indicator for the Soil monitoring and resilience law, soil erosion in 2050, as well as a pressure indicator for good soil health. It is expressed in t/ha/year of soil loss due to soil erosion and the score is calculated based on the land cover fraction of the RUSLE equation. Only the effect of the land cover change on land erosion risk (the c factor in the equation) risk is taken into account for the calculation. The reference for the c factors is Panagos et. al (2015).

KPI10 and KPI11 GHG AFOLU

This KPI can be regarded as a condition indicator for Bioeconomy and RED RES targets and as a pressure indicator for several policies (F2F organic, nutrients and pesticides reduction, Nature restoration law, Soil monitoring and resilience law). It computes the Direct land based (AFOLU) GHG emission per ton of the agricultural production in EU. It is expressed as the change in GHG emissions in

every total NUTS3 region in 2050 as compared to 2020 for the Agriculture, Forestry, and Other Land Uses (AFOLU).

Two different KPIs are calculated:

- KPI10 – Refers to GHG emission changes only related to changes in AFOLU
- KPI11 – Refers to GHG emission changes related to AFOLU plus a 20% reduction in GHG related to change in land management (lower inputs of fertilisers and pesticides).

First, as shown in the Table 61 below, land use conversions are identified and described:

Table 61 Land use conversions

Conversion	Code	Category Description
Stable Forest	A1	Forest Land Remaining Forest Land
Cropland - Forest	A21	Land Converted to Forest (from Cropland)
Grassland - Forest	A22	Land Converted to Forest (from Grassland)
Stable Cropland	B1	Cropland Remaining Cropland
Forest - Cropland	B21	Land Converted to Cropland (from Forest)
Grassland - Cropland	B22	Land Converted to Cropland (from Grassland)
Grassland	C1	Grassland Remaining Grassland
Forest - Grassland	C21	Land Converted to Grassland (from Forest)
Cropland - Grassland	C22	Land Converted to Grassland (from Cropland)
Stable Settlement	E1	Settlements Remaining Settlements
Forest - Settlement	E21	Land Converted to Settlements (from Forest)
Cropland - Settlement	E22	Land Converted to Settlements (from Forest)
Grassland - Settlement	E23	Land Converted to Settlements (from Grassland)

In the AFOLU categories, shrubland is primarily treated as a subtype of grassland. Changes in shrubland due to management or land-use change are reported under the respective conversion categories. The management of carbon stocks and emissions from shrubland is integrated into the overall accounting for grasslands, reflecting their contribution to greenhouse gas inventories.

In addition, default greenhouse gas (GHG) emission factor values for conversions from wetlands to other land categories are calculated according to the IPCC's 2013 Wetlands Supplement and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. These values are primarily for CO₂, CH₄, and N₂O emissions and changes in carbon stocks, particularly in biomass and soil organic carbon. Factors are summarized in the text Box 1 below.

The average emission factors for above ground biomass (2010-2020) are then specified per Member State, per land use conversion type as well as for land remaining the same, as indicated in Table 62 below and further schematized in Figure 51.

Box 1. GHG emissions factors for conversions from wetlands

- 1. Wetlands to Cropland.** Carbon Dioxide (CO₂): Converting wetlands to cropland typically involves drainage and soil disturbance, which can lead to significant emissions of CO₂ from soil organic matter oxidation. The default emission factor for soil carbon loss after drainage and conversion to cropland can vary but is typically high. For example: Soil Organic Carbon Loss: Up to 8 to 10 t C ha⁻¹ yr⁻¹ in peatlands, depending on the climate and type of peat.
- 2. Wetlands to Grassland.** Carbon Dioxide (CO₂): Similar to cropland conversion, draining wetlands to establish grasslands also leads to CO₂ emissions from soil organic matter decomposition, though typically at a slightly lower rate than cropland due to less intensive soil disturbance: Soil Organic Carbon Loss: 5 to 7 t C ha⁻¹ yr⁻¹ in peatlands.
- 3. Wetlands to Forest Land.** Carbon Dioxide (CO₂): Converting wetlands to forest land can initially result in CO₂ emissions due to soil disturbance and drainage but may eventually lead to carbon sequestration as trees grow: Soil Organic Carbon Loss: 2 to 5 t C ha⁻¹ yr⁻¹ initially, but can turn into a carbon sink over time as the forest matures.
- 4. Wetlands to Settlements.** Carbon Dioxide (CO₂): Conversion of wetlands to settlements involves significant disturbance of both biomass and soil carbon pools, leading to high CO₂ emissions: Soil Organic Carbon Loss: Up to 10 to 15 t C ha⁻¹ yr⁻¹, depending on the extent of disturbance and drainage.

Table 62 : Average implied emission factors for above ground biomass (2010-2020) per Member State, per land use conversion and land remaining the same (the column headings correspond to the conversion type)

Country	Conversion Code	StableForest	Cropland - Forest	Grassland - Forest	Wetland - Forest	Stable Cropland	Forest - Cropland	Grassland - Cropland	Wetland - Cropland	Stable Grassland	Forest - Grassland	Cropland - Grassland	Wetland - Grassland	Stable settlement	Forest - Settlement	Cropland - Settlement	Grassland - Settlement	Wetland - Settlement	Stable wetlands	Forest - wetlands	Croplands - wetlands	Grasslands - wetlands
		A1	A21	A22	A24	B1	B21	B22	B24	C1	C21	C22	C24	E1	E21	E22	E23	E24	D11	D21	D22	D23
	Country	100	101	102	104	200	201	202	204	300	301	302	304	400	401	402	403	404	500	501	502	503
AUT	AT	-0.83	-4.47	-4.39	0.50	0.01	4.02	-0.18	9.00	-0.17	4.60	0.26	6.00	-0.52	2.69	-1.97	-1.79	12.50	-0.50	0.00	-9.00	-6.00
BEL	BE	-2.38	-6.75	-7.02	0.50	0.00	15.28	0.48	9.00	0.48	37.36	-0.44	6.00	-0.52	18.74	0.23	-0.25	12.50	-0.50	0.00	-9.00	-6.00
BGR	BG	-1.79	-8.51	-8.05	0.50	0.03	8.01	1.26	9.00	0.00	8.74	0.68	6.00	-0.52	20.50	1.97	0.71	12.50	-0.50	0.00	-9.00	-6.00
CYP	CY	-0.69	-2.88	-2.88	0.50	-0.54	2.93	0.17	9.00	-0.92	2.65	-0.17	6.00	-0.52	4.21	1.42	1.25	12.50	-0.50	0.00	-9.00	-6.00
CZE	CZ	0.28	-8.48	-8.48	0.50	0.00	12.19	0.25	9.00	0.25	13.79	-0.25	6.00	-0.52	15.26	1.92	1.67	12.50	-0.50	0.00	-9.00	-6.00
DEU	DE	-3.94	-3.77	0.11	0.50	0.00	13.82	0.76	9.00	-0.03	14.94	-0.64	6.00	-0.52	2.47	-3.04	-3.80	12.50	-0.50	0.00	-9.00	-6.00
DNM	DK	-2.36	-8.18	-9.13	0.50	0.02	4.66	-0.55	9.00	0.54	8.95	0.93	6.00	-0.52	12.68	-0.18	0.37	12.50	-0.50	0.00	-9.00	-6.00
ESP	ES	-1.90	-4.10	-5.11	0.50	-0.07	1.74	-0.20	9.00	-0.27	6.21	-0.61	6.00	-0.52	5.56	0.37	0.57	12.50	-0.50	0.00	-9.00	-6.00
EST	EE	-0.91	-4.69	-5.18	0.50	0.01	7.21	1.50	9.00	1.51	8.63	-0.64	6.00	-0.52	20.84	2.42	0.92	12.50	-0.50	0.00	-9.00	-6.00
FIN	FI	-1.35	-4.07	-5.02	0.50	0.00	6.82	0.72	9.00	-0.69	3.96	-0.02	6.00	-0.52	4.71	1.08	0.36	12.50	-0.50	0.00	-9.00	-6.00
FRK	FR	-1.87	-5.35	-4.23	0.50	0.01	16.14	0.33	9.00	-0.06	5.38	-0.15	6.00	0.10	14.56	1.60	1.27	12.50	-0.50	0.00	-9.00	-6.00
GRC	EL	-0.62	-3.43	-4.41	0.50	-0.05	8.01	0.03	9.00	0.00	3.41	0.54	6.00	-0.52	1.83	0.96	0.93	12.50	-0.50	0.00	-9.00	-6.00
HRV	HR	-2.65	-1.89	-2.96	0.50	0.17	1.04	-0.36	9.00	-0.19	8.02	0.56	6.00	-0.52	2.27	0.03	0.39	12.50	-0.50	0.00	-9.00	-6.00
HUN	HU	-1.55	-7.37	-7.47	0.50	0.01	3.89	-0.25	9.00	-0.24	9.15	0.19	6.00	-0.52	2.72	0.10	0.35	12.50	-0.50	0.00	-9.00	-6.00
IRL	IE	-3.38	-5.52	-10.68	0.50	-0.03	8.01	0.28	9.00	0.25	9.62	-0.13	6.00	-0.52	11.45	0.75	0.47	12.50	-0.50	0.00	-9.00	-6.00
ITA	IT	-3.38	-3.72	-3.71	0.50	0.15	5.95	1.28	9.00	-0.23	8.02	-0.61	6.00	-0.52	16.30	6.08	4.80	12.50	-0.50	0.00	-9.00	-6.00
LTU	LT	-3.50	-5.52	-5.78	0.50	0.00	7.21	0.32	9.00	0.32	5.12	-0.18	6.00	-0.52	13.67	2.01	1.69	12.50	-0.50	0.00	-9.00	-6.00
LUX	LU	-3.11	-11.37	-11.13	0.50	0.03	11.84	0.14	9.00	0.17	8.95	-0.22	6.00	-0.52	22.63	-0.30	-0.44	12.50	-0.50	0.00	-9.00	-6.00
LVA	LV	-0.74	-0.95	-0.95	0.50	-0.03	2.23	0.91	9.00	-0.21	1.60	-0.41	6.00	-1.65	6.49	5.53	4.62	12.50	-0.50	0.00	-9.00	-6.00
MLT	MT	-0.07	-0.20	-0.68	0.50	-0.17	8.01	1.19	9.00	1.02	8.02	-3.01	6.00	-0.52	16.30	1.63	0.44	12.50	-0.50	0.00	-9.00	-6.00
NLD	NL	-4.66	-13.05	-11.30	0.50	0.01	22.78	0.69	9.00	-0.06	15.19	-0.76	6.00	-0.52	16.83	2.65	1.96	12.50	-0.50	0.00	-9.00	-6.00
POL	PL	-3.15	-2.10	-7.04	0.50	-0.13	12.19	0.44	9.00	0.31	14.94	-0.57	6.00	-0.09	23.56	3.46	3.02	12.50	-0.50	0.00	-9.00	-6.00
PRT	PT	-1.96	-7.08	-6.02	0.50	-0.06	2.84	-0.21	9.00		1.35	0.17	6.00	-0.52	4.57	0.05	0.26	12.50	-0.50	0.00	-9.00	-6.00
ROU	RO	-3.49	-7.84	-3.76	0.50	-0.02	5.76	-1.03	9.00	-0.04	14.78	0.95	6.00	-0.52	38.79	-0.68	0.35	12.50	-0.50	0.00	-9.00	-6.00
SVK	SK	-2.33	-5.69	-5.69	0.50	-0.72	4.62	0.15	9.00	-0.57	6.31	-0.02	6.00	-0.52	13.42	2.13	1.98	12.50	-0.50	0.00	-9.00	-6.00
SVN	SI	-1.49	-2.12	-4.72	0.50	-0.01	12.11	0.53	9.00	-0.88	7.80	0.64	6.00	-0.97	5.42	0.14	-0.39	12.50	-0.50	0.00	-9.00	-6.00
SWE	SE	-1.17	-4.73	-2.23	0.50	-0.08	13.26	0.33	9.00	-0.66	9.21	-0.43	6.00	0.00	7.67	-0.34	-0.67	12.50	-0.50	0.00	-9.00	-6.00
		-2.04	-5.52	-5.52	0.50	-0.06	8.01	0.28	9.00	-0.25	8.95	-0.13	6.00	-0.52	11.85	1.11	0.78	12.50	-0.50	0.00	-9.00	-6.00
		-2.04	-5.33	-5.48	0.50	-0.05	8.24	0.33	9.00	-0.01	9.14	-0.16	6.00	-0.52	12.08	1.11	0.78	12.50				

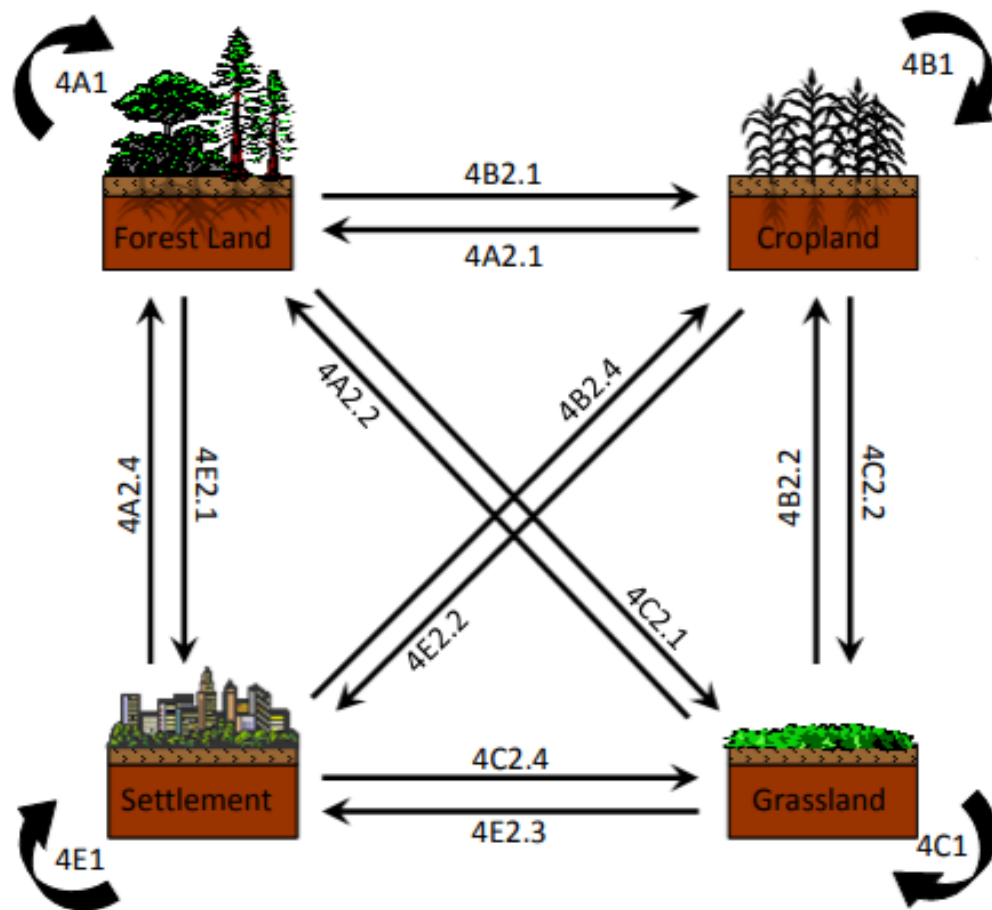


Figure 51 : schema for the computation of emission factors from land use conversions.

KPI 12 and KPI13 Landscape quality

These KPIs are regarded as a condition indicator for the Nature restoration law and operationalized through two indicators:

- KPI12 Flora and nesting suitability index
- KPI13 Landscape diversity change – Shannon evenness index

Regarding KPI12 Flora and Nesting index is based on the approach developed by JRC

Zulian G, Paracchini M, Maes J, Liqueste Garcia M. ESTIMAP: Ecosystem services mapping at European scale. EUR 26474. Luxembourg (Luxembourg): Publications Office of the European Union; 2013. JRC87585.
<https://publications.jrc.ec.europa.eu/repository/handle/111111111/30410>

Regarding KPI13 the first indicator, the heterogeneity of a landscape can be quantified using the Shannon measures for Richness and Evenness. These metrics are a measure of the likelihood that a selected pixel will have the same land cover class as the adjacent pixel. For this study we used the Evenness index, a measure of the relative abundance of pixels of different classes in the area selected, which has a value between > 0 and 1 . For a given number of classes (Richness), an Evenness = 1 is reached when all classes have the same area. Thus, higher values indicate that the number of pixels (area) is more evenly distributed between the land cover classes. Conversely, a value near 0 would indicate that nearly every pixel in the landscape is the same.⁸³

More information on the Shannon Diversity: Richness and Evenness can be found on the Internet: <https://ec.europa.eu/eurostat/statistics-explained/index.php>

[https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Landscape structure indicators from LUCAS](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Landscape_structure_indicators_from_LUCAS)

Archive:Landscape structure indicators from LUCAS - Statistics Explained

KPI14 Nitrogen losses to water

The water quality KPI is regarded as a pressure indicator from the point of view of several policies: F2F pesticides and nutrients reduction, and Nature restoration law.

We considered 2 indicators reflecting this KPI.

⁸³ The following example demonstrates the range of Shannon Evenness and Richness. If an area with 40 pixels has 40 different land cover classes, then the Richness = 40 and the Evenness = 1. If that same 40 pixel area has two land cover classes and one class is represented in only 1 pixel then the Richness = 2 and the Evenness = 0.1687.

- Risk of N concentration in surface and groundwater
- Risk of concentration of pesticides in water. For this indicator please refer to the KPI5 'Pesticides use'.

For the former the computation of the indicator is based on de Vries et al. (2021).

KPI15 Change in ammonia emissions in relation to critical load

This KPI is interpreted as the reduction of the ammonia emissions in sensitive nature areas. It is regarded as a condition KPI for the Nature restoration law (Restoration of sensitive nature) and a pressure indicator for several policies including F2F organic farming, reduction of pesticides and fertilizers and the Nature restoration law (Restoration of sensitive nature, Discontinuation of agriculture in peatlands). It is calculated according to de Vries et al. (2021) and expresses the ammonia emission levels as compared to the critical deposition level exceedance.

KPI 16 UAA

The Utilised Agricultural Area is the area under agricultural production (expressed in ha) and is regarded as a pressure indicator for all the policies in the assessment matrix.

It is the result of the iClue modelling.

Table 63- 1 Overview of target, pressure and condition KPIs

Policy	Indicator issue	Land take - soil sealing	Pesticide use	Fertilizer use	Organic matter	Soil health	Organic farming	Organic farming	Livestock density	Agroecosystems	GHG AFOLU
	Definition of (proxy) indicator Policy goals 2050 in SA	Urban land take from agriculture (%/2020 UAA)	Pesticide use (index)	Agricultural area share with a 20% reduction in fertiliser use.	SOM (organic matter) change 2020-2050	soil erosion risk	Distance to 25% organic farming share in UAA (% of UAA)	Distance to 25% organic farming share in UAA (hectares)	Livestock density LU/ha total agricultural land	% net abandoned agricultural land in Natura 2000 or national designated areas	Change GHG emissions AFOLU
F2F_ Organic	25% of farmland under organic farming		C	C	P		T	T	C		P
F2F_ Pesticides	Reduce by 2030: the use and risk of chemical pesticides by 50% & use of more hazardous pesticides by 50%		T				C	C			P
F2F- Nutrients	Reduce by 2030: Nutrient losses by at least 50%, & no deterioration on soil fertility				P		C	C	P		P
	Reduce by 2030: Fertilizer (organic and mineral) use by at least 20% & no deterioration on soil fertility			T	P		C	C			P
Nature restoration law	4% additional Natura 2000 area						C	C		T	
	1 billion trees extra						C	C			P

Policy	Indicator issue	Land take - soil sealing	Pesticide use	Fertilizer use	Organic matter	Soil health	Organic farming	Organic farming	Livestock density	Agroecosystems	GHG AFOLU
	Definition of (proxy) indicator Policy goals 2050 in SA	Urban land take from agriculture (%/2020 UAA)	Pesticide use (index)	Agricultural area share with a 20% reduction in fertiliser use.	SOM (organic matter) change 2020-2050	soil erosion risk	Distance to 25% organic farming share in UAA (% of UAA)	Distance to 25% organic farming share in UAA (hectares)	Livestock density LU/ha total agricultural land	% net abandoned agricultural land in Natura 2000 or national designated areas	Change GHG emissions AFOLU
	10% landscape elements in all agricultural lands						C				
	Restoration of sensitive nature										
	Discontinuation of agriculture in 16.66% of the agricultural peatlands per Member State						C				P
Soil monitoring and resilience law	Soil sealing: 0 land take in 2050	T									P
	Soil erosion in 2050 < 2 t/ha/year				C	T					P
	Good soil health in 2050			C		C	C				P
Bioeconomy and RED RES targets	Targets for Bioenergy (biofuels, Jetfuels, electricity and heat)										C
	National targets for wind	P									C
	National targets for PV										C

Table 63-2 Overview of target, pressure and condition KPIs (continued)

Policy	Indicator issue	Water quality		Nature restoration	Nature restoration	Agri production	UAA	Landscape quality		Peatlands	GHG AFOLU
	Definition of (proxy) indicator Policy goals 2050 in SA	Risk of N concentration in surface and groundwater	Risk of concentration of pesticides in water	Change in ammonia emissions	Pollinator index	Produced calories and change 2020-2050	Area in agricultural production (ha)	Landscape diversity change	Area with natural land cover	% peatlands restored (ha)	Change GHG emissions AFOLU
F2F_ Organic	25% of farmland under organic farming	P	P	P	P	P	P				P
F2F_ Pesticides	Reduce by 2030: the use and risk of chemical pesticides by 50% & use of more hazardous pesticides by 50%	P	P		P	P	P				P
F2F- Nutrients	Reduce by 2030: Nutrient losses by at least 50%, & no deterioration on soil fertility	P	P	P		P	P				P
	Reduce by 2030: Fertilizer (organic and mineral) use by at least 20% & no deterioration on soil fertility	P	P	P		P	P				P
Nature restoration law	4% additional Natura 2000 area	P	P		C	P	P	C	C		
	1 billion trees extra	P	P				P	C	C		P
	10% landscape elements in all agricultural lands	P	P				P	C	C		
	Restoration of sensitive nature	P	P	C	C		P				

Policy	Indicator issue	Water quality		Nature restoration	Nature restoration	Agri production	UAA	Landscape quality		Peatlands	GHG AFOLU
	Definition of (proxy) indicator Policy goals 2050 in SA	Risk of N concentration in surface and groundwater	Risk of concentration of pesticides in water	Change in ammonia emissions	Pollinator index	Produced calories and change 2020-2050	Area in agricultural production (ha)	Landscape diversity change	Area with natural land cover	% peatlands restored (ha)	Change GHG emissions AFOLU
	Discontinuation of agriculture in 16.66% of the agricultural peatlands per Member State	P	P	P			P			T	P
Soil monitoring and resilience law	Soil sealing: 0 land take in 2050				P	P	P				P
	Soil erosion in 2050 < 2 t/ha/year					P	P				P
	Good soil health in 2050					P	P				P
Bioeconomy and RED RES targets	Targets for Bioenergy (biofuels, Jetfuels, electricity and heat)						P				C
	National targets for wind						P				C
	National targets for PV						P				C

Explanation of symbols for type of indicators:

T Target (policy) indicator	T
C Condition indicator	C
P Pressure indicator	P
CC Carrying Capacity indicator	CC

24. Annex 15 Excel table land use flows 2020-2050 in BAU and SA

See separate Annex in excel format:

https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cmef/sustainability/study-competition-land-use-and-sustainable-farming_en

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