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European landscape changes between 2010 and 2050 under the EU Reference Scenario

EU Reference Scenario 2013
LUISA platform – Updated Configuration 2014

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Abstract

The 'Land-Use-based Integrated Sustainability Assessment' modelling platform (LUISA) is primarily used for the ex-ante evaluation of EC policies that have a direct or indirect territorial impact. It is based on the concept of 'land function' for cross-sector integration and for the representation of complex system dynamics. Beyond a traditional land use model, LUISA adopts a new approach towards activity-based modelling based upon the endogenous dynamic allocation of population, services and activities.

LUISA has been applied to address the competition for land arising from the energy, transport and climate dimensions of EU policies and configured according to the EU Energy Reference scenario 2013 (updated configuration 2014) to produce high-resolution land use/cover projections up to 2050 and a related series of thematic indicators.

This report describes the stocks and the main land cover/use flows (LCF) taking place in Europe in the period 2010-2050 and the processes that cause those flows, thus providing insight on how the European landscape might change if the future happens according to a reference scenario consistent with settings (economic and demographic in particular) and policies in place in 2013 (hence including in particular the 2020 renewable energy targets).

Main findings:

- The extent of the land for housing and leisure (urban) and industrial/commercial and services (ICS) increases, while the area of agriculture, forest and natural land decreases;
- Urban and industrial land are expected to represent the highest share of net formation as % of the initial year (2010);
- Energy crops appear in the model as of 2020 and are expected to reach 135,479 km2 across Europe in 2050;
- Energy crops become the second most important land transformation in Europe (17%); approximately 90 % of the land consumed for energy purposes comes from land for food and feed, followed by forest and natural land;
- While a large proportion of land dedicated to food and feed crops is expected to be converted into dedicated energy crops, the net land losses are very small as a results of the conversion from forest land into food and feed production;
- New forest and natural land compensate in some way for quantity of losses or consumption by other uses; however the high value of the turnover indicator, reveal that those land-uses are unstable and vulnerable to the fast changes driven by economic development and climate changes, thus compromising the biodiversity and habitat conservation status;
- The conversion between farming types represent 35% over the total land changes between 2010 and 2050;

The results show the loss of natural and agricultural land because of ever-ongoing urbanisation and industrialization processes. The loss of natural and agricultural land for food production is even larger because of the advent of energy crops production incited by shifts in the European Energy supply system.

1. Introduction

The European Union is committed to becoming a "sustainable, low-carbon and climate-friendly economy"[1]. In order to achieve this goal and become a resilient Energy Union, an integrated governance and monitoring process1 is put forward to coordinate energy-related actions across different spatial scales, from European to local, and promote coherence among different policy areas.

This strategy applies to all five dimensions of the Energy Union : (1) Energy security, solidarity and trust; (2) A fully integrated European energy market; (3) Energy efficiency contributing to moderation of demand; (4) Decarbonising the economy; and (5) Research, Innovation and Competitiveness.

The integration of spatial dimensions and coordination of policy sectors is of utmost importance for the fourth dimension (decarbonisation). The increasingly ambitious targets of domestic reduction in greenhouse gas emissions and wanted shares of renewable energy consumption commit the European Union to becoming the world leader in renewable energies. Research and investment strategies play a fundamental role in this context. The framework strategy for a resilient energy union1 also explicitly highlights that the EU "will also need to take into account the impact of bioenergy on the environment, land-use and food production".

In fact, the analysis of potential impacts on the land-use system and the functions that it provides, is a crucial component contributing to the success of the Energy Union. The land-use system affects both the demand and the supply of energy. On the supply side, examples are the availability of feedstock for the provision of bioenergy and of land for the installation of other renewables, such as solar energy. On the demand side, the spatial distribution of different users, such as industrial sites and residential buildings, also affects the final energy use of the whole system.

Adding to the complexity is the fact that land is a finite resource, and considering all the possible uses it will be needed for besides energy production, the competition for land among different uses will become fierce. Examples of other land functions for which future demand will increase are production of food for people and feed for animals, provision of timber for material uses, requirement of urban areas for residential purposes and industrial sites for production activities.

Both the quantity and quality (suitability to specific uses or functions) of the land affect its capacity to support not only productive systems, but also ecosystems and their services. The dynamic nature of the land system (resources can be degraded in quantity and quality at a fast pace, while their recovery might require a longer time scale) and the role of climate change require a special effort in order to improve the resilience of the system itself. The European Commission Communication on the Paris Protocol [2] explicitly emphasises the pivotal role of the "land-use sector with regard to resilience of food security, and other environmental, social and economic benefits". For example, the Protocol mentions the potential contribution of ecosystem-based adaptation in reducing flood risk and soil erosion and improving water and air quality.

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[1] COM(2015) 80 final *"ENERGY UNION PACKAGE - COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy".*

[2] COM(2015) 81 final *"ENERGY UNION PACKAGE COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL The Paris Protocol – A blueprint for tackling global climate change beyond 2020".*

Aside from contributing to bioenergy production, affecting the energy demand, and overall guaranteeing food security and other functions, the land system and its changes (land-use changes) are also identified as an important contributor to greenhouse gas emissions. In conclusion, a range of methodologies and tools are required to assess the potential impacts of energy policies on land-uses and functions, and fulfil the commitments put forward by the framework strategy for a resilient Energy Union.

In this context, the Land Use Integrated Sustainability Assessment modelling platform (LUISA), has been developed by the JRC and applied to address the competition for land arising from the energy, transport and climate dimensions of EU policies. This resulted in a high resolution land-use simulation up to 2050, called the EU Energy Reference scenario 2013 (updated configuration 2014 in LUISA)[3]. LUISA is based on the principle that different uses (or functions) compete for the most suitable locations, given available land, assumed demand and policy constraints or incentives. The actual allocation of each land-use is governed by an optimization approach so that, given the modelling assumptions (Baranzelli et al., 2014), the resulting projected landscape represents the best spatial distribution of the land functions (i.e., a system optimum, see Lavalle et al., 2011). This implies that each land-use transition (change) causes trade-offs between different uses (or functions): both the two directly involved in the transition and possibly others (indirect impacts) affecting the society, environment and the capacity to provide ecosystem services.

The first step of the methodology entails the analysis of the main macro drivers responsible of land-use change, and resulting pressures on European land resources[4]. Particular focus has been put on the land required and the land that is potentially available to accommodate the production of food and feed, and energy (bioenergy). At this stage of the analysis, it is possible to compare the availability of land that is suitable for the production of food and feed crops and energy, and how the availability of suitable land changed through time, mostly due to the expansion of competing uses such as residential and industrial areas.

The next step focuses on the analysis of the allocation patterns resulting from the implementation of the reference scenario. In order to better differentiate the two main objectives of the analysis, the results have been organized in two complementary reports. The first report (hereby) describes the stocks and the main land cover/use flows (LCF) taking place in Europe and the processes that cause those flows, thus providing insight on how the European landscape might change if the future happens according to a reference scenario consistent with settings (economic and demographic in particular) and policies in place in 2013 (hence including in particular the 2020 renewable energy targets) (Baranzelli et al., 2014).

The second report[5] investigates in detail the land-uses that are expected to be in direct competition for land (food, feed and energy) as a result of the EU bioenergy targets and

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[3] An updated (2015) definition of Reference Scenario is currently under preparation and still not available. Therefore, the analysis hereby presented has been carried out on the basis of the most up-to-date available macro-economic scenario, including the current policy provisions.

[4] Baranzelli, C., Perpiña Castillo, C., Lavalle, C., Pilli, R., Fiorese, G. (2014). *Evaluation of the land demands for the production of food, feed and energy in the updated Reference Configuration 2014 of the LUISA modelling platform. Methodological framework and preliminary considerations.* EUR 27018 EN. Luxemburg: Publication Office of the European Union.

[5] Baranzelli C, Perpiña Castillo C, Lopes Barbosa A, Batista E Silva F, Jacobs C, Lavalle C. Land allocation and suitability analysis for the production of food, feed and energy crops in the period 2010 - 2050 EU Reference Scenario 2013 LUISA platform – Updated Configuration 2014. EUR 27018. European Commission; 2015. JRC98567

considering the suitability characteristics of the land for these uses. The analysis is carried out per main crop group (cereals, maize, root crops, other arable crops and energy crops), as simulated by the LUISA modelling platform. The results presented highlight where and how the displacement of food and feed crops from highly suitable land to lower levels of suitability can be caused by different drivers, among which the expansion of built-up areas and introduction of dedicated energy crops.

2. Landscape changes across Europe between 2010 and 2050

2.1. Land stock and change accounts

The first step of the analysis entails the quantification of the changes in land-use/cover types over time according to the settings and assumptions of the EU Reference scenario 2014.

Table 1 shows the gains (formation) and the losses (consumption) of the stocks of each land-use/cover category. From this table it is possible to identify the land-use categories that are expected to increase or decrease by 2050.

The results indicate that urban residential and industry/commerce/services (ICS) land use is projected to increase, while agriculture, forest and natural land decreases. In total, between 2010 and 2050, the EU-28 Member States shows a net expansion of urban residential areas by about 25,792 km^2, so that the stocks of this land cover class grow by roughly 16%. Besides the expansion of urban residential, the land used for industry/commerce/services (ICS) also shows a net increase of 6,561 km^2, around 20% of net expansion as compared with 2010.

The most substantial net expansion over the period 2010-2050 in the Reference scenario comes from the development of dedicated Energy Crops (ECR)[6]. The expansion of ECR shows a net increase of 135,479 km^2, taking into account that, in the model, they start their development from 2020 onwards. With the development of ECR, the expansion of urban (16%) and industrial land-uses (20%), the other land-uses/covers show a net reduction: agriculture - 107,700 km^2 or minus 5%; forest - 50,500 km^2 or minus 3%; and natural land -9,618 km^2 or minus 4%.

Although, the percentages of change associated with these land-uses are smaller compared to those of urban and ICS land, this has to be put in perspective due to their larger absolute values. In addition, their turnover indicator reveals that these classes might be more unstable than expected. The turnover indicator signals the percentage of change in the original stock from the start year of the accounting period to the end, so that, if the land in the original stock have changed their use, this indicator will increase even if the aggregate stock has remained stable. The key reason for including this indicator is to be able to discern if land-use patterns are stable or if the expected consumption or loss of a given land cover type is compensated by the formation of new areas of the same type somewhere else. High turnover reflect a lack of stability in the ecological system and therefore suggest that ecosystems may be vulnerable (EEA, 2006). Hence, the higher the land-use turnover, the larger would be the potential negative impacts on biodiversity, ecosystem services and GHG emissions.

The small net decline of forest between 2010 and 2050 (3%) is the result of the balance between the forest land lost for other land-use categories and the formation of the new forest from other land-uses. The turnover indicator shows that in fact approximately 10% of the land turned over. A similar situation occurs with the natural land in Europe appointing a reduction of 4% of the initial year. In this case the indicator shows that actually 15% of the land underwent changes. Further analysis based on a set of environmental indicators produced by LUISA is being performed[7] to better understand if

[6] *"Dedicated energy crops can be defined as crops that are unsuitable for human or animal consumption and are grown for the purpose of producing biomass for energy in an agricultural rather than forestry context"*. (Allen B., 2014)

[7] Perpiña Castillo et al., 2015. An assessment of dedicated energy crops in Europe under the EU Energy Reference Scenario 2013 EU Reference Scenario 2013 LUISA platform – Updated Configuration 2014. JRC99227 Submitted

ecological functions associated to a new forest or natural areas compensate in some way the deficit of provision due to the loss of forest or natural areas somewhere else.

	LUISA land-use types							
	Urban residential	*Industrial*	*Food and feed*	*Energy crops*	*Forest*	*Natural land*	*Other land-uses**	***Total in km²***
A. Land-use 2010	164,222	32,261	1,969,904	0	1,721,533	226,492	251,068	**4,365,481**
B. Losses of initial land-use-cover	238	210	198,477	0	112,182	22,024		**333,132**
C. Gains of new land-use)	26,031	6,771	90,764	135,479	61,680	12,406		**333,132**
D. Net formation of land cover (C-B)	25,792	6,561	-107,712	135,479	-50,502	-9,618		**0**
E. Net formation as % of initial year (D/A*100)	16	20	-5	100	-3	-4		
F. Total turnover of land cover (B+C)	26,269	6,982	289,241	135,480	173,863	34,430		**666,264**
G. Total turnover as % of initial year (F/A*100)	16	22	15	100	10	15		**15**
H. No land cover change	163,984	32,051	1,771,428	0	1,609,350	204,468		**3,781,281**
I. Land-use 2050 (A+D)	190,014	38,822	1,862,192	135,479	1,671,031	216,874	251,068	**4,365,481**

Table 1. Stocks and change account for LUISA projected land-use maps under the Reference scenario, EU-28 between 2010 and 2050

Note: The first and last row of the table show the amount of land in square kilometres for the starting year (2010) and end year (2050). A given land-use can be consumed or formed from 2010 to 2050. The statistics on consumption (B) refer to the losses of the land, while the formation (C) to the gains of new land (for example from 2010 to 2050, 236 km^2 were converted into other land-uses in 2050, while 26,031 Km^2 became urban residential in 2050). The net formation of land describes the total in square kilometres (D) or percentage (E) of land which remains after removing the consumption of initial land from the formation of new land. The turnover of land refers to the amount of land in square kilometres (F) and percentage of the initial year (E) at which a certain land-use type is transformed either for formation of consumption.

*Other land-use changes are refers to water, wetlands and infrastructures (road and rails networks, ports and airports, mineral extraction, dump and construction sites) are non-simulated classes and thus remain static over time in term of both quantity and location.

2.2. Share of the land flows

The land accounting method presented above gives a good overall impression of the trends and dynamics involved in future land-use changes, but lacks insight in the underlying land-use dynamics. The land-use/cover flows (LCF) represent the significant changes that are projected to occur over a period of time. The approach shown here focuses on modelling results that are aggregated to limit the amount of presented data and focus on overall trends. The approach, including aggregation choices, is based on the methodology presented by the European Environmental Agency for 'Land Accounts for Europe'(EEA, 2006) .It was adapted to the LUISA framework and land-use classification scheme (for a detailed description of the method we refer to Annex A).

In the EU-28, the dominant LCF is the conversion within the agricultural land (LCF 4) with a share of 35% of the total land changes between 2010 and 2050 (Figure 1). The second largest LCF is the creation of forest (18%), the third largest the expansion of dedicated Energy Crops (ECR) (17%). The expansion of land for food and feed accounts for 12% of the total land-use changes. In the same period, 7% of the land for food and feed is expected to be abandoned (LCF 7)[8].

Among the lowest shares of the land-use/cover flow in Europe, urban internal transformations (LCF 1) accounts for only 1% which is a relatively small proportion when contrasted to the urban residential expansion. Expansion of urban residential (LCF 2) and of economic sites (LCF 3) represent on average 3% and 1% of the total land-use changes.

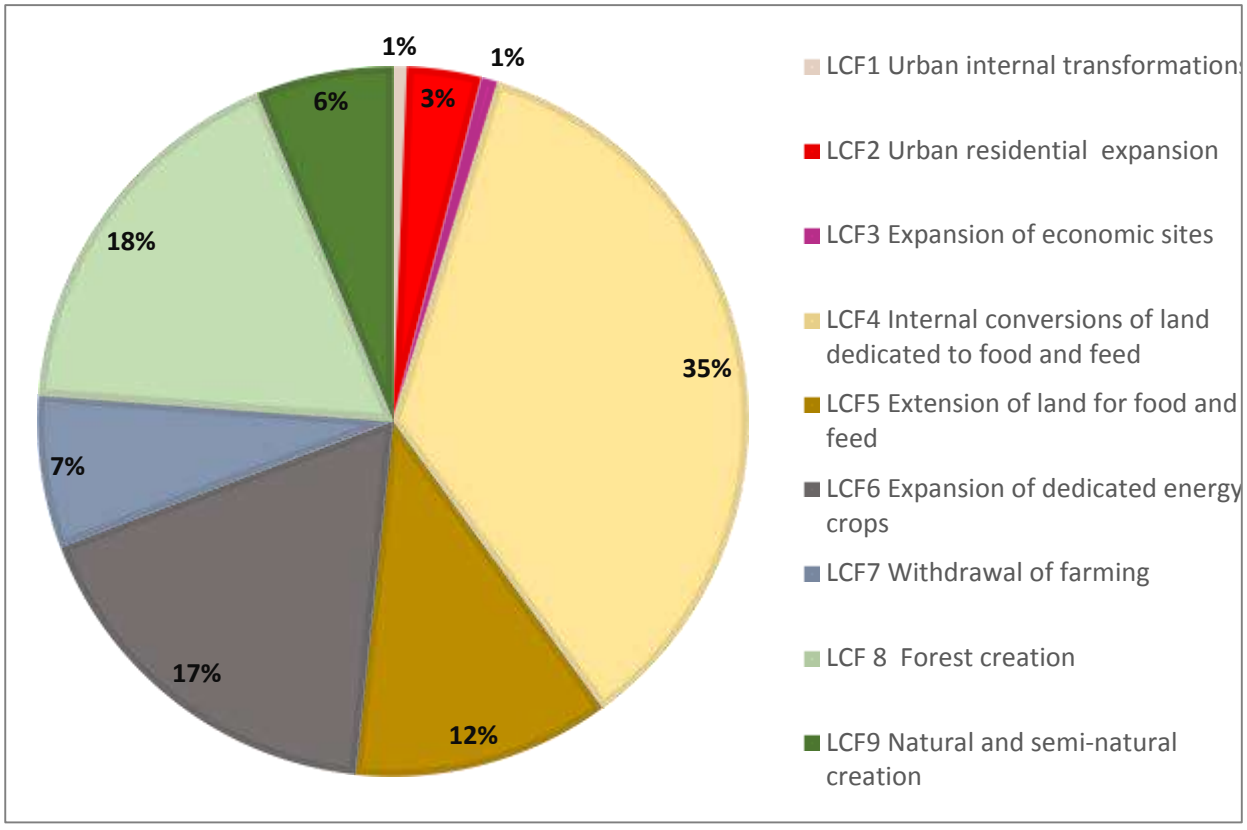


Figure 1. Share of land-use/cover flows in Europe 28.

[8] Food and feed land consumed by forest can be considered either forest creation or withdrawal of farming. In this exercise, it is chosen to highlight the agricultural sector losses.

Figure 2 shows the share of the 9 major LCF per country. The following points can be emphasised:

- Internal agriculture conversions (LCF 4) are dominant in Denmark, Hungary, Czech Republic, Germany, Malta, Lithuania, the United Kingdom, the Netherlands, Romania, Bulgaria, Estonia, Italy and Ireland;
- Creation of forest (LCF 8) is dominant in Croatia, Finland, Spain, Latvia, Portugal and Sweden;
- Expansion of land dedicated to food and feed (LCF 5) is dominant in Greece;
- Expansion of dedicated ECR (LCF 6) is dominant in France and Slovenia;

It should be borne in mind that all of these refer to shares of land cover flows that are dominant in the respective countries and do not show the importance of absolute land-use/cover flows in one MS compared to another.

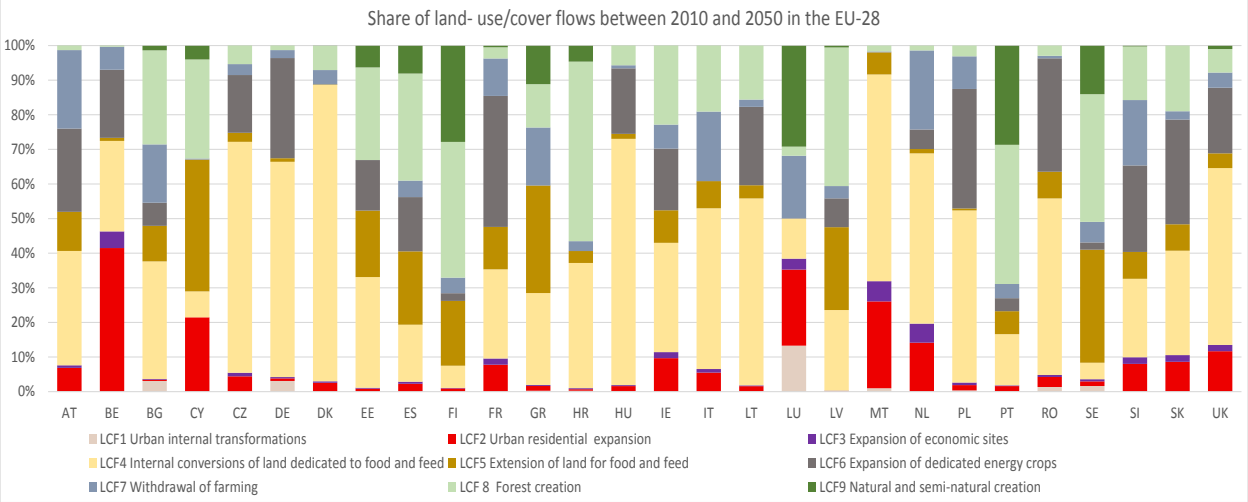


Figure 2. Shares of major Land-use/cover flows (LCF) between 2010 and 2050 by Member States in the EU-28.

2.3. Land-use/covers flows between 2010 and 2050

This section provides detailed information about the actual processes that have resulted in the flows between the different stocks of land cover. The land-use/covers changes between 2010 and 2050, and the main processes that have led to these changes are analysed to describe the patterns of the dominant flows in Europe.

The area transition matrix between 2010 and 2050 is given in Table 2, in km^2. Through this matrix it is possible to identify the net losses and net gains for each land-use/cover in the end of the period of analysis. In order to identify the most important flows between 2010 and 2050, the transitions are also presented as percentage losses and gains for each of the main land-use/cover categories (Figure 3). This information is also useful to complement the turnover indicator presented in Table 1 because it identifies the exchanges between land-uses. For example, approximately 71% of the forest losses were converted to agriculture and - at the same time - 86% of the new forest was converted from agricultural land.

2010 – 2050 area transition matrix

2050 → / 2010 ↓	Unit	Urban residential	Industrial	Food and feed crops	Forest	Energy crops	Natural land	***Net losses in 2050***
Urban residential	km²		238	0	0	0	0	238
Industrial	km²	122		17	2	64	6	210
Food and feed crops	km²	21,216	2,515		52,887	121,281	578	198,477
Forest	km²	4,262	3,309	79,536		13,252	11,823	112,182
Energy crops	km²	0	0	0	0		0	0
Natural land	km²	430	708	11,211	8,792	882		22,024
Net gains in 2050	Km²	26,030	6,771	90,764	61,680	135,479	12,406	***333,123*** / ***333,123***

Table 2. Total area of the flows between land-use/covers between 2010 and 2050

Note: The rows of the table represent the amount of land that has been taken or lost to other land-use/cover classes at the end of the period (i.e. in 2050). For example, in 2010 the agricultural land lost 21,216 km2 to urban residential and 2,515km2 to industrial land. The columns represent the amount of land that have been acquired in 2050 of each on the land-uses/covers. For example, urban residential gained 122 km2 from industrial land and 21,216 km2 from agriculture.

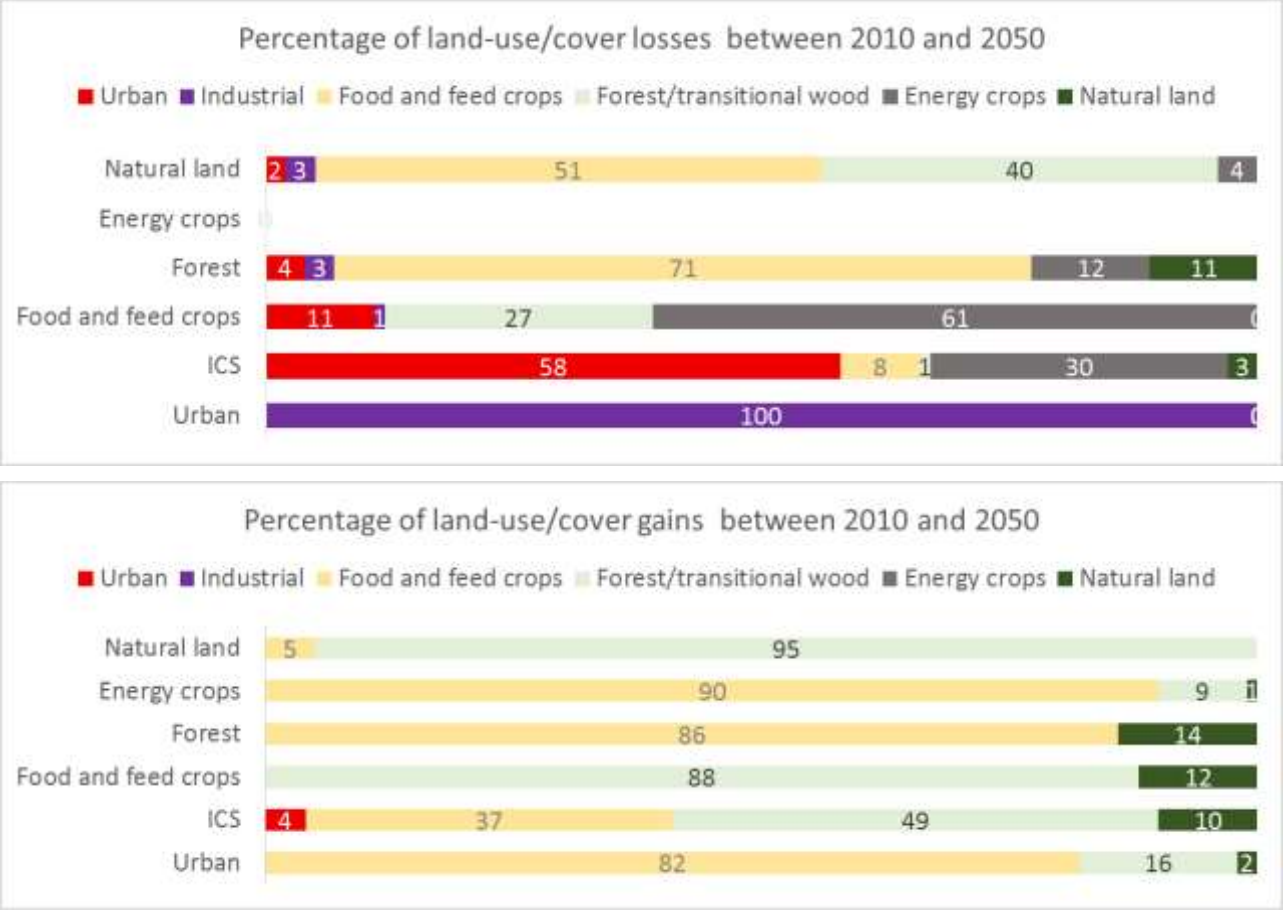


Figure 3. Percentage of the land-use/cover losses (top) and gains (bottom) between 2010 and 2050.

Note: The graphic on the top shows for each land-use/cover the proportion of land lost to any other land-use/cover category. For instance, from the total amount of agricultural land losses, 11% goes to built-up areas. 1% to industrial/commercial/services, 27 % goes to forest and 61 % goes to energy crops. The graphic on the bottom shows for each land-use/cover the proportion of land gain from any other land-use/cover category. Given agriculture as an example, 88% of the agriculture gains are from forest land and remaining 12% are from natural land.

Table 3 quantifies the amount of land that contributed for each LCFs (processes). For example the expansion of economic sites (LCF 3) is mainly due to the transformation of food / feed crops, forest and natural land. Whereas Table 2 shows the total amount of changes that have occurred in favour of urban residential (26,030km^2), in Table 3 we can distinguish if these changes are due to the LCF1 - urban internal transformations process (360km^2), namely a conversion from industrial to urban residential), or if these changes occur due to the LCF2 - urban expansion process (25,908km^2). Resuming, Table 3 gives information on the processes which drive those changes.

Contribution of the land-use changes (km^2)

LCF	Main land cover flows	Urban	Industrial	Food and feed crops	Energy crops	Forest	Natural land	Total
LCF1	Urban internal transformations	122	238	-	-	-	-	360
LCF2	Urban residential expansion	-		21,216	-	4,262	430	25,908
LCF3	Expansion of economic sites		-	2,515		3,309	708	6,533
LCF4	Internal conversions of land dedicated to food and feed	Not applicable since it refers to the internal conversions						-
LCF5	Conversion from other land cover to agriculture	0	17	-	-	79,536	11,211	90,764
LCF6	Conversion from other land cover to dedicated energy crops	-	64	121,281	-	13,252	882	135,479
LCF7	Withdrawal farming	-	-	52,887	-	-	-	52,887
LCF 8	Forests creation and management	-	2	-	-	-	8,792	8,794
LCF9	Natural and semi-natural creation	-	6	578	-	11,823	-	12,406

Contribution of the land-use changes (%)

LCF	Dominant land cover flows	Urban	Industrial	Food and feed crops	Energy crops	Forest	Natural land	Total
LCF1	Urban internal transformations	34	66	-	-	-	-	100
LCF2	Urban residential expansion	-	0	82	-	16	2	100
LCF3	Expansion of economic sites		-	37	-	49	10	100
LCF4	Internal conversions of land dedicated to food and feed	Not applicable since it refers to the internal conversions						-

LCF5	Conversion from other land cover to agriculture	-	0	-	-	88	12	100
LCF6	Conversion from other land cover to dedicated energy crops	-	0	86	-		14	100
LCF7	Withdrawal farming	-	-	90	-		10	100
LCF 8	Forests creation and management	-	1		-	-	99	100
LCF9	Natural and semi-natural creation	-	0	5	-	95	-	100

Table 3. An overview of the individual contributions of the land-use conversions (gains or losses) towards the main land-use/cover flows processes in sq. kilometres (top) and in percentage (bottom).

3. Geographical patterns of the dominant land-use/cover flows (LCF) in the EU-28 at regional level

The effects of the Reference Scenario on the distribution of land-use are rather different across Europe. Figure 4 shows the landscape dynamic between 2010 and 2050 at regional level. Regions coloured in red are the most dynamic over time, meaning that more than 50% of the landscape is expected to change according to the current configuration of the EU policies. Among these regions we can highlight the central and southern part of Portugal, Denmark and Poland. Regions coloured in blue hues are expected to have few landscape changes over the period of analysis. This is the case for the main European capitals, such as London, Berlin and Brussels, as well as, for all the regions in France, Ireland, Croatia, Romania and Bulgaria.

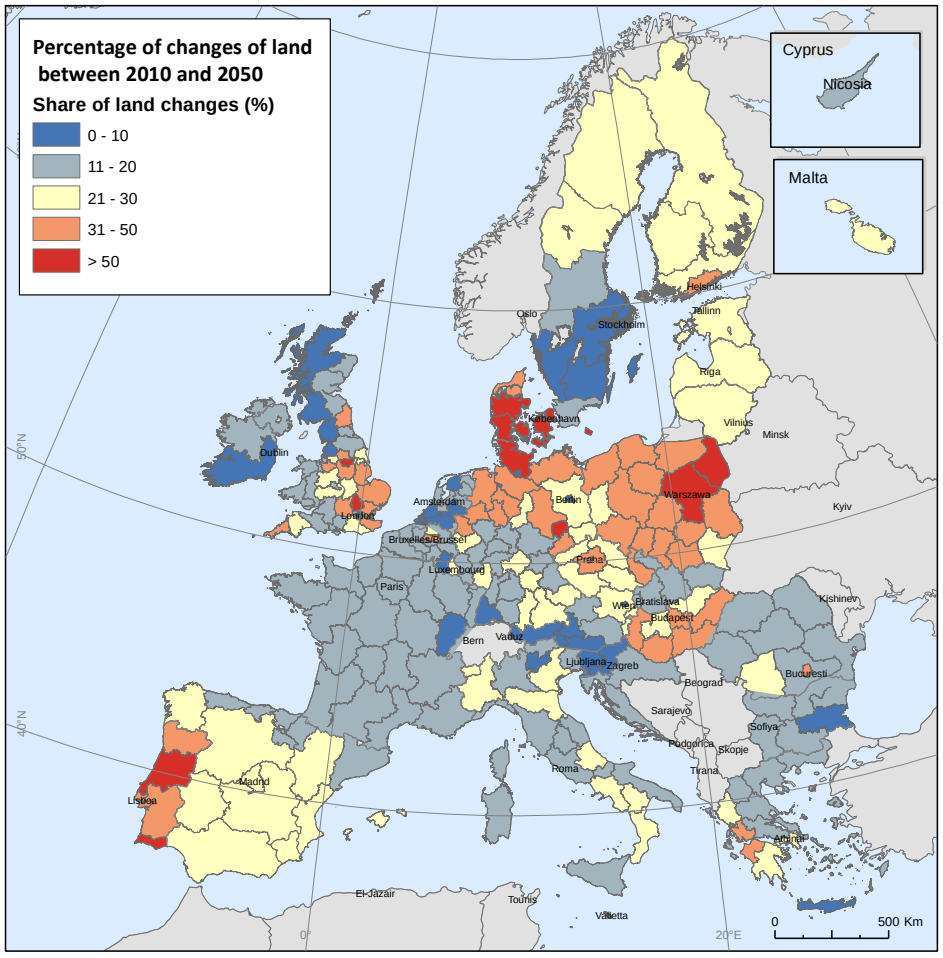


Figure 4. Proportion of land-use changes over non-land-use changes in Europe at regional level (NUTS2) between 2010 and 2050.

LCF 1 - Urban internal transformations

The land-use/cover flow (LCF) 1, 'urban internal transformations' corresponds to the internal transformation of urban areas, which is essentially about recycling of developed urban land, including the following conversions:

- From urban residential to industrial/commercial/services (ICS) land-uses[9];
- From ICS to urban residential;
- From abandoned urban residential to urban residential;
- From abandoned ICS to ICS;
- From abandoned ICS to urban residential;
- From abandoned urban to ICS sites;

According to the modelled reference scenario, the LCF urban internal transformations is rather low (1%) and in the majority of the EU MS the proportion is expected to be '0'. The share of recycling of previously developed land is particularly high in Luxemburg (13%) Figure 5. In absolute terms, the urban internal transformations account for 360 km^2, with approximately 238 km^2 of urban residential areas are expected to be converted into ICS areas and 122 km^2 of ICS land recycled into urban residential areas.

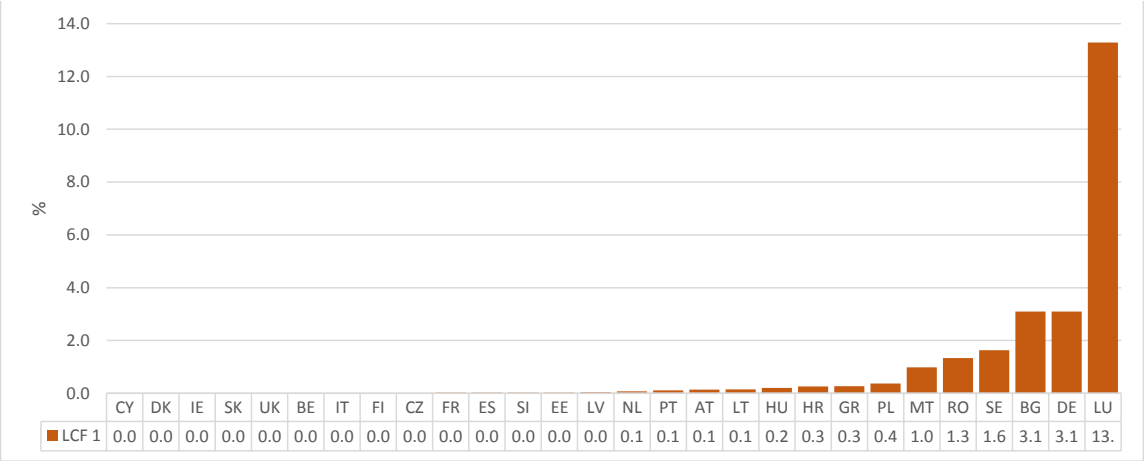


Figure 5. LCF 1 - Urban internal transformations between 2010 and 2050 at Member State level.

At regional level, Berlin and Saarland in Germany are the two regions where this proportion reaches approximately 20% of the total land-use/cover flows (Figure 6). In terms of area, the amount of land recycled in those regions is, however, rather low and the high share of urban internal transformation is due the landscape (i.e. the other land-uses) remaining stable over the period in those regions.

[9] Although technically possible, the direct conversion from/to ICS to/from residential is very unlikely due to the high involved costs.

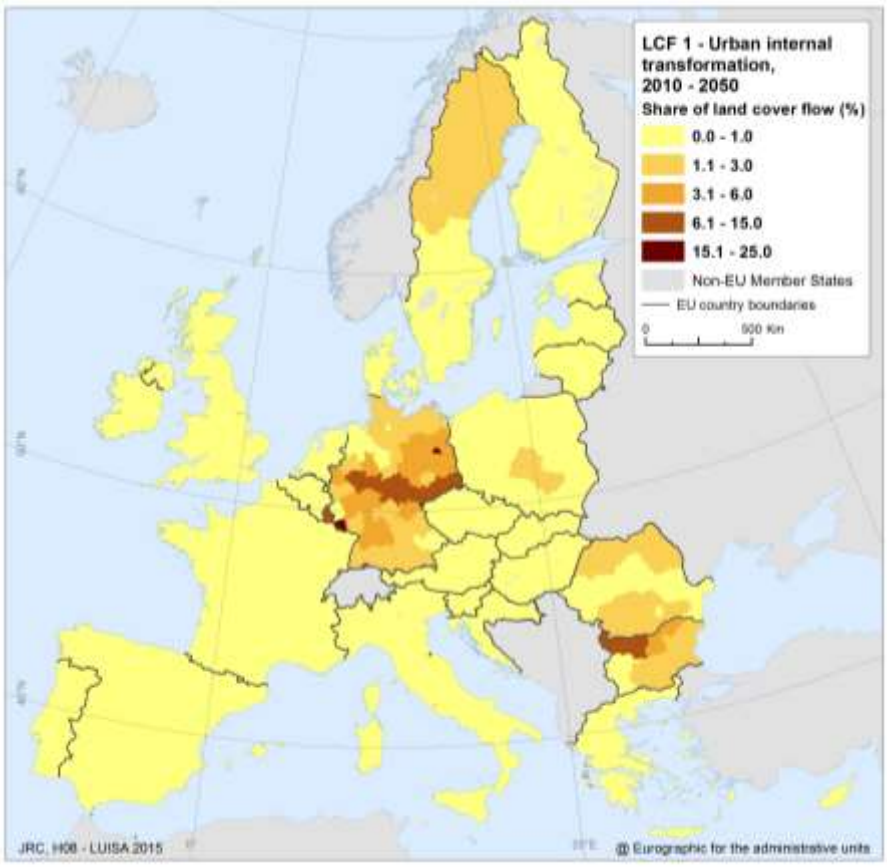


Figure 6. LCF 2 - Urban internal transformations between 2010 and 2050 at NUTS2 level in the EU-28.

LCF 2 - Urban residential expansion

The LCF 2 'urban residential expansion' corresponds to land uptake by urban residential (including residential, sport and leisure facilities) from non-urban land, including the following land-use/cover flows:

- From arable land (including maize, cereals, root crops and other arable) to urban residential;
- From pastures to urban residential;
- From permanent crops to urban residential;
- From forest to urban residential;
- From semi-natural vegetation to urban residential;

Land take has highest impacts on the environment due to sealing of soil, habitat fragmentation and biodiversity loss and will be determined by the balance between the urban land management flows (LCF 1), the sprawl of urban residential (LCF 2) and economic activities (LCF 3). Reducing the share of urban residential and ICS expansion (LCF 2 and LCF 3) by increasing the recycling urban land (LCF 1) is an effective means of avoiding such environmental problems associated with the urban expansion.

The total net formation of urban expansion is 25,908 km^2 in 2050 (Table 3). More than 82% of the land uptake is land dedicated to food and feed production followed by forest and natural land (16% and 2%).

In the EU-28 the land-use/cover flow of urban expansion is on average 3% (three times higher than the share of the urban recycling). In Belgium the share of land-use/cover flows associated with urban residential expansion reach 40%, which in absolute terms corresponds to 1770 km^2. This value is rather high considering the fact that is among the countries with the highest urban expansion (in absolute terms). In addition, Belgium is among the smaller countries across the EU-28 member states. Figure 7 also shows Malta, Luxemburg and Cyprus with more than 20%. In this case it is worth to mentioning that those countries are among the countries with the lowest land-use changes, meaning that the highest shares of urban expansion is mainly due to the few changes occurring in these countries. Indeed, in absolute terms the urban expansion in Malta accounts for 13 km^2, in Luxemburg 120 km^2 and in Cyprus 260 km^2.

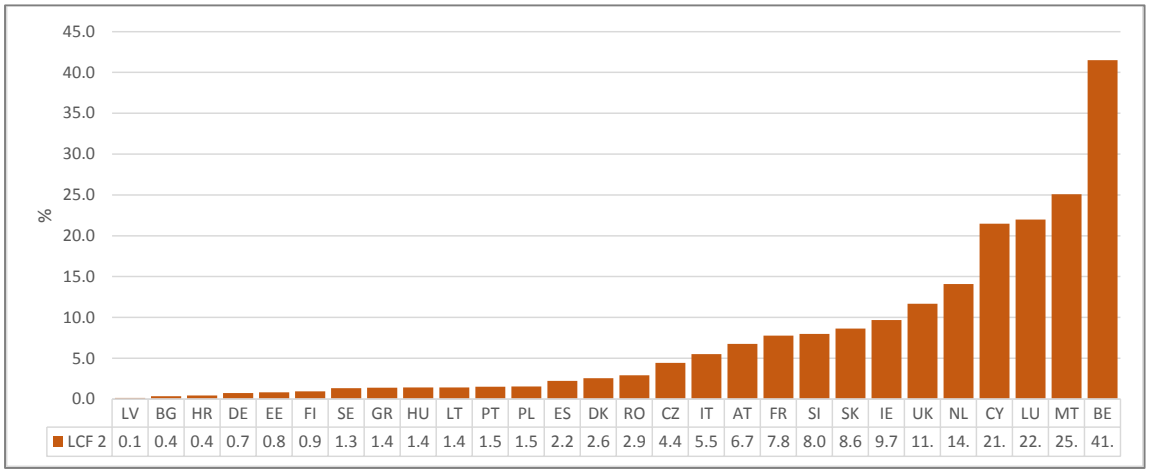


Figure 7. LCF 2 - Urban residential expansion between 2010 and 2050 at MS level.

The LCF associated with urban residential sprawl are mainly concentrated around the existing urban centres. For example, in Brussels, in the Province of Brabant Wallon, Vlaams Brabant, as well as in Wien, Outer London and Prague more than 80% of the land-use changes are caused by the sprawling development (Figure 8).

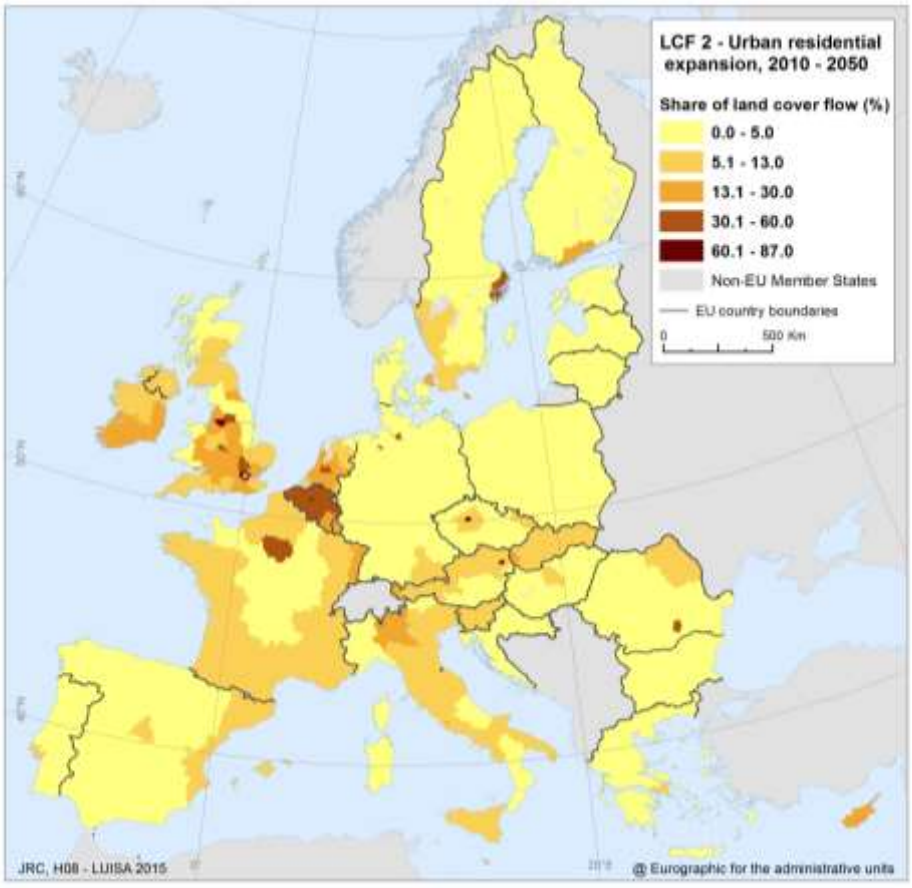


Figure 8. LCF 2 - Urban residential expansion between 2010 and 2050 at NUTS2 level in the EU-28.

LCF 3 – Expansion of economic related activities

The LCF 3 'expansion of economic related activities' corresponds to the land uptake by new economic activities land from non –urban land, including the following land-use/cover flows:

- From arable land (including maize, cereals, root crops) to ICS sites;
- From pastures to ICS sites;
- From permanent crops to ICS sites;
- From forest to ICS sites;
- From semi-natural vegetation to ICS sites;

In EU-28 the rate of expansion of economic sites is among the lowest among all the land cover flows (1%) (Figure 1). This corresponds to a total net formation of 6,771 km^2 in 2050 (Table 3). As opposed to the urban expansion, which takes land primarily from agriculture, ICS is mainly converted from forest (49%) followed by agriculture and natural land (37% and 10% respectively). This fact can possibly be attributed to the historical data on land-use changes which were used for calibrating the model. Historically the residential areas are surrounded by agricultural land while the industrial land is surrounded by forest.

At Member State level, Malta, the Netherlands and Belgium expects more than 4% of ICS expansion (Figure 9).

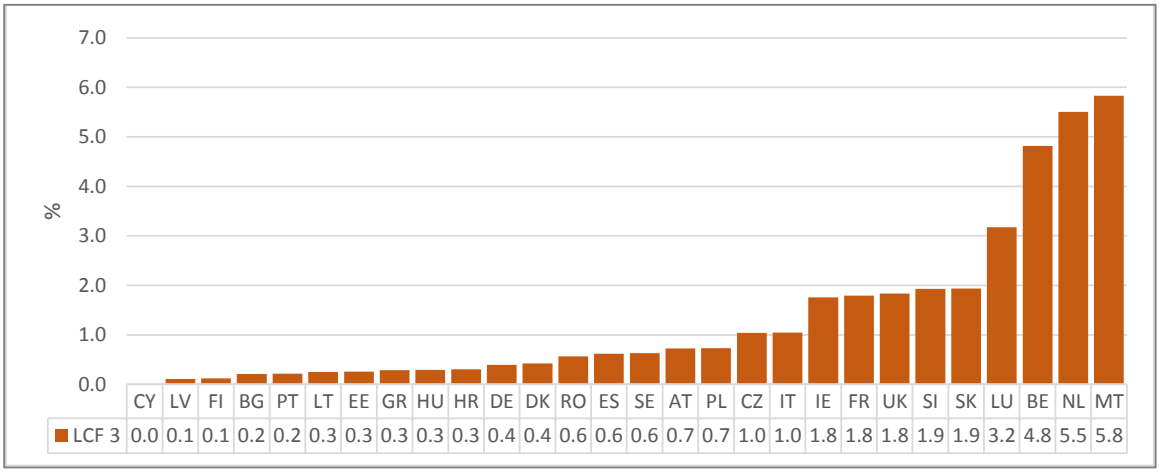


Figure 9. LCF 3 - Expansion of Industrial/Commercial/Services between 2010 and 2050 at Member State level.

The spatial distribution of the LCF 'expansion of ICS sites' for the EU Reference scenario shows the highest impact in existing urban centres (Figure 10). This is the case in Berlin, Greater London, Liverpool, Amsterdam and Brussels where more than 15% of the total land-use changes are caused by the expansion of ISC sites.

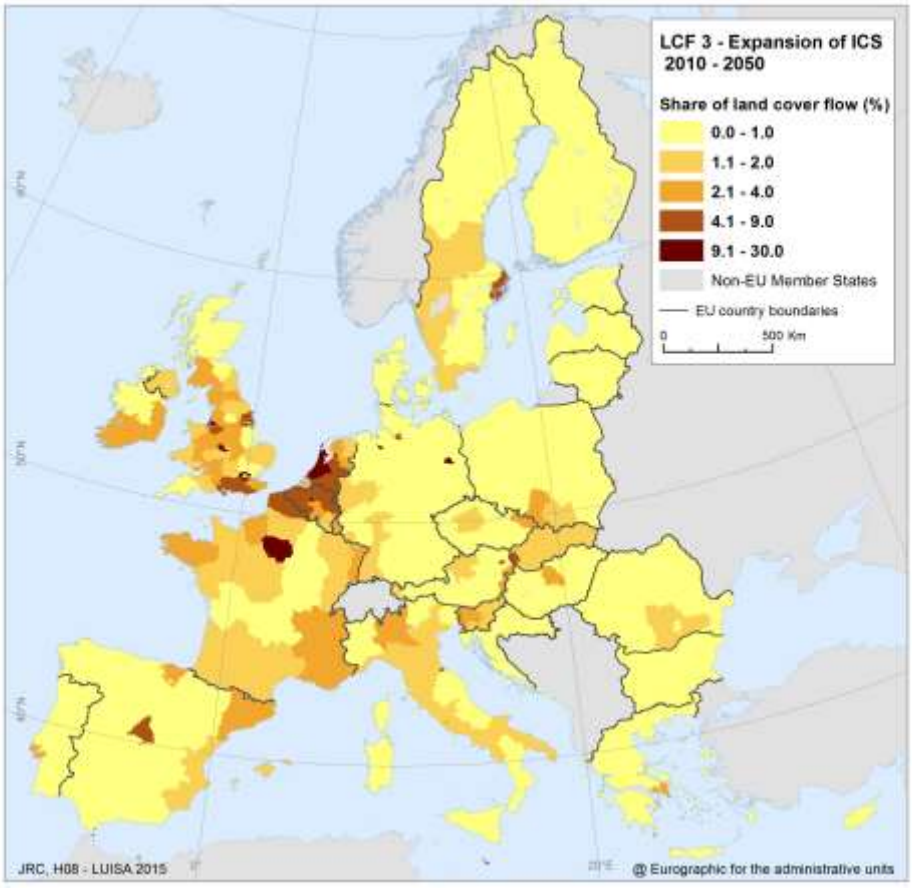


Figure 10. LCF 3 - Expansion of Industrial/Commercial/Services sites between 2010 and 2050 at NUTS 2 level in the EU-28.

LCF 4 – Internal conversions of land dedicated to food and feed

The LCF 4 'Internal conversions of land dedicated to food and feed' corresponds to conversions between farming types, including the conversions:

- between arable land (including maize, roots, cereals and other arable);
- from arable land to pastures and permanent crops;
- from pastures to arable land and permanent crops;
- from permanent crops to arable and pastures;
- from abandonment arable, permanent crops and pastures to any agricultural land are also considered in this category;

According to the EU Reference scenario, in the EU-28 the major land-use changes between 2010 and 2050 are due to the internal conversions of land dedicated to food and feed, on average 35%. However in some countries the changes related to the farming type can be higher than 60%, such as, in Denmark, Hungary, Czech Republic, and Germany (Figure 11).

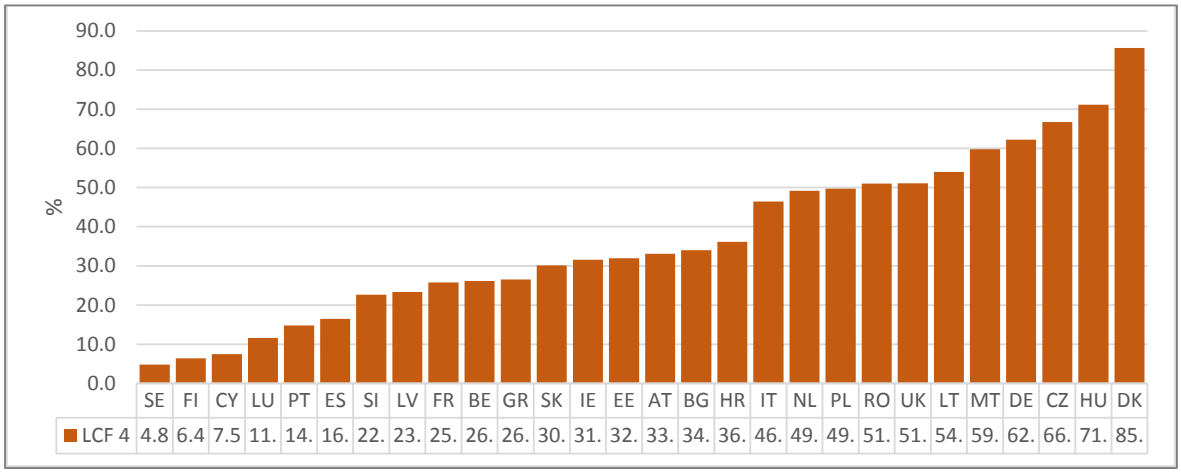


Figure 11. LCF 4 - Internal conversions of land dedicated to food and feed between 2010 and 2050 at Member State level.

At regional level, the highest potential impact of the EU reference scenario in changes within agricultural land is expected to take place in Midtjylland (5,030km^2) and Syddanmark (3,700 km^2) Sjælland (2,670km^2) regions in Denmark and in Lincolnshire region in the UK (1,300 km^2) as well as Leipzig region in Germany (1,080 km^2). In these regions more than 80% of the land-use changes are due to internal conversions of the land for food and feed (Figure 12).

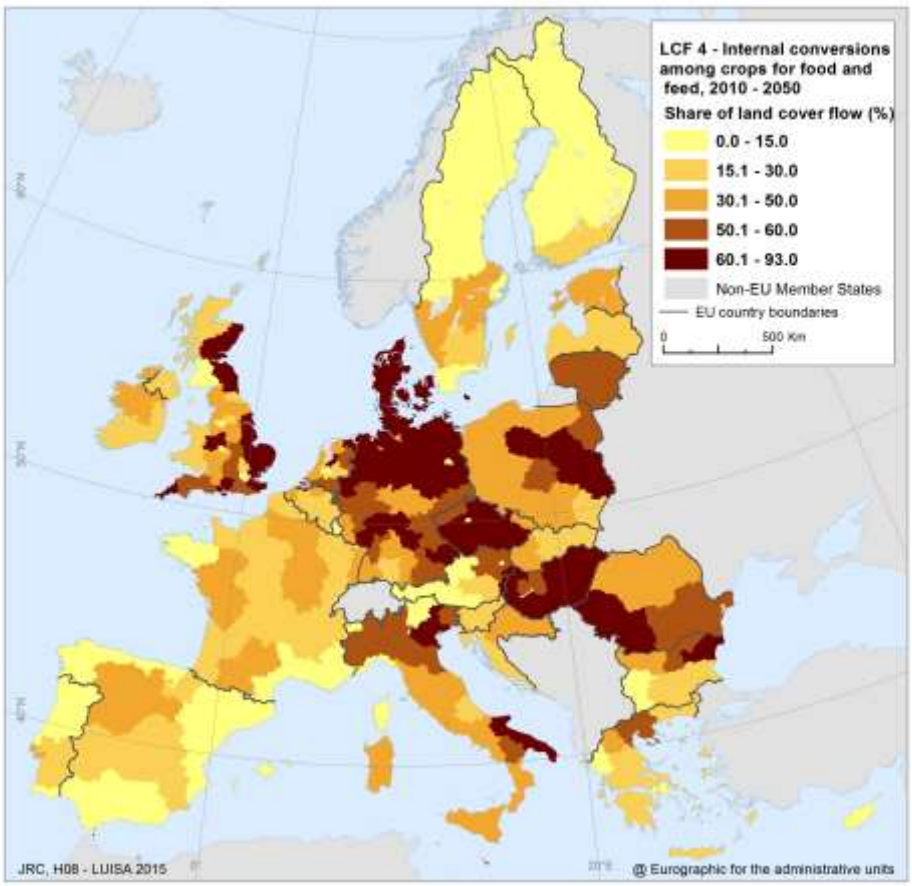


Figure 12. LCF 4 Internal conversions of land dedicated to food and feed between 2010 and 2050 at NUTS 2 level in the EU- 28.

LCF 5 – Expansion of land for food and feed

The LCF 5 corresponds to the 'expansion of land for food and feed', i.e. conversion from other land-uses to land dedicated to food and feed production. The conversions from built-up land (abandoned ICS and urban residential) are also included in this land-use category, though this conversion is unlikely to occur at any meaningful scale. The expansion of land for food and feed takes into account the following conversions:

- From urban residential (through the abandoned urban land) to arable land (maize, cereals, root crops and other arable), pastures, permanent crops – unusual conversion;
- Form ICS to (through the abandoned ICS land) to arable land, pastures, permanent crops -unusual conversion;
- From forest to arable land, pastures, permanent crops;
- From transitional woodland-shrub to arable land, pastures, permanent crops;
- From natural land to arable land, pastures, permanent crops;
- Dedicated energy crops to arable land, pastures, permanent crops;

In the European Union the land-use changes associated with the expansion of land for food and feed average 12%. In Cyprus, the expansion of land for food and feed is the dominant land cover flow (38%). Sweden, Greece and Finland, also expect a high share of expansion of land for food and feed with more than 30% of the total land-use/cover flows (Figure 13).

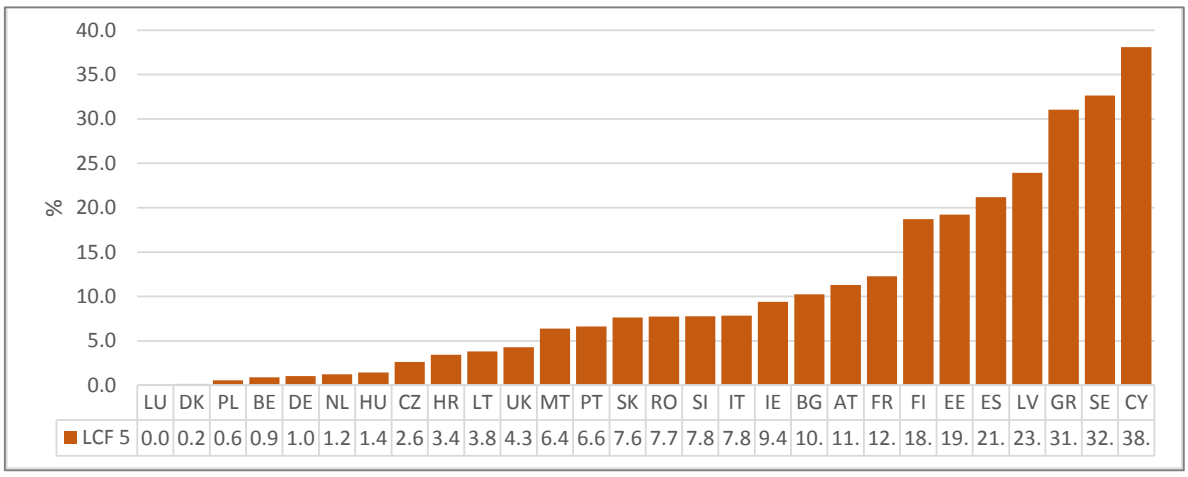


Figure 13. LCF 5 - Expansion of land for food and feed between 2010 and 2050 at Member States level.

The formation of land for food and feed is at the expense of forest (88% of the total for this LCF) followed by natural land (12%) which together amount to a total of 90,747 km^2. Then it can be drawn that land dedicated to food and feed has been used for the energy production while taking land from forest. A small part of land for food and feed (21,216 km^2) has been taken from housing and leisure purposes.

At regional level, the share of land-use/cover flows related to the land for food and feed expansion can reach over 65% , mainly in the Scandinavian regions in particular Småland med öarna and Sydsverige in Sweden, followed by Ionia Nisia and Voreio Aigaio in Greece in the southern part of Europe (above 50%) (Figure 14).

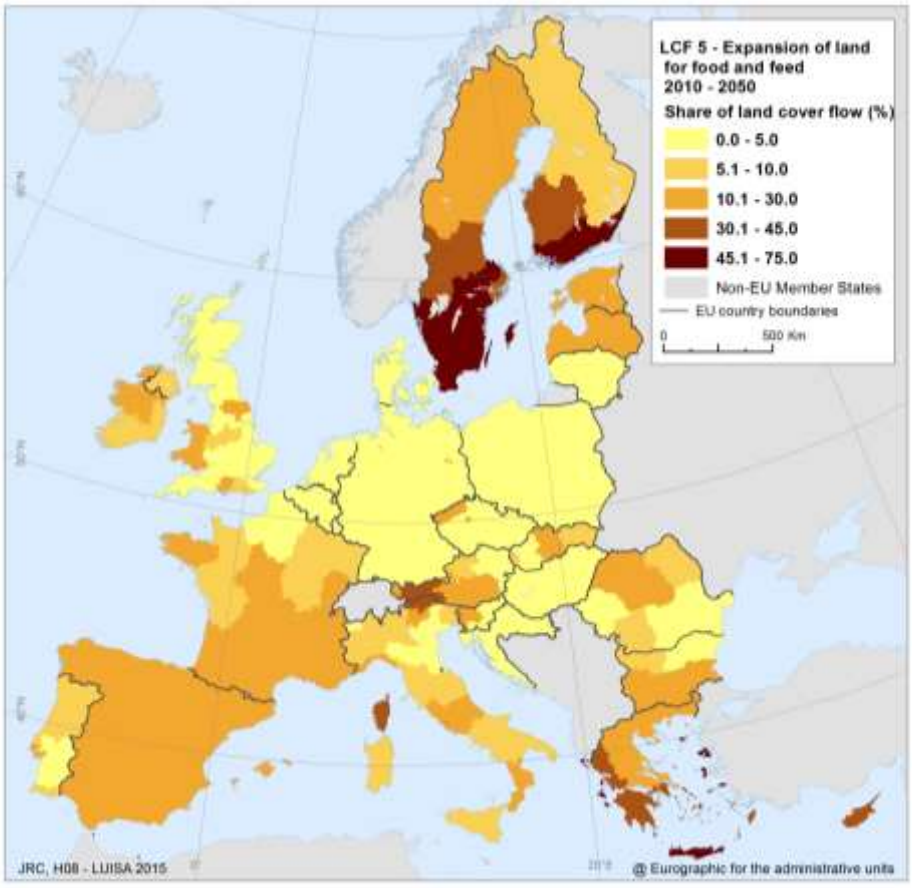


Figure 14. LCF 5 - Expansion of land for food and feed between 2010 and 2050 at NUTS2 level in the EU -28.

LCF 6 – Expansion of dedicated energy crops

Energy crops (ECR) in EU28 occupy 4,730 km^2 in 2020 and 13,550 km^2 in 2050, which represent, on average, 1.3% and 3.6% of Europe's total available land. This corresponds to an increase of 186% between 2020 and 2050, with significant variability between Member States. Poland, France, Germany, Spain, Romania and the United Kingdom are the countries that contribute the most, in terms of acreage, to the production of energy crops, accounting all together for 83% of the European acreage. The results of the modelling exercise reflect the significant renewable energy contribution from energy crops in the EU-28.

Though it is important to estimate the energy crop production and its contribution to the total EU energy consumption, it is also relevant to analyze the underlying land-use conversions. For that objective the flow account of the expansion of dedicated energy crops (LCF 6) can provide more precise information about the land consumed (i.e., the losses ceded by each land-use category) by such expansions. The LCF 6 'Expansion of dedicated Energy Crops' refers to the conversions from other land-uses to land used for the express purpose of producing energy. The expansion of dedicated Energy Crops includes the following conversions:

- From urban residential to dedicated Energy Crops (through the abandoned urban land) – unusual conversion;
- From ICS to dedicated Energy Crops (through the abandoned ICS land) – unusual conversion;

- From arable land, pastures and permanent crops to dedicated Energy Crops;
- From abandoned arable land, pastures and permanent crops to dedicated Energy Crops;
- From forest to dedicated Energy Crops;
- From transitional woodland-shrub to dedicated Energy Crops ;
- From natural land to dedicated Energy Crops;

In the EU-28, around 17% of the total changes between 2010 and 2050 are associated to the land-use changes dedicated to energy crops. The highest impact of the Reference scenario occurs in the central part of Europe, in particular in Poland and Slovakia, in Romania and France with more than 30% of the land-use changes dedicated to the energy crops (Figure 15).

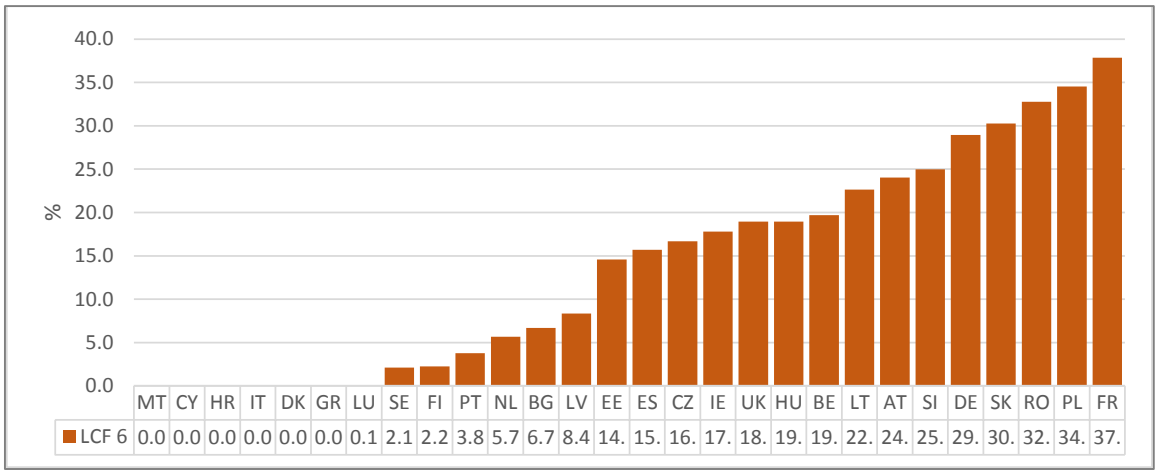


Figure 15. LCF 6 - Expansion of Energy Crops between 2010 and 2050 at Member States level.

The trend at regional level reveals that the expansion of dedicated energy crops is the dominant land-use/cover flow (more than 50% of the total land-use/cover flows) in particular in the French regions, in Tübingen, Freiburg and Stuttgart regions in Germany, and in Podkarpackie and Swietokrzyskie regions in Poland.

In the modelling of the reference scenario, the dominant factor of ECR (LCF6) in 2050 is the **conversion of food and feed crops to energy crops**, making up 90% (121,281 km^2) of the total land-use changes. The second largest LCF in this category is the conversion of **forests,** followed by the flows from natural lands, with shares of 10% (13,252 km^2) and 1% (882 km^2) respectively. Concerning the reconversion of abandoned agricultural land (arable land, pastures and permanent crops) to energy production, the contribution is about 0.03% (43 km^2) of the total changes within this group.

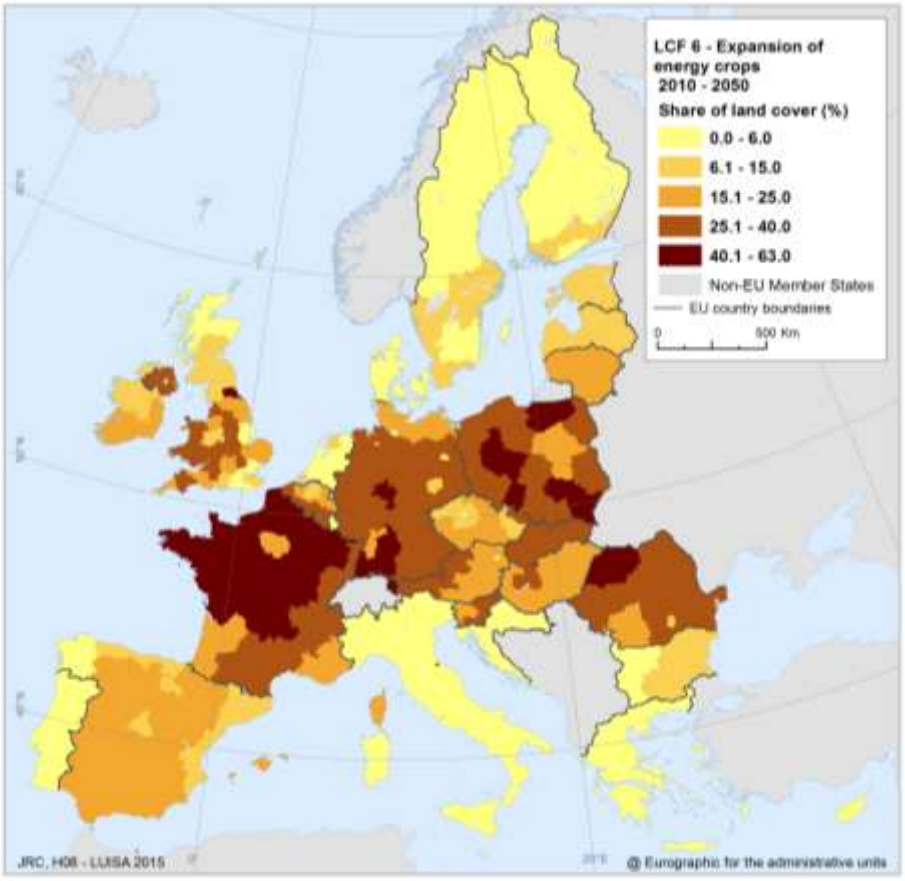


Figure 16. LCF 6 - Expansion of Energy Crops between 2010 and 2050 at NUTS 2 level in the EU-28.

The main concern associated with the agricultural land losses is mainly the reduction of food and feed production. This circumstance might potentially lead to agricultural intensification or more imports resulting in intensification and/or land-use change outside of the EU with its associated environmental impacts (for instance on soils, water and biodiversity).

Figure 17 reports an overview of the total production of energy crops along with the land-uses consumed by expansion of these crops at country level. Two groups are represented in the figure to make easier the interpretation and highlight its relevance. The first group corresponds to agricultural land for food and feed and includes cereals, maize, other arable, permanent crops, root crop, pastures and their associated abandoned lands. The second group represents natural lands that comprise transitional woodland-shrub, forest and other natural lands. In Sweden, Finland, Estonia, Latvia, and Portugal mainly natural lands are used (consumed) in favour of the expansion of energy crops. The remaining countries are predominantly losing agricultural lands for food and feed, particularly Belgium, The United Kingdom, The Netherlands, Germany, Poland, Romania, Bulgaria, Latvia and Slovenia.

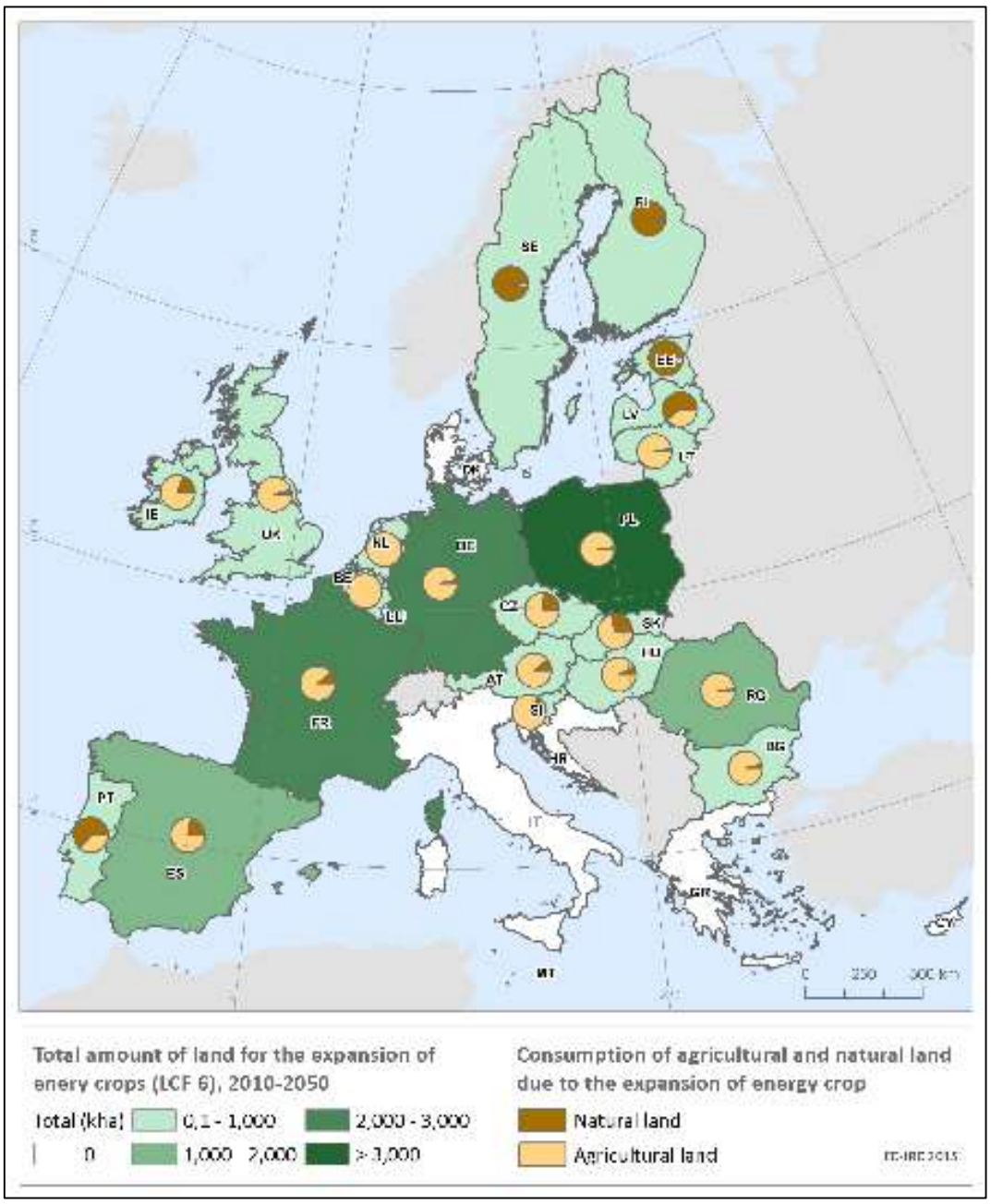


Figure 17. LCF 6 - Expansion of Energy Crops (kha) and land-use consumption (natural and agricultural land) between 2010 and 2050 at country level in the EU-28.

A regional analysis is presented in Figure 18 with regards to the expansion of energy crops at the expense of other land-use categories. In this case a more disaggregated classification is shown in order to identify the dominant land-uses consumed by energy crop production.

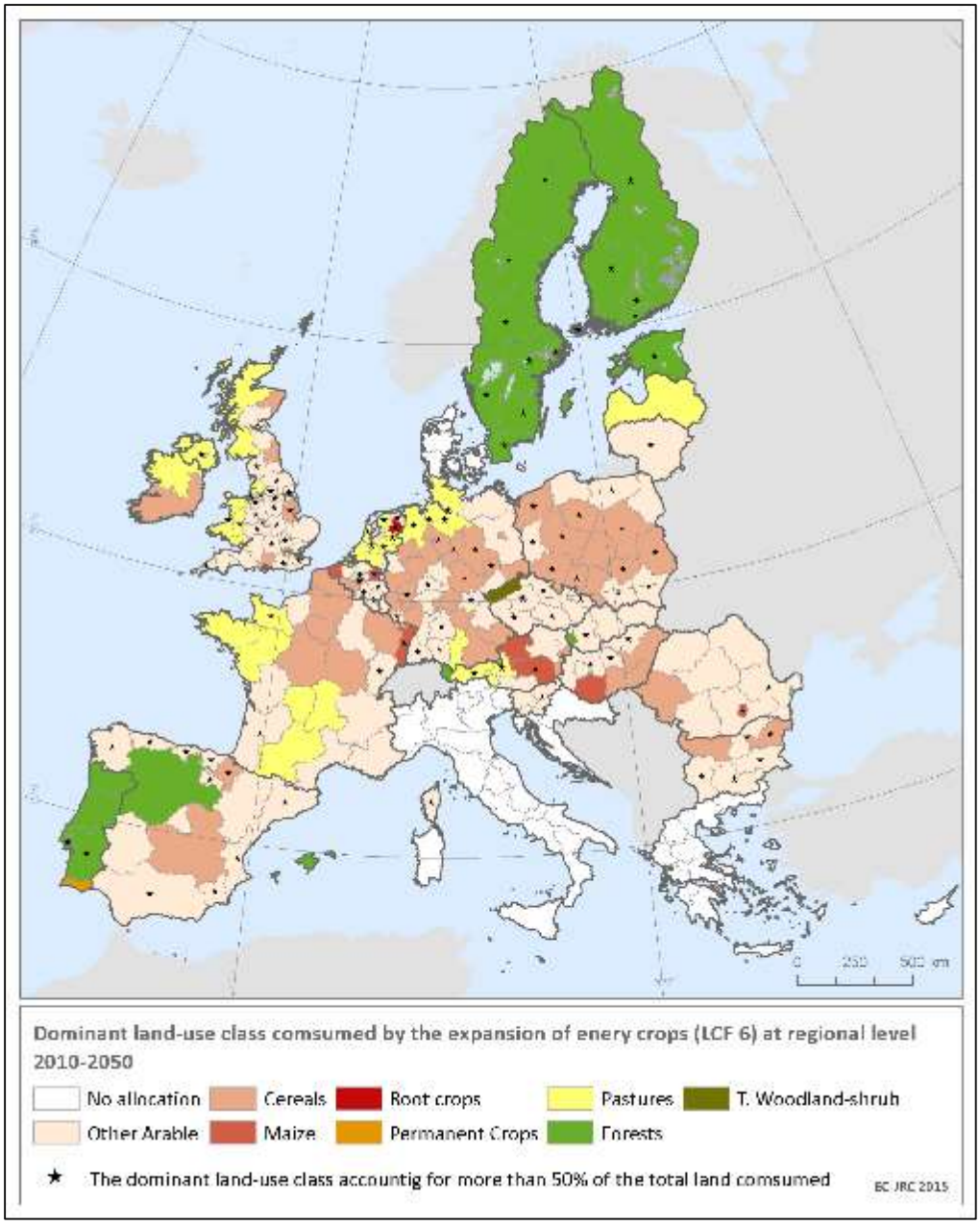


Figure 18. LCF 6 - Expansion of Energy Crops between 2010 and 2050 at NUTS 2 level in the EU-28.

Across Europe, in the majority of regions arable and cereals are the dominant land-use class taken by energy crop expansion. Only in a few regions in central Austria, southeast of Hungary, north of The Netherlands and Belgium root crops are the dominant crops consumed by energy crop production. On the other hand, all the regions in Finland, Sweden, Estonia, most of the regions in Portugal and some in Spain are ceding forest land for the same purpose. Pasture consumption in favour of energy crop expansion is taken place in Ireland, western parts of United Kingdom and Austria, northern parts of The Netherlands and Germany, Latvia and some regions scattered throughout France. Transitional woodland and permanents crops are rarely consumed for energy purpose.

It should be stressed that in some regions the dominant land-use class consumed owing to the expansion of energy crops have a considerable weight compared to the other ones, accounting for more than 50% of the total land consumed (this is symbolized in the map by an asterisk). This flow dominance in some regions can be due to that one land use is governing that region, that is, when the dominant LCF6 flow is from forests, this is probably because the dominant land-use is forest land as well. On the other hand, when the dominant land flows do not reach 50%, there might be an equality between two or three classes being used for energy purposes at the same time without a significant dominant pattern.

LCF 7 – Withdrawal of farming

The land-use/cover flow 'withdrawal of farming' refers to the conversion of active farmland (that is farmed for food and feed) to a non-active state, or to other semi-natural and natural covers, such as forest and natural land. Included conversions are:

- From land for food and feed classes (including permanent crops, pastures, maize, roots, cereals and other arable) to forest (through the abandonment land for food and feed);
- From land for food and feed classes (including permanent crops, pastures, maize, roots, cereals and other arable) to semi-natural vegetation (through the abandoned land for food and feed);
- From land for food and feed classes (including permanent crops, pastures, maize, roots, cereals and other arable) to natural grassland, moors and heat lands and sclerophyll vegetation (herein called natural land) (through abandoned arable, pastures and permanent crops);
- From other arable to abandoned arable;
- From other arable to abandoned permanent crops and abandoned pastures (through permanent crops and pastures respectively);
- From permanent crops to abandoned permanent crops;
- From permanent crops to abandoned arable and abandoned pastures (through other arable, maize and cereals and pastures respectively);
- From pastures to abandoned pastures;
- From pastures to abandoned arable and abandoned permanent crops (through other arable, maize and cereals and permanent crops respectively);

The dominant LCF within this group is the conversion from agricultural land to forest, which reaches 52,887 km^2, followed by the conversion to natural areas 578 km^2. This implies a net afforestation, hence likely to contribute to reduce GHG emissions, with uncertain biodiversity impacts depending on the kind of forest species and the kind of agricultural land management replaced. On the other hand, there is a clear evidence that land dedicated to food and feed is declining. Partially due to the abandonment of agricultural land (0.26%, 139 km^2), which are mostly re-used by the expansion of energy crops.

Around 7% of the land-use changes in EU -28 are expected to occur due to the withdrawal of farming between 2010 and 2050. According to the modelling results, the farmland abandonment will be particularly high in the Netherlands, Austria and Italy, where more than 20% of the land-use changes are due to withdrawal of farming (Figure 19).

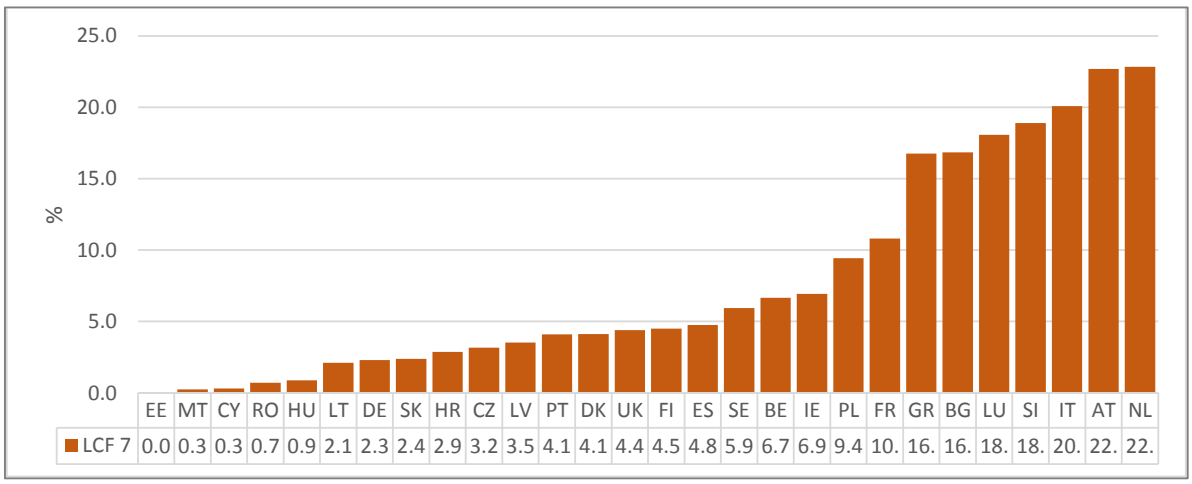


Figure 19. LCF 7- Withdrawal of farming between 2010 and 2050 at Member State level.

At regional level, the Austrian and Italian Alpine regions show the highest share of withdrawal of farming due to the conversion to forest and semi-natural land. In the Netherlands, the regions Gelderland and Friesland also shows high share, however in this case the withdrawal of farming is a consequence of the abandonment of productive crops (Figure 20).

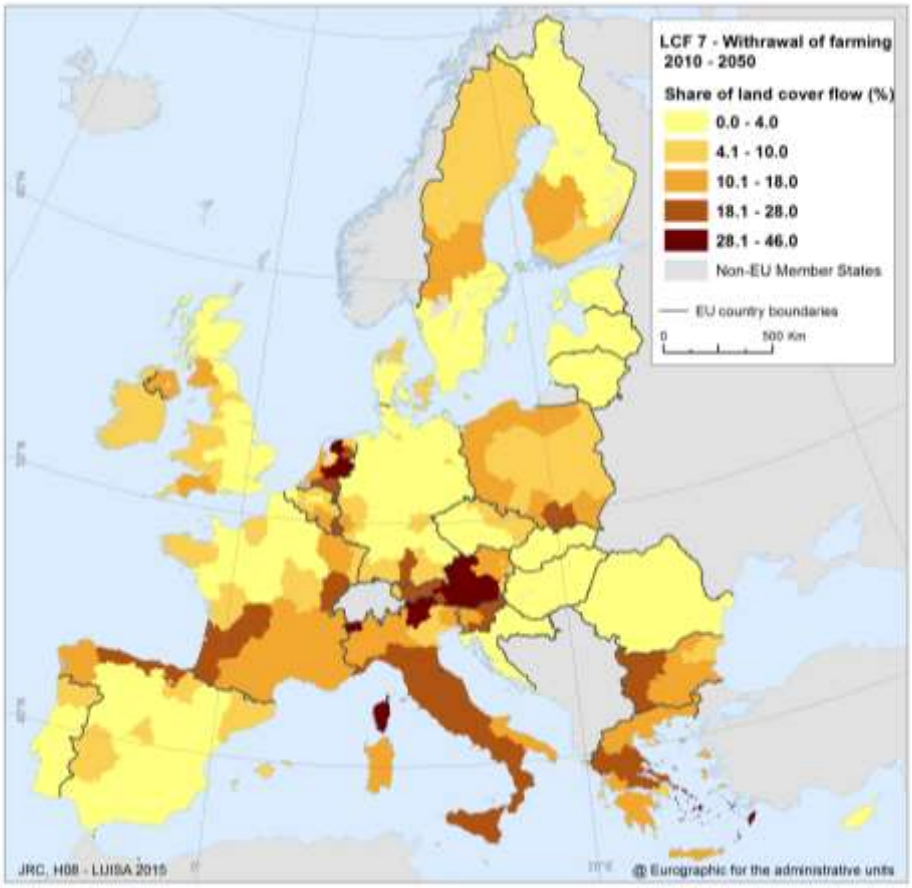


Figure 20. LCF 7 - Withdrawal of farming between 2010 and 2050 at NUTS 2 level in the EU-28.

LCF 8 – Forest creation and management

The land-use/cover flow 'forest creation and management' refers to the expansion of forest areas and comprises all the conversion from other land-uses to forest, in particular:

- From ICS sites to forest;
- From abandoned land for food and feed (including arable, permanent crops and pastures) to forest;
- From transitional woodland and shrub land to forest;
- From natural land to forest;

In the EU-28, the second largest land-use/cover flow is related with forest creation (around 18% of the total land-use changes) (Figure 1). In Croatia, afforestation is the main land-use/cover flow with a proportion of 51%. In Portugal, Latvia, Finland and Sweden an important proportion of land-use/cover flows are also associated to the afforestation of other land-uses (Figure 21).

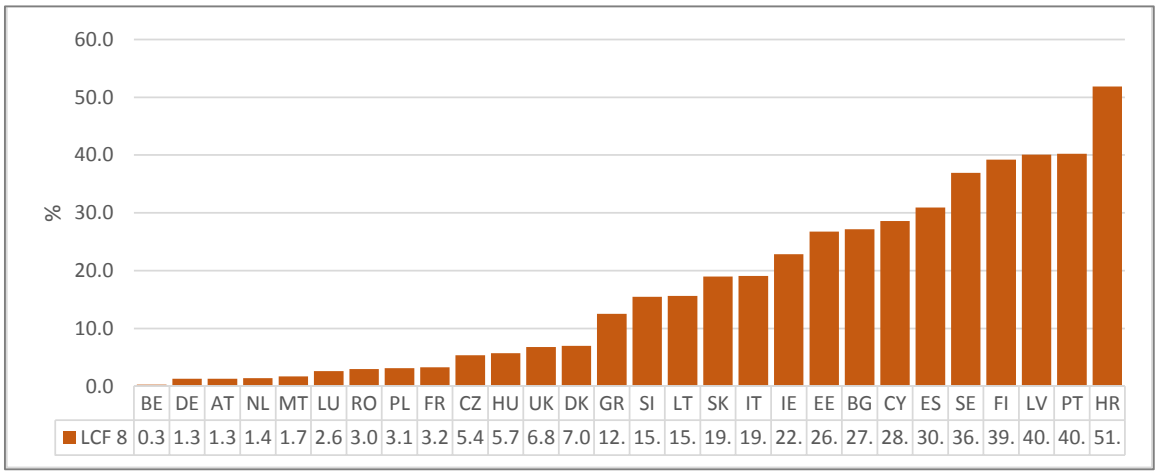


Figure 21. LCF 8 - Forest creation and management between 2010 and 2050 at Member State level.

The total formation of forest in EU between 2010 and 2050 is 61,680 km^2. The dominant LCF within the LCF8 group is the conversion from natural land to forest creation accounting for 99% (8,792 km^2) of the total land-use changes. This reflects a transitional natural process between natural lands being converted to forest lands. It should be mentioned at this stage that the agricultural land converted to forest, which reaches 52,887 km^2 is considered within the group LCF 7 (Withdrawal of farming) instead of forest creation, so that the dominance of transitional natural processes is not surprising. The creation of new forest areas can reduce GHG emissions. Forest canopy protect soils from erosion by water, thus it can contribute to erosion control in areas degraded by this phenomenon.

The LCF 'forest creation and management' is the dominant land cover flow in several EU-28 regions. The spatial distribution of 'forest creation and management' land cover flow shows clear patterns in the European territory. The largest share of forest creation land-

use/cover flow occurs, mostly in the regions located in the southern part of Europe, in the Scandinavian countries and United Kingdom (Figure 22).

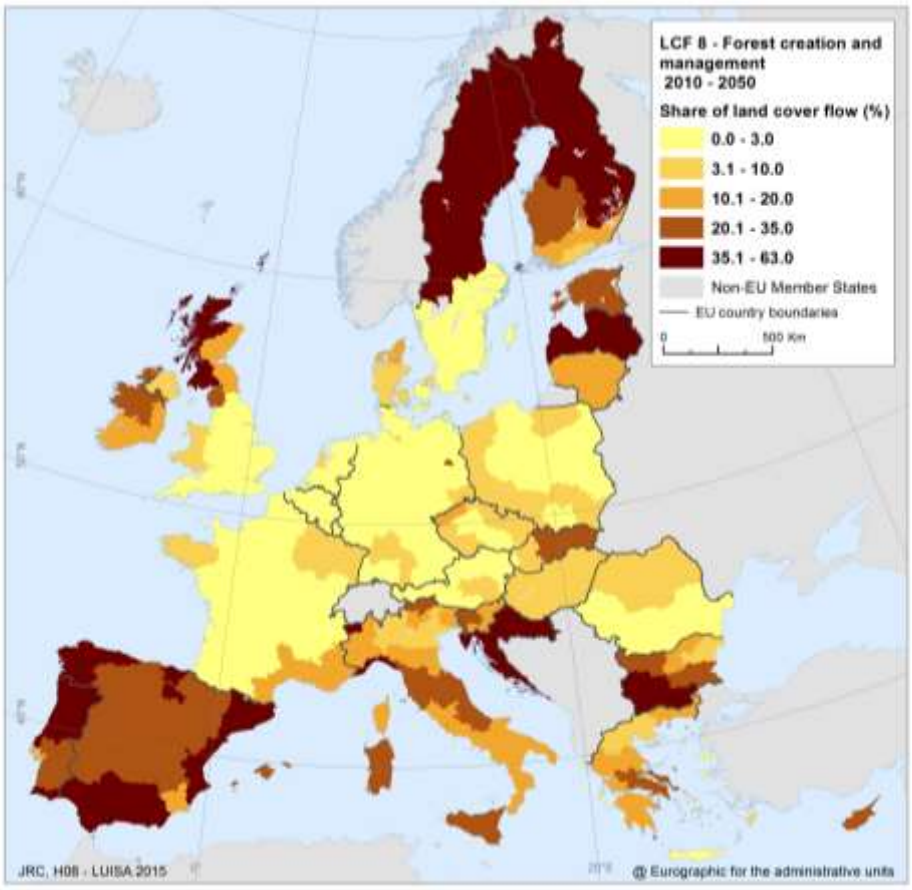


Figure 22. LFC 8 - Forest creation and management between 2010 and 2050 at NUTS 2 level in the EU-28.

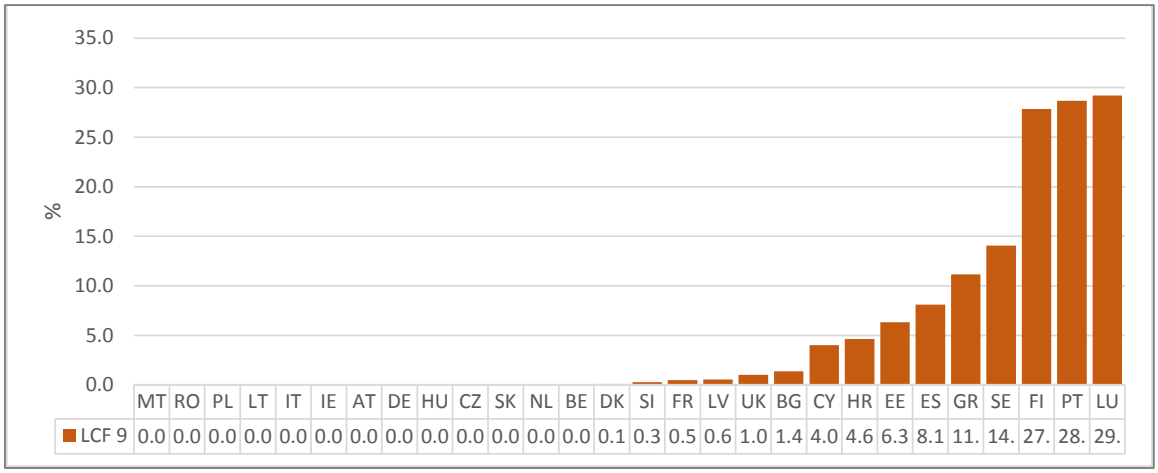
LCF 9 – Natural and semi-natural creation

The natural and semi-natural creation includes the following flows:

- From built-up areas to transitional woodland and shrubland (through abandoned urban and abandoned industrial areas) and natural land –unusual conversion;
- From abandoned industrial land to transitional woodland and shrubland (through abandoned urban and abandoned industrial areas) and natural land –unusual conversion;
- From forest to transitional woodland and shrubland and natural land;
- From abandoned land for food and feed (including abandoned arable, permanent crops and pastures) to transitional woodland and shrubland and natural land;

In the EU-28, almost 6% of the total land-use/cover flows are associated with the development of natural and semi-natural areas (Figure 1). This is a geographically very unevenly spread process. In the majority of the countries, very little or even none conversions from other land-uses to natural and semi-natural vegetation between 2010 and 2050 are expected. The exceptions are Luxemburg, Portugal, Finland, with the latter showing the highest proportion of land conversions from other land-use/covers to natural

and semi-natural vegetation (more than 25% of the total land-use/cover flows) (Figure 23).



	MT	RO	PL	LT	IT	IE	AT	DE	HU	CZ	SK	NL	BE	DK	SI	FR	LV	UK	BG	CY	HR	EE	ES	GR	SE	FI	PT	LU
LCF 9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.6	1.0	1.4	4.0	4.6	6.3	8.1	11.	14.	27.	28.	29.

Figure 23. LCF 9 - Conversions to natural and semi-natural vegetation between 2010 and 2050 at Member State level.

Similar to the previous LCF the spatial patterns shows high flows in the northern and southern parts of Europe. This conversion is particularly high in the southern part of Portugal (Alentejo and Algarve regions) and Pohjois- ja Itä-Suomi (Finland) (Figure 24).

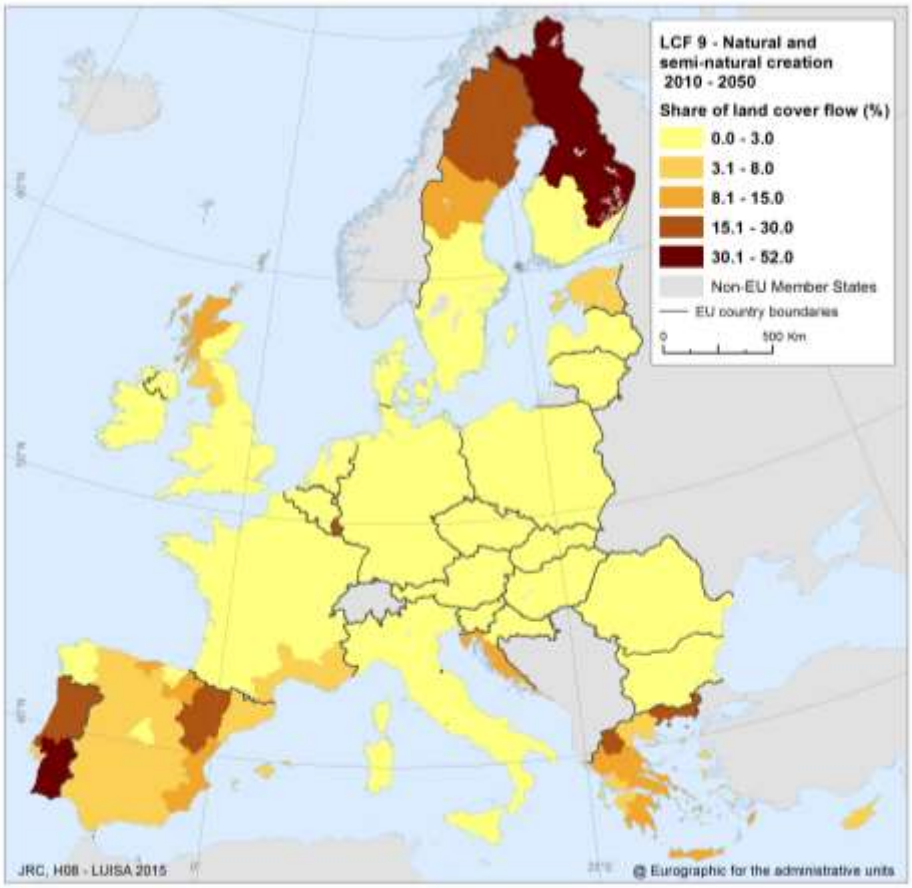


Figure 24. LCF 9 - Natural and semi-natural creation between 2010 and 2050 at NUTS 2 level in the EU-28.

4. Conclusions and remarks

This document presents the results of the analysis of land stocks and flows account at European level for the EU Energy Reference Scenario, as implemented in the LUISA platform. The analysis also shows the most recurrent (dominant) LCFs at regional level. It provides further details on which specific land-use changes are projected to take place. The land account exercise answers the following questions:

What are the main land transformations occurring between 2010 and 2050 under the EU Reference scenario? What are the main processes that triggered the flows between the different land –use/ covers?

- The extent of the land for housing and leisure (urban) and industrial/commercial and services (ICS) increases, while the area of agriculture, forest and natural land decreases;
- Urban and industrial land are expected to represent the highest share of net formation as % of the initial year (2010); in order to reduce the impact of the urban expansion and avoid associated environmental problems, urban expansion should be slowed down and more incentives on 'land recycling' (internal transformations, 'brownfield development') should be created.
- Energy crops appear in the model as of 2020 and 30 years later, they are expected to reach 135,479 km^2 across Europe;
- Energy crops become the second most important land transformation in Europe (17%); approximately 90 % of the land consumed for energy purposes comes from land for food and feed, followed by forest and natural land;
- While a large proportion of land dedicated to food and feed crops is expected to be converted into dedicated energy crops, the net land losses are very small as a results of the conversion from forest land into food and feed production;
- New forest and natural land compensate in some way for quantity of losses or consumption by other uses; however the high value of the turnover indicator, reveal that those land-uses are unstable and vulnerable to the fast changes driven by economic development and climate changes, thus compromising the biodiversity and habitat conservation status;
- The conversion between farming types represent 35% over the total land changes between 2010 and 2050;

The results thus clearly show the loss of natural and agricultural land because of ever ongoing urbanisation and industrialization processes. The loss of natural and agricultural land for food production is even larger because of the advent of energy crops production incited by shifts in the European Energy supply system.

Other steps in the analysis focus on the potential impacts that the loss of agricultural and natural land might have on the provision of ecosystem services and food. The analysis aims to pinpoint to what degree the changes foreseen here may deteriorate those relevant societal functions of European lands.

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List of abbreviations and glossary

Abbreviations

CAP	Common Agricultural Policy of the European Union
EU28	European Union (28 countries)
ENCR	(Dedicated) Energy Crops
GDP	Gross Domestic Product
GHG	Green House Gases
GVA	Gross Value Added
ha	Hectares
kha	Thousands of hectares
ICS	Industry, Commerce and Services
LCF	Land Cover/use Flows
LUISA	Land Use-based Integrated Sustainability Assessment modelling platform
MS	Member State
NUTS	Nomenclature of Territorial Units for Statistics

Glossary

This glossary defines the terminology used in the following technical reports listed below. All the concepts and corresponding definitions are coherent with the LUISA modelling platform configuration, as from Baranzelli et al. (2014).

Baranzelli, C., Perpiña Castillo, C., Lavalle, C., Pilli, R., Fiorese, G. (2014). Evaluation of the land demands for the production of food, feed and energy in the updated Reference Configuration 2014 of the LUISA modelling platform. Methodological framework and preliminary considerations. EUR 27018 EN. Luxemburg: Publication Office of the European Union

Abandoned land

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.

Abandoned land is land in a not productive state, which can be reclaimed back to the original use or possibly converted to other uses, in case demand for such uses be.

Agricultural land

Land that is used for the allocation of other arable land, permanent crops, pastures and energy crops.

Available land

Land available for the production of energy crops is land that, if need be, can be converted from a pre-existing use or cover (e.g. food and feed production, shrub land, etc.) to the

cultivation of dedicated energy crops. The only simulated land uses considered not available for being converted to dedicated energy crops, are urban and industrial.

Built-up

Aggregated land use class, including land used for residential and industry/commerce/services uses. Built-up land constitutes a subset of the total artificial areas, which include transport infrastructures as well.

Degraded and contaminated land

Land affected by contamination and, in general, degradation processes that affect its quality. In particular, the following categories are identified: soils with high/medium saline concentration, soils affected by severe erosion, and soil contaminated by heavy metals. All these categories are considered potentially suitable for the expansion of energy crops.

Energy crops

Crops dedicated to production of energy. This category comprehends non-food, lignocellulosic crops, belonging to the 2nd generation feedstock. Species included are both herbaceous and woody: miscanthus, switchgrass, reed canary, giant reed, cardoon, willow, poplar and eucalyptus.

Food and feed crops

Crops used for the production of food and feed, grouped in: cereals, maize, root crops and other arable. The specific agricultural commodities included in each of these groups are determined by the CAPRI model.

Forest

Forest land is simulated as a unique land cover class, encompassing the categories conifers, broadleaves and mixed forests.

Indirect land use change (ILUC)

Dedicated energy crop production typically takes place on cropland which was previously used for other agriculture such as growing food or feed. Since this agricultural production is still necessary, it may be partly displaced to previously non-cropland such as grasslands and forests. This process is known as indirect land use change (ILUC).

Industry/commerce/services land

Land that is used for industrial activities, commerce and services.

Land use/cover flow

Land use refers to the purpose that the land serves, such as recreation, wildlife habitat or agriculture, without the need to describe the surface cover present on the ground. For example, a recreational type of land use could occur in a forest, shrub land, grasslands or on manicured lawns.

Land cover refers to the surface cover on the ground, be it vegetation (natural or planted), urban infrastructure, water, bare soil or other. For instance, forest, as land cover may be used for timber production, wildlife management or recreation.

Land use/cover flows refers to transfers (gains and losses) of land area between different use/cover types.

Land-use allocation

It is the spatial distribution of the land among different functions, assuming the land requirements dictated by macro drivers and modelled by specialised sector models. The spatial allocation mechanism is based on a multinomial discrete choice method and it is

governed by local biophysical suitabilities, socio-economic and neighbourhood factors, land-use transition rules and policy constraints/incentives.

Land demand

Also referred to as land claim and land requirement, it is the amount of land that, in a specific geographical context (national or sub-national) and in a given year of the simulation horizon, is demanded/claimed/required in order to satisfy the assumed economic and demographic projections.

Land take

The area of land that is taken by artificial uses, such as residential buildings and supporting infrastructures/services, industry/commerce/services, and transport infrastructures and supporting areas.

Natural land

Natural land comprises transitional woodland-shrub, forest and other natural lands. This last group, in turn, includes scrub and/or herbaceous vegetation associations, natural grassland, moors and heathland and sclerophyllous vegetation.

Suitability of the land

The biophysical suitability of the land to be cultivated for the production of food and feed crops (cereals, maize, root crops and other arable) and energy crops.

Each crop mentioned above has a dedicated suitability layer, whose main components are related to soil characteristics, climate, current agricultural patterns and potential application of fertilisers. Each of these suitability layers is expressed on a scale from 0 – not suitable, to 1 – very suitable.

Urban land

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.

List of Figures

Annex A: Land-use/cover flows methodology

The information presented in this report is organized in an accounting framework presented in the ' Land Accounts for Europe ' - European Environmental Agency report (EEA, 2006). The 'land accounts' approach is a systematic way to report the stock and changes, and the processes that have resulted in the flows across the land-use/cover.

The analysis of the land-use/cover changes under the Reference Scenario is fundamental to understand the implications of the energy target on the land functions.

The classification of land-use changes at Member State and Regional level (NUTS 2) was derived in three steps:

1. **Land-use/cover flows codes raster**: each land-use category has a code associated, which in LUISA goes from 1 to 22 land-use types (Table 1 in Annex A); this step aims combining the codes of the two projected land-use maps (at grid level) so that a unique output value is assigned to each unique combination of input values, e.g. if other arable (code 3) is converted into forest (code 6), this LCF will be coded as '36'; the land-use maps derived from LUISA has 17 modelled land-use categories (Table 1 from Annex A) which produce 200 possible pairings of all potential initial and final land-use categories (Table 2, Annex A); the final output is a raster with 100 m^2 classified in 200 possible LCF;
2. **Aggregation of the LCF at regional and member state (MS) level:** in order to derive the LCF per regions and MS, the LCF raster was cross tabulated with the NUTS 2 and NUTS 0 administrative units; the results of this process is a table which summarize the amount of land in each LCF per region or member state.
3. **Group the LCF into 9 major categories of change:** in order to handle the matrix easily, the changes were aggregated into 9 major categories of changes; the output of this process is the share of each LCF over the total changes (in percentage) presented in the graphic format at MS level and maps at regional level.

The major types of land transformation are:

- LCF 1 – Urban internal transformations of urban areas;
- LCF 2 – Urban residential expansion: land uptake by urban residential (including residential, sport and leisure facilities) from non-urban land;
- LCF 3–Expansion of economic related activities: land uptake by new industrial/commercial/services (ICS) land from non–urban land;
- LCF 4 – Internal conversions of land dedicated to food and feed: conversions between farming types (arable, permanent crops and pastures);
- LCF 5 – Expansion of land for food and feed: conversion from forested and natural and semi-natural land to land for food and feed;
- LCF 6 – Expansion of dedicated Energy Crops (ECR): conversions from other land-uses to land used for the express purpose of producing energy;
- LCF 7 – Withdrawal of farming: refers to the farmland abandonment and other conversions from agriculture activity in favour of forests or natural land ;
- LCF 8 – Forest creation and management: refers to the expansion of forest areas and comprises all the conversion from other land-uses to forest;
- LCF 9 - Natural and semi-natural expansion/creation

Table A 1. LUISA land-use/cover categories codes, names, direct correspondence with CLC classes, modelled classes.

Code	*name*	*Direct correspondence with Corine Land Cover classes*	*Modelled*
1	Urban	*YES*	*YES*
2	Industry	*YES*	*YES*
3	Other Arable	*YES*	*YES*
4	Permanent Crops	*YES*	*YES*
5	Pastures	*YES*	*YES*
6	Forests	*YES*	*YES*
7	Transitional woodland-shrub	*YES*	*YES*
8	Cereals	*NO*	*YES*
9	Maize	*NO*	*YES*
10	Root crops	*NO*	*YES*
11	Abandoned Arable Land	*NO*	*YES*
12	Abandoned Permanent Crops	*NO*	*YES*
13	Abandoned pastures	*NO*	*YES*
14	Abandoned Urban	*NO*	*YES*
15	Abandoned Industry	*NO*	*YES*
16	Energy Crops	*NO*	*YES*
17	Natural land	*YES*	*YES*
18	Infrastructure	*YES*	*NO*
19	Other Nature	*YES*	*NO*
20	Wetlands	*YES*	*NO*

21	Water Bodies	*YES*	*NO*
22	Urban green leisure	*YES*	*NO*

Table A 2 – Classification of land-use/cover flows.

Code	Land Cover flow category description	From	to	LCF CODE
LCF 1	Urban Internal transformation	1	2	12
		1	14	114
		1	15	115
		2	1	21
		2	15	215
		3	14	314
		3	15	315
		4	14	414
		4	15	415
		5	14	514
		5	15	515
		6	14	614
		6	15	615
		7	14	714
		7	15	715
		8	14	814
LCF 2	Urban residential Residential expansion	6	1	61
		7	1	71
		8	1	81
		3	1	31
		5	1	51
		10	1	101
		9	1	91
		17	1	171
		4	1	41
		15	1	151
		16	1	161
		11	1	111
		13	1	131
		12	1	121
LCF 3	Sprawl of economic sites	6	2	62
		15	2	152

		8	15	815
		9	14	914
		9	15	915
		10	14	1014
		10	15	1015
		11	15	1115
		12	15	1215
		13	15	1315
		17	15	1715

		17	2	172
		7	2	72
		8	2	82
		3	2	32
		5	2	52
		9	2	92
		10	2	102
		4	2	42
		13	2	132
		12	2	122
		11	2	112

Code	*Land Cover flow category description*	From	to	LCF CODE
LCF 4	**Internal conversions of land dedicated to food and feed**	4	3	43
		5	3	53

Code	*Land Cover flow category description*	From	to	LCF CODE
LCF 4	**Internal conversions of land dedicated to food and feed**	4	8	48
		5	8	58

		8	3	83
		9	3	93
		10	3	103
		11	3	113
		12	3	123
		3	4	34
		5	4	54
		8	4	84
		9	4	94
		10	4	104
		11	4	114
		12	4	124
		13	4	134
		3	5	35
		4	5	45
		8	5	85
		9	5	95
		10	5	105

		9	8	98
		10	8	108
		3	9	39
		4	9	49
		5	9	59
		8	9	89
		10	9	109
		3	10	310
		4	10	410
		5	10	510
		8	10	810
		9	10	910
		13	11	1311
		13	12	1312
		11	12	1112
		11	13	1113
		12	11	1211
		12	13	1213

		11	5	115
		12	5	125
		13	5	135
		3	8	38

Code	*Land Cover flow category description*	From	to	LCF CODE
LCF 5	Conversion from other land cover to agriculture	1	5	15
		2	3	23
		2	4	24
		2	5	25
		2	8	28
		2	9	29
		2	10	210
		6	3	63
		6	4	64
		6	5	65

Code	*Land Cover flow category description*	From	to	LCF CODE
LCF 5	Conversion from other land cover to agriculture	15	10	1510
		17	3	173
		17	4	174
		17	5	175
		17	8	178
		17	9	179
		17	10	1710
LCF 6	Conversion from other land cover to New Energy Crops	1	16	116
		2	16	216
		3	16	316

		6	8	68
		6	9	69
		6	10	610
		7	3	73
		7	4	74
		7	5	75
		7	8	78
		7	9	79
		7	10	710
		15	3	153
		15	4	154
		15	5	155
		15	8	158
		15	9	159

Code	*Land Cover flow category description*	From	to	LCF CODE

		4	16	416
		5	16	516
		6	16	616
		7	16	716
		8	16	816
		9	16	916
		10	16	1016
		11	16	1116
		12	16	1216
		13	16	1316
		14	16	1416
		15	16	1516
		17	16	1716

Code	*Land Cover flow category description*	From	to	LCF CODE

LCF7	Withdrawal of farming	3	6	36
		3	7	37
		3	11	311
		3	12	312
		3	13	313
		3	17	317
		4	6	46
		4	7	47
		4	11	411
		4	12	412
		4	13	413
		4	17	417
		5	6	56
		5	7	57
		5	11	511
		5	12	512
		5	13	513

LCF 7	Withdrawal of farming	9	6	96
		9	7	97
		9	11	911
		9	12	912
		9	13	913
		9	17	917
		10	6	106
		10	7	107
		10	11	1011
		10	12	1012
		10	13	1013
		10	17	1017

		5	17	517
		8	6	86
		8	7	87
		8	11	811
		8	12	812
		8	13	813
		8	17	817

Code	*Land Cover flow category description*	From	to	LCF CODE
LCF 8	**Forests creation and management:**	2	6	26
		7	6	76
		11	6	116
		12	6	126
		13	6	136
		17	6	176
LCF 9		1	7	17

	Natural and semi-natural creation	2	7	27
		6	7	67
		11	7	117
		13	7	137
		15	7	157
		17	7	177
		1	17	117
		2	17	217
		6	17	617
		7	17	717
		11	17	1117
		12	17	1217
		13	17	1317
		15	17	1517

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