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Indicators Engineering for Land Uptake and Agricultural Loss. A Study in European Countries

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Abstract

Soil and its associated ecosystem services are indispensable resources for human survival on the planet. Current models of economic and social development exert unprecedented pressures and demands on the land, creating an unsustainable imbalance. The objective of this work is to assess the land use changes that have occurred in EU countries from 1990 to 2018 through CORINE Land Cover. Particular attention has been paid to the urban conversion of soils to agricultural use, as primary production represents one of the most tangible ecosystem services provided by soils, the quantification of which is complex due to the synergistic effect between them. The study has analyzed and evaluated the agricultural losses resulting from urbanization for all EU countries and produced an economic estimate of these losses. The results show that the prevailing transformations are those of anthropogenic origin and in particular urbanization at the expense of agricultural areas, although with different drive forces in the various countries. The importance of knowing the extent of this phenomenon lies in the possibility of implementing targeted corrective actions aimed at limiting, mitigating and compensating the effects of anthropogenic soil transformations.

Keywords

Land Uptake, Agricultural Loss, Urban Areas, Indicators Engineering

1. Introduction

Soil is an extremely important resource that is not rapidly renewable and is vital for our health and the economy, as well as for the production of food and new medicines (Foley et al., 2005; European Commission, 2020). Sustainable land use is the foundation of all UN Sustainable Development Goals (SDGs). Indeed, in order to achieve the 17 SDGs, including those of the social and economic nature, intact soils capable of delivering essential ecosystem services are indispensable (Folke et al., 2016). As highlighted by the European Commission in the EU Biodiversity Strategy 2030: "in the EU, the degradation of soil is having considerable environmental and economic consequences. Poor land management, such as deforestation, overgrazing, unsustainable farming and forestry practices, construction activities and land sealing are among the main causes of this situation." Therefore, soils must be managed in a way that preserves their potential to provide goods and services. These services are lost or weakened due to the pressure generated by certain factors such as the climate crisis, water pollution, atmospheric pollution (Agrawal, 2005; Emberson et al., 2003; Ruddock & Lopes, 2006) and soil pollution (Ashraf et al., 2010; Levers et al., 2018; Falcucci et al., 2007), the abandonment of the countryside and urban conversion is defined as "the total or partial replacement of the land cover with consequent loss of the original function" (Prokop et al, 2011; EEA, 2017; Munafò, 2021). This study identifies prevailing landscapes and land use transformations in order to investigate the phenomenon of urban land conversion at both European and national scales. Specifically, two macro-types of landscape-environmental mosaics have been identified: the first includes areas with a predominantly anthropogenic physiognomy that tend to be more "managed", while the second includes areas of greater environmental or transition quality and much less regulated by planning forms. The areal changes that have occurred over time are not always been regulated. In some cases which are spontaneous and influenced by the market, economic crises and local or global events without specific control (Zanfi, 2013; Romano et al., 2018). The diachronic assessment of urban soil conversion has made it possible to estimate, also in economic terms, the loss of one of the main ecosystem services: agricultural production. Estimating the loss of ecosystem services in quantitative terms, even more so in economic terms, is a complex task; one of the reasons is the synergistic effect between them. Taking this into account, the study produced an assessment of the equivalent agricultural loss in Europe between 1990 and 2018. The results made it possible not only to identify the extent of the phenomenon but also to take appropriate measures aimed at mitigating the effects of anthropogenic soil transformations.

2. Materials and Methods

The study analyzed the territories of the United Kingdom and the EU Member States minus the countries of Malta, Luxembourg and Cyprus. Specifically, the analysis covered, as shown in **Figure 1**, the European continental areas and in the case of island states only the major ones. Starting from the 44 land cover categories defined by the European classification proposed in the Corine Land Cover (CLC) (Büttner, 2014; Bossard et al., 2000), excluding maritime environments, six

Country	Study area [kmq]	Inhabitants 2018
European Union	4360128	510430058
Austria	83944	8822267
Belgium	30664	11398589
Bulgaria	110994	7050034
Croatia	53333	4105493
Czech Republic	78873	10610055
Denmark	41501	5781190
Estonia	41190	1319133
Finland	332957	5513130
France	539649	66918941
Germany	355746	82792351
Greece	110094	10741165
Hungary	93009	9778371
Irish Republic	69474	4830392
Italy	250394	60483973
Latvia	64587	1934379
Lithuania	64801	2808901
Netherlands	36236	17181084
Poland	311878	37976687
Portugal	88735	10291027
Romania	238362	19530631
Slovakia	49024	2066880
Slovenia	20272	5443120
Spain	493461	46658447
Sweden	442297	10120242
United Kingdom	232856	66273576

Figure 1. Study area and demographic characteristics.

European Landscape Macrosystems (ELM) consisting of artificial areas covered by urbanisation (U), intensive agriculture (IA), extensive agriculture (EA), forests (F), natural and semi-natural areas (SN) and water bodies (W) were extracted. In most cases the assignment is quite automatic, while some clarifications must be made for the inclusion of CLC categories "221", "222", "223" in the ELM "IA" or "EA". These types of land use have different connotations, however for the first two AIs prevail, while EAs predominate for the last one. The ELM mosaics (Table 1) were then grouped into two macrosystems: ELM^ = (U + IA + EA) and ELM* = (F + SN + W) with ELM^ comprising mosaics with predominantly terrestrial artificialization and ELM* those with the most important areas in terms of ecological-environmental quality and connection between ecosystems. It is useful to recall that urbanised areas are defined as those intended for urban functions, replacing or maintaining natural soil. They therefore include built-up land and land used for ancillary functions of the settlement, such as public and private gardens, sports facilities, dirt roads and other service areas, excluding the suburban road network.

Data comes from several sources. Those relating to territorial units (NUTS: Nomenclature des Unités Territoriales Statistiques) and demographic data come from the portal of the Statistical Office of the European Union (https://ec.europa.eu/eurostat/, 2020). The geographical dataset of the territorial units is at a scale of 1:1M. This dataset is mainly derived from EuroBoundary Map v 2020 (Eurogeographics, Reference Date 2018.12.31) and was obtained by

Table 1. Cluster of ELM systems obtained from CLC categories.

ELM macrosystem	ELM system	CLC code	CLC categories
ELM^	U	111	Continuous urban fabric
		112	Discontinuous urban fabric
		121	Industrial or commercial units
		122	Road and rail networks and associated land
		123	Port areas
		124	Airports
		131	Mineral extraction sites
		132	Dump sites
		133	Construction sites
		141	Green urban areas
		142	Sport and leisure facilities
	IA	211	Non-irrigated arable land
		212	Permanently irrigated land
		213	Rice fields
		221	Vineyards
		222	Fruit trees and berry plantations
	EA	223	Olive groves
		231	Pastures
		241	Annual crops associated with permanent crops
		242	Complex cultivation patterns
		243	Land principally occupied by agriculture, with significant areas of natural vegetation
		244	Agro-forestry areas
ELM*	F	311	Broad-leaved forest
		312	Coniferous forest
		313	Mixed forest
	SN	321	Natural grasslands
		322	Moors and heathland
		323	Sclerophyllous vegetation
		324	Transitional woodland-shrub
		331	Beaches, dunes, sands
		332	Bare rocks
		333	Sparsely vegetated areas
		334	Burnt areas
		335	Glaciers and perpetual snow
	W	411	Inland marshes
		412	Peat bogs
		421	Salt marshes
		422	Salines
		423	Intertidal flats
		511	Water courses
		512	Water bodies
		521	Coastal lagoons
		522	Estuaries

generalisation of the 1:100K scale. Land cover data is derived from Corine Land Cover (CLC), a project that began in 1985 (base year 1990) with updates produced in 2000, 2006, 2012 and 2018. The dataset, from the Copernicus project portal (https://land.copernicus.eu/pan-european/corine-land-cover, 2020), is based on the classification of land cover/land use from satellite imagery through semi-automatic procedures. The standard division into 44 classes is divided into 3 levels. Minimum Mapping Unit (MMU) is 25 ha for areal phenomena and 100 m for linear phenomena (MMW). The time series is completed by change layers (CHA) with MMU 5 ha. Data for agricultural loss assessments such as national wheat yields between 1990 and 2018, national annual wheat production and import data for the year 2018, come from the Food and Agriculture Organization (FAO) of the United Nations portal, http://www.fao.org/faostat/en/#data/QC). Agricultural yields, expressed per hectare (ha), are values calculated by noting the annual production (tonnes/year) of dry cereals and the area actually harvested. National selling prices for wheat (absolute prices expressed in €/100 kg of harvest) were found on the Eurostat website in the agriculture section, minus the figure for France and Ireland. For the latter, this information comes from the FAO portal. The time reference for all statistics is a calendar year.

Given the plurality of variables and the extent of the data to be processed, a set of indices was structured to allow rationalisation of the information and a clear and effective view of the phenomena studied. The definitions of the indices used are schematically shown in **Table 2**. Density (Urban Density and Agricultural Density) expresses as a percentage the area of a given system over the total territory in a given reference year. The Urban Variation Ratio makes it possible to analyse diachronically the variation of urban areas in a given territory while the urban conversion rate (UCS expressed in km2/y) makes it possible to detect the energy of the studied phenomenon. In addition, the extent to which each of the six landscape systems has been affected by land-use transitions was also investigated at national level. For the latter, reference was made to 3 categories: areas with higher biopermeability (ELM*), urban areas (U) and agricultural areas (A). For the evaluation of the lost equivalent agricultural production, change layers were used, with reference to two periods (1990-2000 and 2000-2018) and, specifically, the transformations of the AI and EA systems into the U system defined in **Table 1** were considered. For each state, the agricultural land converted for urban purposes was associated with the agricultural yield of wheat in order to obtain the equivalent potential loss (CPL in **Table 2**) and thus, taking into account the population, also the lost production per capita (LPC in **Table 2**). It should be noted that the demographic data refers to the entire national territory, while the land consumption data only refers to continental areas. The agricultural yield used is specific to each country and is obtained as the average value of the agricultural yields of national soils cultivated with wheat and refers to the years 1990 to 2018. For the assessment of the economic loss, the average price to the seller for the year 2018 was combined with the Crop Production Potential Loss. In addition, European countries have been grouped by geographical area, the breakdown of which is shown in Table 3.

Table 2. Main indices used.

Main indexes	
Urban density $UD_t = \frac{SurU_t}{A_r}[\%]$	$SurU_t$ = urban surface area at time t A_r = reference surface area
Urban variation ratio $UVR_{t_1-t_2} = \frac{SurU_{t_2} - SurU_{t_1}}{SurU_{t_1}}[\%]$	$SurU_t$ = urban surface area at time t
Urban conversion speed $UCS_{t_1-t_2} = \frac{SurU_{t_2} - SurU_{t_1}}{n}\left[\frac{\text{kmq}}{\text{year}}\right]$	$SurU_t$ = urban surface area at time t n = number of years between t_1 and t_2
Agriculture density $AD_t = \frac{SurA_t}{A_r}[\%]$	$SurA_t$ = agriculture surface area at time t A_r = reference surface area
Crop production potential loss $CPL_{t_1-t_2} = \Delta Sur_{A-U} * \overline{Y}_{wheat}\left[\frac{\text{tonne}}{\text{year}}\right]$	ΔSur_{A-U} = land take from agriculture areas between t_1 and t_2 $\overline{Y}_{wheat}$ = mean yield for wheat
Lost crop production per capita $LCP_{t_1-t_2} = \frac{CPL_{t_1-t_2}}{Pop_t}\left[\frac{\text{tonne}}{\text{year} * \text{inhab.}}\right]$	$CPL_{t_1-t_2}$ = Crop production potential loss Pop_t = inhabitants at time t

Table 3. Geographical subdivisions adopted.

Countries				
Eastern Europe	**Western Europe**	**Northern Europe**	**Central Europe**	**Southern Europe**
Bulgaria	Austria	Belgium	Austria	Bulgaria
Croatia	Belgium	Denmark	Czech Republic	Croatia
Czech Republic	Denmark	Estonia	France	Greece
Estonia	Finland	Finland	Germany	Italy
Hungary	France	Irish Republic	Hungary	Portugal
Latvia	Germany	Latvia	Poland	Romania
Lithuania	Greece	Lithuania	Slovakia	Spain
Poland	Irish Republic	Netherlands	Slovenia	
Romania	Italy	Sweden		
Slovakia	Netherlands	United Kingdom		
Slovenia	Portugal			
	Spain			
	Sweden			
	United Kingdom			

3. Result

Processing the status layers of the CORINE data shows that in 2018, almost half of the European territory was occupied by agricultural areas (27% IA and 19% EA), about one third by forests (32%) and the remainder by semi-natural environments (12%), water bodies (5%) and urbanised areas (5%). Since 1990 the coverage values have followed a negative trend for EA, IA and SN to the benefit of the remaining landscape systems as shown in **Table 4**.

About 50% of the exclusively man-made (U) system belongs to four countries: Germany, France, the United Kingdom and Poland; the other 50% is accounted for by the remaining 21 countries. For the period 2000-2018, the average European urban conversion rate (UCS) was 1790 km^2/y, which means that every year an average area equal to that of the city of London (the third largest European city) has been urbanised, thus reaching 32,200 km^2 urbanised in 18 years, an extension equal to that of Belgium and Luxembourg. Looking at Western Europe alone, the conversion rate for the period 2000-2018 was 1376 km^2/y, which is more than twice as high as the corresponding rate for Eastern Europe of 414 km^2/y.

The UD (Urban Density) value for 2018 exceeded the European average (5.03%) in 13 countries and the highest values, in all chronological sections, were recorded in the countries of north-western Europe with a peak for Belgium, which already in the 1990 s stood at 20%. On the contrary, as shown in **Figure 2**, the lowest values were reached by Sweden and Finland. The biggest change is in the Netherlands, which has increased from 10.1% to 14.7% in about 30 years. An analysis of the UVR (Urban Variation Ratio) between 2000 and 2018 shows that Spain has increased its urban areas by about 3/5, a trend followed in Eastern Europe by Poland and Latvia. As far as agricultural areas are concerned, it appears that, on average in 2018, about 45.5% of the national territories were used for agricultural purposes and the analyses carried out show a progressive although weak annual decrease of −1.5‰ on average. Also in 2018, as shown in **Figure 3**, 14 countries had an AD heat index higher than the European average with more than 50% of the land used for this purpose, 9 showed an AD greater

Table 4. Trend of European landscape systems from 1990 to 2018 (for 1990, data for the United Kingdom, Finland and Sweden are not available).

	1990	2000	2006	2012	2018
U	4.34	4.27	4.65	4.97	5.03
IA	32.25	26.93	27.13	26.96	26.98
EA	23.61	20.13	19.03	18.77	18.68
F	26.84	31.31	31.67	32.43	32.50
SN	10.88	12.79	12.62	11.95	11.90
W	2.07	4.57	4.90	4.91	4.91

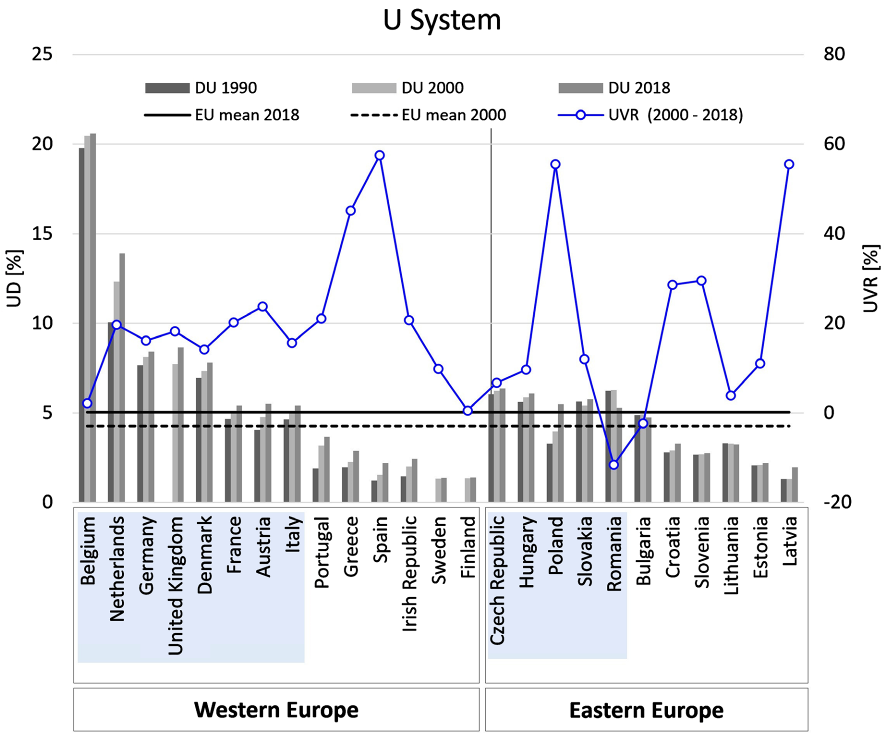

Figure 2. Trend of Urban Landscape Macrosystem in European countries (1990-2018). Urban density (UD) in European countries for 1990, 2000 and 2018 (bars). The horizontal black line represents the European average value for 2000 (dotted line) and for 2018 (continuous line). The countries highlighted in light blue exceed the European 2018 UD.

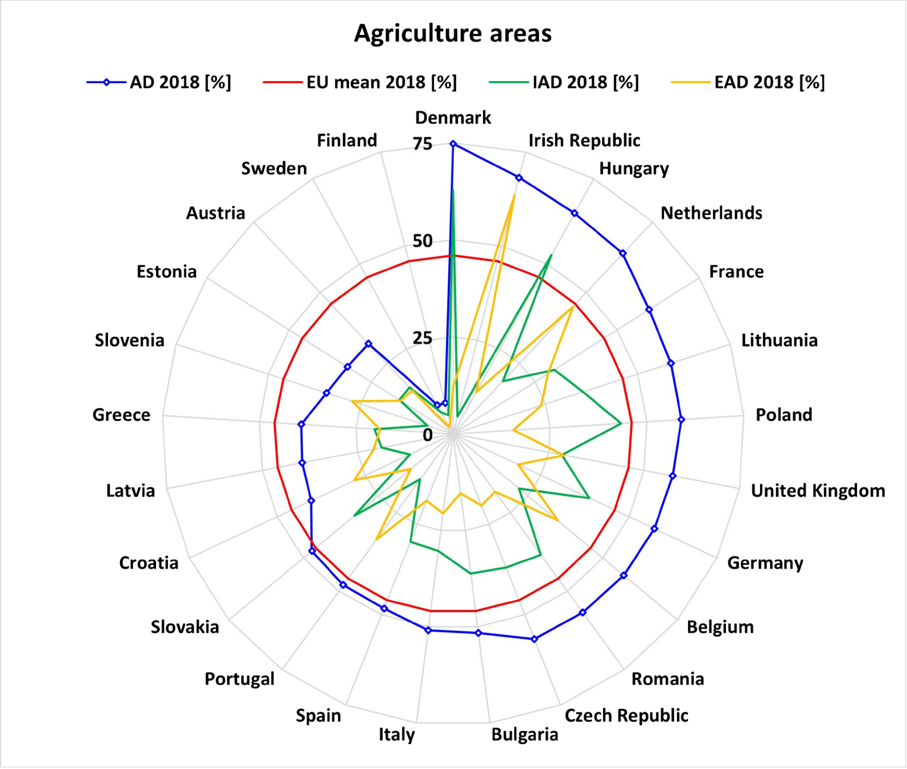

Figure 3. Agricultural cover ratio in European countries.

than 30%, while the lowest values characterized the Scandinavian (Sweden and Finland) countries where for morphological and climatic reasons AD < 10%. The results for Ireland and Denmark were interesting, with around two thirds of the latter covered by agricultural land, and although this value was high it was still lower than in 1990 (80%). Ireland showed a stable AD over time at 68%, Hungary also showed similar values but lost about 3 percentage points in 30 years. As indicated above, this decreasing trend is common to all the territories considered, even if the values are different: they range from a minimum loss of 25 km^2 in 30 years for Bulgaria to a maximum of 17,600 km^2 for Poland. In total, almost 75,000 km^2 of agricultural land was lost, an area larger than that of BENELUX.

Land use changes between 1990 and 2018 amounted to approximately 30 million hectares. As represented schematically in the Sankey diagram in Figure 4, 26% of these transformations were in agricultural areas and 72% in more biopermeable environments. The major transformations are internal to the categories considered, which indicates for example in the case of agricultural land, a change of crop or in the case of urban areas a change of the urban fabric. Generally speaking, transformations outside the identified classes have very low values, but a particular case is represented by the conversion of agricultural areas into urbanised areas, which accounts for 7% of the total. Urban transformation, as shown in Figure 5, has decreased over time but agricultural areas remain the most affected.

Between 1990 and 2000 about 750,000 ha (corresponding to about 80% of the total) of the urban areas derived from the transformation of this type of soil, between 2012 and 2018 the contribution decreased to 240,000 ha (about 57% of the total), while the interclass transformation grows, in fact of the changes to

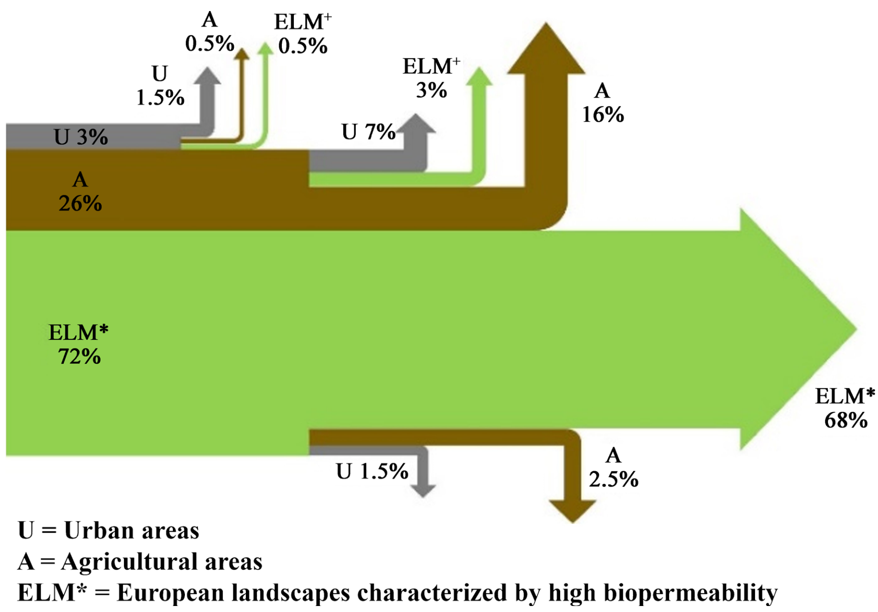

Figure 4. Sankey diagram for Land Use/Land Cover changes analysis (1990-2018).

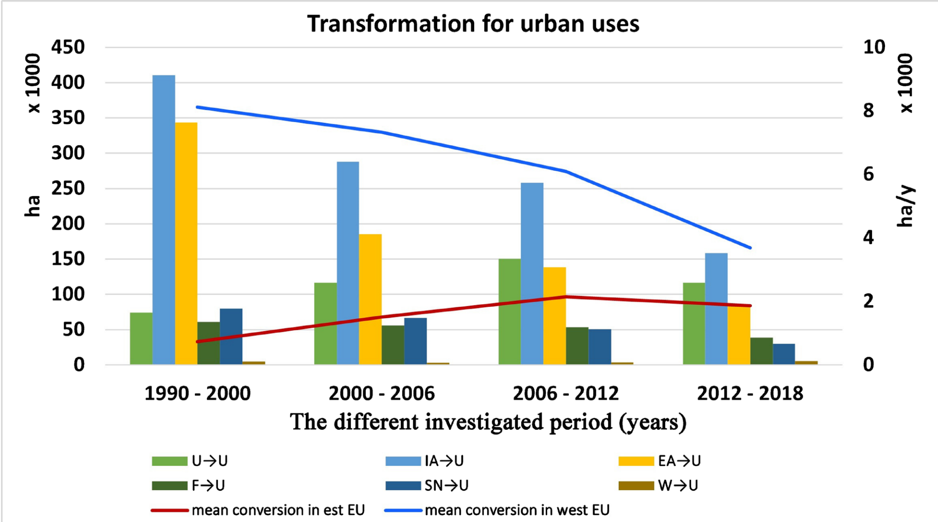

Figure 5. Land-to-Urban conversion matrix (bars) in the two distinct time periods and land uptake rate trends (ha/year) for European land.

urban use in the last investigated period, almost 30% occurred in this category, a value more than tripled compared to that of the 90s (8%), probably linked to infilling practices. The annual average conversion for the Western European countries showed a decreasing trend, going from over 8100 ha/y (1990-2000) to 3688 ha/y (2012-2018), while for the Eastern countries the trend was first increasing with a maximum of 2144 ha/y (2006-2012) and then decreasing to 1868 ha/y (2012-2018). It should be noted that in this case the maximum value reached was in any case lower than the minimum recorded for the Western area. Between 1990 and 2018, urban land conversion in Europe amounted to more than 2 million hectares, 80% of which involved agricultural land. At the national level, it appears that for 75% of the countries, more than two thirds of the transformations for urban purposes took place on agricultural soils, which for 14 out of the 25 countries considered, mainly involved category IA soils. The highest values were recorded in Germany, Spain and France with more than 300,000 ha consumed by each. In the case of the Netherlands, land consumption in the period under review amounted to 150,000 ha, of which 145,000 ha was agricultural land. This corresponds to approximately 6% of the total national agricultural area (reference year 2000), while in the other countries the figure is much lower and is generally below or slightly above one percentage point. Slovenia is the country with the lowest value of 1141 ha, of which less than half was on previously agricultural land. In order to investigate the agricultural loss related to this phenomenon, the CPL (Crop production potential loss) index was introduced. It enables the quantification of agricultural loss with reference to a specific crop, which in the present case is wheat. The value of the agricultural wheat yield for the European Union (EU28), although there have been fluctuations over the years, tends to grow linearly. This is undoubtedly due to the agricultural model aiming at a strong quantitative growth of products with large use of chemicals accompanied by technological development applied to both machinery (for all stages from field preparation to harvesting) and seeds (molecular biology, epigenetics...) (Agrawal & Rakwal, 2012; Springer & Schmitz, 2017; Scotch et al., 2009; Black & Bewley, 2000). This trend is generally followed by all Member States, but yields vary according to geo-pedological, climatic, technological and morphological conditions. Specifically, while the European average is 5 t/ha in 2000 and 5.4 t/ha in 2018, the 7 countries where the yield is higher than this value are all in north-western Europe, and in particular in 2018 the highest values were in Ireland (8.4 t/ha), the Netherlands (8.6 t/ha) and Belgium (8.5 t/ha). Assigning to each country the average value of agricultural yields measured from 1990 to 2018, the conversion of agricultural land for urban purposes between the 1990s and 2018 resulted in a loss of potential agricultural production (CPL) of 10 Mt of wheat per year in Europe, 40% of which due to urban conversions between 1990 and 2000 and the remaining 60% to those between 2000 and 2018. At the national level, as shown in **Figure 6**, France and Germany lost more than 2 million tonnes of wheat annually, followed by the Netherlands (1.2 Mt/y) and Spain (859,000 t/y). These 4 countries with 7 Mt/y together account for 70% of European CPL. For some states the 1990-2000 figure is not available (UK, Sweden, Finland) and for Latvia there are no conversions of agricultural land to artificial surfaces to be detected. In Germany, the losses associated with the urban conversion of agricultural land in the years 1990-2000 exceeded by almost half a million tonnes per year the CPL associated with the period 2000-2018, which

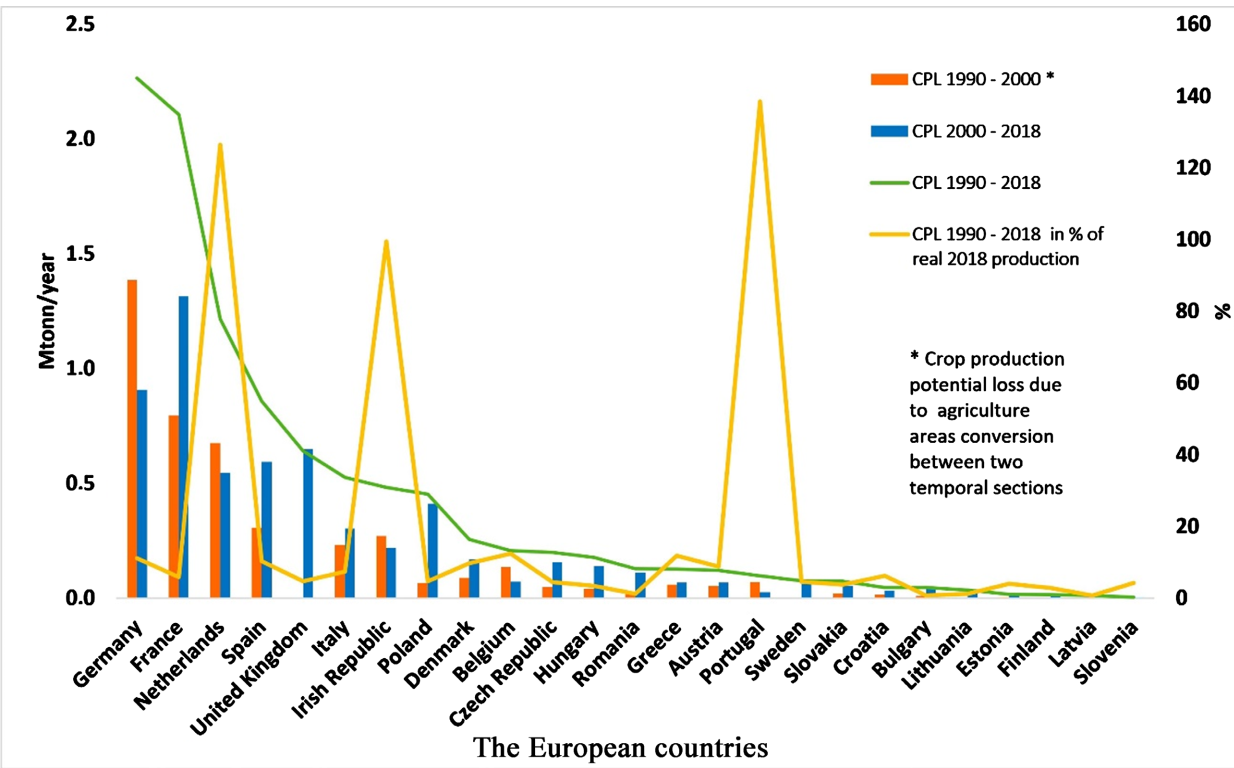

Figure 6. Potential lost agricultural production (CPL) among the time sections.

was almost twice as long. Four other countries showed this trend, namely the Netherlands, Ireland, Belgium and Portugal. For Spain, Denmark and Croatia, the CPL 1990-2000 was about half that of the following two decades, although of course with different values (between 1990 and 2000 Spain = 300,000 t/y, Denmark = 87,000 t/y and Croatia = 10,000 t/y). Slovenia had the lowest CPL value, although the variation between the two investigated periods was 10 times greater. Similar trends were observed in other countries such as Poland (+500%) and Romania (+400%). Considering that the average per capita use of wheat for food purposes in Europe is 107 kg/y, these unproduced quantities would be enough to satisfy the food needs of 66 million Europeans for one year (equivalent to the population of France) and almost 110 million people if the average per capita consumption is considered to be worldwide (66.6 kg/y). Every European country imports wheat; if we compare the value of 2019 imports with the CPL we see that the Czech Republic, France, Hungary, Ireland and Slovakia with their potential agricultural production could have more than met their domestic needs without resorting to imports. France, for example, imported 380,000 tonnes of wheat, which is less than 20% of what is not produced annually as a result of urban conversion of agricultural land. The LPC index measures the potential output lost per capita and the geography of European values is shown in Figure 7(a). Ireland has the highest value at around 100 kg/y/inhabitant for transformations between 1990

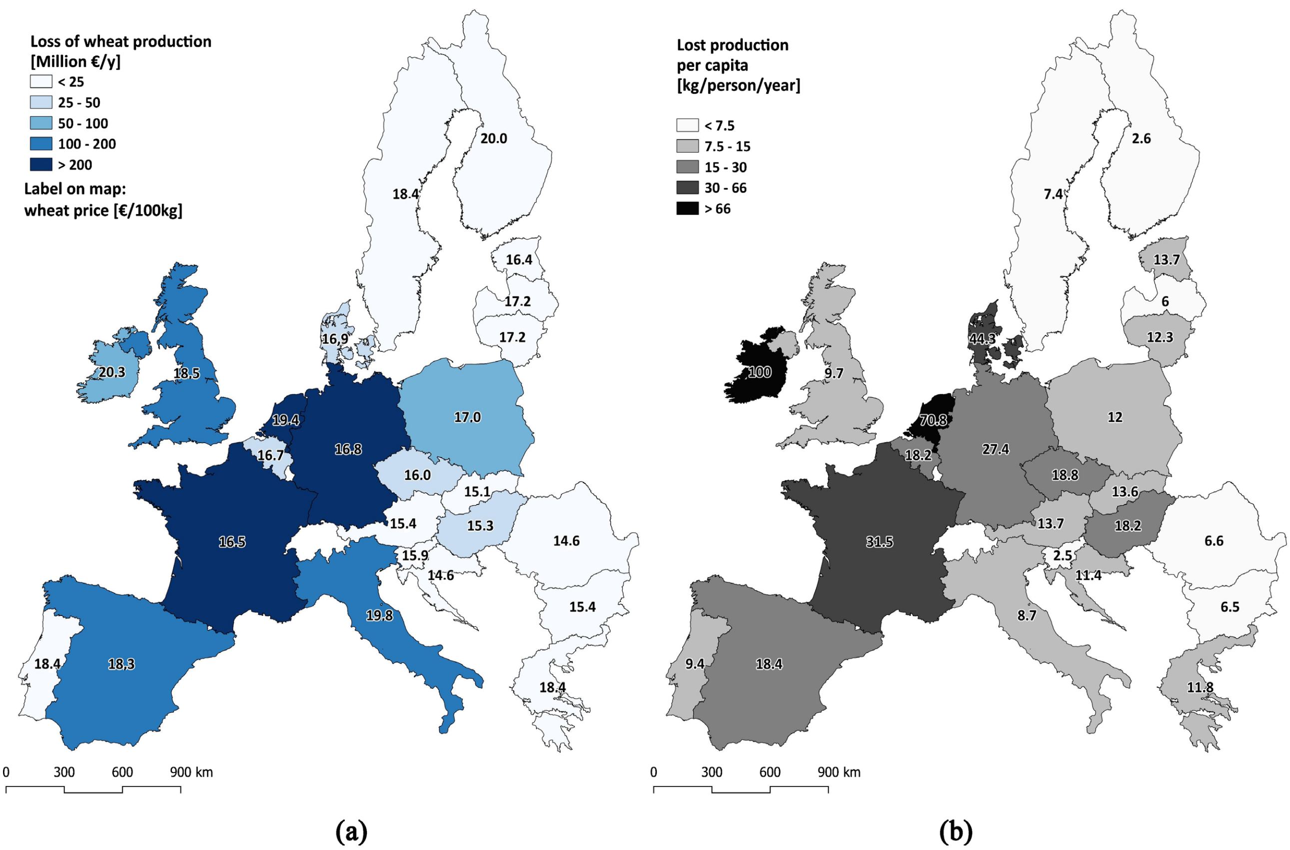

Figure 7. Agricultural loss due to land consumption in European countries in (a) and (b).

and 2018, followed by the Netherlands with 70.8 kg/y/inhabitant. Both states exceed the world average per capita food requirement of 66.6 kg/y/ab (FAO, 2017). LPCs higher than 30 kg/y/ab are France (31.5 kg/y/ab) and Denmark with 44.3 kg/y/ab, which is equal to the per capita annual requirement of a Central American citizen. Still high values of 15 - 30 kg/y/inhabitant are found mainly in Central and Eastern Europe (Germany, Belgium, Czech Republic, Hungary and Spain). Ten countries are in the second range (7.5 - 15 kg/y/inh), most of them in the east, with Austria and Slovakia having the highest values (around 13 kg/y/inh). The remaining 6 countries do not exceed 7.5 kg/y/inhabit, all of which are in Eastern Europe and include the Scandinavian countries as well as Latvia, Romania and Bulgaria. The lowest value is recorded in Slovenia (2.5 kg/y/inhabitant) followed by Finland (2.6 kg/y/inhabitant). Wheat prices paid to the producer are collected periodically by the Union based on data provided by the individual countries. Here the 2018 data is used as the most recent ones are incomplete. Prices vary from country to country and remain around the European average of €17/100kg, with Romania and Croatia having the lowest price at €14.61/100kg and Irish producers the highest at €20.3/100kg. National prices and the equivalent lost potential production mean that the loss of revenue, linked to the loss of European agricultural production, amounts to €1.8 billion per year or 91% of the value of European agricultural production of durum wheat in 2018 and 8% of that of wheat and spelt in the same year. The countries in which earnings shortfalls are lowest are mainly located in the East, particularly in the Scandinavian, Baltic and Balkan countries. The lowest loss is in Slovenia with 0.81 M€/y followed by Latvia (1.98 M€/y) and Sweden (2.91 M€/y). The highest losses are estimated for Germany (381 M€/y), France (347 M€/y) and the Netherlands with 236 M€/y, which is 91% of the Dutch wheat and spelt production in 2018. Significant values are also estimated for Portugal and Ireland, the latter losing around 98 M€/y equivalent to 101% of the value of national wheat and spelt production in 2018.

4. Discussion

In Europe, urbanised areas have increased from 4.2% to 5% since 2000, covering a total area of 210,000 km^2, an area equal to that of Great Britain. The national UD values in some cases deviate significantly from the European average. This is the case in the Netherlands and Belgium, which reached the highest recorded value (20.9%). The evaluation of the UVR showed that variations greater than 50% occurred in Spain, Poland and Latvia, with some cases showing a negative value, probably due to the technical characteristics of the data. Between 1990 and 2000, the acquisition mode changed from manual photo-interpretation of satellite images to Computer Aided Photo-Interpretation (CAPI) and since 2006, change layers (CHA) have become the main output of CLC. From this reporting year onwards, the status layers were obtained by merging the change layers with the status layer of the previous reporting year, in order to maintain the advantages of the higher resolution of the CHAs in the overall data. The use of a higher resolution datum makes it possible to carry out a more accurate identification of the prevailing land use in a given area and therefore, areas that had been ascribed as urban, due to the greater detail have been better identified (**Figure 8(a)**, **Figure 8(b)**), which justifies the results found.

Furthermore, the methods used for the cartographic acquisition of CLC data (MMU 25 ha and minimum width of linear elements equal to 100 meters) do not make it possible to detect all dispersed settlements (Romano & Zullo, 2013) present in some of the countries analyzed, such as Italy, Spain, Albania and Greece. Many new settlements (residential or tourist accommodation) have the typical characteristics of sprawl (Egidi et al., 2020; Henning et al., 2015), due to obvious reasons tied to economic return, settlements can be ascribed to the sprinkling model owing to their building density and extremely low coverage ratios (Dutta & Das, 2019; Urbieta et al., 2019; Saganeiti et al., 2018; Romano et al., 2017). This type of settlement is often developed spontaneously or subject to poor land-use planning control, compounded by the lack of underlying urban planning, making it extremely impactful from the standpoint of landscape, energy, land consumption and management costs (Carruthers & Ulfarsson, 2003; Manganelli et al., 2020; Thompson, 2013).

The fragmented morphology of the type landscape generates problems in the use of medium-low resolution geographical layers, which, for example, are suitable to capture well-defined urban margins (**Figure 9(a)**), typical of Northern European cities, but makes them less reliable for analyses where the settlement pattern is highly dispersed (Romano & Zullo, 2013; Romano et al, 2017). In fact, in these cases both the MMU of 25 ha and that of 5 ha are too high to detect this type of settlements that often have the size of the single building or aggregates of a few units as shown in **Figure 9(b)**. These problems are less evident for other land cover types which, on the contrary, have larger extensions and are more compatible with the CORINE MMU.

(a) (b)

Figure 8. Comparison of urban areas reported by CLC 2000 (in red) and CLC 2006 (in yellow) with the actual situation in 2006 in Romania in (a) and (b).

(a) (b)

Figure 9. CLC figure (in red) for compact (a) and dispersed (b) urbanization compared to the actual condition detected by satellite imagery.

5. Conclusion

Agricultural soils should first and foremost ensure adequate food supply. However, the development of a model of agriculture, particularly since the 1950s, aimed at strong quantitative growth in low-quality production has generated significant environmental impacts. In addition to the environmental problems directly generated by this unsustainable model, there are also those related to the climate crisis, the emission of air pollutants (Emberson et al., 2003; Schenone & Lorenzini, 1992), water and soil pollution (Mahmoud & Ghoneim, 2016; Okoronkwo et al., 2005; Feleafel & Mirdad, 2013). Bearing in mind the 2030 Agenda's goals on poverty, hunger and achieving health and well-being, the research presented here aims at making a contribution in this direction. Analyses have shown the potential agricultural production lost as a result of urban land conversion in terms of both economic and food needs. To these estimates, we should add, although they are not included in the discussion, the potential losses related to the abandonment of cultivated land. The loss of used agricultural areas is also caused by the abandonment of the countryside, particularly in hill and mountain areas, fuelled by the economic difficulties that have affected agriculture in many areas and for many years. The loss of agricultural soils and their degradation is of growing concern (European Commission, 2012; UN, 2015), exacerbated by climate change that, due to increasingly frequent extreme weather events, is constantly endangering harvests. As already pointed out, what has emerged in this research could underestimate the real extent of the phenomenon, especially in those areas where the landscape is highly fragmented (Italy, Romania, Portugal). Surely the use of higher resolution data would make the analysis more accurate, but at present, although high-resolution data (Urban Atlas) are available, they have an extension limited to some geographical areas. In any case, the study, despite the limitations, clearly shows the effect that urbanization has on the ability of European countries to produce food and also highlights that, although the phenomenon and its extent were known (Gardi et al., 2015), little or nothing has been done in concrete terms. The initial institutional enthusiasm that led to the drafting of a proposal for a European directive on soil protection (COM (2006) 232) was followed by several documents that were dense in content (European Commission, 2011; European Commission, 2012; European Commission, 2013) and that inter alia set the goal of zero net land occupation increase by 2050. However, the level of cogency proved to be very low. The lack of sensitivity shown by the Member States regarding this issue has resulted in an increase in urbanized land of 16,000 km^2 between 2006 and 2018 and therefore requires the introduction of stringent regulatory constraints, which have proved effective in other sectors such as energy. The systematic application of de-sealing techniques, currently applied mainly in Western Europe and in particular in Northern Europe, with the restoration of the surface layer of the soil and of all its functions, could certainly contribute both to increasing the amount of land for agricultural use and to curbing the effects of urban soil conversion that this study has highlighted.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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