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Land Use Indicators in the Context of Land Use Efficiency

Barbara Kalisz [1,*], Krystyna Żuk-Gołaszewska [2], Wioleta Radawiec [3] and Janusz Gołaszewski [4]

[1] Department of Soil Science and Microbiology, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland
[2] Department of Agrotechnology and Agribusiness, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland
[3] Department of Genetics, Plant Breeding and Bioresource Engineering, Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland
[4] Center for Bioeconomy and Renewable Energies, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland
* Correspondence: barbara.kalisz@uwm.edu.pl

Abstract: In recent decades, the land use changes induced by various economic activities in agricultural ecosystems have affected many aspects of human life. This is the reason why land use change is considered as one of the agriculture-related environmental impacts in a sustainability assessment of food and bio-based products. At the same time, the methodology applied for the quantification of land use change effects is still under intensive research, stimulating scientific discussions. The overall objective of this paper is to fill the gap in knowledge of responsible and sustainable land use management. Specifically, the research provides a comprehensive set of land use change indicators in the context of land use change and land use efficiency. The indicators can be measured based on publicly available databases with the applicability to agricultural sustainability assessment of land use change on a local, regional and global scale. The high share of artificial land and dominant agricultural use of land with low land use intensity were noted in Belgium, Luxemburg, Netherlands, Slovenia, Cyprus, Croatia, Finland, Germany, and United Kingdom. However, land use efficiency was also low. In turn, heterogeneous land cover (but less artificial areas than in other EU countries) and heterogeneous land uses with diverse land use intensity were noted in Austria, Bulgaria, Denmark, Estonia, France, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Spain, and Sweden. The challenge in future research could be aggregation of different indicators in assessing the similarity of land use between countries.

Keywords: sustainable land use; land cover; land use intensity

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1. Introduction

Sustainable and rational land use, and land use efficiency (LUE) are of global importance [1]. The land-based environmental sustainability thresholds have been already established in the Planetary Boundaries [2,3]. Rockstrom et al. [2] ranked land-system change as one of the planetary boundaries, and proposed the boundary quantification to be no more than 15–20% of global ice-free land surface used as cropland. Because this boundary is a complex global aggregate, the spatial distribution, and intensity of land-system change is critically important for the production of food, regulation of freshwater flows, and feedbacks to the functioning of the Earth System [2]. Subsequently, Steffen et al. [3] proposed that the land-system change boundary should be expressed as the percent of original forest cover remaining from pre-industrial levels, and should not exceed 54–75%. The Planetary Boundaries also provide a guideline for the implementation of the Sustainable Development Goals (SDGs) [4]. The UN Report defines sustainable development as the one that 'seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future'. Sustainable development emphasizes, among others, the efficient use of resources on Earth. Land use changes are considered critical for sustainable development [5]. With the rapid urbanization, rural transformation and the development of modern agriculture, the land becomes fragmented and land use changes threaten sustainable development. Scientists and environmental protection agencies have long warned that urbanization is irreversible [6], leads to landscape fragmentation, reduces the potential of ecosystems to provide ecological services [7], causes irreversible loss of land, and contributes to other changes [6]. In the last few years, also due to the COVID-19 pandemic, the global food crisis has become a critical issue [8]. Using cultivated land resources efficiently and reasonably has become the focus of and a challenge to sustainable development worldwide [9]. The over-exploitation of agricultural resources and pollution of the agricultural areas threaten food security and agricultural sustainable development [10].

Land use change (LUC), and land cover change is associated with the changes of land surface. Land use includes the way the land is used as pasture, arable land, forest, etc. Land cover refers to the cover of the surface of the Earth with a type of vegetation, bare soil, infrastructure, water, etc., but does not describe the use of land, which can differ for the same land cover type. Generally, land cover change encompasses alterations in tilled land, forests, grasslands, pastures, wetlands and urban areas [11]. Changes in land cover can directly affect biodiversity, primary production, soil quality, runoff, and deposition rates as well as sources and sinks for carbon, considered on a local, regional and global scale [12]. Land cover of a particular area is somehow consistent with soil and climatic conditions, with human effect in landscape evolution. Europe lies in three climatic zones, i.e., the northern part is in the subpolar zone, the middle part in the temperate zone (occupies the largest area), and the southern part in the subtropical zone. Also, the continental features of climate are spatially visible from the west to the north of Europe. In comparison with the other continents, Europe has a very fragmented landscape, mainly as a result of the development of agriculture, industry and urbanization, leaving merely 15% of the natural landscape intact [13,14].

The arrangements, activities, and inputs that people undertake in a certain land cover type to produce, change or maintain it is the way people use the land [15]. The predominant land uses include agriculture, pasture, forestry, extraction of resources and settlements. The land cover is closely associated with ecosystem services that humans exploit through agricultural, forest, grasslands, and aquatic production followed by other activities related to tourism, urban development, environment protection, conservation and enhancement of natural land resources. LUC can mean shifts from agricultural use to urban use, extensive to intensive grassland, from intensive tilling to fallow land, or deforestation, etc. [16,17]. The LUC is directly associated with agricultural production [18]. The croplands and pastures, occupying about 40% of land surface and composing the largest terrestrial biomass stock on the planet are changed due to different demands related mostly to continuing population growth and diversion of agricultural land for non-agricultural purposes [19]. The competition for land is growing [20], and the use of agricultural land is based on the intensity of production, expansion of land [21] or its conversion to other uses [22]. Therefore, it is anticipated that the growing pressure for agricultural land area, and mitigation of environmental impact caused by direct and indirect LUC may be compensated by improved land use efficiency. Efficient land use constitutes a mix of land uses and in context of agriculture refers to the effective agricultural production Special attention should be paid to land fragmentation which has a significant negative impact on production efficiency [23] and land use sustainability. LUC should also be associated with the implementation of agricultural practices to alleviate the impact on biomes mostly by reduction of nitrogen and phosphorus loads to the environment and conservation of biodiversity.

Nowadays, land use change is the result of economic and political decisions, and, to a lesser extent, environmental or social considerations [24]. Since the way the land is used involves many potential trade-offs, some of them can result in a negative impact, causing degradation of soil, water, biological resources, the loss of ecosystem services, while others lead to a positive expansion of urban land into productive soils, etc. [25,26]. As the demand for food is growing, the competition for land is increasing, with land grabbing being on focus. Land grabbing was initially focused on acquiring vast areas of land in developing nations to grow food for their own people amidst a fear of food scarcity [27]. The global land grab is therefore an epitome of an ongoing and accelerating change in land use and its associated resources (for example water) from small-scale toward large-scale, resource-depleting uses (among others: monocultures, large-scale hydropower generation) [28,29]. Zhang et al. [30] show that the metrics of land-cover and land use change are related to agriculture and water use. The transfer of land property rights impose change of agricultural production structure [27]. Although the land use remains agricultural, its use intensity is greater affecting sustainable end efficient land uses. The environmental sustainability of agricultural production highly depends on the available land area which does not cause adverse effects (increased GHG emissions, water pollution, loss of biodiversity) on various land use types [31] and has a beneficial effect on productivity, reduced pesticide use and carbon balances [32].

Concurrently with the expansion of the land area for agricultural production, land use intensification seems to be the main prerequisite to meet the growing demand for products [22,33]. Therefore, since land expansion is limited [34], intensification is becoming more important [35]. There is also an urgent need to protect the remaining undisturbed ecosystems, which are often rich in carbon, minerals and water as well as conserving aesthetic value of landscapes and biological diversity [34]. To assess the long-term potential for further agricultural and bio-based production as well as the possibilities for future land use development, it is essential to determine current land uses, and indicators of LUC. The issues of rational land use are urgent at every scale, local, regional and global. Therefore, it is important to set up a portfolio of understandable indicators on land use composition that can be easily implemented in land management systems. Such indicators would help to accurately reflect the development nature, trends and expected outcomes in relation to a particular territory [1]. It has been underlined for the decades that LUC measures and models should be constantly developed [24,36–38]. The application of models for policy and planning is hampered by uncertainty [24]. The models should also rely on valid source data for various regions. With respect to the EU, the knowledge of the pattern of LUC is essential to plan and conduct agricultural production. Tools are needed to assess the impact which the Common Agricultural Policy (CAP) had on landscape in the past or may have in the future. The valid assessment of LUC requires homogeneous data to compare landscape diversity between regions or between two different periods. One of the most important conditions for the development of countries is the proper management on the available land area, which needs to be underpinned by the principles of sustainable development and monitoring of easily applicable measures. Considering the importance of land use change as one of the planetary boundaries and regional land use aspects, it is necessary to measure the LUC not only globally, but also on national, regional and local levels. DeFries et al. [39] emphasized that global analyses, although necessary, are insufficient unless they are connected with finer-scale (local, regional) research. The analyses ought to take into account the regional/local issues and specificities, which, at global scale, can be invisible.

The objective of this study was to select a set of land use change indicators together with the metrics, addressing source data in public databases, and to describe the results in the context of land use efficiency. The indicators were analysed for the European Union region, so that they enable to account for biogeographical diversities in land cover and environmental land use aspects. There are diverse methodological approaches to analyzing land use issues. Regarding obtaining the data for the calculation of indices, it is difficult to get them from field research than from public sources which also enable the analyses of the dynamic change in land use. The selected indicators represent a set of conditions, and convey information about a change. Indicators are necessary to monitor changes over time, and to assess the effects of, among others, policy changes and management practices, and for evaluating the sustainability of land use. The approach of selection of indicators is provided in detail in the next chapter.

2. Materials and Methods

A set of selected indicators addresses LUC and LUE in the EU countries. Although in the literature [24,25,36–40] there are many indices and indicators that describe the changes in land use, most of them can be applied to a limited area (field, farm, district, sometimes region). In our paper the country-based data were considered essential.

First, we determined what are the main factors that affect the land use in a country or region. Basically, land use is influenced by climatic conditions, topographic conditions, socioeconomic conditions, tax policy, and other political factors [24]. Since the main land use types are agricultural and residential [13], we focused on the agricultural aspect of LUC.

Subsequently, a search of studies considering the land use indicators was conducted in Web of Science and Scopus databases using a combination of words and phrases: land use change, land use efficiency, agriculture intensity, land use intensity.

Finally, we determined the criteria for the selection of indicators (the numbering reflects the importance):

1. Scientific relevance: the indicator captures an acknowledged key issue for a given land use aspect, according to the scientific community.
2. Reliability/robustness: the indicator can be calculated based on available data (globally available databases) and recognized methods, without necessity of separate studies, preferably robust for benchmarking, if not in absolute value.
3. Representativeness: the indicator takes part of the complete array of relevant environmental issues, avoiding overlapping.
4. Political and/or social priority: the indicator captures an issue on the political agenda (debated at European level, addressed by the UN in SDGs)
5. Most used in literature: this criterion is de facto considered by points 2 and 3, but is not relevant per se.

Considering agriculture-related land use in the EU, the final set of selected indicators were composed of the three static indicators including land use diversity index (H), land use intensity (LUI) and land use efficiency (LUE) and five dynamic indicators representing rate of change of the main types of agriculture related land use change, i.e., agricultural land, cropland, grassland and other types use as well as the rate of fertilization change. The land use diversity index (H) provides a broader information than the number of land use types because it takes into account the area under different land cover. LUI and LUE refer to crop production only. They reflect the human impact on the land use caused by rapid population growth and increasing demand for food which make bio-based agricultural sectors a top priority, for both economic and environmental reasons [41]. The definition and measures related to LUI are very different [21,42], and can be estimated separately for any type of land cover. In our paper the estimates of LUI are based on grain crops because of their dominant role in the EU cropland area (>60%). Land use efficiency (LUE) is an economic category which takes into account the land use effect and the resources consumed to achieve the effect.

Based on the above criteria, the relevant indicators were selected and described in Table 1.

Table 1. Selected land cover and land use indicators.

Indicator	Formula
Index of Land Cover (*ILC*) [14]—percentage ratio of the share of land cover for a specific item in a country (i.e., cropland/agriculture) normalized to the European value [100%], where: $l_{c/u}$ land cover item $S^m_{l_{c/u}}$ share of land cover item in country m $\overline{S}_{l_{c/u}}$ share of land cover item $l_{c/u}$ in Europe The index enables to rank diversities among the EU countries for a given land cover or land use class. In the case of assuming a threshold (e.g., 10–50%) for a given land cover category the EU countries can be classified in groups I: share is larger than the upper bound (e.g., >110%), II: share is close to the EU value (90–110%), III: share is below the lower bound (<90%).	$I_{l_{c/u}} = \frac{S^m_{l_{c/u}}}{\overline{S}_{l_{c/u}}} 100$
Land use diversity index (*H*) [43]—the indicator describes the diversity of land use types within a given land area, where: m is the number of land use types P_k is the percentage of land use type k If m = 1, then H = 0, the minimum. When m goes to infinity, H reaches its maximum. One of the properties is the index is that it enables to compare land use types within a land area.	$H = -\sum_{k=1}^{m} P_k log_2(P_k)$
Land Use Intensity (*LUI*) [44]—this indicator is based on parameters associated with inputs for crop production, where: c_i is cropland intensity for year I F_{ert} is total fertilizer input in kg per ha, p_{crop} is a proportion of cropland per land area p_{grain} is a proportion of grain crops (cereals) per cropland $c_i = F_{ert} \times p_{crop} \times p_{grain}$ where c_i is cropland intensity for year. c_{min} and c_{max} are minimal and maximal values of c_i, respectively F_{ert} is total fertilizer input in kg per ha. p_{crop} is a proportion of cropland per land area. The *LUI* index is standardized by ranging the individual values of the data matrix between 0 (min) and 1 (max), by subtracting the minimum observed for each variable and dividing by the range. LUI_c relies on input-based information on land-use intensity, including fertilization, cropland area and grain crop area.	$LUI_{c_i} = \frac{c_i - c_{min}}{c_{max} - c_{min}}$
Land Use Efficiency (LUE_c) [1]—it is the ratio of the number of harvested hectares required to produce a tonne of harvested crop (cereals). Meaning the primary measure of efficiency of land use for a given production. The evaluation of *LUE* is used to support a decision-making in land-use management and to promote a land use in better and more efficient way.	$LUE_C = \frac{Area\ (harvested)}{Harvested\ production}$
Land use change speed/the rate of land use change (K_i) [45]—describes the change area per year, where: K_i is the change speed of the i-type of land use U_a U_b is the area of a certain land use type at the beginning and end of the study period m is the number of land use types T is the time duration Positive value refers to upward trend and negative value refers to downward trend.	$K_i = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100$

The data necessary for the selected indicators were downloaded from the official, valid databases of EUROSTAT (https://ec.europa.eu accessed on 1 December 2021) and FAOSTAT (http://www.fao.org accessed on 1 December 2021). The EUROSTAT database provides comparable statistical information at the European level. The national data, prepared according to the harmonized methodology, are consolidated and comparable. EUROSTAT provides land cover/use statistics in addition to the traditional statistics linked to a particular land cover/use type. This information is collected through the LUCAS survey, which is carried out directly by EUROSTAT. The important specific land cover/use data collection activities concern agriculture (crop statistics and the Farm Structure Survey), forestry, and the environment (https://ec.europa.eu/eurostat/ accessed on 1 December

2021). The FAOSTAT data of land cover area is aggregated at the national level and by land cover category following the international land cover classification of the United Nations System of Environmental-Economic Accounting Central Framework. Land Use domain contains data on land use and agricultural practices that are relevant to monitor agriculture, forestry and fisheries at national, regional and global levels. Statistics related to agricultural land area are an integral component of SDG indicator 2.4.1—Proportion of agriculture area under productive and sustainable agriculture (https://www.fao.org/faostat/en/ accessed on 1 December 2021). The data from the above-mentioned databases go along with the international statistical standard. They are consistent with the data presented by the Intergovernmental Panel on Climate Change (IPCC), used by countries for reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

The databases were searched for complete datasets for all the indicators specified in Table 1, and for that reason the years of 2010 and 2017 were selected for further study. Raw data were checked for errors, miscalculations or missing data (the data missing from one database were supplemented from the other). Then the datasets extracted from the above-mentioned databases have been sorted, compiled in a spreadsheet and recalculated according to the equations in Table 1. The datasets comprised:

- Total area of each studied country;
- Area of various land cover types: woodland, cropland, grassland, shrubland, artificial land, bare land, wetland, water;
- Area of land uses for agriculture, forestry and fishing, unused and abandoned areas, services and residential areas, heavy environmental impact areas;
- Nitrogen, phosphorus and potassium use on croplands;
- Area of harvested grain crops (cereals), production of cereals.

During the investigation, we also listed the limitations of the study:

- The data provided in the EUROSTAT and FAOSTAT databases may not contain all the necessary information to calculate the indicators because some national data are not available. For example, in FAOSTAT database, the region response rate (in 2021) was as follows: Africa 19%, Americas 38%, Asia 63%, Europe 90%, Oceania 25% (data from FAOSTAT methodological notes; faostat.org).
- The ILC/H indicators are limited only to the land use/land cover categories available in databases. If there are some other categories of local aspect, they may not be taken into account when calculating ILC/H. However, neglecting local peculiarities could have little impact on the overall estimate due to presumably small areas of local land cover/land use categories.
- LUI suggested in the study is related to crop production only and takes no account of grassland related indicators (frequency of mowing or intensity of livestock grazing)
- LUE index is related to cereals only and does not comprise other harvested areas.

Statistical analysis was performed to determine the degree to which land use diversity (H), land use intensity (LUI) and land use efficiency (LUE) were correlated with the rate of specific land use changes (Ki agriland, Ki cropland, Ki grassland, Ki other land) and fertilization (Ki fertilization). Relationships between land use indicators were determined using Spearman's rank correlation procedure. This non-parametric measure of correlation does not require normally distributed data and is a relatively robust against outliers. The agglomerative hierarchical cluster analysis using Ward's method was applied to group the countries having compatible indices. The reason for clustering was to arrange countries into groups in such a way that the degree of linking countries belonging to the same group was as large as possible, and with countries from other groups as small as possible. At the same time the basis for choosing the Ward's method was its efficiency that stems from using an analysis of variance approach to estimate the distance between clusters. In general, this approach minimizes the sum of the squared deviation of any two clusters that may be formed at each stage of the analysis. In result, the EU countries were clustered given the similar aspects of land use change. Statistical analysis was supported by the statistical package STATISTICA 13 StatSoft Poland.

3. Results

The share of different land cover categories varied across the European Union, depending on the physical characteristics of the land area and climatic conditions. Three land cover categories that dominated in the EU were woodland (1.6 × 106 km^2), cropland (0.97 × 106 km^2) and grassland (0.91 × 106 km^2). Other land cover types occupied approximately 0.85 × 106 km^2. Index of land cover (ILC) higher than the EU average was noted in Finland, Sweden, Estonia, Portugal, Greece, Spain, Cyprus, the Netherlands, Ireland, the United Kingdom and Malta (Figure 1). In Finland, Sweden, Ireland, the UK, Croatia and Estonia, the high share in land area was recorded mainly to woodland and wetland land cover, shrubland and bare land were prominent in the countries of the Mediterranean region. The Netherlands had a very high share of artificial land and water, Malta had the highest land area covered with artificial land, whereas Ireland and the United Kingdom were noted for shrubland, grassland, and wetland.

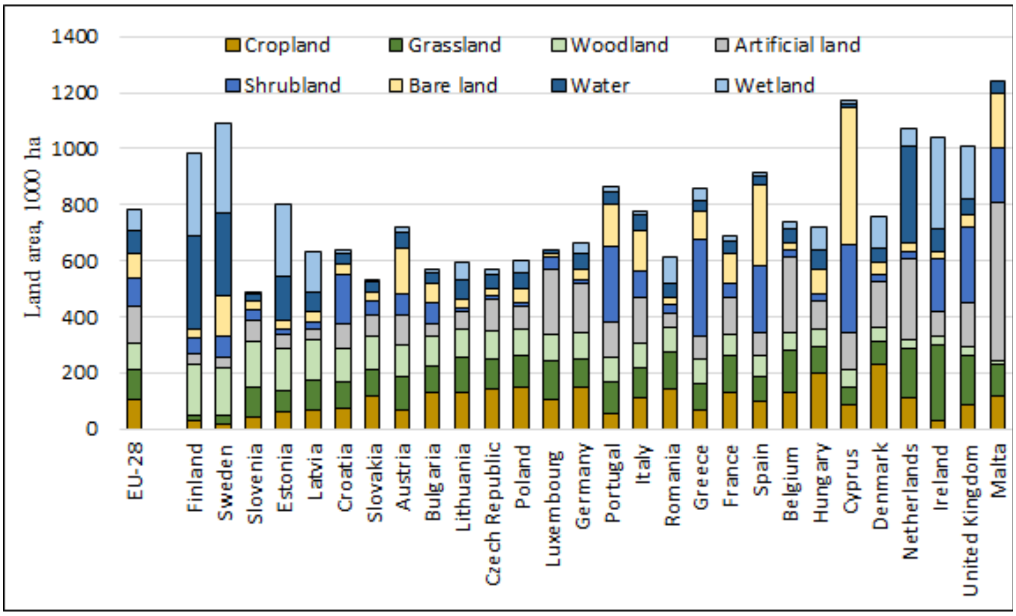

Figure 1. The share of land cover categories in the EU countries (mean values for EU-28 bar).

The smallest land cover area was noted for inland Central European countries—Slovakia, Slovenia, Czech Republic and Romania (see bars in Figure 1). The data presented in Figure 1 were used to estimate the index of land cover (ILC) in order to examine spatial patterns in the countries within the EU and to rank diversity.

Figure 2 shows the current ILC for main land change categories associated with biomass-related primary production: cropland, grassland, woodland as well as artificial land. In general, one dominant land cover category is associated with limited land cover in another category or categories. In Denmark and Hungary the share of cropland was over 50% higher than the EU average. In the Netherlands, Ireland and the UK the share of grassland was over 50% higher than in the EU, whereas in Finland, Sweden, Estonia and Latvia the share of woodland and in Malta, the Netherlands and Belgium the share of artificial land was over 50% higher than the EU average.

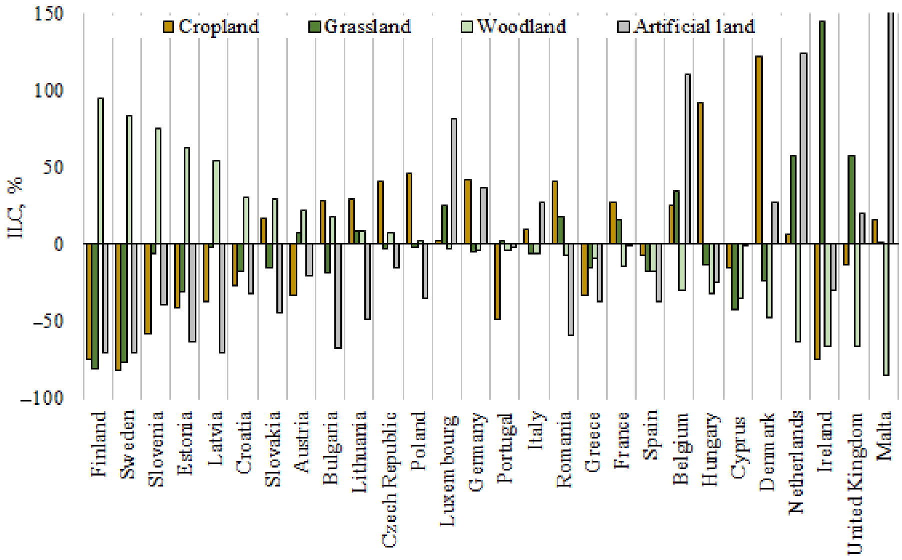

Figure 2. Index of land cover (ILC) for cropland, grassland, woodland and artificial area in the EU countries as percentage increase/decrease in relation to the average area of those categories in the EU-28.

A measure of the variety of land uses inside a given land area is provided by the land use diversity index based on Shannon's diversity index, e.g., [46]. The greater land use diversity implies a smaller risk of land degradation and a higher biodiversity. In the EU, the land use diversity index H ranged between 0.987 (Malta) and 1.957 (Portugal) in 2010, and 0.989 (Malta) and 1.982 (Greece) in 2017 (Table 2). The H index in Belgium, Bulgaria, France (only in 2010), Italy, Portugal and Greece (only in 2017) was higher than the average in the EU. The land use diversity index increased between 2010 and 2017 in Croatia, Cyprus, Czech Republic, Estonia, Germany, Greece, Hungary, Luxemburg, Malta, Romania, Slovakia, Slovenia, Spain. In the other EU countries, the land use diversity index decreased.

Table 2. Land use diversity and land use efficiency in the EU.

Country	2010			2017		
	H	**LUI**	**LUE**	**H**	**LUI**	**LUE**
Austria	1.839	0.204	0.169	1.832	0.213	0.160
Belgium	1.956	0.778	0.107	1.945	0.594	0.110
Bulgaria	1.928	0.319	0.248	1.889	0.373	0.182
Croatia	1.745	0.604	0.183	1.824	0.302	0.175
Cyprus	1.212	0.083	0.500	1.235	0.023	0.498
Czech Republic	1.781	0.384	0.213	1.898	0.642	0.182
Denmark	1.559	0.931	0.170	1.552	1.000	0.145
Estonia	1.671	0.061	0.406	1.692	0.091	0.252
Finland	1.078	0.049	0.319	1.076	0.001	0.253
France	1.929	0.542	0.141	1.917	0.558	0.145
Germany	1.904	0.906	0.150	1.907	0.641	0.138
Greece	1.919	0.140	0.246	1.982	0.069	0.266
Hungary	1.732	0.516	0.212	1.754	0.744	0.173
Ireland	1.730	nodata	0.134	1.551	nodata	0.114
Italy	1.943	0.211	0.188	1.920	0.170	0.193
Latvia	1.704	0.110	0.360	1.697	0.177	0.235

Table 2. *Cont.*

Country	2010			2017		
	H	LUI	LUE	H	LUI	LUE
Lithuania	1.862	0.353	0.362	1.886	0.533	0.236
Luxembourg	1.889	0.700	0.179	1.890	0.572	0.187
Malta	0.987	0.091	0.213	0.989	0.124	0.208
Netherlands	1.899	0.382	0.117	1.884	0.233	0.114
Poland	1.879	1.000	0.279	1.873	0.957	0.238
Portugal	1.957	0.028	0.298	1.956	0.007	0.211
Romania	1.839	0.218	0.300	1.875	0.232	0.191
Slovakia	1.855	0.242	0.268	1.859	0.342	0.206
Slovenia	1.520	0.194	0.167	1.524	0.162	0.180
Spain	1.831	0.232	0.304	1.853	0.244	0.361
Sweden	1.195	0.004	0.222	1.186	0.005	0.167
United Kingdom	1.816	0.704	0.144	1.805	0.650	0.138
European Union	1.921	0.373	0.199	1.918	0.355	0.181

The scientific understanding of land use change encompasses the quantification of land use intensity (LUI). Intensive management of tree plantations or intensive cultivation and overgrazing without applying measures for land protection may result in soil/land erosion, desertification, physical and chemical soil degradation. Consequently, such lands are often abandoned and are no longer used for agriculture or forestry purposes. In the EU, the land use intensity in 2010 was the lowest (below 0.1) in Cyprus, Estonia, Finland, Malta, Portugal and Sweden. Lower values than the EU average were also determined for Austria, Bulgaria, Greece, Italy, Latvia, Lithuania, Romania, Slovakia, Slovenia and Spain. In 2017, the lowest values were again noted for Cyprus, Estonia, Finland, Portugal, Sweden and Greece, with values lower than the EU average also determined for Austria, Croatia, Italy, Latvia, Malta, the Netherlands, Romania, Slovakia, Slovenia and Spain (Table 2). The highest index (around 1) was identified for Denmark, Germany and Poland in 2010. In 2017, this result was confirmed for Poland and Denmark, but for Germany the index was distinctively lower 0.641 (Table 2). In comparison with 2010 the land use intensity in 2017 increased in 15 countries (Austria, Bulgaria, Czech Republic, Denmark, Estonia, France, Hungary, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia, Spain and Sweden) and six of them exceeded the EU average.

LUE takes into account the resources consumed to achieve the effect and in the EU, the land use efficiency was similar in 2010 and 2017 (Table 2). LUE decreased in twenty-one EU countries, and it increased only in seven states (Belgium, France, Greece, Italy, Luxemburg, Slovenia, Spain), suggesting that fewer cereals were grown on the same area.

During the analyzed time period (2010–2017), in the EU on average, the use of land for agricultural purposes, and crop cultivation, decreased, but the land use for forestry and other land uses increased (Figure 3). A decrease in agricultural land use was noted in eighteen countries, and a decrease in crop cultivation occurred in sixteen. The decrease of agricultural use and crop cultivation use in Austria, Czech Republic, Greece, Hungary, Italy, Portugal, Romania, Slovakia, Spain and Sweden coincided with an increase in fertilization.

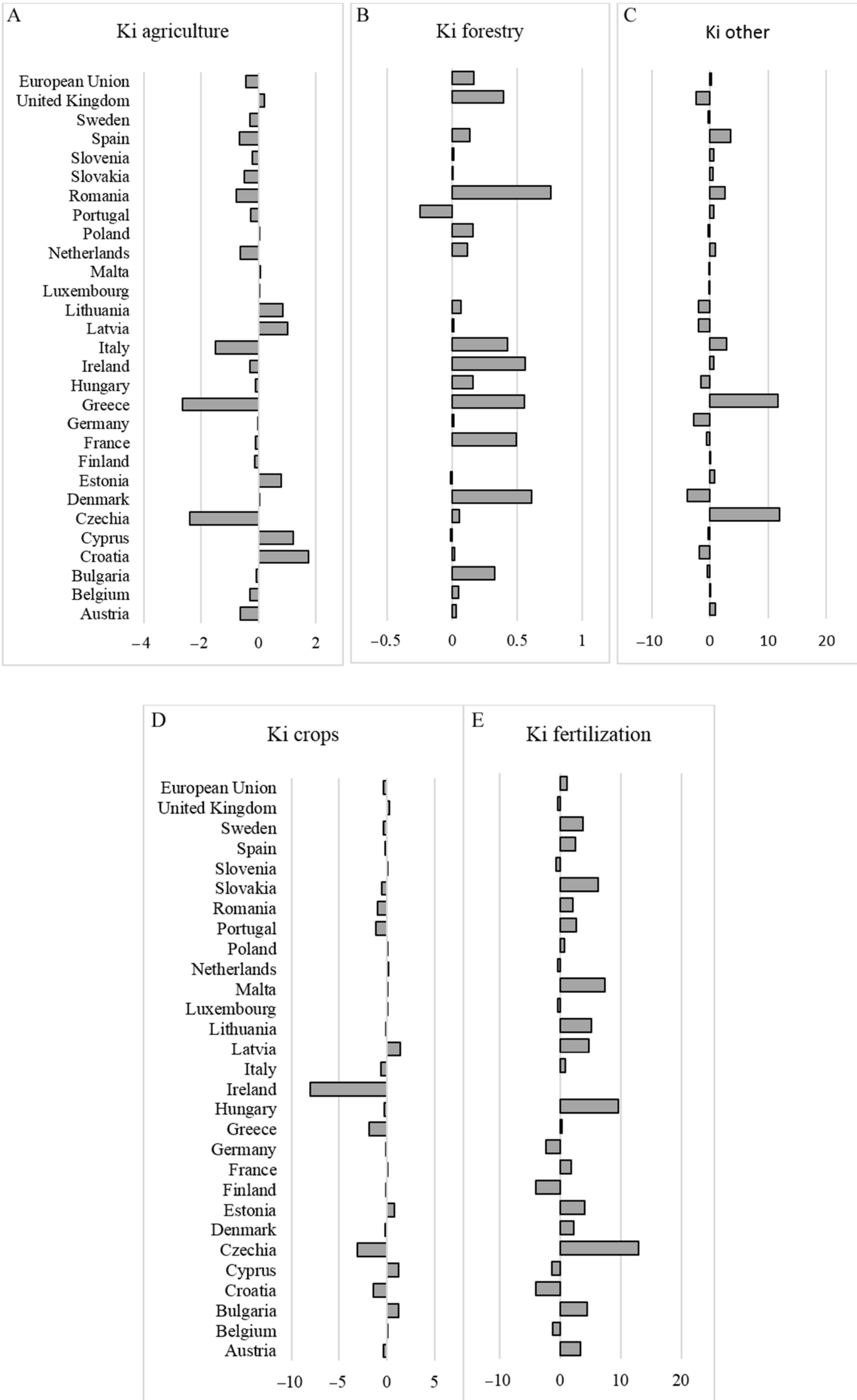

Figure 3. The rate of changes of land use for agriculture (**A**), forestry (**B**), other purposes (**C**), crops (**D**) and fertilization (**E**).

The matrix of the Spearman's rank correlation coefficients confirmed a negative correlation (r = −0.410) between land use diversity, and the rate of agricultural land change. It means that the higher rate of agricultural land change the lower land use diversity (Table 3). The land use intensity was positively correlated with the rate of forestland changes (r = 0.524) and negatively with the rate of other land changes (r = −0.430). The other correlations were insignificant. In general, the estimates of Spearman's correlation coefficients were relatively small that can suggest that the studied LUC indicators will contribute independently to the real net or gross land use change.

Table 3. The matrix of Spearman's rank correlation coefficients between land use change indicators (data for 2017).

Indicator	K_i Agriland	K_i Cropland	K_i Forestland	K_i Other	K_i Fertilization
H	−0.410 *	−0.234	0.292	0.239	−0.058
LUI	0.134	0.050	0.524 *	−0.430 *	0.087
LUE	0.115	0.064	−0.327	0.277	0.150

* significant at $p \leq 0.05$.

On the basis of the indicators studied, countries with a similar land use were grouped into clusters (Figure 4). Belgium, Luxemburg, the Netherlands, Slovenia, Cyprus, Croatia, Finland, Germany and the United Kingdom formed one group. These countries lie in three climatic zones (Finland—subpolar zone, Cyprus and Croatia—subtropical zone, Belgium, Luxemburg, the Netherlands, Slovenia, Germany and United Kingdom—temperate zone), nevertheless these countries, excluding Slovenia, are in the western part of Europe, where industrialization had occurred earlier than in the other parts of Europe. The second cluster was composed of Czechia and Spain, and the third one consisted of the remaining 17 countries, with different climates of middle and eastern Europe.

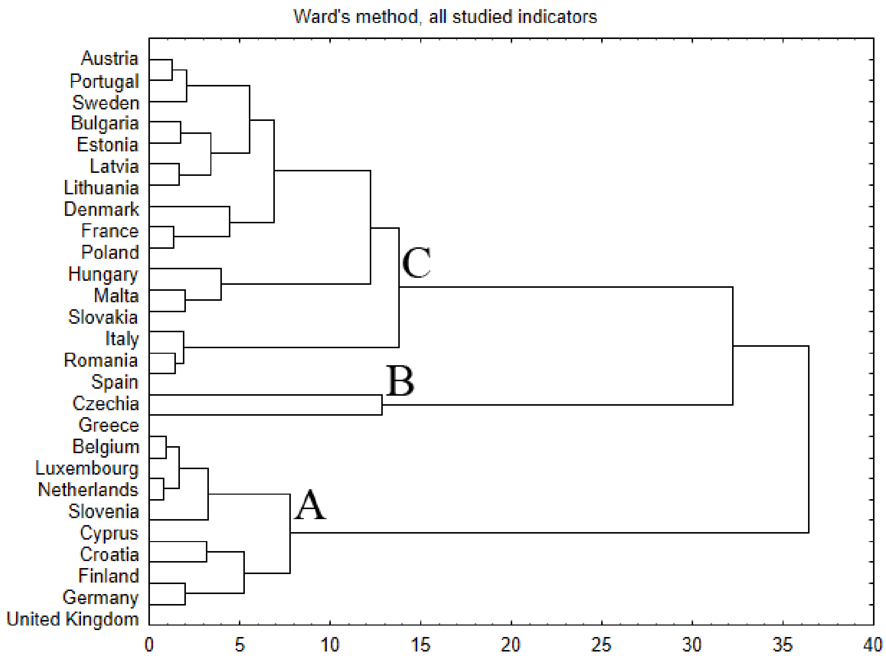

Figure 4. Hierarchical cluster analysis of land use change in the EU countries (**A**–**C** are country clusters described in Table 4).

The issues raised in our study were combined with the results of hierarchical clustering of the EU countries based on land cover/use indicators (Table 4). Based on general knowledge of country description and indicators from our study we found common features for A–C clusters, which we summarized in the 'overall characteristics' in Table 4, from which it can be concluded that countries in cluster A demonstrate the most sustainable agricultural land use, although general land use efficiency is not high.

Table 4. Overall characteristics of countries based on cluster analysis.

Cluster	Countries	Overall Characteristics
A	Belgium, Luxemburg, Netherlands, Slovenia, Cyprus, Croatia, Finland, Germany, United Kingdom	- geographic location in three climatic zones - the western part of Europe, where industrialization and urbanization occurred earlier than in other parts of Europe. - a high share of artificial land in land cover, - dominant agricultural use of land, - a lower land use intensity in the analyzed period 2010–2017 with a simultaneous decrease in fertilizers input, - in 2010 most of the countries had low land use efficiency index, - the rate of land use (K_i) for crops or forestry was positive in the majority of countries.
B	Czech Republic, Greece	- geographic location in different climatic zones - the decrease of agricultural land and cropland use - similar land use diversity indices in 2010 while differentiated in 2017, - negative rate of agricultural land use (including crops), - positive rate of land use for forestry, other purposes and increased fertilization use.
C	Austria, Bulgaria, Denmark, Estonia, France, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Spain, Sweden	- geographic location in three climatic zones of eastern, central and southern Europe, - heterogeneous land cover and land use, - less artificial areas, - diverse land use intensity changes with simultaneous increase in fertilizers input.

4. Discussion

The impact of LUC on the environment in the context of demand for food and bioenergy has received international attention [47]. The rates of land cover change have been increasing at an alarming level for the last three decades [48], especially in humid and subhumid areas [25], which were often in sites along roads [48], and in agricultural areas [47].

The land cover and land use data form the basis for spatial and territorial analyses, which in many respects are increasingly important for policy planning. According to Article 17 of the Habitats Directive [49], it is necessary to monitor the conservation status of natural sites, and their diversity at the global, regional and national levels. Such an obligation implies the need for obtaining data comparable in time and space. The need to have comparable land use data is a matter that has been posed already in 1980s by the first CORINE Land Cover program (CORINE Land Cover Product User Manual (Version 1.0). European Union, Copernicus Land Monitoring Service 2021, European Environment Agency EEA). The indicators used in this study (area of land cover types, ILC, Ki) may comprise a minimal set of them to monitor the status of land diversity and its changes across Europe [6,23,27,50]. The long-term monitoring of land cover changes can be relevant to policy makers aiming to provide a diagnosis of the current tendency and future prediction of LUC, as well as to scientists working on land use and land cover related research issues [51]. The index of land cover diversity refers to land uses variety in a certain area and indirectly can be related to specific climatic conditions of that area. The climate in the EU countries located in the north favors the formation and development of wetlands (mires) and forests. Towards the south of Europe, the climate becomes milder and favours the development of grasslands and use of the land in agriculture. In the southernmost parts of Europe, where the climate is warm and the summer is long, bare land and artificial land dominate, presumably mostly occupied by the hospitality, industry, and urban facilities.

The structure of land use in the European Union shows a relationship with the land cover type. Although these two concepts are interlinked, and often conflated in classification schemes [52], their meaning is different, therefore the LUC diversity within the EU is also important to monitor the status and changes in land use. In the EU, approximately 40% of land is used for agriculture, and 10% for residential, commercial and industrial purposes [53], whereas our study proved that the area of artificial landcover is larger (see Figure 1). The use of land in each country is strongly connected with natural conditions (climate, water, soil, land relief, geology, fauna and flora) and socio-economic factors (urbanization, industry, agriculture, economic potential). Therefore, differences between countries reported in this paper point out the fact that it is not possible to present a single common feature which would indicate similarities of LUC. European countries are characterized by very varying population and urbanization, and therefore land use changes were different [6,23]. For example, grasslands are mainly concentrated in EU countries, where forests were either depleted in the past by processes of deforestation, clearance or clearcutting or due to alternative land use. This is the case in Ireland, most of the United Kingdom (except eastern parts) and the Netherlands (see Figures 1 and 2). In these countries the land use diversity index (H) was high but the land use efficiency (LUE) was low (see Table 2). The LUE should be monitored overtime in Europe at the country level, as this research has been neglected in European statistics [6].

The land use diversity index reflects the richness of various land use types or prevalence of one land use type. High values of this index are associated with a mixed land use, which implies higher biodiversity and therefore lower susceptibility of land to ecological degradation. Lower values of H index are therefore indicative of one or two dominant land use types. The lowest land use diversity was estimated in Finland, Sweden and Cyprus, which can be associated with a high share of one land use type, i.e., forestry in the case of Sweden and Finland and other than forestry and agricultural use in the case of Cyprus. In northern European countries, the dominant land use for forestry was owing to the large woodland cover (Eurostat Regional Yearbook 2010 and 2017). A high LUE index (higher than the average in the EU) and the lowest LUI index estimated in our studies support those findings.

LUC is necessary for any economic development and social progress [54]. Models of LUC which take into consideration the Planetary Boundaries suggest that more sustainable food production can be achieved by shifting agricultural land use to mid-latitude regions of the northern hemisphere and replacing pastures in Europe with cropland [55]. Our study showed that the tendency in the EU countries is different—the agricultural land use, including cropland, was decreasing (see Figure 3). Further expansion of agricultural land use in Europe seems impossible, as it would presumably mean high intensification of production leading to the loss of biodiversity and greater CO_2 release from agricultural sectors. The expansion of one land use type in Europe and, consequently, intensification of production, may interfere with the implementation of SDGs [4]. Although the priority of the changes in land use is given to agriculture, there is a knowledge gap that inhibits our understanding of the dynamics and patterns of LUI [21]. The study revealed that in the EU, LUI was not high, as most of the countries had a low index of LUI in the studied period. However, at the same time, the effectiveness of land use showed a negative trend. The LUE in the majority of the EU countries was decreasing in the studied period (see Table 2). In those countries, sustainable land management should be evaluated and monitored to stop the negative trend. Intensification is not related to complex changes or detrimental effects of land use, but should be regarded multidimensionally, which would include inputs to the production system, outputs from the production system, and changes in ecosystem properties [17,56]. The land-based production will have to rely on an increase in yields rather than on expansion of land use [21,57,58]. However, such 'intensification' ought to be sustainable as much as possible, and the conditions of such sustainable intensification must be identified [59,60]. It should also be noted that the growing demand for food and the investors' interest in the agricultural sector have led to large-scale land grabbing of farming land all over the world, including EU countries, especially in Hungary, Romania and Bulgaria [61] and the change in agricultural land use intensity should be monitored specifically, as this may have negative effects for the environment [62–65].

The presented indicators reveal the status of land cover and land use in the EU countries. They enable decision makers and interest groups to compare the country land cover to the EU average (ILC), to see what are diversities in land use (H), to show intensity of agricultural land use (LUI) and land use efficiency (LUE). On the other side, indicators presenting aspects of land use in time (Ki) can play an important role in decisions on mitigating negative impacts on natural ecosystems and human environments, especially in relation to agricultural ecosystems. Accordingly, the indicators can support the implementation of the ambitious goals of the 2030 Agenda (SDGs).

Land use and land cover changes impact the terrestrial ecosystem services significantly, including the crucial ones for humans, i.e., provisioning and regulating services. There are no interlinks between the current LUC analysis and the spatial planning policies. It means that, the important pathway for the future research will be the integration of those two aspects [66]. The other focus of future research is to mitigate the conflict between build-up land and cultivated land at the local scale and to indicate the priority pathways for future land use changes in order to coordinate efficiently the changes at the local scale [67]. The research development of this issue from a local level to a quantification of the dynamics of land use change at the global level is critical in tackling modern societal challenges such as food security, climate change, and biodiversity loss [68].

5. Conclusions

The presented results show that the change in agricultural land use, coupled primarily to economic development, is today the undisputed cause of various, often unfavourable, environmental and social impacts. Accordingly, responsible and sustainable land management requires a meaningful set of indicators. The key indicators are targeted at a specific land use aspect related mostly to the absolute or percentage value of land use change and land use efficiency. Based on this research, a universal and comprehensive set of land-use indicators is proposed together with the metrics. In the selection of indicators, the following criteria were employed: benchmarking applicability for the EU countries, scientific relevance, reliability and robustness, representativeness and most frequent usage in literature. The final set combined seven indicators, including static indicators: index of land diversity, land use intensity and land use efficiency and dynamic indicators: the rates of change in the period 2010–2017 in agricultural land, cropland, forestland, other land and fertilization. All of the considered indicators can be measured against publicly available databases applicable to assessing the sustainability of agricultural land-use change at local, regional and global scales.

The single indicators were used in the comparison of the specific land use aspects across the EU countries. Consequently, seven indicators were used in the classification of the EU countries with the physical characteristics of the land area and climatic conditions as determinants.

The comparison of the EU countries on the basis of single indicators in the period 2010–2017:

1. dominant category of land cover:
   - woodland: Finland, Sweden, Ireland, the UK, Croatia and Estonia;
   - wetland, shrubland and bare land: the countries of the Mediterranean region;
   - artificial land and water—The Netherlands;
   - artificial land: Malta;
   - shrubland, grassland and wetland: Ireland and the United Kingdom.
2. increase in land use diversity: Belgium, Bulgaria, France, Italy, Portugal and Greece,
3. increase in land use intensity: Austria, Bulgaria, Czech Republic, Denmark, Estonia, France, Hungary, Latvia, Lithuania, Malta, Portugal, Romania, Slovakia, Spain and Sweden,

4. decrease in land use intensity: Belgium, France, Greece, Italy, Luxemburg, Slovenia, Spain,
5. decrease in agricultural use and crop cultivation use coincided with an increase in fertilization: Austria, Czech Republic, Greece, Hungary, Italy, Portugal, Romania, Slovakia, Spain and Sweden.

The comparison of the EU countries on the basis of combined indicators enabled the classification of the EU countries into three groups:

- Group A: Belgium, Luxemburg, Netherlands, Slovenia, Cyprus, Croatia, Finland, Germany, United Kingdom. Determinants: geographically located in the three climatic zones; the western part of Europe, where industrialization and urbanization occurred earlier than in other parts of Europe; a high share of artificial land in land cover, dominant agricultural use of land, a lower land use intensity with a simultaneous decrease in fertilizers input; low land use efficiency index, the rate of land use for crops and forestry was positive in the majority of countries.
- Group B: Czech Republic, Greece. Determinants: geographic location in different climatic zones; the decrease in agricultural land and cropland use.
- Group C: Austria, Bulgaria, Denmark, Estonia, France, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Spain, Sweden. Determinants: geographic location in three climatic zones of eastern, central and southern Europe; heterogeneous land cover and land use; less artificial areas; diverse land use intensity changes with a simultaneous increase in fertilizer input.

The databases used in the study sometimes do not contain all necessary information for calculation of indices or some indicators do not allow to consider all relevant factors, as listed in the Section 2. However, the selected indicators represent a set of conditions, and convey information about a change. They are necessary to monitor changes over time, and to assess the effects of policy changes and management practices, and for evaluating the sustainability of land use. The set of indicators analysed in this study is intended to become usable by researchers and policy makers dealing with analysis of land use changes. The LUC analysis should be integrated into the spatial planning policies, and should serve as a tool of trends to foresee possible land use changes.

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