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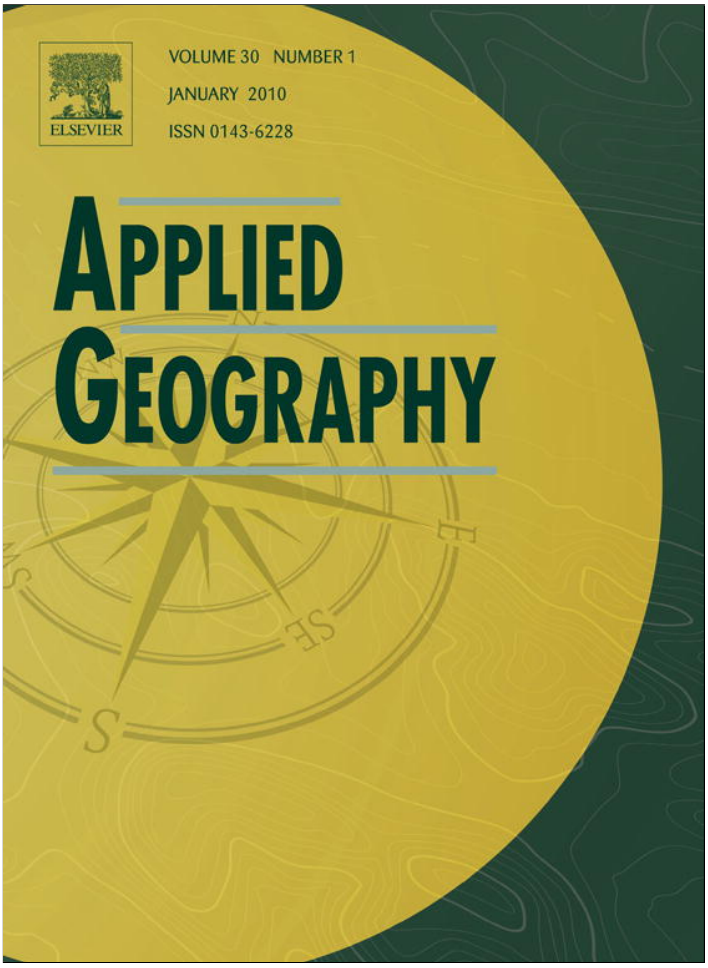
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Determining changes and flows in European landscapes 1990–2000 using CORINE land cover data

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ABSTRACT

The CORINE land cover (CLC) data derived from satellite images for the period of the 1990s and 2000 (± one year) provide information about land cover changes for a substantial part of Europe. Availability of these data can contribute to new approaches to the assessment of the European landscape, for instance in the context of environmental and economic accounting, diversity, modelling of its properties, etc. These possibilities are given by the fact that land cover reflects the biophysical state of the real landscape. The paper contains information about frequency and areas of CLC and their changes in the period 1990–2000, but above all in the processes – flows (LCF) that take place in the European landscape. Results of statistical analysis and maps demonstrate the frequency and rate (by two values: one above and another below the mean LCF rates) of the following processes: urbanisation (LCF1), intensification of agriculture (LCF2), extensification of agriculture (LCF3), afforestation (LCF4), deforestation (LCF5) and construction of water bodies (LCF6). LCF1 was most conspicuous in the Netherlands (2.1% of total country's area), LCF2 in Ireland (3.3%), LCF3 in the Czech Republic (over 3.5%), LCF4 in Portugal (over 4%), LCF5 in Portugal (over 3.5%) and LCF6 in the Netherlands and Slovakia (over 0.1%). The overall area of identified land cover changes in 24 European countries in the period 1990–2000 was around 88,000 km^2 which equals 2.5% of their total area. Details presented concerning the LCF frequency and rate will certainly contribute to the overall awareness and anticipation of possible developments in the European landscape.

Introduction

Urbanisation, industrialisation, and intensive agriculture often result in rapid landscape changes, losses of ecological capacity, diversity, and scenic beauty, as well as damage to historically valuable cultural landscape (Bastian, Krönert, & Lipský, 2006, p. 359). These problems have been analysed for Europe by Pedroli, Pinto-Correia, and Cornish (2006). CORINE land cover 2000 (CLC2000) contributes to the knowledge of the land cover (LC) and its changes in 24 European countries between 1990 and 2000. They are presented by Haines-Young and Weber (2006) and in Weber (2007). The basic aim of these studies is to show how CLC data can be applied to environmental and economic accounting through stockpiles and flows (land cover changes) analysis.

As the physiological features of landscape objects are well registered on satellite images, they are a valuable information source about LC for different monitoring programmes with the CORINE Land Cover (CLC) projects among them. They were

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used to generate LC data layers for substantial sections of the European countries for the 1990s and 2000 (Büttner et al., 2004; Feranec, Hazeu, Christensen, & Jaffrain, 2007; Heymann, Steenmans, Croissille, & Bossard, 1994; Nunes de Lima, 2005).

For the purpose of this study, landscape is defined as a part of the Earth's surface with its components as perceived by humans (Hartshorne, 1939). The cognitive process of the landscape has discerned its material and energetic base – *land* on one side and its outer appearance – *scape* on the other. In accordance with Bastian et al. (2006, p. 362) "*the land* represents *the biophysical unit* – an aspect of landscape which is determined by its natural components (geological and geomorphologic structure, soil, water, climate, flora and vegetation, fauna)." In contrast to the *biophysical unit,* the term *landscape* describes elements that are determined not only by natural conditions but also by human influences (Bastian et al., 2006, p. 363). The natural, modified (cultivated) and artificial objects integrated in the landscape have also specific physiognomy identifiable through LC (Feranec & Otahel, 2001; Snacken & Antrop, 1983). Hence, LC reflects the biophysical state of the real landscape (including the effects of human activity on the biophysical unit). This is the reason why LC data are increasingly used for the derivation of various landscape attributes such as its changes, diversity, forecasting, etc. and in the modelling of its different properties. Weber (2007, p. 2) for instance, considers the CLC90 and CLC2000 data layers "the core elements for integration of the European Environmental Agency's information system as a basic module that structures ecosystem accounts and bridges the realms of land use, biodiversity and water".

The aim of this paper is:

a) to present the frequency (occurrence) and the area (extent) of CLC classes, their changes and the derivation of basic processes – flows in the landscape, and to represent important information for environmental-economic accounting and
b) to provide spatial aspects proper to LC change flows in 24 European countries during the period 1990–2000 for potential environmental landscape assessment.

Review of approaches regarding land cover flows in the landscape

CLC change shows a categorical change, when one LC class or its part(s) is replaced by other class(es) (cf. Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004). As LC is an indivisible part of the landscape, it reflects its states in different stages of development. This is the reason why LC changes can be considered the relevant information source about processes (flows) in the landscape.

Aggregated flow accounts were constructed by assigning the various types of LC transformation to different categories of land use change. The categories of land use change were delineated by e.g. Stott and Haynes-Young (1998, p. 248) as follows:

– *Intensification* – a flow which represents the transition of an LC type associated with low intensity usage to a higher intensity usage (e.g. semi-natural cover type to arable cover),
– *Extensification* – a flow which represents the transition of an LC type associated with high intensity usage to a lower intensity usage (e.g. improved grassland cover type to semi-natural cover type),
– *Afforestation* – a flow which represents the planting or natural regeneration of trees,
– *Deforestation* – a flow involving the clearance of trees,
– *Development* – a flow involving the transformation of open land to urban, industrial or transport uses, and
– *Reclamation* – a flow involving the creation of open land from areas previously developed (e.g. reclamation of mineral workings).

According to Stott and Haynes-Young (1998), there are transformations between cover types, which remain within the major land use categories and do not involve land use change. These flows include crop rotation, grassland rotation, semi-natural changes (e.g. succession), woodland rotation (e.g. the conversion of broadleaf to a conifer plantation) and redevelopment (e.g. the conversion of industrial to residential cover types).

In contrast to the preceding authors, the study of Feranec et al. (2000, pp. 132–136) introduces the landscape change analysis approach. Definitions of landscape change types based on LC information from the CLC database(s) are as follows:

– *Intensification of agriculture* – Changes of meadows – pastures or forest to arable land, as well as changes of arable land to vineyards, orchards, berry plantations, greenhouse management, etc. This definition accepts the general principles of agricultural production understood in the context of the LC classes analysed.
– *Extensification of agriculture* - Changes of vineyards, orchards and berry plantations to arable land or grasslands, and changes of arable land to grasslands. For this type of landscape change, it is also important to take into account the abandoned agricultural land-land out of use for three or more years; it can change later into class 231 *Pastures* and even later into 324 *Transitional woodland shrubs*.
– *Urbanisation (industrialisation)* – Changes of mainly agricultural and forest land into urbanised land (construction of buildings destined for living, education, health care, recreation and sport) or industrialised land (construction of facilities for production, all forms of transport, power generation, construction connected with enlargement of water reservoirs and ponds).

– *Enlargement or exhaustion of natural resources* – Changes of agricultural, forest and other types of land to areas of mineral mining, and their enlargement or exhaustion in the corresponding localities.
– *Afforestation* – Natural or man-induced changes in areas after felling, changes of meadows – pastures or arable land into forests in various stages of growth.
– *Deforestation* – Clear-cut, devastation of forest by anthropogenic activity, natural disasters, etc.
– *Other landscape changes – changes caused by various anthropic activities like* the recultivation of former mining areas, dump sites, etc.

The aim of the LACOAST (LAnd cover changes in COASTal zones) Project was also to identify LC changes in a 10 km wide coastal zone of Europe in 1975–1990 using the CLC90 database and Landsat MSS satellite images from the 1970s (Perdigao & Christensen, 2000). Changes of LC in the quoted period included five LC change flows: urban development, agricultural development, afforestation (wasteland), swamping and creation of water bodies.

BIOPRESS is strongly linked to CLC 1990 and 2000, as it uses the same 44 classes nomenclature and, like LACOAST and MURBANDY, it looks back into the past. But what makes BIOPRESS unique is its focus on the identification of historical changes (1950 – 1990 – 2000) in LC for the purpose of measuring changes in habitats and their biodiversity:

– LC and LC changes for 59 transects that are partially situated in NATURA 2000 sites[1], were described for three time horizons (Köhler, Olschofsky, & Gerard, 2006).
– The scale of the acquired aerial photography varied between 1:8 000 and 1:20 000. The photographs were interpreted to identify the 44 CLC classes and achieve a minimum mapping unit of 0.5 ha.
– The types of LC changes (as determined by the 44 CLC) were grouped and renamed to represent types of ‘pressure’ on biodiversity, such as urbanisation, arable intensification, abandonment, afforestation, deforestation, and drainage (Köhler et al., 2006).

Haines-Young and Weber (2006) present the most extensive and detailed document about land accounting based on the CLC data. It contains nine major types of LC flow (LCF) and also a more detailed flow account. The following nine LC flows were described: LCF1 – urban land management, LCF2 – urban residential sprawl, LCF3 – extension of economic sites and infrastructures, LCF4 – agriculture internal conversion, LCF5 – conversion from forested and natural land to agriculture, LCF6 – withdrawal of farming, LCF7 – forest creation and management, LCF8 – water body creation and management, LCF9 – changes of LC due to natural and multiple causes.

The concept of LC flows was also applied to the Burkina Faso territory (Jaffrain, 2006). Two LC databases of 1992 and 2002, named BDOT (*Base de donnees d'occupation des terres*) are derived from the CLC nomenclature and specification but are adapted to the Soudan-Sahelian region. The objective was to show among other things, the main trend and pressure over the natural and semi-natural areas (forest, savannah, steppe) that took place between 1992 and 2002. Thus, nine flows (at the first level) have been identified showing the ‘stock’ available for some LC classes in the different LC data, and providing also the changes (both in terms of quantity and quality) in this decade between different LC works.

LC change flows derived from the second level CLC data, as applied in this paper, are described below.

Methodology

Haines-Young and Weber (2006, p. 9) provides “an overview and discussion of some of the key results that have emerged from the construction of environmental accounts for land and ecosystems” in 24 European countries. The methodology applied in this study generalizes a derivation of flows (LCF) in the landscape on the basis of the second CLC data level and presents their spatial aspects through LCF intensity maps (see below) in the mentioned European countries. The results will enhance the environmental-economic accounting in spatial assessment of landscape change areas by the application of CLC data.

The basic input information about LC changes in Europe during the decade of 1990–2000 is represented by the change data layer CLC90/2000. Its derivation is characterized in detail in the works of Nunes de Lima (2005) and Feranec, Hazeu, Christensen, and Jaffrain (2007). A review of LC classes, which are part of the change database CLC90/2000, is in Table 1.

The derivation of the main LCFs for the second level of CLC classes has been carried out by the means of the conversion table (Table 2). This conversion table or in other words “the matrix of flows“ groups LC changes of the same type (where the aspect of use is preferred to the biophysical aspect, i.e. the physical state of the particular object in time when the satellite image was taken). There are $15 \times 142 = 210$ possible combinations of one-to-one changes between the 15 CLC classes at the second level.

The changes, which are grouped into what is referred as LCFs, are classified according to six major land use processes (see Table 2 and Fig. 1):

[1] NATURA 2000: At the heart, the Birds Directive and Habitats Directive is the creation of a network of sites called Natura 2000. All EU Member States contribute to the network of sites in a Europe-wide partnership from the Canaries to Crete and from Sicily to Finnish Lapland.

Table 1
CLC nomenclatutre (Bossard, Feranec, & Oťaheľ, 2000; Heymann et al., 1994).

1 Artificial surfaces
11 Urban fabric
111 Continuous urban fabric
112 Discontinuous urban fabric
12 Industrial, commercial and transport units
121 Industrial or commercial units
122 Road and rail networks and associated land
123 Port areas
124 Airports
13 Mine, dump and constructions sites
131 Mineral extraction sites
132 Dump sites
133 Construction sites
14 Artificial, non-agricultural vegetated areas
141 Green urban areas
142 Sport and leisure facilities
2 Agricultural areas
21 Arable land
211 Non-irrigated arable land
212 Permanently irrigated land
213 Rice fields
22 Permanent crops
221 Vineyards
222 Fruit trees and berry plantations
223 Olive groves
23 Pastures
231 Pastures
24 Heterogeneous agricultural areas
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
3 Forest and semi-natural areas
31 Forests
311 Broad-leaved forests
312 Coniferous forests
313 Mixed forests
32 Scrub and/or herbaceous vegetation associations
321 Natural grasslands
322 Moors and heathland
323 Sclerophyllous vegetation
324 Transitional woodland-scrub
33 Open spaces with little or no vegetation
331 Beaches, dunes, sands
332 Bare rocks
333 Sparsely vegetated areas
334 Burnt areas
335 Glaciers and perpetual snow
4 Wetlands
41 Inland wetlands
411 Inland marshes
412 Peat bogs
42 Maritime wetlands
421 Salt marshes
422 Salines
423 Intertidal flats
5 Water bodies
51 Inland waters
511 Water courses
512 Water bodies
52 Marine waters
521 Coastal lagoons
522 Estuaries
523 Sea and ocean

Table 2
Conversion table.

		2000s classes														
		11	12	13	14	21	22	23	24	31	32	33	41	42	51	52
1990s classes	11	**0**	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	12	7	**0**	7	7	7	7	7	7	7	7	7	7	7	7	7
	13	7	7	**0**	7	7	7	7	7	7	7	7	7	7	6	7
	14	7	7	7	**0**	7	7	7	7	7	7	7	7	7	6	7
	21	1	1	1	1	**0**	2	3	3	4	4	7	7	7	6	7
	22	1	1	1	1	3	**0**	3	3	4	4	7	7	7	6	7
	23	1	1	1	1	2	2	**0**	2	4	4	7	7	7	6	7
	24	1	1	1	1	2	2	3	**0**	4	4	7	7	7	6	7
	31	1	1	1	1	5	5	5	5	**0**	5	5	5	7	6	7
	32	1	1	1	1	2	2	2	2	4	**0**	5	7	7	6	7
	33	1	1	1	1	2	2	2	2	4	4	**0**	7	7	6	7
	41	1	1	1	1	2	2	2	2	4	4	7	**0**	7	6	7
	42	1	1	1	1	2	2	2	2	4	4	7	7	**0**	6	7
	51	1	1	1	1	7	7	7	7	4	4	7	7	7	**0**	7
	52	1	1	1	1	7	7	7	7	4	4	7	7	7	7	**0**

1 – urbanisation (industrialisation), 2 – intensification of agriculture, 3 – extensification of agriculture, 4 – afforestation, 5 – deforestation, 6 – water bodies construction and management, 7 – other changes (recultivation, dump sites, unclassified changes, etc. – did not take into consideration in LCF context).

– (LCF1) Urbanisation – a flow, which represents the change of agricultural (classes 21, 22 and 23) and forest land (classes 31, 32 and 33), wetlands (classes 41 and 42) and water bodies (51 and 52) into urbanised land (the construction of buildings designed for living, education, health care, recreation and sport) as well as industrialised land (the construction of facilities for production, all forms transport and electric power generation) (see Table 2 and Fig. 1).

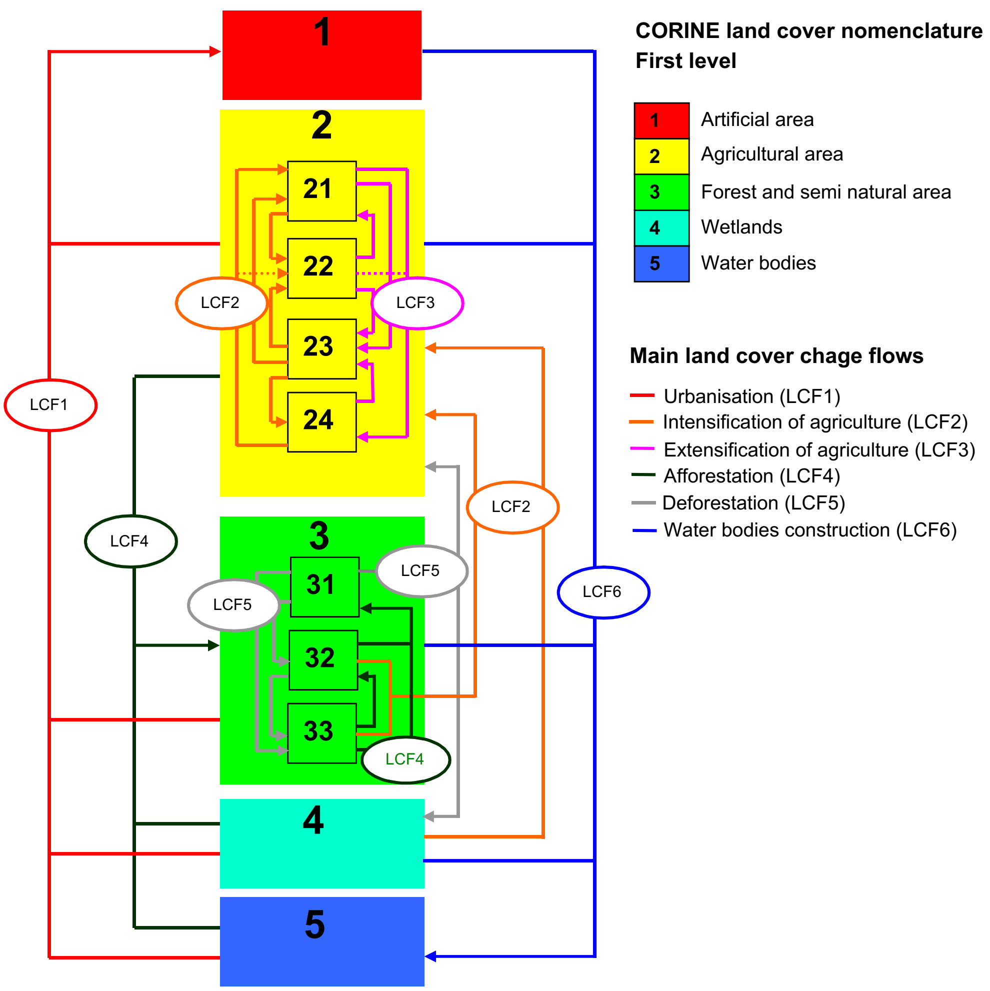

Fig. 1. Relation between the LC change flows and CLC classes.

- (LCF2) Intensification of agriculture – a flow, which represents the transition of LC types associated with lower intensity use (e.g. from the natural area – classes 32, 33, except forest class 31 and wetland – class 4) into the higher intensity use (see Table 2 and Fig. 1). The internal conversion of agriculture in a sense of more intensive use is also included in this flow. This characteristic accepts general principles of agricultural production (e.g. involving more inputs per unit land to raise productivity) in the context of the analysed LC classes (cf. Stott & Haynes-Young, 1998). Inputs include the use of artificial fertilizers, weed killers, fungicides, insecticides, pesticides growth regulators, etc. This trend in agriculture also involves modern technology such as agricultural mechanization, genetic selection, irrigation and drainage system, and soilless cultivation.
- (LCF3) Extensification of agriculture – a flow, which represents the transition of the LC type, associated with a higher intensity use (classes 21 and 22) to the lower intensity use (classes 23 and 24) (see Table 2 and Fig. 1). It involves mainly the social response to land constraints (cf. Stott & Haynes-Young, 1998).
- (LCF4) Afforestation – a flow, which represents forest regeneration – the establishment of forests by planting and/or natural regeneration (change of classes 21, 22, 23, 24, 33, 41, 42 into classes 31 and 32) (see Table 2 and Fig. 1).
- (LCF5) Deforestation – a flow involving forest land (class 31) changes into another LC or damaged forest (classes 21, 22, 23, 24, 32, 33 and 41, e.g. the tree canopy falls below a minimum percentage threshold of 30%) (see Table 2 and Fig. 1).
- (LCF6) Water bodies construction and management – a flow involving the change of mainly agricultural (classes 21, 22, 23 and 24) and forest land (classes 31 and 32) into water bodies (see Table 2 and Fig. 1).

Table 3
Changes of CLC classes in 1990–2000 in 24 European countries (in km^2) – on example of France.

CLC code	[+] increase	[−] decrease	Difference
111	0.00	0.00	0.00
112	551.41	16.78	534.63
121	380.04	2.52	377.52
122	106.41	0.60	105.81
123	2.35	0.00	2.35
124	9.44	2.75	6.69
131	219.58	117.87	101.71
132	10.81	19.04	−8.23
133	137.69	136.01	1.68
141	1.93	2.53	−0.60
142	109.17	2.18	106.99
211	1059.83	938.90	120.93
212	0.00	0.00	0.00
213	3.93	0.20	3.73
221	55.65	89.98	−34.33
222	75.52	75.41	0.11
223	0.50	1.23	−0.73
231	473.32	1179.39	−706.07
241	0.00	0.00	0.00
242	235.75	670.92	−435.17
243	146.78	125.73	21.05
244	0.00	0.00	0.00
311	1156.08	1044.50	111.58
312	2187.72	2188.93	−1.21
313	340.92	267.28	73.64
321	24.71	96.55	−71.84
322	27.64	72.29	−44.65
323	163.84	116.53	47.31
324	3408.14	3644.86	−236.72
331	8.11	10.12	−2.01
332	0.68	13.43	−12.75
333	14.40	4.73	9.67
334	102.26	290.58	−188.32
335	0.00	0.00	0.00
411	2.92	6.74	−3.82
412	0.00	0.10	−0.10
421	0.46	2.29	−1.83
422	0.39	0.48	−0.09
423	0.09	1.38	−1.29
511	6.99	4.22	2.77
512	129.89	8.38	121.51
521	0.37	0.29	0.08
522	0.00	0.00	0.00
523	0.00	0.00	0.00

All data characterizing the frequency and areas of CLC90 and CLC2000 classes are available on the web page of the Environment Agency (EEA, see reference). LC changes between 1990 and 2000 in 24 European countries, which were obtained by the comparison of CLC90 and CLC2000 data layers, are expressed by the increments and losses of LC in the quoted decade. As the table *Changes of CLC classes in 1990–2000 in 24 European countries (in km^2)* cannot be published in its entirety due to the extensive amount of information, the paper only brings a portion of the material which demonstrates the LC changes in France (See Table 3).

The percentage of the total country surface affected by LCF1-6 (Figs. 2, 4, 6, 8, 10 and 12) has been calculated as follows: (LCF area/**S** territory)$\times$100 = % LCF; **S** = total country area.

The combination of these Figs. (2, 4, 6, 8, 10 and 12) with Figs. 3, 5, 7, 9, 11 and 13 offers the possibility to perceive not only the size but also the spatial aspects of LC changes at the level of 24 European countries by the identification of processes (LCF) that incited them (urbanisation, intensification of agriculture, extensification of agriculture, afforestation, deforestation, construction and management of water bodies). Individual areas of LC change are mostly too small to be presented in the form of a map at the national or even European level; therefore, the advantage of a grid rate summarizing individual changes in a regular grid pattern is often used (Feranec et al., 2000). In our paper, the 3 $\times$ 3 km grid has been selected as a compromise between the spatial distribution presentation of the processes at the European level and the available map scale. The mean LCF rate value quoted in maps in Figs. 3, 5, 7, 9, 11 and 13 is the ratio of the area of LC changes standing for the corresponding LCF and the area of all squares of the grid 3 $\times$ 3 km, in which the corresponding changes took place. A transparent area comparison of individual LC change types in 24 European countries is in Table 4.

It is important to emphasize that the area of square is 900 hectares (3 $\times$ 3 km) and if the mean rate of extensification is for instance 4.7%, then the change is only concerned with 42.3 hectares. It means that within this square plots, a contrary process may have taken place as well; in other words, in the same square a more pronounced intensification or other processes may have occurred.

So adapted (processed) CLC data are considered suitable for the process of environmental accounting and quick LC change assessment.

National statistical data

Conventional national statistics accessible in statistical yearbooks and those published by national statistic offices are available for different analyses and assessments in European countries. These data, unlike the CLC data, have been obtained based on functional attributes and their legal status according to the cadastral maps. A difference may exist between the legal status and the real land use (for example, forest is not necessarily found on forest land and this is the reason why the area of forest land does not always coincide with the area of real forest growths, etc.). Differences between the CLC and national statistic (NS) data are demonstrated in an example of Slovakia (see Table 5).

If national statistical data are also applied in the environmental accounting, their combination or comparison with the CLC data should be seen as complementary (see the example of Slovakia, Table 5), because:

- The number of classes in the CLC nomenclature is substantially higher than that of NS and it also contains classes that are missing in the NS (for example, heterogeneous agricultural areas – 24, shrub and/or herbaceous vegetation association – 32, open space with little or no vegetation – 33 etc.),
- Distinct differences also exist in the content of CLC and NS classes as a consequence of their different definitions and area of the minimum identified portion (25 ha for CLC); however, it is not at all limited in the NS dataset. Differences between the CLC and NS data concerning the meadows vs. pastures (see Table 5) are considered the most significant as an area of biannual fodder crops (grasses) grown on arable land, which under the crop rotation in the NS are classified under grasses

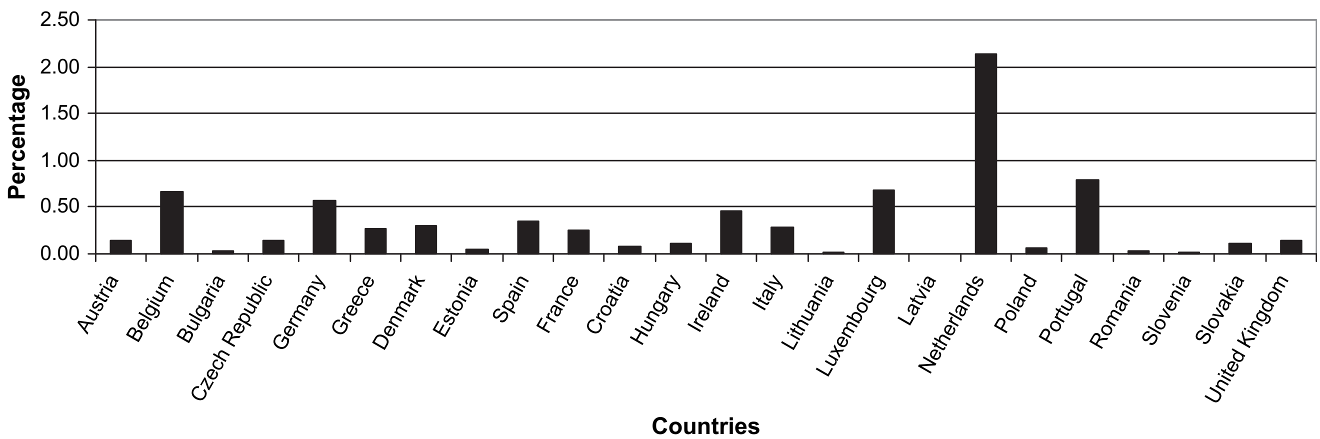

Fig. 2. Percentage of the total country surface affected by urbanisation (LCF1).

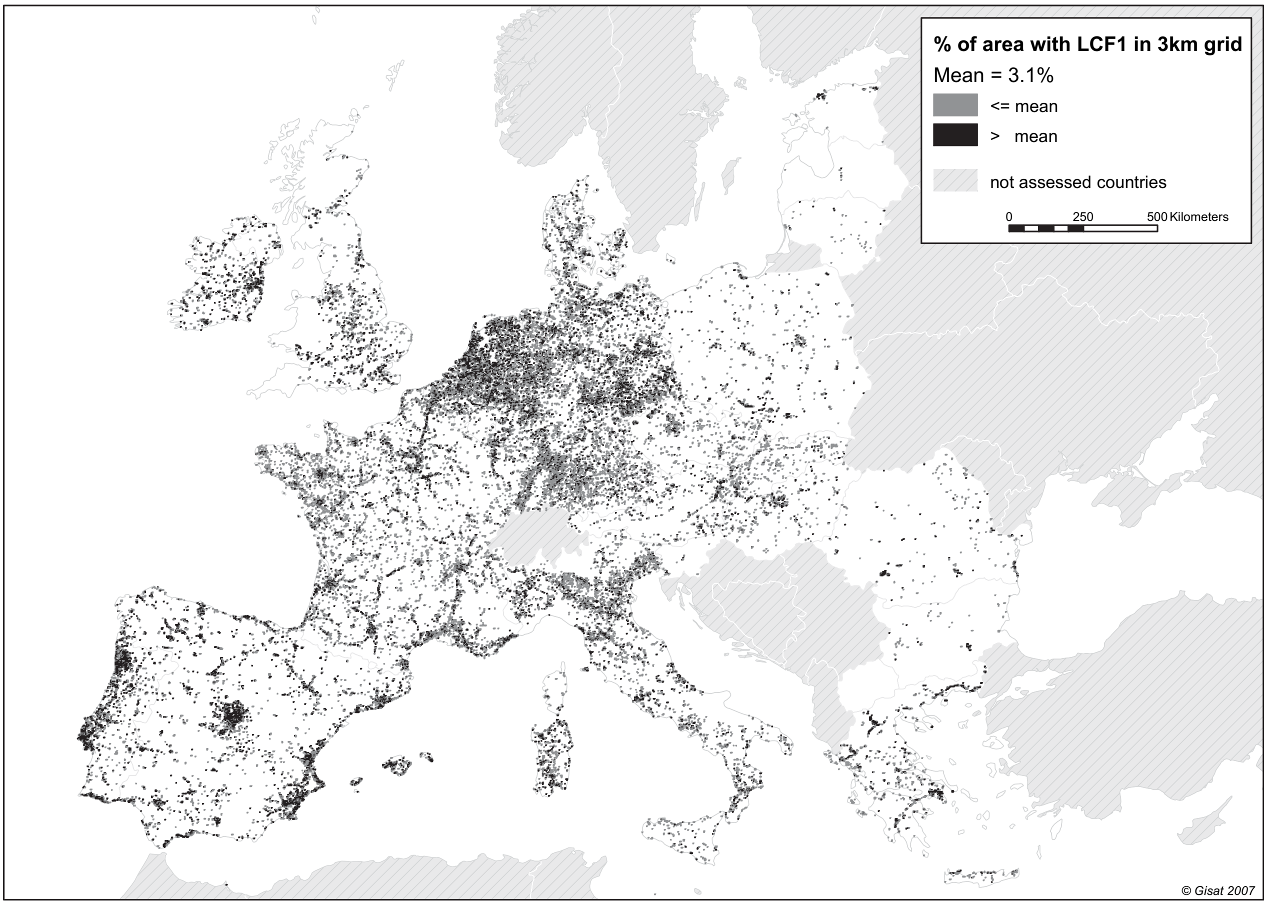

Fig. 3. Spatial distribution of urbanisation in 24 European countries.

and arable land while the CLC nomenclature class 231 contains areas where grass growths have existed for more than five years. The distinct differences in the area of this class in the compared datasets are probably also due to interpretation errors as the spectral characteristics of grassland, cereals and fodders in certain phenophases are very similar and their identification on satellite images from one time horizon only is problematic.

- CLC data provide information about the spatial arrangement of individual LC classes while the NS data are only linked to administrative units and are derived from cadastral data.

The existing differences between the NS and CLC data result from different methodologies which were applied to their collection (Feranec, Šúri, Oťaheľ, Cebecauer, & Soukup, 2001). The possibilities of using the NS data in LC accounting/environmental accounting are limited as their number of classes is substantially smaller (Feranec & Otahel, 2001; Feranec, Šúri,

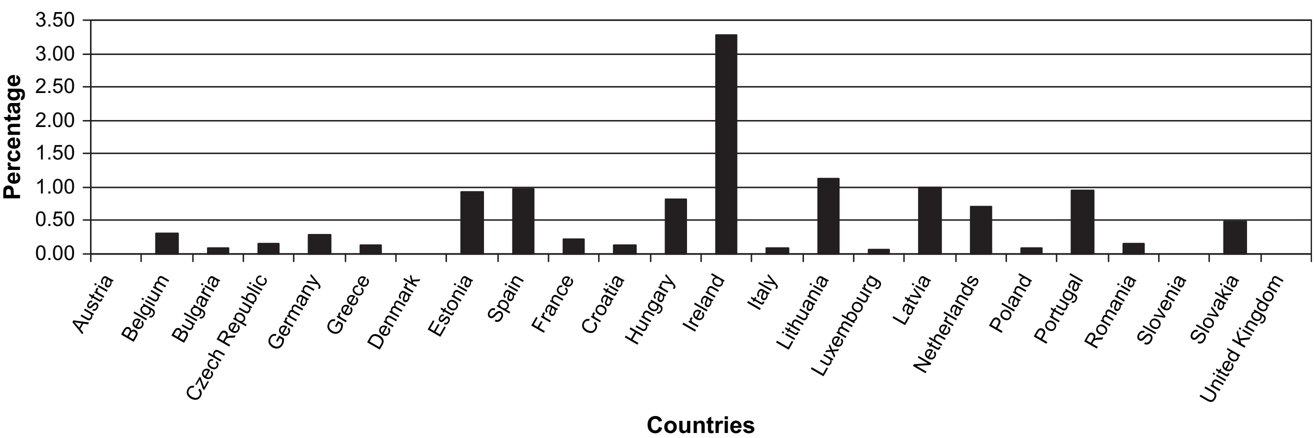

Fig. 4. Percentage of the total country surface affected by intensification of agriculture (LCF2).

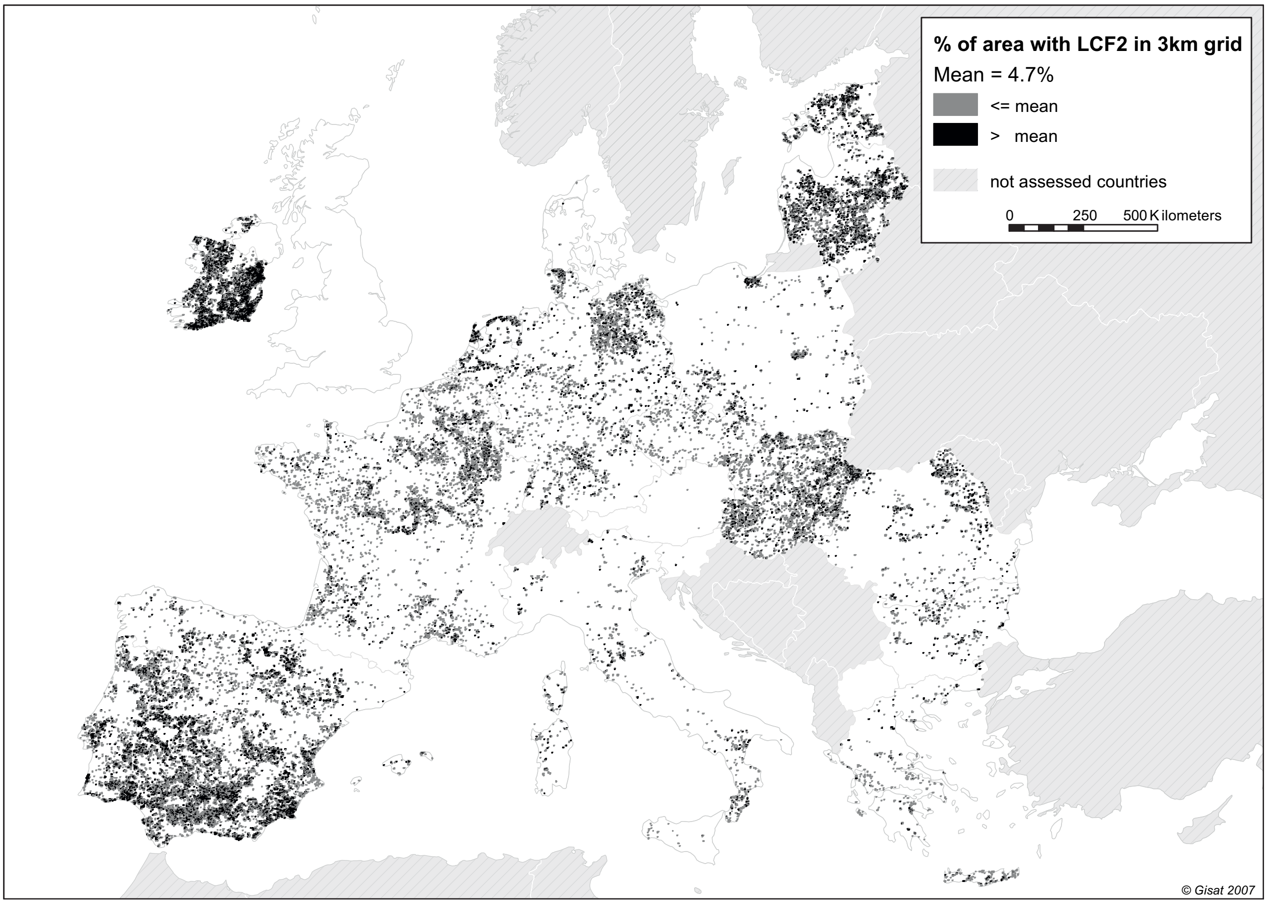

Fig. 5. Spatial distribution of intensification of agriculture in 24 European countries.

Oťaheľ, Cebecauer, & Soukup, 2001), and spatial distribution is rough. However, they can be useful in the verification of CLC area extents, which are rather homogeneous in terms of content (for example, permanent crops) both at the regional and national levels.

Characteristics of obtained results

Weber (2007) asserts that CLC data layers can also be used in LC change assessment at the level of regions, river basin catchments, coastal zones or bio-geographic areas. Results presented here provide information about LCF at the level of 24 European countries. Their specific virtue is that they offer information about the area and rate value of identified LCF (see Figs. 2, 4, 6, 8, 10 and 12), as well as about their spatial distribution in 24 European countries (see Figs. 3, 5, 7, 9, 11 and 13).

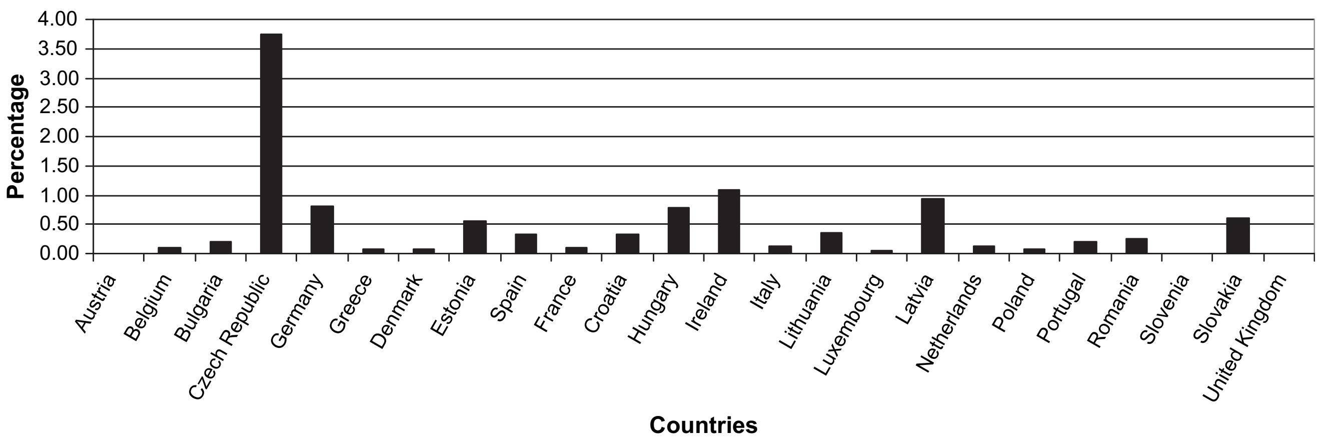

Fig. 6. Percentage of the total country surface affected by extensification of agriculture (LCF3).

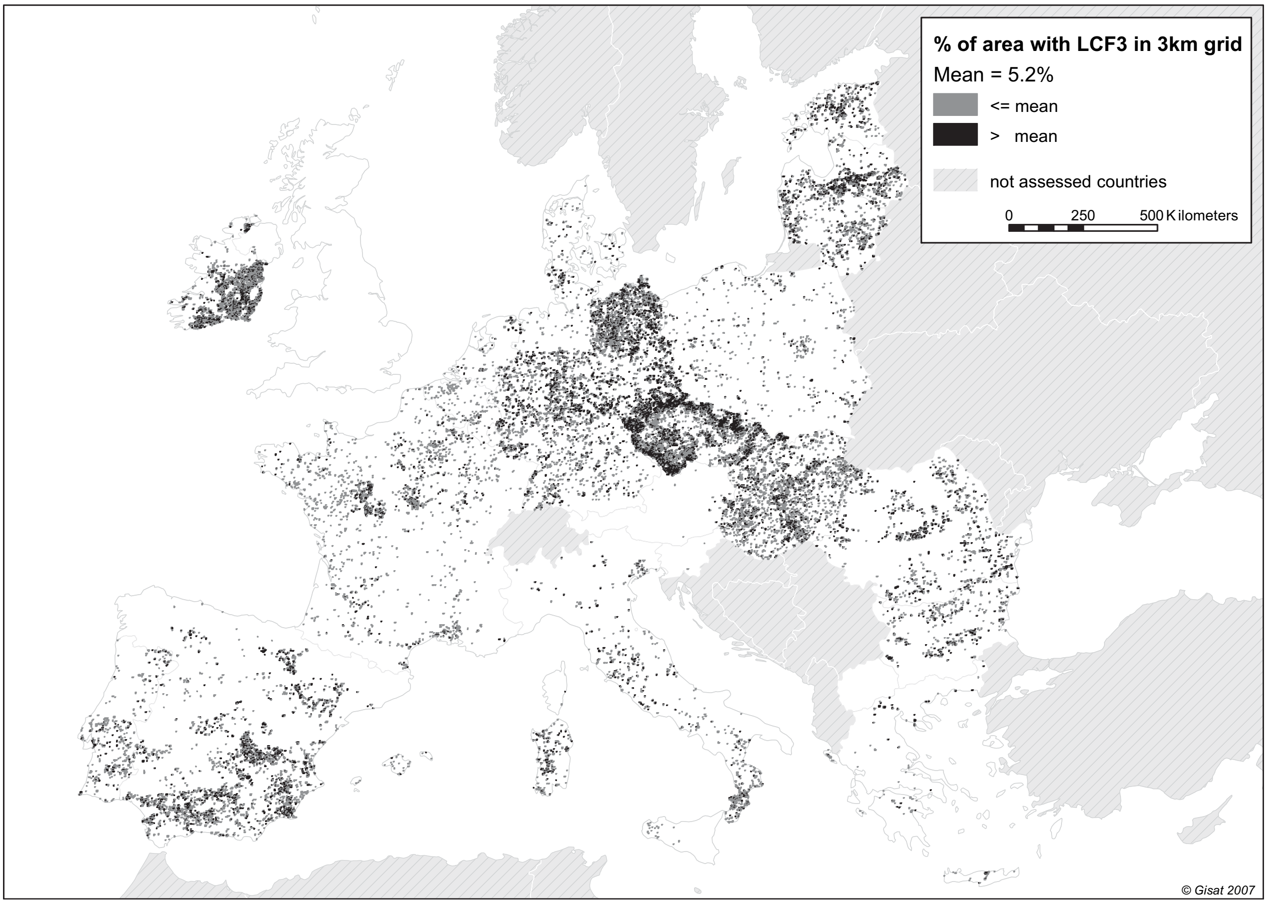

Fig. 7. Spatial distribution of extensification of agriculture in 24 European countries.

Urbanisation (LCF1)

The urbanizing process is manifested by the enlargement of artificial surfaces (CLC classes 11x, 12x, 13x and 14x), i.e. the construction of new buildings, industries, etc. Not only are the rates of urban growth accelerating, but the patterns of urban growth are becoming more dispersed (Hasse, 2008; p. 117). The most distinct and extensive urbanizing processes were observed in Germany, Spain, France, the Netherlands, Italy and Portugal (Table 4). Particularly low urbanisation was observed in 11 countries of central and eastern Europe (Table 4). The percentage of urbanisation in the total area of a country is greatest in the Netherlands (2.14%), followed by Portugal (0.79%), Luxembourg (0.69%), Belgium (0.66%) and Germany (0.57%) (Fig. 2). It is very low in central and eastern European countries: the Czech Republic (0.14%), Slovakia and Hungary (0,11%) and in other countries in this part of Europe where it is below 0.1%. Fig. 3 shows the spatial distribution and intensity of the urbanizing

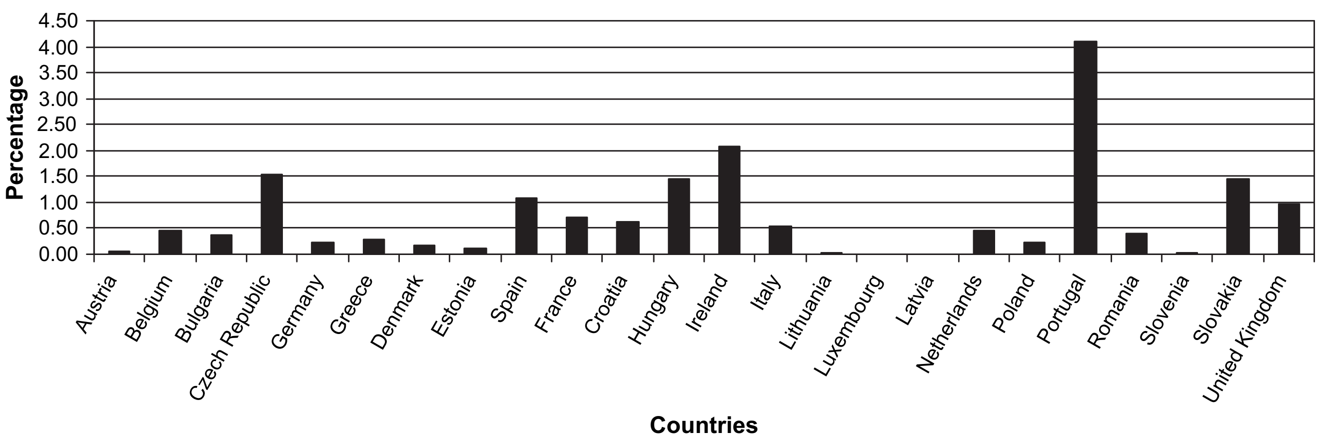

Fig. 8. Percentage of the total country surface affected by afforestation (LCF4).

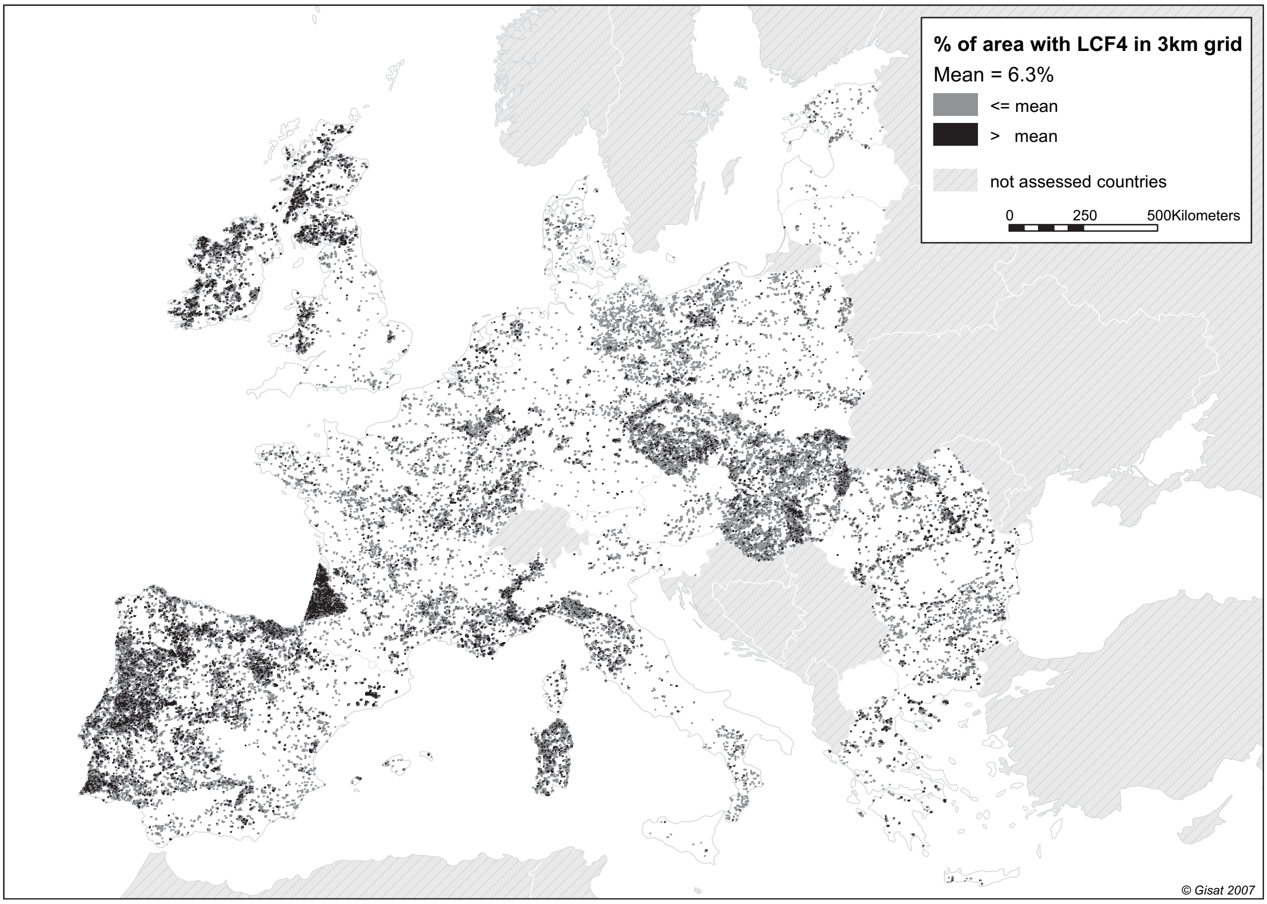

Fig. 9. Spatial distribution of afforestation in 24 European countries.

process (urbanisation expressed by the rate value in 3 km grid squares). The mean LCF1 rate value in affected grids (3 km grids where urbanisation takes place) has reached 3.1% of the grid area. This figure depicts the distribution of grids below and above the mean LCF1 rate in assessed European countries.

Intensification of agriculture (LCF2)

Table 2 contains changes of CLC classes resulting from agricultural intensification processes. Table 4 demonstrates that the most extensive LC change areas induced by the intensification of agriculture occur in Spain, Ireland, France and Germany. The percentage of intensified farming of the overall area of the country is greatest in Ireland (3.28%), Lithuania (1.13%), Latvia (1.00%) while it is below 1% in the remaining countries. Negligible change of this type (below 0.1%) was observed in Austria,

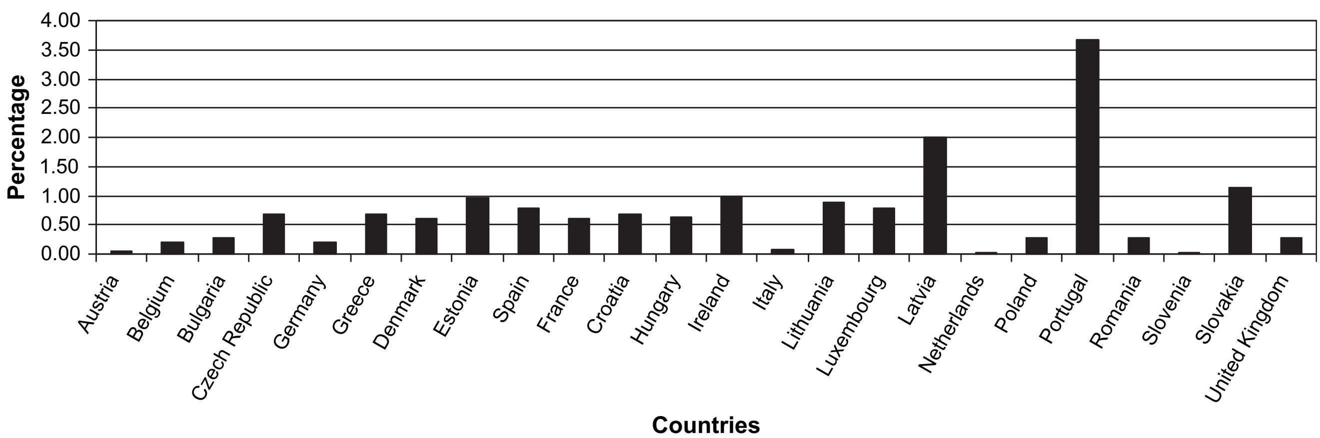

Fig. 10. Percentage of the total country surface affected by deforestation (LCF5).

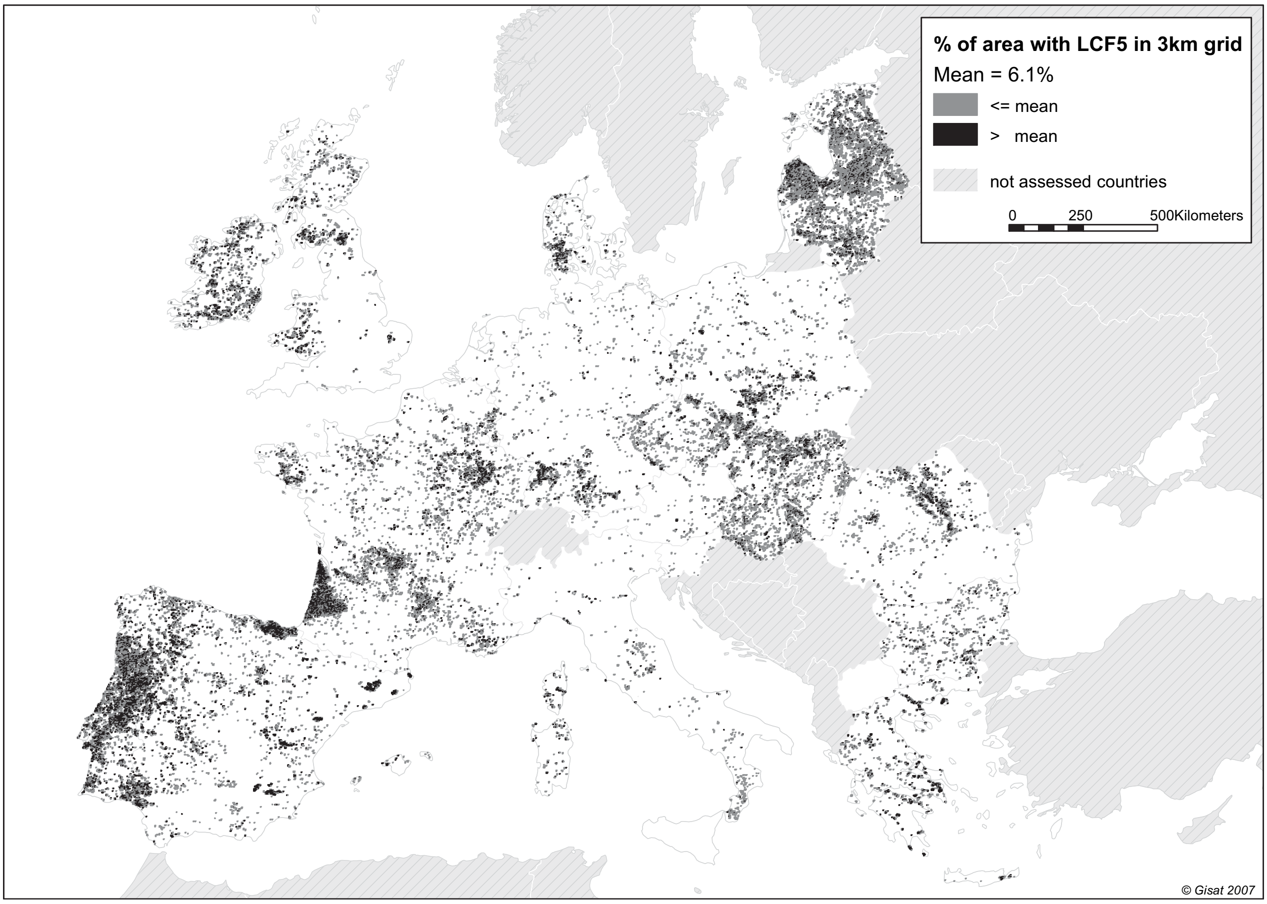

Fig. 11. Spatial distribution of deforestation in 24 European countries.

Bulgaria, Denmark, Italy, Luxembourg, Poland, Slovenia, and United Kingdom (Fig. 4). The results suggest that changes of agricultural landscape in favour of new areas with higher agricultural production were not great. Agricultural intensification rate and its spatial distribution expressed by 3 km grid squares are presented on Fig. 5. The mean intensified agriculture (LCF2) rate value in grid squares where LCF2 changes occurred is 4.7%.

Extensification of agriculture (LCF3)

Changes of agricultural landscape in favour of extensification are fairly balanced. As far as their size is concerned, extensification is greatest in the Czech Republic, Germany, Spain, and Ireland. The percentage of agricultural extensification in the overall area of the country stands out in the Czech Republic (over 3.50%) and Ireland (slightly over 1%), while it is below 1%

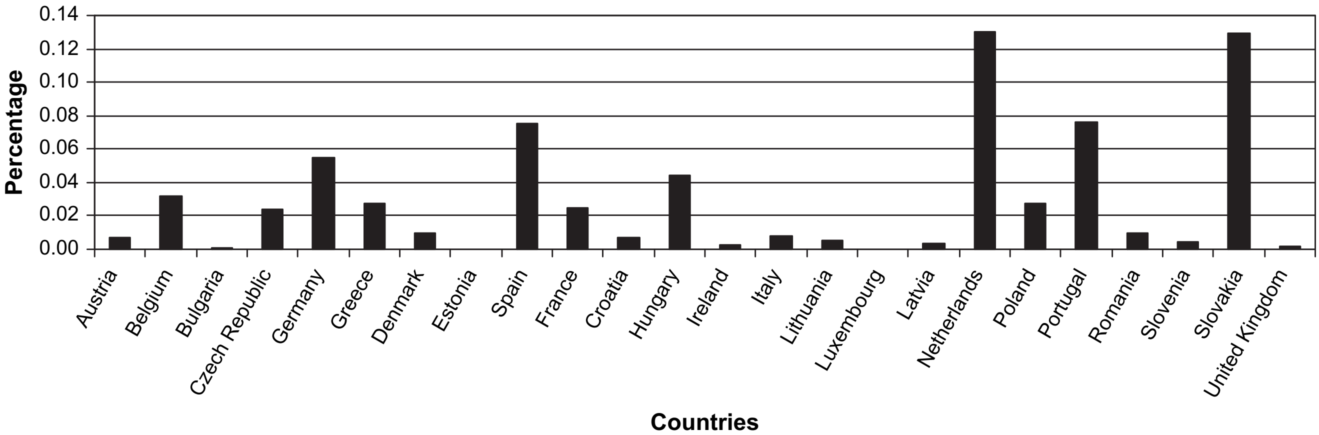

Fig. 12. Percentage of the total country surface affected by water bodies construction and management (LCF6).

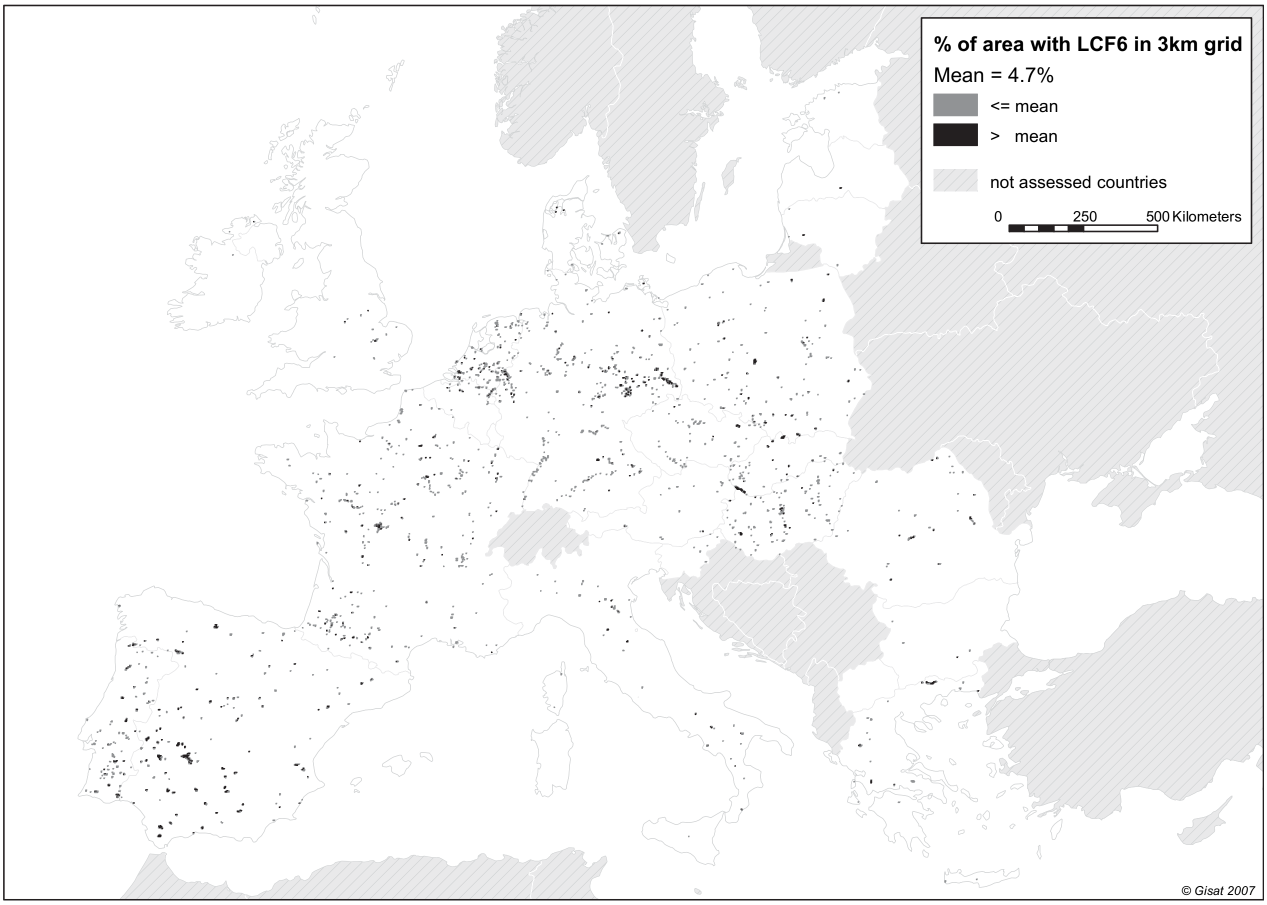

Fig. 13. Spatial distribution of water bodies construction in 24 European countries.

Table 4
Area comparison of individual LC change flows in 24 European countries (in km^2).

Country	0	1	2	3	4	5	6	7	Total country area	Total change area	% of change area
Austria	83,638.80	118.99	3.17	7.96	56.60	49.97	5.96	17.72	83,899.17	260.37	0.31
Belgium	30,096.61	201.62	93.14	29.46	143.02	60.40	9.67	44.98	30,678.90	582.29	1.90
Bulgaria	109,872.27	35.19	106.47	219.65	396.28	295.68	1.34	8.30	110,935.18	1062.91	0.96
Czech Republic	73,827.34	113.83	124.87	2961.15	1,218.17	548.68	18.70	90.24	78,902.98	5075.64	6.43
Germany	353,357.90	2,066.85	1,044.46	2902.58	818.75	731.34	198.92	522.56	361,643.36	8285.46	2.29
Greece	130,059.48	357.60	187.51	87.83	381.59	906.07	36.81	73.08	132,089.97	2030.49	1.54
Denmark	43,526.41	132.46	2.98	35.77	73.63	263.12	4.27	25.80	44,064.44	538.03	1.22
Estonia	44,196.51	25.10	417.85	253.34	49.91	441.50	0.12	12.85	45,397.18	1200.67	2.64
Spain	487,771.92	1750.59	4,971.31	1662.50	5434.44	4,008.01	382.00	240.88	506,221.65	18,449.73	3.64
France	541,006.19	1386.70	1,257.89	569.13	3923.62	3364.78	136.82	269.93	551,915.06	10,908.87	1.98
Croatia	55,445.91	47.67	79.80	179.63	359.96	386.31	4.21	12.17	56,515.66	1069.75	1.89
Hungary	89,434.66	100.89	757.70	724.83	1359.29	581.62	41.25	63.15	93,063.39	3628.73	3.90
Ireland	65,057.73	319.60	2,316.01	764.69	1476.56	692.61	1.86	18.59	70,647.65	5589.92	7.91
Italy	297,913.93	837.70	262.56	376.63	1652.24	219.37	25.00	43.26	301,330.69	3416.76	1.13
Lithuania	63,679.56	7.18	740.77	239.07	18.54	582.20	3.49	9.63	65,280.44	1600.88	2.45
Luxembourg	2550.95	17.78	1.72	1.11	0.32	20.03	0.00	1.09	2,593.00	42.05	1.62
Latvia	62,067.79	1.21	650.78	601.88	2.30	1,286.58	2.25	0.00	64,612.79	2545.00	3.94
Netherlands	38,210.69	851.22	278.57	46.62	184.83	13.25	51.96	220.16	39,857.30	1646.61	4.13
Poland	310,141.63	199.11	292.17	229.90	735.99	868.31	86.14	103.82	312,657.07	2515.44	0.80
Portugal	80,448.42	705.09	856.95	188.04	3652.67	3,271.77	67.96	44.36	89,235.26	8786.84	9.85
Romania	235,500.73	80.76	391.16	586.55	919.80	672.53	23.19	48.93	238,223.65	2722.92	1.14
Slovenia	20,254.17	3.01	1.61	0.25	5.13	6.76	0.84	5.85	20,277.62	23.45	0.12
Slovakia	47,096.87	53.51	240.13	296.09	709.50	559.47	63.60	17.81	49,036.98	1940.11	3.96
United Kingdom	244,171.38	364.97	0.00	0.01	2425.67	691.07	5.38	70.05	247,728.54	3557.15	1.44

0 – no change, 1 – urbanisation (industrialisation), 2 – intensification of agriculture, 3 – extensification of agriculture, 4 – afforestation, 5 – deforestation, 6 – water bodies construction and management, 7 – other changes (recultivation, dump sites, unclassified changes, etc.).

Table 5
Comparison of CLC data with the national statistics (NS) in 1990 and 2000 (in ha) (Feranec, 2006).

Classes of national statistics (NS)	CLC[a]	1990		2000	
		CLC90	NS87	CLC2000	NS2000
Built/up areas	11 + 12	255 597	122 462	259 772	219 340
Arable land	21	1 676 062	1 513 794	1 670 350	1 450 519
Vineyards	221	27 777	31 892	25 369	27 705
Fruit trees, hop plantations and berry plantations	222	13 134	22 696	10 594	19 629
Meadows and pastures	23	319 923	816 294	300 559	865 222
	24	425 527		432 838	
Forests	311 + 312 + 313 + 324	2 081 775	1 977 185	2 100 970	2 001 249
	33	12 025		11 478	
	41	5 883		4 397	
Ponds and water bodies	51	21 939	93 931	28 198	93 104
Other areas			248 977		149 109
Gardens			77 712		77 619
Other CLC classes	131 + 132 + 133 + 141 + 142 + 321 + 322	66 041		61 158	
Total		4 905 683	4 904 943	4 905 683	4 903 496

[a] Codes of CLC classes are explained in Table 1.

in the remaining countries. Apart from the Czech Republic, the above mentioned percentage oscillates around 0.20–0.93% in central and eastern European countries. It is even lower in Slovenia and Poland (Table 4 and Fig. 6). Changes of arable land (21x) into 231 (abandonment of land), those of permanent cultures (22×) into CLC classes 21x and the like, dominate in extensification processes. Agricultural extensification rate and its spatial distribution expressed using 3 km grid squares are presented on Fig. 7. The mean extensification of agriculture (LCF3) rate value in grid squares where LCF3 changes occurred is 5.2% (Fig. 7). This trend is also to be confirmed by using other data.

Afforestation (LCF4)

The regeneration of forest is the most prominent LC change in Europe. The increase of afforested areas is depicted in Table 4. The most distinct changes in favour of classes 31x and 324 were identified in Spain (more than 5000 km^2), France (around 4000 km^2) and Portugal (more than 3000 km^2). The percentage of afforestation of the overall country's area is most distinct in Portugal (over 4%). It is over 2% in Ireland and in Slovakia; whereas, the Czech Republic, Hungary are around 1.50% (Fig. 8). Negligible values of this indicator have been established for Austria, Lithuania, Luxembourg, Latvia and Slovenia. Afforestation is connected with the natural development of forest, for instance on abandoned pastures (231) and the like, but above all due to man-induced developments (planting after logging or calamities). The rate values and spatial distribution of afforestation flows (LCF4) which are expressed by 3 km grid squares are presented on Fig. 9. The mean rate value of the scope of this process in affected grids (where afforestation took place) has reached 6.3%.

Deforestation (LCF5)

Processes leading to deforestation are connected with logging and various natural catastrophic situations (strong winds, etc.) or emissions that cause the forests to die. As far as the area is concerned, the greatest losses of forest have been observed in Spain, France, and Portugal (over 3000 km^2) and Latvia (over 1000 km^2). Losses of forest below 1000 km^2 were established in the remaining European countries (Table 4). The percentage of deforestation in the overall country's area is greatest in Portugal (more than 3.50%). Around 2% was established in Latvia (Fig. 10). The prevalence of deforesting processes over afforestation was established for Greece, Denmark, Estonia, Croatia, Lithuania, Luxemburg, Latvia and Poland. The rate and spatial distribution of deforestation flows (LCF5) expressed by 3 km grid squares is presented on Fig. 11. The mean rate value of the scope of this process in affected grids (where deforestation took place) has reached 6.1%.

Construction and management of water bodies (LCF6)

The results suggest that the area of water bodies increased in many European countries assessed: in Spain (by more than 350 km^2), Germany (around 200 km^2), France (by more than 100 km^2) and in the Netherlands, Poland, Portugal and Slovakia by more than 50 km^2 (see Table 4). Increased area of water bodies in the context of the present landscape structure is considered a positive change as it contributes to the water balance of the landscape. The percentage of constructed water bodies (LCF6) in the country's overall area is greatest in the Netherlands and Slovakia (about 0.13%). It is below 0.1% in the remaining countries (Fig. 12). The rate and spatial distribution of LCF6 flows expressed by 3 km grid squares is presented in Fig. 13. The mean rate value of the scope of this process in affected grids (where LCF6 took place) has reached 4.7%.

Discussion

The presented results provide information about LC changes (magnitude and structure) and the derivation of processes, i.e. flows (LCF). The latter determines changes in the landscape, spatial distribution of these changes on maps (Figs. 3, 5, 7, 9, 11 and 13) their rate and distribution within the 3×3 km grid. The numerical (statistical) and map outputs represent the consolidated overview of LC/LU related processes in Europe and contribute to the recent *land and ecosystem accounting methodology* activities. Information about LC may be particularly valuable for the identification of proximate *causes – human activities or immediate actions that directly affect land use* and *underlying causes* (Geist & Lambin, 2002; Lesschen, Verburg, & Staal, 2005). LC change assessment will be also applicable in the *DPSIR (Driving forces – Pressure – State – Impact – Response)* methodology (Smeets & Weterings, 1999).

The results of the thematic accuracy assessment of CLC2000 using an independent data source, particularly the LUCAS (European Land Use/Cover Area Frame Statistical Survey), confirmed (Büttner & Maucha, 2006, pp. 5–6):

– the total reliability of CLC2000 is $87.0 \pm 0.8\%$;
– the highest class-level reliability ($> 95\%$) was obtained for rivers (class 511), lakes (512), industrial and commercial units (121) and discontinuous urban fabric (112);
– the two largest CLC classes: arable land (211) and coniferous forest (312) were estimated to have a level of reliability between 90 and 95%; two other agricultural classes: agro-forestry (244) and permanently irrigated land (212) also demonstrated a similar level of reliability;
– the lowest class-level reliability (below 70%) was obtained for the sparse vegetated class (333) and mineral extraction sites (131).

Assessment of the thematic accuracy of CLC2000 (Büttner & Maucha 2006) has shown that classes 11 and 12 are notable for greater than 95% reliability of their identification. This might have positively influenced the identification of the corresponding LC changes as well as the percentage of the total country surface that was affected by urbanisation and makes the characterization of LCF1 more reliable. Figs. 2 and 3 demonstrate that LCF1 with a value over 2% from the total surface of the country has clearly manifested in the Netherlands. The value of LCF1 over 0.5% was calculated for Belgium, Germany and Portugal. The lowest LCF1 percentage (around 0.2%, see Fig. 2) of the total country area has been obtained in the countries of Central and Eastern Europe specifically in Bulgaria, Estonia, Croatia, Hungary, Lithuania, Latvia, Poland, Romania, Slovenia, and Slovakia. These results suggest that after the 1989 political and economic transition, urbanisation (including the urban sprawl) was less intensive in Central and Eastern European countries and more intensive in Western European countries especially in the Netherlands, Germany, Portugal, and Belgium.

The thematic accuracy in the identification of landscape classes, especially agriculture and forestry, was over 90% (Büttner & Maucha 2006). Therefore LC changes and calculated LCF2, LCF3, LCF4, LCF5 and their graphical representation were most likely influenced by the quoted accuracy. More than 3% of the total area of Ireland corresponds to the intensification of agriculture, i.e. LCF2 (Figs. 4 and 5). It is by far the highest value compared to other European countries (due to changes in the agricultural policy, changes of agricultural commodity market, as well as changes in the structure of ownership, etc.). Such a clear manifestation of LCF2 in Ireland is associated with the practicing of a grass-arable land rotation system. The values around 1% of the country's area that correspond to LCF2 were found in Estonia, Hungary, Lithuania, Latvia, and Slovakia (Fig. 4). The restitution and privatisation of farmland and changes of the agrarian policy in the post-socialist countries after 1989 can most likely explain this phenomenon.

The extensification of agriculture dominated in the Czech Republic where LC changes (mostly LCF3) amounted to more than 3.5% of the total country's area (Figs. 6 and 7). This is a consequence of arable land abandonment and grass overgrowth as a consequence of changes in agriculture that occurred in several European countries after 1989. The quoted process manifested for instance in Germany (mainly in the eastern part), in Estonia, Hungary, Latvia and Slovakia. This process was less intensive in Western European countries (except for Ireland). Moreover, the agricultural landscape in the UK did not indicate significant changes in LC especially in those that would be part of both an intensification and/or extensification process (Figs. 4–7). This is a sign of agricultural land stability.

Afforestation and deforestation (LCF4, LCF5) played the most important role in Portugal where it reached around 4% of the total country's area. The most significant changes regarding the forest cover occurred in the Czech Republic, Spain, France, Ireland and Slovakia (Figs. 8–11). These changes were associated mostly with logging, subsequent planting and forest regeneration procedures.

LC changes in favour of water reservoirs (quoted as water bodies in CLC nomenclature) construction and management (LCF6) were most extensive in the Netherlands, Slovakia, Portugal, Spain, Hungary, and Germany. The thematic accuracy in the identification of classes 511 and 512 is more than 95% (Büttner & Maucha 2006), i.e. the presented scope and occurrence of landscape changes in favour of LCF6 is considered satisfactorily accurate (Figs. 12 and 13).

It was found (Feranec, Šúri, Oťaheľ, Cebecauer, & Soukup, 2001) that NS data and CLC data differ (see Table 5) as a result of the different classification methods used. Hence, it seems that the application of NS data in the process of environmental accounting is problematic.

It is assumed that the presented results will increase the awareness and assessment accuracy of landscape changes based on information about LC, in our case CLC. They also contribute to the further specification of the relationships existing between LC changes and the landscape change. The defined LCFs indicated (through LC change) that they are also connected with the occurrence of additional changes in the landscape (e.g. the enlargement of urban areas that can be connected with changes in population density, investment increase, industrial or production infrastructure, etc.). The previously discussed methodology, based on LCF spatial distribution patterns, will contribute to the understanding and forecasting of an area's landscape development.

The land rotation system in the grassland arable areas indicates an intensification and extensification of agriculture in a given country (change of grasslands into arable land indicates intensification; change of arable land into grassland indicates extensification).

The fact that the frequency and rate of LCF are specific for individual countries, since they are determined by different drivers, must also be considered. This is why, for instance, a pronounced extensification of agriculture ends on the border of the Czech Republic and does not continue to the NE of Austria and SE of Germany. It reflects a variety of changes in agricultural policies and changes in the agricultural commodity market as seen in the Czech Republic between the years 1990–2000. These drivers were missing in the SE part of Germany and the NE part of Austria.

Conclusions

The above mentioned applied methodology has widened the options of the CLC1990 and CLC2000 data layers as well as the CLC1990/2000-changes in the landscape change assessment in Europe. In this project, LCF1-6 were derived using LC changes. They determine the following frequency of processes that have occurred in landscape: urbanisation (LCF1) – most distinct in the Netherlands, intensification of agriculture (LCF2) – most distinct in Ireland, extensification of agriculture (LCF3) – most prevalent in the Czech Republic, afforestation (LCF4) – most distinct in Portugal, deforestation (LCF5) – most distinct in Portugal, and the construction and management of water bodies (LCF6) – most distinct in the Netherlands and Slovakia. Their graphic image is provided by six maps (Figs. 3, 5, 7, 9, 11 and 13).

For a better overview, the LCF rate was assessed by 3×3 km grid suitable for the characterization of European LC. However, the size of the grid can be changed and information about LCF can be obtained both on national and regional levels. Such information can be analysed in the context of different socio-economic activities that are typical in the development of individual European countries. But the alluded analysis was not the aim of this study.

Another contribution of this applied methodology dwells in the provision of statistical characteristics about the real condition of LC in the 1990–2000 period; the increase or decrease of individual CLC classes during the studied period, (Table 3), sizes of individual LCFs, and the percentage of their rate per country (Table 4, Figs. 2, 4, 6, 8, 10 and 12). The combination of these data with the national statistical data can have a complementary effect in environmental accounting.

The area of identified LC changes in 1990–2000 in the 24 European countries is close to 88,000 km^2, equalling to almost 2.5% of their total areas. The greatest changes in LC areas were found in Portugal (9.85% of the total country's area), Ireland (7.91%) and in the Czech Republic (6.43%). The least LC changes (less than 1% of total country's area) were found in Austria, Bulgaria, Poland, and Slovenia. Table 4 contains a summarized overview of LC changes in the analysed countries.

The total reliability of CLC2000 data is $87.0 \pm 0.8\%$ (Büttner & Maucha, 2006). This value is based on an independent CLC interpretation performed on the LUCAS data. Therefore, it can be concluded that the 85% accuracy requirement specified in the technical guidelines (EEA-ETC/TE, 2002) has been fulfilled.

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