PFG 2013 / 5, 0473–0482
Stuttgart, October 2013

Report

Surveying European Landscape Dynamics

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Keywords: land use, land cover, landscape monitoring, area statistics, European area frame survey, LUCAS

Summary: Observing and monitoring of European landscape dynamics has moved a big step forward. Just recently preliminary results from a 2012 field survey on land cover and land use within the framework of LUCAS have been published by Eurostat covering all 27 European Union (EU) member states. Eurostat is the statistical office of the EU and responsible for providing precise statistics at EU scale. After more than a decade of development, Eurostat has achieved a consolidated approach through the "Land Use/Cover Area frame statistical Survey – LUCAS". It focusses on the current status, and – in combination with the previous LUCAS survey in 2009 – became an instrument to extract land use and land cover change dynamics in Europe with statistical precision for the first time. LUCAS is a stratified area frame survey on the basis of a regular point grid covering the whole European Union and has become an operational Eurostat standard to provide geostatistic information.

It was initiated as a pilot in 2000 and evolved since then through various test surveys in different European member states and by a number of scientific studies. Since 2009 it is running operationally and was executed in 2012 covering for the first time all EU27 member states.

Next to the methodical summary this paper aims to report about the successful implementation of the official estimation framework for land use and land cover data in Europe and the availability of such a tremendous data source. Until recently this was not available at the given level of detail and precision.

Area frame survey techniques and other means of landscape monitoring had been discussed since decades (Benedetti et al. 2010). The evolution of and decisions regarding LUCAS have been documented by various scientific papers. The reader is now invited to follow the references to the freely accessible documents including the technical specification.

Zusammenfassung: *Kartierung der Landschaftsdynamik Europas.* Die Erfassung und Überwachung dynamischer für die europäische Landschaft bedeutender Prozesse ist einen wichtigen Schritt vorangekommen. Erst kürzlich wurden vorläufige Ergebnisse einer umfassenden Feldkartierung in 2012 zur aktuellen Entwicklung europäischer Landnutzung und Landbedeckung in allen 27 EU-Mitgliedsstaaten von Eurostat im Rahmen von LUCAS veröffentlicht. Eurostat ist die Statistikbehörde der Europäischen Union und verantwortlich für die Bereitstellung von statistischen Daten auf europäischer Ebene. Nach einer mehr als 10-jährigen Entwicklung hat Eurostat mit der Kartierung "Land Use/Cover Area frame statistical Survey – LUCAS" erstmalig alle Staaten der EU anhand dieser konsolidierten Methodik erfasst. Der Schwerpunkt der neuen Kartierung liegt auf der Erfassung des aktuellen Zustands. In Kombination mit der vorangegangenen Kartierung von 2009 ist zum ersten Mal ein Instrument entstanden, mit dem Veränderungsdynamiken der Landnutzung und Landbedeckung in Europa einheitlich und detailliert extrahiert werden können. LUCAS ist eine stratifizierte Flächenstichprobe auf der Basis eines regelmäßigen Punktrasters, das die gesamte Europäische Union abdeckt. Sie ist zu einem operationellen Eurostat-Standard geworden, um geostatistische Informationen bereitzustellen.

Die LUCAS-Erfassung wurde im Jahr 2000 als Pilotprojekt eingeführt und im Rahmen verschiedener Testkartierungen und Studien schrittweise entwickelt und konsolidiert. Seit 2009 läuft LUCAS als operationelles Projekt und wurde 2012 zum ersten Mal für alle 27 Mitgliedstaaten der EU durchgeführt.

Dieser Artikel soll neben einer methodischen Zusammenfassung die erfolgreiche Implementierung der Erfassung von Landbedeckungs- und Landnutzungsdaten in Europa sowie deren Verfügbarkeit als umfangreiche Datenquelle herausstellen. Bis vor kurzem waren diese Daten auf dem

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DOI: 10.1127/1432-8364/2013/0193 1432-8364/13/0193 $ 2.50

This paper provides a summary of the current methodical status, reflects the outcomes of the LUCAS 2012 survey in selected countries, and furthermore recommends investigating the free available LUCAS database which can be a tremendous basis for future research.

jetzigen Stand bezüglich Details und Präzision nicht verfügbar.

Techniken zu Flächenstichproben und zu anderen Verfahren für das Landschaftsmonitoring werden seit Jahrzehnten diskutiert (Benedetti et al. 2010). Die Entwicklung von und Entscheidungen betreffend LUCAS wurden in verschiedenen wissenschaftlichen Veröffentlichungen dokumentiert. Diese frei verfügbaren Veröffentlichungen und die technischen Spezifikationen können interessierte Leser über die angegebenen Referenzen finden.

Der vorliegende Beitrag gibt einen Überblick über den aktuellen methodischen Status, reflektiert die Ergebnisse der LUCAS-Kartierung 2012 in ausgewählten Ländern und soll anregen, den frei verfügbare LUCAS Datenbestand, der eine wichtige Basis zukünftiger Untersuchungen sein kann, zu erkunden.

1 Introduction

The statistical magazine of European statistics SIGMA, published by Eurostat explains: "The Land use/cover area frame survey (LUCAS) was initially developed to deliver, on a yearly basis, European crop estimates for the European Commission. With time, the survey has become essential in providing policymakers and statisticians alike with increasing amounts of data on different forms of land use in Europe and proved to be a useful tool in the area of environmental monitoring." LUCAS is developed and executed by Eurostat, the statistical office of the EU representing the European Commission (EC). Its task is to provide high quality statistics at European level (European Commission Eurostat 2013).

Today, the principle LUCAS methodology is consolidated and implies a fully harmonized procedure. The georeferenced area frame sampling survey is based on a stratified point grid and provides precise in-situ information on landscape, biodiversity, selected agro-environmental parameters – as well as land cover, land use and landscape dynamics related through its changes.

Approaches to area estimates in various applications, including and excluding remote sensing, have been widely discussed during the past decades. The most recent works are from Gallego (GEOSS 2008) and Benedetti (2010). In general, various attempts had been executed on a European scale to extract area estimates by means of remote sensing. Czaplewski (1992) has explored already the bias of purely remote sensing based estimators. Recently Gallego et al. (2010) discussed the technical limitations of remote sensing in view of the statistical requirements and con-

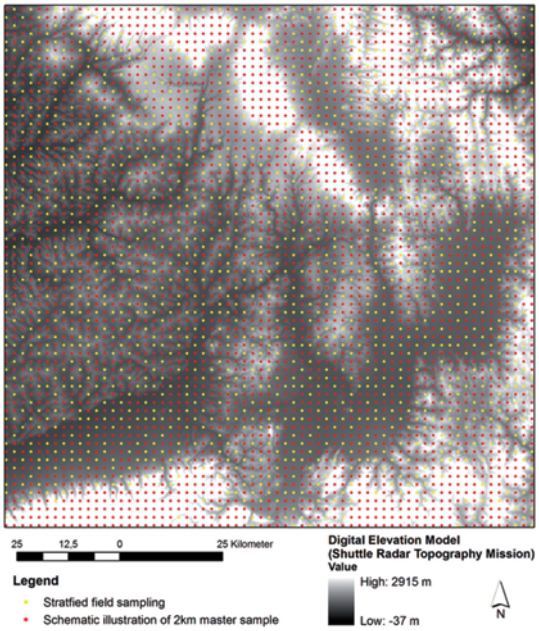

Fig. 1: LUCAS two stage sampling design, yellow: stratifed field sample, red: schematic illustration of a 2 km grid as a master sample, background image: digital elevation model by Shuttle Radar Topography Mission © Nasa.

cluded that the omission and commission errors of remote sensing products must be significantly lower than the expected statistical coefficient of variances. As such remote sensing approaches for area estimation in a European context proved to be insufficient and are the main reason for implementing the field survey based area frame approach, which has been used in Europe in a number of countries on a national level, e.g. in France, Italy and Bulgaria.

In the following, the LUCAS strategy will be explained. The recent sampling is a two-phase sampling approach. In the first phase the master sample consists of a regular grid of points spaced 2 km into each cardinal direction and covering all EU member states with approximately one million points. Each point was photo-interpreted and assigned to one out of 7 pre-defined land cover strata. From this stratified master sample a sub-sample ("field sample") is extracted for each field survey campaign. See a schematic illustration of the two stage sampling in Fig. 1 – the original master sampling is not publically available.

The early LUCAS approaches are described by Delincé (2001) and the European Commission Eurostat (2003). The introduction of a new sampling design and improved instructions are explained by Jacques & Gallego (2005) as well as by Martino & Fritz (2008).

Various test surveys in different European member states (2001/2002, 2003, 2005/2006, 2007, 2008) and a number of scientific studies (2002, 2005, 2006 – 2008) were carried out. The survey started on an operational basis with the campaigns in 2009 at the EU23 level. The last year's campaign in 2012 covered all 27 EU member states for the first time, representing an area of about 4.3 Mio km^2.

This is a result of 13 years of close inter-institutional collaboration between Eurostat, the EC Directorates General (DG) for Agriculture, the DG for Environment, the EC Joint Research Centre (JRC), the European Environment Agency (EEA), the National Statistics Authorities of the member states, and numerous research institutions as well as private companies. According to the European Commission Eurostat (2010) they achieved all together:

- a high level of harmonization and standardization of the data collection,
- a consolidated standard questionnaire and nomenclature for the data collection,
- a very high completeness of data and metadata,
- a powerful tool for the validation at the level of data providers,
- transparent documentation of the data validation system, including,
  - different actors/levels of control,
  - various training steps,
  - continued monitoring of the work,
  - independent data quality checks,
  - full traceability of corrections and enhancement procedures,
- a combination with a good ability to react quickly and flexibly to specific user demands for tailor-made data extractions.

The results of LUCAS form the basis of spatial and territorial analyses and are increasingly crucial for policy planning in many respects. They are also used for nature protection, forest and water management, urban and transport planning, agricultural policy, natural hazards prevention and mitigation, soil protection & mapping, monitoring climate change and biodiversity (European Commission Eurostat 2013).

Next to Eurostat the most prominent users for LUCAS data are JRC, GMES / Copernicus, EEA and CORINE Land Cover. The LUCAS 2012 survey is co-financed by the following Directorates-General of the European Commission: DG Agriculture and Rural Development, DG Enterprise and Industry, DG JRC, and DG Environment.

2 LUCAS Approach

The main LUCAS principle is the detection of land use and land cover as separate parameters by means of in-situ field observations. In this sense land cover is understood as the physical coverage of the Earth's surface and land use as the socio-economic function of the land (European Commission Eurostat 2012a). In LUCAS, land cover data is discriminated in 69 classes and land use data in 33 classes. The data is observed by visiting each point and a transect line, which originates at the LUCAS

sample point and extends 250 m towards the east. (Fig. 2).

Along these geographically defined and statistically sampled transect lines all changes in land cover and the occurrence of linear elements are recorded – with the aim to monitor and to compare the heterogeneity of European landscapes.

Furthermore, each LUCAS sample point and its transect are documented by a consistent set of digital landscape and transect photos. The landscape photos are taken at the point in each cardinal direction (north, east, south, west, Fig. 3) (European Commission Eurostat 2012a and 2012b).

In addition to these obligatory survey components the multi-purpose concept of LUCAS allows the addition of special environmental parameters into the monitoring, such as the soil sample survey in LUCAS 2009 (see section 3 below).

Fig. 2: Schematic illustration of LUCAS point and transect in Bulgaria. Landscape photo © European Union, source: LUCAS 2012.

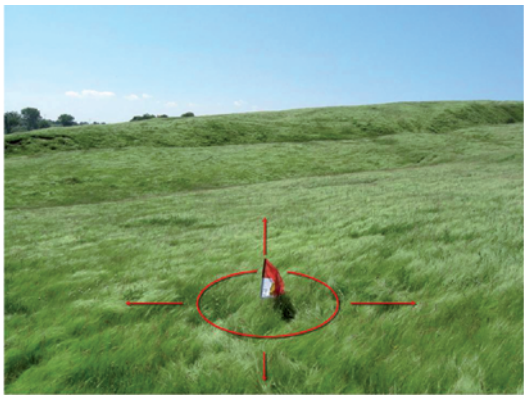

Fig. 3: Schematic illustration of LUCAS point and cardinal directions of landscape photos in Bulgaria. Landscape photo © European Union, source: LUCAS 2012.

All surveyors are bound to technical instructions defined by Eurostat to ensure the data comparability of the observed features. For storage and transmission all data, landscape photos and recorded GPS tracks have to be entered into a specially designed Data Management software Tool (DMT) (see European Commission Eurostat 2012a). This is mandatory for any LUCAS data processing and ensures an unbiased and a safe storage and transmission of the data. This DMT is a closed system which logs any processing step and allows full supervision of eventual non sampling errors. It is also used as a primary base for quality control at each administrative level.

3 Recent Outcomes

The most recent outcome is the consolidated LUCAS approach as described in section 2. This has been achieved through various test surveys and scientific studies, as described below.

The surveys which have been carried out between 2001 and 2007 demonstrated the general feasibility of the LUCAS procedure. In parallel, a number of scientific studies tried to explore the possibilities of extracting parts of the LUCAS observables by means of Remote Sensing (RS) or by extracting those from other data sources such as national statistics. The latter turned out to be incompatible in terms of timing and nomenclature. The approach of employing remote sensing proved to be not as effective as the field surveys. Despite the outcomes and in addition to the general limitations of remote sensing based estimations (see section 1 above) the feasibility of exploring synergies between LUCAS requirements and remote sensing means had been investigated by Eurostat and JRC studies (Gosepath et al. 2002, Haub et al. 2005). It was clearly identified that neither digital orthophotos with accuracies in the range of today's very high resolution satellite data (< 0.5 m ground resolution) nor sensors with coarser resolutions (10 m – 20 m) can contribute any information

of added value to the given LUCAS strategy. The discrimination between land use and land cover would require inacceptable changes of the concept such as a simplified nomenclature, in order to match with the information that can be extracted from remote sensing data. In the LUCAS application, costs and accuracy of remote sensing approaches do not lead to a more economical solution. The required statistical precision cannot be provided sufficiently by means of remote sensing, but are most efficiently met by in-situ surveys.

Further studies have been carried out to assess the multiple use of LUCAS field survey-data. As one of the outcomes of the prospective study 20 EU legislations were identified to which LUCAS can contribute relevant reporting or monitoring variables. A total of 121 parameters were found which could have an impact on the implementation of the legislations or would assist to fulfil reporting duties (Haub et al. 2007). In particular the European Commission (2007) identified the following strengths of LUCAS:

- high thematic precision,
- high representativeness,
- harmonized survey approach,
- accurate change detection,
- flexible survey structure,
- fast execution (up-to-date information).

The successful realisation of the LUCAS 2009 survey finally proved that the entire LUCAS procedure has become fully operational. The first results of the 2009 survey were published by Eurostat nine months after the end of the survey via the Eurostat website (European Commission Eurostat 2013), as well as results on the following landscape indicators:

- land cover,
- land use,
- landscape indicators,
  - landscape richness,
  - landscape structure,
  - landscape dissection,
  - landscape Shannon diversity Index,
  - landscape Shannon evenness Index,

at EU23 level have been published by Palmieri et al. (2011).

3.1 *Overall Status of LUCAS*

The 2012 survey campaign is currently the main achievement in the LUCAS framework. It was the largest LUCAS campaign so far and includes all 27 EU member states. The total point sample consists of 270,276 points, of which most were visited in the LUCAS 2009 survey.

This draws a precise picture of the land use changes during the past three years.

Additionally, the LUCAS 2012 results contribute directly to different Copernicus services, previously known as Global Monitoring for Environment and Security (GMES). In the framework of the CORINE land cover database update – which is as well linked to 2012 as a reference period – LUCAS will contribute the recent and harmonized ground truthing.

The field campaign was completed in November 2012, the data flow and the data correction ended in March 2013 and preliminary results were released on the Eurostat website in May 2013.

3.2 *LUCAS Soil Component*

Besides the land use/cover survey campaign, the LUCAS soil component which has been incorporated in the LUCAS 2009 survey in EU23 has in 2012 been completed for the remaining countries.

It is aimed to improve the quality of soil modelling and monitoring in Europe. This exercise is jointly organised by Eurostat, DG Environment, and DG JRC. The outcome of the soil component will be used for a number of purposes, including updating European soil maps, validating soil models, and measuring the quantity of organic carbon in soil (European Commission Eurostat 2012a).

During the survey in 2009 soil samples have been collected in EU23 from more than 20,000 LUCAS point locations. These samples, weighing around 11 tonnes in total, are stored at the European Soil Archive Facility at the JRC in Ispra, Italy. The samples have been analysed for the parameters texture, organic matter content, pH, and heavy metals, in order to assess the state of the soil across Europe (European Commission JRC 2012). The

remaining soil samples were collected in 2012 in Romania and Bulgaria at 2,091 additional locations, and on Malta and Cyprus (19 and 90 samples respectively) in 2009/2010 in cooperation between the JRC and the Maltese and the Cyprian soil survey organisations. To conclude, it was the first widespread soil survey of the EU (European Commission JRC 2012) including all EU member states. First results of this database and derived information on the regional variability of cropland topsoil properties were published by Tóth et al. (2013).

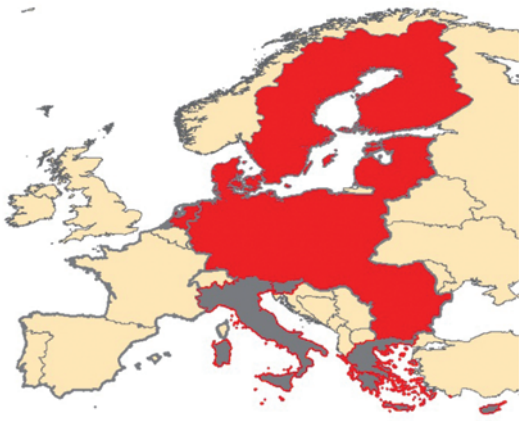

Fig. 4: Overview of LUCAS 2012 Lot 3 and 4 (red) and the technical cooperation with Lot 5 aiming at harmonized technical approaches (grey).

3.3 *Outcomes of LUCAS 2012 in selected Countries*

The following section provides an insight to the LUCAS 2012 survey in selected countries. This closer look is given to the survey in northern, central and south eastern EU-countries, which were grouped in 2012 into Lot 3 and Lot 4 (Fig. 4).

Those countries were covered with 136,621 sample points and observed by a partnership of 10 institutions under the leadership of EFTAS: eoVision (AT), Ministry of Agriculture and Food (BG), GEODIS Brno (CZ), Vides Eksperti (Baltics), Geodézia (HU), GEODIS Romania (RO), IBS GEO-CAD (PL), VUPOP (SK), FORAN (SE) and EFTAS (DE, DK, FI). For both lots EFTAS was in charge of the tech-

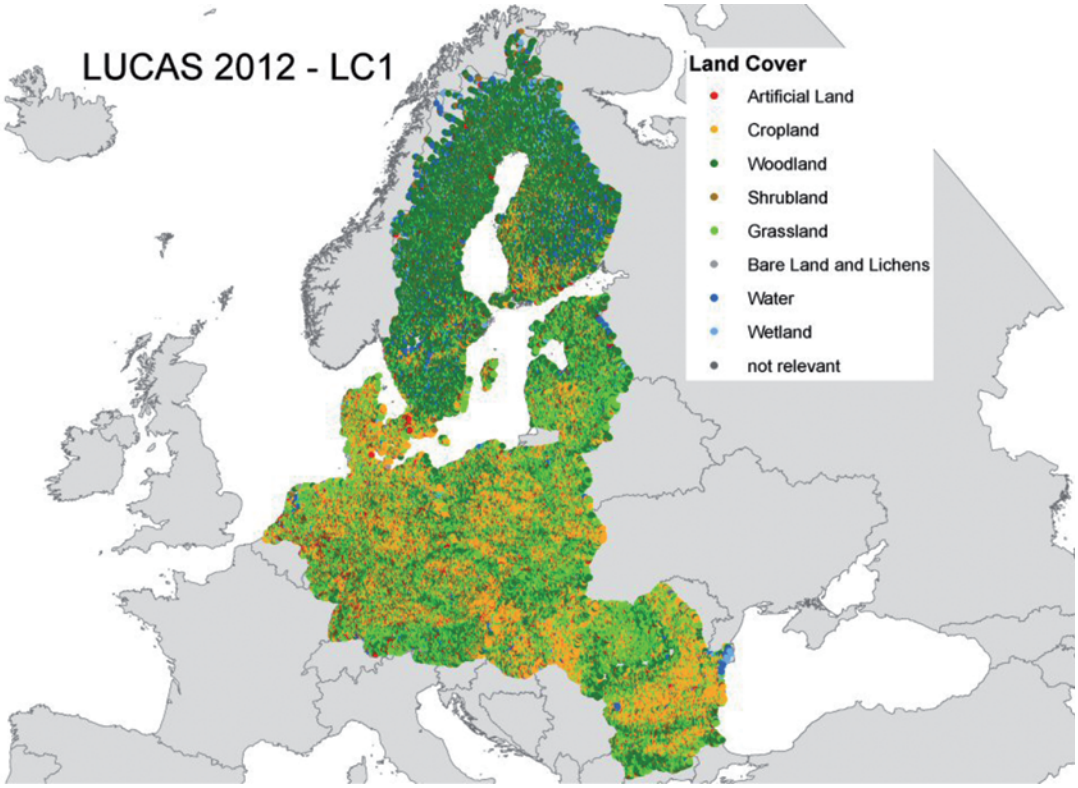

Fig. 5: LUCAS 2012 – Main Land Cover Lot 3 and 4 © Eurostat.

nical coordination, quality control, reporting and the contractual as well as the financial management with Eurostat and the subcontractors.

The Lots 3 and 4 of the LUCAS survey 2012 were successfully carried out between April and November 2012. In order to achieve this goal, 281 surveyors worked in the field with an average workload of approximately 490 points per working package. The median observation distance of 2 m documents a high accessibility of the sample points, varying from 1 to 3 metres in the different countries. In the selected 14 countries 85% of the points were been reached closer than 100 m, compared to the predefined positions. Only 6% were above 100 m. For additional 9% of points photo interpretation in the field was necessary due to accessibility limitations. This was done by means of recent orthophoto maps which were available for each point as part of an individual field survey document. The maps in Figs. 5 and 6 display the distribution of the main observed land cover and land use classes throughout the 14 countries.

All surveyed points underwent different quality checks, at first by the regional office in each country and then by the central office at EFTAS. There, the EFTAS team verified each dataset before the final delivery. This gradual control procedure guaranteed a high consistency of the datasets which is an utmost requirement for statistical usability. In order to ensure that Eurostat finally achieves precise estimates it is part of the technical obligations and part of the contract to deliver 99% of compliant data. As such all data had been channeled through an interactive and visual quality control process by means of the DMT consisting of:

- automatic plausibility checks during the data entry of the surveyors.
- verification of the documentation of the survey condition. Those are comprehensively recorded with standardized metadata.
- verification of standardized landscape photos and track logs as important measure to trace non-sampling errors.
- clarification and correction of inconsistencies.

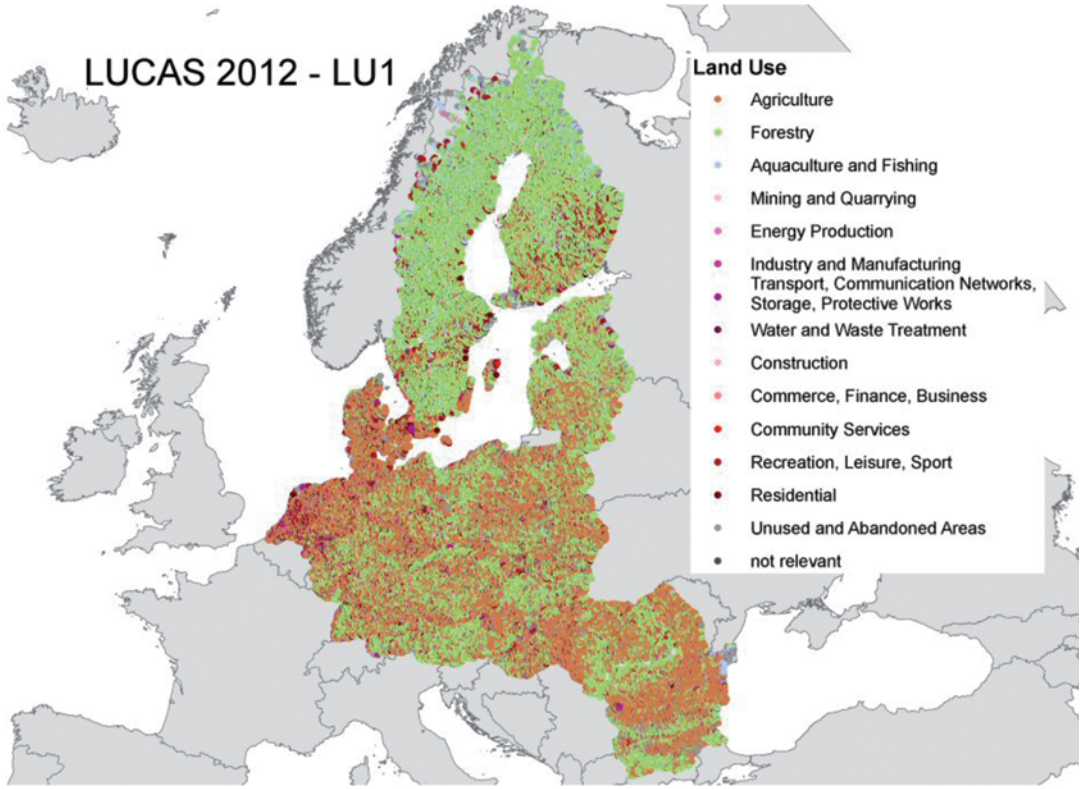

Fig. 6: LUCAS 2012 – Main Land Use Lot 3 and 4 © Eurostat.

The 2012 survey campaign was successfully executed and delivered in time with a very low internal rejection rate in the above selected countries of 0.32%.

4 Conclusions

This paper is a report of a practical application with a potentially high relevance for researchers. It introduces the LUCAS dataset and methodology. Although the technology is not new, such a detailed and complete land cover and land use database has never been available at this scale before.

The article provides a summary of the LUCAS 2012 outcomes in 14 European member states, which jointly built the dataset collected under the leadership of EFTAS:

- LUCAS samples: 136,621,
- area: about 2.3 Mio km^2,
- population: more than 210 Mio.,
- survey period: less than 8 months,
- internal rejection rate: 0.32%,

The reasons to opt for an in-situ survey and against remote sensing were discussed recalling the goal of a precise area estimation framework under European conditions at a European scale. Despite of ideas to extract the geostatistic information required by LUCAS from other sources such as national statistics or remote sensing there is currently no other precise, reliable and more cost efficient approach than LUCAS. Even if all required information defined by the LUCAS survey could be extracted from other sources, still huge costs would exist for achieving the required low omission and commission errors and for harmonizing the sampling time and the nomenclature.

Given that stakeholders tend to mix both concepts frequently, the following comparison shall illustrate that there are currently no alternatives to LUCAS in Europe: even if all required variables could be extracted from remote sensing data, the simple price per km^2 for a recent very high resolution (VHR) satellite image (around 25 €/km^2) would be 10 times higher than the costs of LUCAS 2012 for the same area. Whereas it is questionable that any VHR satellite constellation would be effective enough to cover the whole of Europe within less than the nine month survey period without clouds – not to count additional processing costs for achieving less than 1% omission and commission errors.

These facts are illustrating the strength of the European LUCAS survey framework. It is a consolidated approach which provides precise information on land use and land cover dynamics in a reliable and cost effective way. Beyond the generation of area estimates it allows the extraction of agro-environmental indicators at a continental scale.

In addition to the outcomes of the numerous pilot surveys and scientific studies executed by Eurostat and JRC in the past 13 years, the 2012 survey proved that it is unique in the world and has currently no alternative in Europe. Its strengths are:

- level of detail,
- harmonized technical approach over 27 EU member states,
- nomenclature standards, common field observations instructions, the mandatory data entry tool,
- the requested common quality assurance and quality control system with a very low level of maximum 1% of inconsistencies,
- execution within one particular vegetation period,
- feasibility at the given cost ranges,

The whole survey approach meets the growing demand for precise agro-environmental land use and land cover dynamics information. It is also the basis for currently ongoing projects to explore the feasibility of a similar approach for African authorities (GMFS 2012).

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Fig.1: Background image SRTM © NASA.

Fig. 2: Landscape pictures are copyright by the European Union represented by Eurostat on behalf of the European Commission.

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Acknowledgement

First of all we would like to thank the LUCAS team at Eurostat and JRC for the cooperation and guidance.

Special thanks shall be given to the EFTAS LUCAS 2012 partnership and all our involved surveyors and colleagues, represented by Gerald Mansberger (eoVision), Yavor Yordanov (Ministry of Agriculture and Food, Bulgaria), Miloš Sedláček (GEODIS), Vita Turuka (Vides Eksperti), Hung Tran Quoc (Geodézia), Michał Wyczałek and Waldemar Sowinski (IBS GEO-CAD), Ciprian Pricop (GEODIS Romania), Vladimir Hutar (VUPOP) and Tobias Jonmeister (FORAN). We also thank Agriconsulting and Kitry for the great cooperation.

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Manuskript eingereicht: Mai 2013
Angenommen: Juli 2013