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Justus-Liebig-University Giessen

***Analysing Regional Differences of Agricultural Land Use  
and Land-Use Change (2005-2010) in Hesse, Germany***

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“I declare that the dissertation here submitted is entirely my own work, written without any illegitimate help by any third party and solely with materials as indicated in the dissertation.

I have indicated in the text where I have used texts from already published sources, either word for word or in substance, and where I have made statements based on oral information given to me.

At all times during the investigations carried out by me and described in the dissertation, I have followed the principles of good scientific practice as defined in the ‘Statutes of the Justus Liebig University Gießen for the Safeguarding of Good Scientific Practice’.”

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## List of publications

This thesis is based on the following research articles:

- 1) Lüker-Jans, N., Simmering, D., & Otte, A. (2016). Analysing Data of the Integrated Administration and Control System (IACS) to Detect Patterns of Agricultural Land-Use Change at Municipality Level. *Landscape Online*, 48, 1-24.  
DOI: 10.3097/LO.201648
- 2) Lüker-Jans, N., Simmering, D., & Otte, A. (2017). The impact of biogas plants on regional dynamics of permanent grassland and maize area – The example of Hesse, Germany (2005-2010). *Agriculture, Ecosystems and Environment*, 241, 24-38.  
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Author's contribution:

In the two research articles being part of this multiple-paper thesis, I had the main responsibility for data preparation, data analysis and writing. The co-authors contributed to the study designs and provided helpful ideas and criticism.

# Chapter 1

## **Analysing regional differences of agricultural land use and land-use change (2005-2010) in Hesse, Germany – Synthesis**



*This chapter provides the background and the methodological concept of this thesis and states its aims and objectives. It summarises the results and conclusions of the two publications the thesis is based on by considering a wider context. Additionally, recommendations for future developments of political instruments in agriculture are presented.*

## Background

Agricultural land use does not only produce food and fodder as well as fibre and fuel, it also creates landscapes (Kristensen, 2016; Meeus, 1995). Although natural factors like soil, topography, and in particular climate, etc. determine different environments and thus landscapes, it is the cultivation of land which has caused a variety of heterogeneous landscapes (Meeus, 1995). Over hundreds of centuries, the interaction between man and nature has shaped the former natural landscape to a cultural landscape, with agricultural cultivation being one of the main influencing factors (Kristensen, 2016). In Europe, there is hardly any landscape which remained natural, most of them are utilised in any way by man (Meeus, 1995). Today, in the European Union (which means the EU-27) 40.1% of the total area was used for agriculture in the year 2007 (EC, 2012).

Naturally, central Europe would be a natural landscape dominated by closed forests with interspersed, open areas which were more or less large, and oftentimes by an open vegetation on specific areas like floodplains, poor soils and continental regions (Kunes et al., 2008; Soepboer & Lotter, 2009; Svenning, 2002). Since sedentism and the beginning agricultural cultivation, the forests were stubbed which created an open landscape. Subsequently, the species number of flora and fauna increased because the newly formed cultural landscape provided more habitats. Although some species became extinct, all in all biodiversity as well as the number of habitats grew significantly (Duelli & Obrist, 2003; Ellenberg & Leuschner, 2010). Thus, in central Europe flora and fauna owed their abundance to agricultural land use and, in consequence, are more or less dependent on it (McClure, 2013; Stoate et al., 2009). Indeed, agricultural cultivation did not only promote species diversity but additionally diversity of habitats and genetic diversity (Waldhardt, Simmering, & Albrecht, 2003).

This positive effect lasted about till the beginning of the twentieth century. Afterwards, the industrialisation strongly influenced agricultural land use by for example the increased application of modern machines. This development went on continuously, and from the middle of the twentieth century onwards, environmental problems caused by agricultural land use have arisen. Thus, modern land use provoked serious concerns over its impacts on the environment, ecosystem functioning and biodiversity etc. (Stoate et al., 2001). Of course, with modern management practices, it was possible to reach high crop yields going along with an increased efficiency (Waldhardt et al., 2003). However, the usage of fertilisers, pesticides, irrigation as well as high-yield crops, a less diversified crop rotation, enlarged fields and the removal of boundary vegetation implied an intensive land use with negative consequences for biotic and abiotic resources (Stoate et al., 2001; Tilman, Cassman, Matsons, Naylor, & Polasky, 2002). Concurrently, many agricultural sites are also threatened by abandonment. On these sites, the traditional, diverse agricultural cultivation has and is still been given up. The consequence of these developments is that the former cultural landscapes with its diverse habitats and structures will be changed to simplified and homogenised, and therefore,

monotonous landscapes (Harvolk, Kornatz, Otte, & Simmering, 2013; Reger, Sheridan, Simmering, Otte, & Waldhardt, 2009).

Both trends in agriculture, marginalisation and intensification, affect the environment in a rather negative way (Bürge, Hersperger, & Schneeberger, 2004; Stoate et al., 2009), for example, they are considered to be the main driving factors for the decrease of biodiversity (Waldhardt et al., 2003). Of course, agricultural land use has always been a matter of change due to varying management practices and several demands on it. Consequently, the cultural landscape will always be dynamic and thus developing (Cabrera, 2015; Meeus, Wijermans, & Vroom, 1990). But the recent developments as well as the projected need of an increased food production for the global population in the future has raised the claim of sustainability in agriculture (Tilman et al., 2002). In general, European land use is expected to experience ongoing changes in the coming decades (Keenleyside, Baldock, Hjerp, & Swales, 2009; Rounsevell, Annetts, Audsley, Mayr, & Reginster, 2003; Sanderson, Kucharz, Jobda, & Donald, 2013). Hence, a thorough understanding of past and recent land-use dynamics is essential in order to understand how agricultural land use might develop in the future and to set management programs for a sustainable cultivation.

In the European Union (EU), the Common Agricultural Policy (CAP) has a strong impact on the developments in land use (Strijker, 2005). The EU has set several regulations to steer the agricultural production and to lessen the possible negative impacts on the environment. Concerning the latter purpose, in 1992 the so-called MacSharry reform was introduced with the aim – amongst others – to enhance an ecologically sensitive production in agriculture (Gomez y Paloma, Ciaian, Cristoiu, & Sammeth, 2013; Hartmann, Thomas, & Luick, 2006). Since that time, farmers will get payments if they voluntarily oblige themselves to comply with an ecologically beneficial cultivation and/or animal husbandry. These agri-environment schemes have featured a couple of revisions since their introduction. But farmers are not only supported through agri-environmental payments, the major support is offered through the direct payments. All farmers in the EU are justified to get them – of course they have to apply for. The direct payments are an area payment, i.e. they refer to the cultivated area of farmland (Reger et al., 2009). Hence, by supporting the agricultural sector through these transfer payments, the CAP is an important determining factor in land use (Gomez y Paloma et al., 2013).

In order to ensure that direct support payments are implemented and carried out correctly, the member states of the EU were obliged to implement the Integrated Administration and Control System (IACS). It consists of four parts: an identification system for farmers, a so called Land Parcel Identification System (LPIS) which registers all agricultural fields, an identification system for payment entitlements, and, if member states utilise animal-based measures, an identification and registration system for animals (EC, 2015). Since 2004, in order to achieve direct payments, every year farmers have to register all agricultural parcels of land and the cultivated crops. As a result, IACS data provide information on land use at the field level on an annual basis as well as information on field size, farm type, legal structure, livestock etc. Thus,



IACS data provide spatially and temporally precise information on agricultural land use and its changes. However, until now studies using IACS data are scarce, but see some studies of recent times (for example: de Longueville, Tychon, Leteinturier, & Ozer, 2007; Harvolk et al., 2013; Kirchweiger & Kantelhardt, 2015; Nitsch, Osterburg, Roggendorf, & Laggner, 2012; Trubins, 2013).

An understanding of past and recent dynamics in agricultural land-use requires on the one hand data which provide solidly quantitative and spatially differentiated information and on the other hand a classification method which can detect how and where land use changed and to assume future changes (Jansen & di Gregorio, 2002). Hence, a classification method should be a spatial and temporal reference system for land-use changes and, subsequently, can be used as a monitoring, modelling and planning tool (Pesch, Schmidt, Schroeder, & Weustermann, 2011; Schröder, Pesch, & Schmidt, 2007). Analysing and classifying land use has been a prominent research topic in landscape ecology, but studies describing the regional pattern or even the sub-regional pattern are rare (Mendoza, López Granados, Geneletti, Pérez-Salicrup, & Salinas, 2011; Pinter & Kirner, 2014), aside from some very few studies (for example: Gellrich & Zimmermann, 2007; Rounsevell et al., 2003). Large-scale drivers of land-use change such as policies or market conditions are spread at a national or even continental scale. However, their effects are known to vary at a (sub-)regional level (Bieling, Plieninger, & Schaich, 2013; Gallant, Loveland, Sohl, & Napton, 2004; Rounsevell, Ewert, Reginster, Leemans, & Carter, 2005; Uthes et al., 2011). Thus, there is a need for classification methods which incorporate the spatial level of sub-regions (Mendoza et al., 2011; Stoate et al., 2009).

In Europe, in recent years another important factor for changes in land use has developed, which is the cultivation of bioenergy crops. Thus, a competition between different types of land use arose (Rounsevell et al., 2006). Due to the political and consequently financial fostering, the area of bioenergy crops has considerably and rapidly increased (Svoboda et al., 2013). Especially, the production of biogas has become important since biomethane from anaerobic digestion of crops can be used for electricity production. In Germany, the production and utilisation of biogas has been promoted by the Renewable Energy Act (German: Erneuerbare-Energien-Gesetz, EEG). The EEG, firstly passed in 1991 and reformed in 2004 and 2008, gives feed-in tariffs for electricity generated from biogas. Since these tariffs are higher than the tariffs for electricity from fossil fuels and are guaranteed for 20 years (Lupp et al., 2014), they represent a profitable new income possibility for farmers (Amon et al., 2007). Consequently, this support policy has resulted in a notable increase in the number of biogas plants and also in the average plant size and therefore in an increase of the area of bioenergy crops (Delzeit, Britz, & Holm-Müller, 2012). From 2004 to 2013, in Germany the number of biogas plants increased from 2,010 to 7,772, and the average electrical power per plant grew from 123 to 454 kW<sub>el</sub> (BMELV, 2013).

With biogas plants farmers also can comfortably dispose surplus animal manure which is important especially in areas of intensive livestock farming. Thus, the occurrence of biogas plants correlates with the distribution of livestock farms (Delzeit & Kellner, 2013). However,

biogas plants also occur in regions where maize (*Zea mays*) is cultivated since maize is the dominant feedstock used for methane production because of and above all its high methane yield (Schulze Steinmann & Holm-Müller, 2010). Indeed, the biogas boom of recent years coincided with a significant expansion of maize cultivation (Britz & Delzeit, 2013). In Germany, in the year 2012 the area of silage maize grew by 28,000 ha to a total of 2.1 million ha, of which approximately 900,000 ha were used as bioenergy maize (DBV, 2012). However, it is not clear to what extent biogas plants (and the associated financial subsidies) are the causal driver of this development. In this controversy, it has to be considered that the cultivation of maize has a high relevance for cattle farming, since silage maize is an important cattle fodder. As a result, cattle farming promotes maize cultivation especially in regions with intensive milk production. However, the number of cattle has increased by only 0.9% to 12.7 million from 2013 to 2014 (DBV, 2014), therefore cattle farming is considered to be only a minor reason for the rapid increase in maize cultivation (Laggner, Orthen, Osterburg, & Röder, 2014).

Another topic in this controversy is how biogas plants and the associated cultivation of silage maize have contributed to the conversion and therefore the loss of permanent grassland. The preservation of permanent grassland is of high relevance due to several reasons: Permanent grassland contributes to biodiversity, because it can feature the most species-rich habitats (Lewis, Pakeman, Angus, & Marrs, 2014; Wilson, Peet, Dengler, & Pärtel, 2012). If managed traditionally (Wellstein, Otte, & Waldhardt, 2007), it combines ecosystem functions like storage of high carbon stocks, protection from soil erosion, water retention and nutrient holding (Chen, Marhan, Billen, & Stahr, 2009; Conant, Paustian, & Elliott, 2001; Prochnow et al., 2009). Additionally, permanent grassland is part of the cultural landscape and it contributes to recreation and tourism (Hopkins & Holz, 2006). In Europe as well as in Germany, permanent grassland is in danger of being intensified, converted into arable land or being abandoned. In Germany from 1993 to 2012, the area of permanent grassland decreased from 5,251,000 ha to 4,631,000 ha, an absolute loss of 620,000 ha (-11.8%). In contrast, the area of arable land has remained rather stable. In 1993, arable land comprised 11,676,000 ha, and in 2012 11,834,000 ha (BMELV, 2013). This loss of permanent of permanent grassland coincides with the growing number of biogas plants and the increased maize cultivation. However, it is not clear if biogas plants are a causal driver or just a temporal coincidence in the decreasing area of permanent grassland.

Altogether, the presented developments suggest that there are interactive influences and dependencies among biogas plants, maize cultivation and livestock farming. Nevertheless, it remains unclear how these relationships are like and, additionally, in which way they might affect the area of permanent grassland.

## Objectives

Given this background, the main objective of this thesis was to analyse the regional differences of agricultural land use and land-use change, taking into consideration the spatial and temporal variations of these dynamics.

As described in two separate papers, the study aims at (i) developing a classification method to detect spatial and temporal differences of the patterns of agricultural land use (Chapter 2), and at (ii) examining the area changes of permanent grassland and maize as well as analysing if there is a relationship of biogas plants and, for comparison, livestock farming to the changes in agricultural land use (Chapter 3).

The main data set were data of the Integrated Administration and Control System (IACS) containing information on agricultural land use for the years 2005 to 2010. The federal state Hesse was chosen as study region due to its various biogeographical regions comprising both marginal and intensively used agricultural landscapes.

To this end, the specific objectives of this study were:

- 1) to identify 'types of agricultural land-use patterns and dynamics (TLPDs)' at the scale of municipalities, based on the thesis of Reger, Otte, & Waldhardt (2007) who studied past land-use change in a marginal landscape, and
- 2) to characterise the identified types by using physical landscape attributes (elevation, slope, temperature and precipitation) and the intensity of livestock farming (expressed by livestock data, i.e. cattle and pig numbers, and a livestock density index), as well as
- 3) to quantify the area changes of permanent grassland and maize, both at the spatial level of Hesse as a whole and at the level of its municipalities, and
- 4) to investigate if there is a statistically reliable association between the existence of biogas plants and maize area as well as biogas plants and the conversion of grassland, here at the spatial level of Hesse as a whole and five sub-regions. The results were compared with the association between livestock density and, again, maize area and the conversion of permanent grassland.

## The study region Hesse in Germany

The federal state Hesse has a size of 21,115 km<sup>2</sup> and is subdivided into 430 municipalities (HSL, 2012). Hesse is characterised by a variety of different landscapes (Pletsch, 1989). Due to physical site conditions like relief, climate and soil types, it comprises areas both favourable and unfavourable for agriculture. In consequence, Hesse features an agricultural land use ranging from intensively used to marginal agricultural landscapes and a mixture of the two.

Hesse belongs to the central German mountain threshold which is characterised by a spatial alternation of basins and swales (<300 m a.s.l., planar to colline altitude level) and elevations (>300 m a.s.l., submontane to montane altitude level). The highest point lies in the eastern low mountain range, which is the Rhön (950 m a.s.l.). Additionally, there are many elevations higher than 550 m a.s.l. which are distributed to the whole area of Hesse. In contrast, the basin sites have altitudes of 100-200 m a.s.l. in the south and 150-250 m a.s.l. in the north. These large-scale structures are like a morphologically structuring axis in a north-south direction (Jungmann & Brückner, 2005). As a result, climate shows distinct regional differences and is divided in two parts. The lowlands are notably warm featuring a mean annual temperature of 9-10 °C and a mean annual precipitation (1971-2000) of 500-700 mm. In the highlands, mean annual temperature is about 5 °C and mean annual precipitation (1971-2000) is 1,200-1,300 mm which means that these regions are rather cold (Mollenhauer, 2005).

Due to orographic and climatic conditions, soil types are diverse (Lotz, 1995; Pletsch, 1989). In the lowlands, the main substrates of pedogenesis are loess and windborne sands. In the Rhine-Main area, soil types are usually Umbrisol and Umbrisol Protospodic featuring a high permeability. The average temperatures (1981-2010) are high, especially in late spring (10-11 °C) and summer (18-20 °C) (HLNUG, 2016). These sites are dry and field irrigation has to be applied. North of the Main river, the lowlands are dominated by loess, soils types are mainly Umbrisol Protospodic, Phaeozems and Luvisols which all enable a high agricultural profitability (Schaldach, 2004). In contrast, in the highlands the pedogenesis is shaped by a mixture of weathered parent rock material and loess resulting usually in base-poor soil types. Umbrisols and Podzols are prevalent which are rather unfavourable for agricultural cultivation. The highlands also have soil types with a high base saturation like Cambisols (Sabel, 2005). These sites are suitable for agricultural cultivation (Harrach, 2005; Schaldach, 2004).

Land use in Hesse is various and diversified. In the year 2010, 42% of the total area was used for agriculture, 40% for forestry and 16% for settlement and traffic (HSL, 2012). Hesse is the federal state of Germany holding the highest proportion of forest (Rödig, 2005). Whereas the forestry area slightly increases (832,501 ha to 847,681 ha, 1980-2010), the area of agricultural land concurrently decreases (983,393 ha to 890,334 ha, 1980-2010) (HSL, 2010; Pletsch, 1989). Since Hesse is characterised by distinct highlands with rather unfavourable physical conditions for agriculture, in 2010 the proportion of permanent grassland was 37%, the proportion of

arable land amounted to 62% (HSL, 2012). For comparison, in Germany permanent grassland comprised 29% and arable land 71% of the utilised agricultural land in 2010 (DBV, 2010). In the Hessian highlands, land use varies between the predominant grassland, agriculture and forestry depending on soil quality, relief and climate. Here, usually land use is practised non-intensively (Graß, 2005), and there is a diverse mosaic of habitats and a high number of species (Simmering, Waldhardt, & Otte, 2013). Thus, agricultural cultivation and biodiversity are closely correlated (Otte, Donath, Waldhardt, & Schwabe-Kratochwil, 2010). In contrast, due to favourable physical conditions agricultural land use of the lowlands is intensive (Freund, 2002). Here, grain is the dominant crop with a proportion of 64% on arable land in 2010, of which 55% was wheat and 29% was barley (HSL, 2012). Other important crops are vegetables, sugar beet and in some cases vines and fruits (Schaller, 2005). In recent years, the cultivation of maize (*Zea mays*) and rapeseed (*Brassica napus*) has increased. Especially silage maize used as bioenergy crop featured a significant area growth (HMUELV, 2011a). From 2009 to 2010, the area of silage maize increased by 10% and covered 8% of the arable land (HMUELV, 2011b).

In Hesse, livestock farming is an important factor in agriculture. About 70% of the agricultural income still results from animal products (Graß, 2005). Nevertheless, Hesse is not a region of intensive livestock farming. Pig and cattle stocks and also the number of relevant farms have decreased. From 2003 to 2010, the number of farms producing animal products decreased from 20,234 to 13,466 farms. In 2010, the average livestock was 0.6 LU per ha utilised agricultural land (in Germany as a whole: 1.1 LU/ha). Total livestock added up to 469,750 livestock units (LU). Livestock farming is practised predominantly in the north and the east and here on a rather intensive level (HMUELV, 2011b). In contrast, livestock farming in the highlands, especially cattle breeding featuring milk production, is managed at a non-intensive level. Therefore, the proportion of species-rich grassland is rather high in Hesse (Otte et al., 2010). But the number of dairy cattle farms and dairy cows has also decreased. From 1979 to 2010, the number of dairy cows was reduced from 299,000 to 149,000 (HMUELV, 2011b). Thus, meadowland of the marginal regions is in danger to be given up which consequently will influence the species richness.

The agricultural structure featured various changes in the last decades, and these developments are expected to continue (Graß, 2005). From 1971 to 2010, the total number of farms decreased from 90,900 to 17,900 (HMUELV, 2011b). The released farm land was absorbed by the remaining farms. In consequence, also farm sizes changed. In 1999, the average farm size was 26 ha, it increased to 43 ha in 2010 (74 ha for full-time farms and 24 ha for part-time farms) (HMUELV, 2011b). In Germany, in 2010 the average farm size was 56 ha (DBV, 2012). Hesse is a land of part-time farming, which means that 68% of the farms were managed in part-time in 2010 (HSL, 2012). For comparison, in Germany as a whole the proportion of part-time farms was 50% (DBV, 2012). In Hesse, part-time farming was possible due to non-agricultural employment alternatives which were close to the place of living, especially in the middle and in the south of the state. As a result, part-time farms cover 32% of the agricultural land in Hesse (Graß, 2005).

## Material and methods

The main data set for analysing regional differences of agricultural land use and land-use change were data of the Integrated Administration and Control System (IACS). IACS is an instrument in application of the European Common Agricultural Policy (CAP) and mandatory for all member states. Farmers have to register to this system in order to get direct payments if applying for. IACS data provide information on land use at the field level on an annual basis as well as information on field size, farm type, livestock etc. (EC, 2015).

The data used for this study were IACS data of the federal state Hesse for the years from 2005 to 2010, made available by the Hessian Agency for Environment and Geology (HLUG, undated). The data set contained one GIS polygon layer for each year featuring all registered fields and their land use in the respective year. These layers were intersected with a polygonal layer of the 430 Hessian municipalities which was provided by the German Federal Office for Cartography and Geodesy (BKG, 2011). IACS data consists of four land use classes: arable land, permanent grassland, permanent crops and non-agricultural area. Added together, they represent the utilised agricultural land (UAL). In order to analyse the changes in land use, we calculated seven variables for each of the 430 municipalities based on the IACS data set (see Table Syn-1 for a detailed description).

**Table Syn-1**

Variables of agricultural land use based on IACS data (HLUG, undated)

Variable	Description
<i>Permanent grassland</i>	
1. Permanent grassland area, 2005 (% of util. agr. land)	Proportion of permanent grassland in 2005 as percentage of utilised agricultural land *
2. Permanent grassland area, 2010 (% of util. agr. land)	Proportion of permanent grassland in 2010 as percentage of utilised agricultural land *
3. Expansion of permanent grassland area, 2005-2010 (%)	Average annual expansion rate as percentage for the proportion of permanent grassland area in the time period 2005-2010
4. Conversion of permanent grassland 2005 to arable land 2010 (% of grassland 2005)	Permanent grassland converted into arable land between 2005 and 2010, as percentage of grassland area in 2005
<i>Maize</i>	
5. Maize area, 2005 (% of arable land)	Proportion of maize area in 2005 as percentage of arable land **
6. Maize area, 2010 (% of arable land)	Proportion of maize area in 2010 as percentage of arable land **
7. Expansion of maize area, 2005-2010 (%)	Average annual expansion rate as percentage for the proportion of maize area in the time period 2005-2010

\* Relating to the maximum area of utilised agricultural land from 2005-2010. \*\* Relating to the maximum area of arable land from 2005-2010.

This thesis was divided into two separate substudies presented in two publications.

In the first substudy, presented in the research article “Analysing data of the Integrated Administration and Control System (IACS) to detect patterns of agricultural land use and land-use change at municipality level” (Chapter 2), variables number 1, 4, 6 and 7 (see Table Syn-1) of the variables of agricultural land use were used.

The second substudy, presented in the research article “The impact of biogas plants on regional dynamics of permanent grassland and maize area – The example of Hesse, Germany (2005-2010)” (Chapter 3), considered all seven variables of agricultural land use (see Table Syn-1).

For the analyses of IACS data, the Spatial Analyst tool which is included in the Geographical Information System ArcGIS 10 was used (ESRI, 2010).

The aim of the first substudy was to classify the Hessian municipalities according to the patterns of agricultural land use and land-use change. For that purpose, besides the aforementioned variables of agricultural land use, further variables had to be considered which were both physical landscape attributes and livestock numbers. These variables are known to be relevant determinants for agricultural cultivation, consequently they correlate with land-use change processes (Hietel, Waldhardt, & Otte, 2004, 2007; Pan, Domon, de Blois, & Bouchard, 1999; Schneider & Pontius, 2001). Physical landscape attributes were expressed by: (i) elevation, (ii) slope, (iii) temperature, and (iv) precipitation, provided by the Hessian State Office for Land Management and Geoinformation (HVBG, undated) and by the German Weather Service (DWD, 2013). Livestock numbers were expressed by: (i) the number of cattle, (ii) the number of pigs, and (iii) livestock density. The information was taken of the Hessian agricultural statistics (HSL, 2012). For each of the 430 municipalities in Hesse, the means of these variables were calculated. The following statistical process was a k-means cluster analysis (MacQueen, 1967) based on the four selected variables of agricultural land use. To this end, the 430 municipal means of these four variables were allocated to different clusters. The results were clusters which represent types of agricultural land-use patterns and dynamics (TLPDs) for the study region Hesse. Subsequently, both physical landscape attributes and livestock numbers were considered to check the derived clusters for plausibility. With the help of the non-parametric Kruskal-Wallis one-way ANOVA (analysis of variance) by ranks (Dormann & Kühn, 2011), significant differences between the TLPDs were revealed. For a detailed description of the design of the first substudy please see the part “Methods” of chapter 2 of this thesis.

The second substudy focused on the temporal and spatial dynamics of permanent grassland and maize area as well as on the potential effect of the operation of biogas plants on land use. Based on the IACS data set, the seven variables of agricultural land use (see Table Syn-1) were calculated for the 430 municipalities and for Hesse as a whole. In a second step, we also analysed data of the Hessian communal statistics (HSL, 2003, 2007, 2010, 2013, 2015) which provided data on land use at the spatial level of Hesse, with the aim to check the IACS data for plausibility. After this analysis, the relationships of changes in agricultural land use to the

possible drivers biogas plants and, for comparison, livestock were investigated. For this purpose, two more variables had to be calculated. Firstly, since the assumption was that the influence of biogas plants on land use is higher the nearer a biogas plant is, the relevant variable was calculated as distance of municipalities to the next biogas plant. Secondly, the variable considering information on livestock was expressed as livestock density. This variable has been calculated in the first substudy, so that we could use these calculations. In order to analyse the relationships of bioenergy production and livestock farming to land-use changes, the subsequent statistics were a correlation and regression analysis. For correlation analysis, the correlation coefficient after Pearson was applied which is the special case of a linear correlation (Köhler, Schachtel, & Voleske, 2012). Concerning regression analysis, a multiple linear regression analysis was calculated based on the two independent variables distance of municipalities to next biogas plants and livestock density index (Rudolf & Kuhlisch, 2008). The dependent variables, i.e. the variables to explain, were maize area in 2010, expansion of maize area 2005-2010 and conversion of permanent grassland 2005-2010 (see Table Syn-1). Correlation and regression analysis were conducted at the spatial level of Hesse as a whole and at the spatial level of five Hessian sub-regions. For further information to the design of the second substudy please see the part “Material and methods” of chapter 3.

For all statistical analysis of this thesis, Statistica software was used (StatSoft. Inc., 2011, 2014).

## **Main results and conclusions**

### *Agricultural land use and land-use change*

Analysing changes in agricultural land use has been a major scope in landscape research (Coppedge, Engle, Fuhlendorf, Masters, & Gregory, 2001; Fukamachi, Oku, & Nakashizuka, 2001). Typically, the research studies investigate the processes of land-use change over space and time (e.g. Nitsch et al., 2012; Pan et al., 1999), the underlying driving forces (e.g. Bürgi et al., 2004; Hietel, Waldhardt, & Otte, 2005) as well as the consequences for ecosystem functioning and abiotic resources (e.g. Kandziora, Dörnhöfer, Oppelt, & Müller, 2014; Waldhardt, Simmering, & Otte, 2004). Although these studies used various spatial scales, studies describing the regional pattern of agricultural land use, and how this pattern differs within sub-regions, are still rare (Mendoza et al., 2011). Thus, there is a need for analyses of land use which consider a spatial level of regions or even sub-regions. Furthermore, it is just as important that these analyses are promptly conducted in order to consider recent possible driving forces, for example the cultivation of energy crops. Finally, since European agricultural land use is likely to undergo further changes (Keenleyside et al., 2009; Keenleyside & Tucker, 2010; Sanderson et al., 2013), analysing land-use change will stay an important research topic in the future. Therefore, this thesis investigated land use and land-use change while



considering the regional differences and recent dynamics in land use based on the IACS data set at the example of Hesse.

The first substudy on changes in the patterns of land use (Chapter 2) detected spatially and temporally differentiated types of agricultural land-use patterns and dynamics (TLPDs), and revealed that these changes in land use occur at sub-regional level. In Hesse, five different TLPDs could be identified, which represent five different sub-regions. The first sub-region, TLPD A, was characterised as the arable land type. Here, the utilised agricultural land of these municipalities is dominated by arable land, in return the proportion of permanent grassland is low (14.2% in 2005), which is beneath the average rate for Hesse (37.0%). Since the physical attributes elevation and slope as well as temperature and precipitation are favourable for cultivation, this sub-region belongs to the intensively cultivated areas in Hesse. There is a distinct conversion of permanent grassland to arable land, because 3.2% of the grassland area in 2005 was converted to arable land in 2010. This conversion rate is the highest for the entire study region. The average annual expansion rate for maize is 6.9%, which means land use changed in favour of maize. The livestock density is with 0.3 LU/ha the lowest of the five sub-regions, whereas the pig stock is the highest one. In the second sub-region, which is TLPD B and called the maize type, both variables the proportion of maize area (18.7% in 2010) and its average annual expansion rate (12.1% from 2005-2010) are the highest ones. Thus, in this sub-region the dynamics in land use favoured the cultivation of maize. Furthermore, permanent grassland is also involved in land-use changes due to a conversion rate of 2.2%. Livestock density is comparatively high because of high cattle numbers. This suggests that the reason for this relatively high proportion of maize area is both cattle farming and its need for fodder. But biogas production could also be a reason, however this remains unclear. The next detected sub-region in Hesse, TLPD C, represents an intermediate type. In this sub-region, livestock density is at an average (0.5 LU/ha in 2010), the proportion of grassland (34.8% in 2005) is around the Hessian mean, and the proportion of maize area (5.0% in 2010) is the lowest compared to the other sub-regions. Noticeable is the fact, that the conversion of grassland to arable land is the second highest (2.8%). Thus, here land-use change occurred by conversion of grassland. The last two sub-regions could be consolidated since they feature alike variables of land use. In sub-regions of both TLPD D and E, the grassland type and the grassland-maize type, physical conditions are unfavourable for agricultural production. Here, arable cultivation is difficult and consequently the proportion of grassland is very high (TLPD D: 55.1% and TLPD E: 80.2% in 2005). Livestock densities are with each 0.7 LU/ha the highest ones in the study region which is due to high numbers of cattle. Surprisingly however, these sub-regions feature a land-use change in favour of maize which is indicated by both the expansion rate of maize and the proportion of maize on arable land. Whether these dynamics are induced only by cattle farming or also by biogas production was analysed in the second substudy of this thesis. In summary, in Hesse the most suitable sub-regions for agricultural cultivation featured an ongoing process of intensification. In these sub-regions, arable land is the main land use, a progressive land-use change occurred to the disadvantage of permanent grassland which

means it was converted to arable land and will likely in the future. Livestock farming is of minor importance with the exception of sometimes pig farming on a rather intensive level. In sub-regions with rather unfavourable physical conditions, permanent grassland is the predominant land use, especially in mountainous areas. But on the remaining arable land, there is a slight land-use change in favour of maize. Here, livestock farming is dominated by cattle farming which is managed on a relatively intensive level.

Building upon the first substudy, the second substudy (Chapter 3) investigated the changes in land use on the example of permanent grassland and maize area at the scale of the Hessian municipalities, and, above all, analysed if there is a statistically reliable relationship of biogas plants to these land-use changes. For comparison, livestock farming was also considered as a possible influencing factor. The analysis revealed that in Hesse permanent grassland has decreased, especially since 2007 this decrease is continuous. Based on IACS data, from 2005 to 2010 there is an area decrease of -1.4% (i.e. 298,078 ha in 2005 to 294,052 ha in 2010). Permanent grassland primarily gets lost in the highly productive regions with intensive agricultural cultivation which are the lowlands and the floodplains of the south, the south-west and the north. These regions are the arable land type, the maize type and the intermediate type (TLPD A, B and C) of the first substudy. In contrast, the maize area increased significantly from 6.5% to 9.3% of arable land which is an area growth of +41.7% (i.e. 31,510 ha in 2005 to 44,654 ha in 2010). Thus, the cultivation of maize has become a relevant factor in land-use change as already revealed in the first substudy. However, since the percentage of maize area differs considerably, its relevance for land-use change depends on the sub-region. Maize is cultivated predominantly in the south, the east and in parts of the west with low mountain ranges as well as in the north of Hesse which are the maize type as well as the grassland and grassland-maize type (TLPD B, D and E). Furthermore, the results of the second substudy proved that there are statistically significant relationships between the existence of biogas plants and the livestock density to the exemplarily analysed variables of agricultural land use, i.e. maize area in 2010, expansion of maize area from 2005 to 2010 and conversion of grassland 2005 to arable land 2010. First of all, there were distinct relationships between livestock density and maize area but depending on the detected sub-regions. Especially in sub-regions with a high maize proportion, the relationships were existent. In contrast, livestock density does not correlate with the expansion of maize area (with just one exception for TLPD A, the arable land type). Finally, the correlations between livestock density and conversion of grassland were minor and only evident in the sub-regions of TLPD A, the arable land type, and TLPD B, the maize type, and TLPD E, the grassland-maize type. In contrast, the existence of biogas plants featured different relationships. The correlations between biogas plants and maize area were weaker than the correlations of livestock density. But the correlations of biogas plants to the expansion of maize area were significant and, notably, apparent at all spatial scales, i.e. for Hesse as a whole and for all five sub-regions. At last, biogas plants also correlated with the conversion of grassland for Hesse as a whole and for four sub-regions. In summary, the two independent variables biogas plants and livestock farming could reliably

describe the dependent variables maize area, expansion of maize area and conversion of permanent grassland. The hypothesis that biogas plants and livestock farming are drivers of land-use change but depending on the region could thus be confirmed. Consequently, in Hesse both the existence of biogas plants and the livestock farming can serve as an indicator for the changes in permanent grassland and maize area.

The results of both substudies corroborated the general trends of intensification and marginalisation in European agriculture. Since these trends are opposing, there is a kind of polarisation in European agriculture (Keenleyside et al., 2009). Intensification and marginalisation or even abandonment act simultaneously, which means that both developments correlate with each other (Bruns, Ipsen, & Bohnet, 2000; Van Eetvelde & Antrop, 2004). In the study region Hesse, on the one hand there are highly productive regions with favourable physical conditions for agricultural cultivation. These sites are used on an intensive level and this is expected to be continued or even strengthened in the future. On the other hand, there are sites with rather unfavourable conditions, for example in mountainous regions. These regions have featured a process of marginalisation for several decades, which means that especially arable cultivation was given up and replaced by permanent grassland, forestry or it was completely abandoned (Reger, 2008). In recent years, a new challenge occurred for the marginal regions in Hesse. Since maize cultivation is profitable even on marginal sites, the proportion of maize has increased. This development was evident in the sub-regions of TLPD D and E, which belong to the marginal regions (Chapter 2). Since maize cultivation is practiced on an intensive level due the use of pesticides and mineral fertiliser, these sites are in danger of being intensified. Thus, the general European trends of intensification and marginalisation are also evident in Hesse, but these trends appear rather small-scaled differentiated as the identified sub-regions demonstrate (Chapter 2).

The two trends of intensification and marginalisation are still the major way of change in agriculture (van Vliet, de Groot, Rietveld, & Verburg, 2015) and, additionally, are one of the most important threats to ecosystem functioning (Poudevigne & Baudry, 2003; Stoate et al., 2009). Intensification and marginalisation were reported for several countries in Europe, for example Norway and Sweden (Fjellstad & Dramstad, 1999; Trubins, 2013), the United Kingdom (Keenleyside et al., 2009), the Netherlands (Valbuena, Verburg, Veldkamp, Bregt, & Ligtenberg, 2010), Austria (Pinter & Kirner, 2014), Switzerland (Gellrich & Zimmermann, 2007; Schneeberger, Bürgi, & Kienast, 2007), the younger member states of the European Union like Poland, Hungary and Romania (Kovacs-Hostyanszki & Baldi, 2012; Sanderson et al., 2013; Schmitt & Rákossy, 2007), the Mediterranean countries like Spain, Italy and France (Bracchetti, Carotenuto, & Catorci, 2012; Corbelle-Rico, Crecente-Maseda, & Santé-Riveira, 2012; de Aranzabal, Schmitz, Aguilera, & Pineda, 2008; Monteiro, Fava, Hiltbrunner, Della Marianna, & Bocchi, 2011; Van Eetvelde & Antrop, 2004), and also for other regions of Germany (Bender, Boehmer, Jens, & Schumacher, 2005; Waldhardt & Otte, 2003; Wellstein et al., 2007).

Also the process of homogenisation is an important factor in European agriculture (Jongman, 2002). Homogenisation means a loss of the regional differences. Since farmers have to

compete on an international market, agricultural management practices become similar across the continent and, above all, due to financial reasons land use is more and more practised intensively, more specialised and on larger spatial scales, i.e. with enlarged field sizes (Fjellstad & Dramstad, 1999; Jongman, 2002). The development towards a homogenised landscape is also obvious in Hesse. Here, it is TLPD A, the arable land type, where the process of homogenisation is evident. This sub-region is dominated by arable land due to favourable physical conditions, the proportion of permanent grassland is with 14.2% low, and the conversion rate of permanent grassland is with 3.2% the highest in the study region. Thus, permanent grassland gets lost and the area of arable land still increases. Additionally, in recent years the number of biogas plants and thereby the area of silage maize grew significantly, which is mirrored by an expansion rate of maize area of 6.9%. Hence, in TLPD A the trend goes towards arable land and maize cultivation. Similar developments are apparent in TLPD B, the maize type. Here, the trend also goes towards arable land and maize cultivation, yet the proportion of permanent grassland is still higher (29.6%). In summary, due to this onesided and intensive cultivation these sub-regions feature a homogenised and monofunctional landscape lacking the former cultural diversity, spatial heterogeneity and accompanying biodiversity (Jongman, 2002).

Another trend in European agriculture is the cultivation of energy crops. The EU has set ambitious goals concerning the production of renewable energies. To meet these goals, the cultivation of bioenergy crops was politically and, in consequence, financially supported. Thus, in recent years the agricultural area used for energy crops grew significantly (Söderberg & Eckerberg, 2013). In this thesis, it was analysed how the general trend of an increased bioenergy production affected agricultural land use (Chapter 3). The focus was set on biogas plants and to what extent they cause changes in land use since in Germany the number of biogas plants featured a considerable increase in recent years (Delzeit et al., 2012). In Germany, the Renewable Energy Act (German: Erneuerbare-Energien-Gesetz, EEG) is the instrument which promoted the cultivation of bioenergy plants. It a story of success since its fostering in deed has led to an increase in bioenergy production. But this development is based mainly on a few energy crops, especially maize (Lupp et al., 2014). Maize is predominantly used as feedstock for biogas plants. Therefore, the fostering policy by the EEG has resulted in a considerable increase in the number of biogas plants. A growing number of biogas plants and an attending maize cultivation is not only the case in the study region Hesse, but also in other federal states in Germany, for example in Rhineland-Palatinate (Breitenfeld, 2012), Lower Saxony (Laggner et al., 2014; Wiehe, von Ruschkowski, Rode, Kanning, & von Haaren, 2009) and Schleswig-Holstein (Kandziora et al., 2014).

However, the number of biogas plants differs by region which means there are significant differences within the federal states (Lupp et al., 2014). This was also true for Hesse. In Hesse, the number of biogas plants differs among the sub-regions detected in the first substudy. In TLPD A, the arable land type, the number of biogas plants was the highest (42 biogas plants). In TLPD E, the grassland-maize type, the numbers were the lowest (11 biogas plants). Thus, in

Hesse the number of biogas plants goes along with the land-use type, i.e. the more land use is practised intensively the higher is the number of biogas plants. In the study region, the sub-regions of intensive land use feature the most biogas plants, whereas the sub-regions with non-intensive cultivation only have few biogas plants. Thus, the results show that in Hesse biogas plants have led to a further intensification in sub-regions where agricultural cultivation has already been intensive. This process of a further intensification is due to an increased maize cultivation and a conversion of permanent grassland. Our findings are in line with a study conducted for other regions within Europe and which reported a more intensive land use because of bioenergy production (Pedroli et al., 2013). As proposed in the first substudy, in these Hessian sub-regions it is important to lessen the intensity of land use in order to enhance biodiversity and ecosystem services.

The impact of biogas plants respectively the cultivation of its main feedstock maize is a matter of debate. Of course biogas plants belong to renewable energy sources, but some authors claim that this kind of energy production is not the best choice since it is of a lower productivity per area, i.e. plenty of area for little energy, compared to photovoltaic plants or wind energy, for example (Hampicke, 2013b). Additionally, the main feedstock maize is discussed controversially since its cultivation might cause a reduced crop diversity, high amounts of mineral fertiliser and pesticides, soil consolidation and soil erosion, negative effects on biodiversity and landscape scenery (Lupp et al., 2014; Wiehe et al., 2009). Nevertheless, maize cultivation has not to be obligatorily negative. In marginalised regions, which are the sub-regions of TLPD D and E (grassland and grassland-maize type) of the study region, where land use is in danger to be abandoned, maize cultivation can be a good opportunity to maintain agricultural land use assumed that it is practised at a non-intensive level (Pedroli et al., 2013). Therefore, the effects of bioenergy production on land use are site-specific which means it depends on the sub-region with its specific environmental attributes, its type of land use and the management practices (Pedroli et al., 2013).

In this thesis, both substudies revealed that land use differs at the level of the identified five sub-regions. Thus, the patterns and dynamics in land use occur at the local level (Lupp et al., 2014; Pedroli et al., 2013), which means that decisions on land use and management practices are taken at this spatial scale (Harvolk et al., 2013). In consequence, this knowledge should be used to create appropriate political instruments. Policy with its legislation, financial fostering and steering measurements are known to be an important influence in agriculture (Strijker, 2005), which in Europe is the CAP (Heißenhuber & Krämer, 2011). Some authors even claim that in Europe the CAP is more important for decision making of farmers than socioeconomic or technical changes (Corbelle-Rico et al., 2012). Even if political instruments are just one influencing factor, by means of this it is possible to affect agricultural cultivation and this should definitely be done with the aim of a sustainable agriculture. Sustainability in land use is of utmost importance since modern agriculture is connected to several environmental problems (Stoate et al., 2001).

The development in the renewable energy sector is a prime example to show that political instruments have a major influence on land use. The fostered cultivation of energy crops could feature negative as well as positive effects on the environment. In this thesis, the analysed example of biogas plants revealed that in Hesse their fostering caused an additional intensification of land use due to maize cultivation. Therefore, an adjusted policy for renewable energy production would be comfortable for the Hessian sub-regions of intensive land use. But due to still high incentives, maize cultivation is the crop with the highest economic profitability (Schulze Steinmann & Holm-Müller, 2010). Thus, it is a recommendation to abolish the hitherto existing subvention policy (Bauhus et al., 2012). Instead, biogas plants should be run with manure cattle and with municipal waste since these substrates do not consume (agricultural) area. Additionally, the subvention policy should foster biogas crops which cause a higher biodiversity and numbers of habitats even if their yield per area is lower compared to silage maize (Hampicke, 2015). For example, this aim can be achieved if biogas plants are run with biomass from grassland, a production form which is already established and which also can effect the environment positively assumed that grassland management is traditional (Prochnow et al., 2009).

Another political instrument to steer agriculture towards sustainability are agri-environment-climate schemes. The participation of farmers in agri-environment-climate schemes is essential, since by means of this several aims are intended, for example a sustainable land use or just the maintainance of agriculture in marginalised regions. But up to now, the necessary claiming by farmers is still too rare (Dobbs & Pretty, 2008). Therefore, agri-environment-climate schemes have to be enhanced by an increased incentive which offer a sufficient economic alternative. For example, the agri-environment payments are no possible choice compared to the incentives for biogas producers (Russi, Margue, Oppermann, & Keenleyside, 2016). Indeed, the policy of supporting renewable energies with high incentives has led to the biogas boom of the past years which also happened in the study region. In general, there are two cases: In regions of intensive farming with a high production of agricultural goods, the enrolment of farmers in the agri-environment-climate schemes is low because the incentives are lesser than the profit of conventional cropping. In low-productive regions, the payments are attractive and consequently farmers take part in order to secure their income (Hampicke, 2013a). This behaviour of farmers is also apparent in the study region. In the high-productive regions of the south and the north, the average amount of agri-environment-climate payments was 0 to 40 Euro per ha utilised agricultural land, whereas this amount rose to more than 70 Euro per ha in the marginal regions of the eastern and western highlands (HMUELV, 2011b). Furthermore, in Hesse the area proportion of part-time farms amounted to 32% of the utilised agricultural land in 2003 (Graß, 2005). This dimension is of political heaviness since particularly part-time farmers enrol to agri-environment-climate schemes. In general, in order to meet the site-specific environmental conditions the schemes should be improved by considering a lower spatial level of land use (Cormont et al., 2016; Fürst, Helming, Lorz, Müller, & Verburg, 2013) which is the level of sub-regions as this thesis has revealed.

## *Data base and methodology*

This thesis is based mainly on data of the Integrated Administration and Control System (IACS). IACS data provide information on agricultural land use and also, as the case may be, information on animal breeding. Since these data are collected annually and at field level, information on land use is at a highly disaggregated level (Nitsch et al., 2012). Furthermore, the thematic content is rich because in the IACS data set farmers even have to declare which crops are cultivated at the fields. Thus, the thematic accuracy of IACS data is also high (de Longueville et al., 2007).

However, there are some limitations in the IACS data. Within the member states of the European Union, IACS data are collected differently. Every member state has its own system. For example, the spatial identification of the agricultural land-use unit is managed differently (Inan et al., 2010; Sagris, Wojda, Milenov, & Devos, 2013). In some states, for example in Sweden and France (Rizzo, Martin, & Wohlfahrt, 2014; Trubins, 2013), the basis of the IACS data is the so-called agricultural block which can consist of several fields with different crops. Even within one state, IACS data could be collected differently which is the case for Germany. In Hesse, the basis of IACS data set is the single field (Chapter 2). This is not necessarily the case for other federal states in Germany. Among the federal states, there are differences of IACS data concerning the structure and the differentiation of land use as well as information on the farm, its area of cultivation and the reference area for GIS-analyses (Osterburg, Nitsch, Laggner, & Roggendorf, 2009). Therefore, there is a need for harmonisation and standardisation of IACS data across the European member states (Inan et al., 2010; Sagris et al., 2013). With a consistent European-wide IACS data set, these data could also be used for scientific research, for example for analysing and comparing land use within Europe as this thesis demonstrated.

Another limitation of IACS data is the fact that not all farmers apply for direct support payments. Consequently these fields are not included in IACS data which means that the actually utilised agricultural area is not completely recorded. Furthermore, it is possible that farmers declare their fields in the one year, and in another year they do not, although these fields are still cultivated. As a result, in IACS data the registered fields vary each year (Nitsch et al., 2012). To answer the question of how many hectares are missing is difficult, and would require further research. However, it is reasonable to assume that IACS data mirror the major proportion of the utilised agricultural land because farmers need the direct support payments for their economic survival.

Despite this unknown missing proportion of land-use area, IACS data feature some advantages compared to other data sets collecting data on agricultural land use. For example, the Hessian agricultural statistics used in the second substudy of this thesis (Chapter 3) have the shortcoming that also a certain proportion of agricultural area is missing which is due to the

limit of detection (in German: Erfassungsgrenze). This means that only fields with a stated area will be recorded in agricultural statistics and these limits even vary over time. Thus, a number of smaller fields is not included in this data set. Consequently, regions with smaller farm sizes and smaller fields, which is the case in the southern part of Hesse for example, will be mirrored incompletely in agricultural statistics. Additionally, due to the variations in the limits of detection the comparability between the recorded years is not possible.

In summary, until now IACS data represent the most complete and most up-to-date dataset for agricultural land use concerning space and time as well as content. Thus, despite the mentioned limitations, the IACS data are unique in order to be used as time series of land use at field level which, consequently, enables them to be a basis for policy decisions (Corbelle-Rico et al., 2012; Rizzo et al., 2014; Trubins, 2013). For example, IACS data could be used as the basis for offering targeted agri-environment-climate schemes. These schemes are key measures of agri-environment policies and are thus of high relevance for sustainability in agriculture. Since their realisation is time and cost intensive, it is important to have a manageable tool at hand (de Longueville et al., 2007). With IACS data it would be possible to create maps which can serve as the basis for the development of the agri-environment-climate schemes. Maps are known as powerful tools for representing the needed information, nevertheless in order to serve as a management tool they have to be of high accuracy (Schmit, Rounsevell, & La Jeunesse, 2006). IACS data could create such maps, and consequently could be the basis for policy decisions since geospatial information is of utmost importance to implement the aims of European agricultural policy. Thereby, the use of the IACS data base would be far beyond its originally planned intent (Tóth & Kucas, 2016). However, if the number of farmers applying for direct support payments might decrease in the future, the percentage of the actual agricultural land mirrored in IACS data will become smaller and smaller (Trubins, 2013). Therefore, in order to maintain the accuracy of this data set, it is of high importance that direct payments stay an economic incentive for farmers.

## *Perspectives*

This thesis showed that agricultural land use and land-use change are obvious at the spatial level of sub-regions. The general trends in agriculture which are intensification and simultaneously marginalisation or abandonment are evident in the study region. Also, the biogas boom of the past years was apparent in the study region. This development contributed to the intensification of land use due to an increased area of maize. Furthermore, the existence of biogas plants caused to a certain extent the conversion of grassland. Thus, in Hesse biogas plants were detected as an influencing factor for changes in land use.

Based on recent forecasts, in Germany as a whole bioenergy fields (primarily the intensive crops rapeseed and maize) will increase to an area of 3.7 million ha in the year 2020 (DVL,



undated), beside the ongoing trend of intensification of agricultural cultivation, so that new conflicts of goals are expected. Therefore, both the protection of permanent grassland and a non-intensive land use is important.

In this context, the CAP of the EU could be an adequate instrument for nature protection measures, provided that these measures are target-oriented, financially sufficient for the stakeholders and adopted to the spatial level of sub-regions, i.e. to the local level. In this context, agri-environment-climate schemes can be a powerful method. In Germany, the responsibility for the concrete design and content of these measures lies in the hands of the federal states. The EU-regulations give wide scope, so that the federal states should make demands on this, more than they did until now. Therefore, in the next fostering period after the year 2020, the German federal states should create site-specific schemes and above all should increase the financial subsidies.

Agricultural land use has a large impact on the diversity of habitats and species as well as ecosystem functioning (Kristensen, 2016). Thus, the aim in agriculture has to be sustainability since thereby the future challenges like climate change, the loss of biodiversity, growing food demands etc. can be met (Tilman et al., 2002). With adequate agri-environment-climate schemes, a sustainable agricultural production could be achieved. Environmental protection and agricultural production need one another since a high biodiversity was usually created through agricultural land use. In consequence, a sustainable agriculture is the sole way for the future. Therefore, in order to summarise this with the words of Wu (2013):

„Sustainability or sustainable development is a necessity, not a choice.“

## References

- Amon, T., Amon, B., Kryvoruchko, V., Zolltisch, W., Mayer, K., & Gruber, L. (2007). Biogas production from maize and dairy cattle manure - Influence of biomass composition on the methane yield. *Agriculture, Ecosystems and Environment*, 118, 173-182.
- Bauhus, J., Christen, O., Dabbert, S., Gauly, M., Heißenhuber, A., Hess, J., . . . Weingarten, P. (2012). Ernährungssicherung und nachhaltige Produktivitätssteigerung. Stellungnahme des Wissenschaftlichen Beirats für Agrarpolitik beim Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz. *Berichte über Landwirtschaft*, (90/1), 5-34. Retrieved from <http://www.bmel.de/SharedDocs/Downloads/Ministerium/Beiraete/Agrarpolitik/Stellungnahme-Ern%C3%A4hrungssicherung.html>
- Bender, O., Boehmer, H. J., Jens, D., & Schumacher, K. P. (2005). Using GIS to analyse long-term cultural landscape change in Southern Germany. *Landscape and Urban Planning*, 70, 111-125.
- Bieling, C., Plieninger, T., & Schaich, H. (2013). Patterns and causes of land change: Empirical results and conceptual considerations derived from a case study in the Swabian Alb, Germany. *Land Use Policy*, 35, 192-203.
- BKG (Bundesamt für Kartographie und Geodäsie) (Cartographer). (2011). Verwaltungsgebiete 1:250.000 (Administration units 1:250,000). Retrieved from [http://www.geodatenzentrum.de/geodaten/gdz\\_rahmen.gdz\\_div](http://www.geodatenzentrum.de/geodaten/gdz_rahmen.gdz_div)
- BMELV (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz). (2013). Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland 2013 (Statistical yearbook concerning feeding, agriculture and forest of the Federal Republic of Germany 2013). Retrieved from <http://www.bmelv-statistik.de/de/statistisches-jahrbuch/>
- Bracchetti, L., Carotenuto, L., & Catorci, A. (2012). Land-cover changes in a remote area of central Apennines (Italy) and management directions. *Landscape and Urban Planning*, 104, 157-170.
- Breitenfeld, J. (2012). Maisanbau 2010 - Mais wächst auf knapp einem Zehntel des Ackerlandes (Cultivation of maize - Maize grows on ca. 10% of arable land in Rhineland-Palatinate). *Statistische Monatshefte Rheinland-Pfalz*, 02/2012, 129-134. Retrieved from [http://www.statistik.rlp.de/no\\_cache/veroeffentlichungen/statistische-monatshefte/](http://www.statistik.rlp.de/no_cache/veroeffentlichungen/statistische-monatshefte/)
- Britz, W., & Delzeit, R. (2013). The impact of German biogas production on European and global agricultural markets, land use and the environment. *Energy Policy*, 62, 1268-1275.
- Bruns, D., Ipsen, D., & Bohnet, I. (2000). Landscape dynamics in Germany. *Landscape and Urban Planning*, 47, 143-158.
- Bürgi, M., Hersperger, A. M., & Schneeberger, N. (2004). Driving forces of landscape change - current and new directions. *Landscape Ecology*, 19, 857-868.
- Cabrera, A. P. (2015). The Landscape of the Dehesa in the Sierra Morena of Jaén (Spain) - the Transition from Traditional to New Land Uses. *Landscape Online*, 43, 1-15. doi: 10.3097/LO.201543
- Chen, H., Marhan, S., Billen, N., & Stahr, K. (2009). Soil organic-carbon and total nitrogen stocks as affected by different land uses in Baden-Württemberg (southwest Germany). *Journal of Plant Nutrition and Soil Science*, 172, 32-42.
- Conant, R. T., Paustian, K., & Elliott, E. T. (2001). Grassland management and conversion into grassland: Effects on soil carbon. *Ecological Applications*, 11, 343-355.
- Coppedge, B. R., Engle, D. M., Fuhlendorf, S. D., Masters, R. E., & Gregory, M. S. (2001). Landscape cover type and pattern dynamics in fragmented southern Great Plains grasslands, USA. *Landscape Ecology*, 16, 677-690.

- Corbelle-Rico, E., Crecente-Maseda, R., & Santé-Riveira, I. (2012). Multi-scale assessment and spatial modelling of agricultural land abandonment in a European peripheral region: Galicia (Spain), 1956-2004. *Land Use Policy*, 29, 493-501.
- Cormont, A., Siepel, H., Clement, J., Melman, T. C. P., WallisDeVries, M. F., van Turnhout, C. A. M., . . . de Snoo, G. R. (2016). Landscape complexity and farmland biodiversity: Evaluating the CAP target on natural elements. *Journal for Nature Conservation*, 30, 19-26.
- DBV (Deutscher Bauernverband). (2010). *Situationsbericht 2011. Trends und Fakten zur Landwirtschaft (Report of situation 2011. Trends and facts concerning agriculture)*. Berlin: Deutscher Bauernverband.
- DBV (Deutscher Bauernverband). (2012). *Situationsbericht 2012/13. Trends und Fakten zur Landwirtschaft (Report of situation 2012/13. Trends and facts concerning agriculture)*. Berlin: Deutscher Bauernverband.
- DBV (Deutscher Bauernverband). (2014). *Situationsbericht 2014/15. Trends und Fakten zur Landwirtschaft (Report of situation 2014/15. Trends and facts concerning agriculture)*. Berlin: Deutscher Bauernverband.
- de Aranzabal, I., Schmitz, M. F., Aguilera, P., & Pineda, F. D. (2008). Modelling of landscape changes from the dynamics of socio-ecological systems. A case of study in a semiarid Mediterranean landscape. *Ecological Indicators*, 8, 672-685.
- de Longueville, F., Tychon, B., Leteinturier, B., & Ozer, P. (2007). An approach to optimise the establishment of grassy headlands in the Belgian Wallon region: A tool for agri-environmental schemes. *Land Use Policy*, 24(2), 443-450.
- Delzeit, R., Britz, W., & Holm-Müller, K. (2012). Modelling regional input markets with numerous processing plants: The case of green maize for biogas production in Germany. *Environmental Modelling & Software*, 32, 74-84.
- Delzeit, R., & Kellner, U. (2013). The impact of plant size and location on profitability of biogas plants in Germany under consideration of processing digestates. *Biomass and Bioenergy*, 52, 43-53.
- Dobbs, T. L., & Pretty, J. (2008). Case study of agri-environmental payments: The United Kingdom. *Ecological Economics*, 65, 765-775.
- Dormann, C. F., & Kühn, I. (2011). *Angewandte Statistik für die biologischen Wissenschaften (Applied statistics for biological sciences)*. (2., durchgesehene, aktualisierte, überarbeitete und erweiterte Auflage). ohne Ort.
- Duelli, P., & Obrist, M. K. (2003). Regional biodiversity in an agricultural landscape: the contribution of seminatural habitat islands. *Basic and Applied Ecology*, 4, 129-138.
- DVL (Deutscher Verband für Landschaftspflege). (undated). Reform der Gemeinsamen Agrarpolitik (GAP) für die Zeit nach 2013. Entwicklung vielfältiger Kulturlandschaften - eine zentrale Aufgabe. Standpunkte des Deutschen Verbandes für Landschaftspflege e.V. (DVL) (Reform of the Common Agricultural Policy (CAP) for the time after 2013. Development of manifold cultural landscapes - a central task. Viewpoints of the German Association for Landcare). Retrieved from <http://www.lpv.de/themen/agrar-und-regionalpolitik/agrarreform.html>
- DWD (Deutscher Wetterdienst) (Cartographer). (2013). ohne Titel (no title). Retrieved from <https://werdis.dwd.de>
- EC (European Commission). (2012). Europe in figures. Eurostat yearbook 2012. Retrieved from <http://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-CD-12-001>
- EC (European Commission). (2015). Integrated Administration and Control System (IACS). Retrieved 02.11.2015, from [http://ec.europa.eu/agriculture/direct-support/iacs/index\\_en.htm](http://ec.europa.eu/agriculture/direct-support/iacs/index_en.htm)
- Ellenberg, H., & Leuschner, C. (2010). *Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht (Vegetation of central Europe and the Alps in a ecological, dynamic and historic view)*. (6., vollst. neu bearb. und stark erw. Aufl.). Stuttgart: Ulmer.

- ESRI. (2010). ArcGIS 10.0. Redlands, CA, USA.
- Fjellstad, W. J., & Dramstad, W. E. (1999). Patterns of change in two contrasting Norwegian agricultural landscapes. *Landscape and Urban Planning*, 45, 177-191.
- Freund, B. (2002). *Hessen (Hesse)*. Gotha, Stuttgart: Klett-Perthes.
- Fukamachi, K., Oku, H., & Nakashizuka, T. (2001). The change of a satoyama landscape and its causality in Kamiseya, Kyoto Prefecture, Japan between 1970 and 1995. *Landscape Ecology*, 16, 703-717.
- Fürst, C., Helming, K., Lorz, C., Müller, F., & Verburg, P. H. (2013). Integrated land use and regional resource management - A cross-disciplinary dialogue on future perspectives for a sustainable development of regional resources. *Journal of Environmental Management*, 127(S1-S5).
- Gallant, A. L., Loveland, T. R., Sohl, T. L., & Napton, D. E. (2004). Using an Ecoregion Framework to Analyse Land-Cover and Land-Use Dynamics. *Journal of Environmental Management*, 34(Suppl. 1), S89-S110.
- Gellrich, M., & Zimmermann, N. E. (2007). Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning*, 79, 65-76.
- Gomez y Paloma, S., Ciaian, P., Cristoiu, A., & Sammeth, F. (2013). The future of agriculture. Prospective scenario and modelling approaches for policy analysis. *Land Use Policy*, 31, 102-113.
- Graß, K. (2005). Landwirtschaft in Hessen (Agriculture in Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 41-44.
- Hampicke, U. (2013a). Agricultural Conservation Measures - Suggestions for their Improvement. *GJAE (German Journal of Agricultural Economics)*, 62(3), 203-214.
- Hampicke, U. (2013b). *Kulturlandschaft und Naturschutz (Cultural landscape and nature conservation)*. Wiesbaden: Springer Spektrum.
- Hampicke, U. (2015). Energiepflanzen in der Agrarlandschaft (Energy crops in the agricultural landscape). *Handbuch Naturschutz und Landschaftspflege, VII:2:2.1*, 1-24. doi: 10.1002/9783527678471.hbnl2014003
- Harrach, T. (2005). Die naturräumliche Gliederung und Naturraumtypen Hessens (Biogeographical classification of Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 27-30.
- Hartmann, E., Thomas, F., & Luick, R. (2006). Agrarumweltprogramme in Deutschland. Anreiz für umweltfreundliches Wirtschaften in der Landwirtschaft und Kooperationen mit dem Naturschutz (Agri-environment schemes in Germany. Incentive for an environmentally friendly production in agriculture and cooperations in nature protection). *Naturschutz und Landschaftsplanung*, 38(7), 205-213.
- Harvolk, S., Kornatz, P., Otte, A., & Simmering, D. (2013). Using existing landscape data to assess the ecological potential of *Miscanthus* cultivation in a marginal landscape. *Global Change Biology (GCB) Bioenergy*, 1-15. Retrieved from doi:10.1111/gcbb.12078
- Heißenhuber, A., & Krämer, C. (2011). Analyse agrar- und umweltpolitischer Maßnahmen bezüglich ihrer Auswirkungen auf die Agrobiodiversität (Analysis of agricultural and environmental political measures regarding their impact on agricultural biodiversity). In F. Begemann, S. Schröder, D. Kießling, C. Neßhöver & V. Wolters (Eds.), *Neue Wege zur Erhaltung und nachhaltigen Nutzung der Agrobiodiversität - Effektivität und Perspektiven von Fördermaßnahmen im Agrarbereich. Schriftenreihe des Informations- und Koordinationszentrums für Biologische Vielfalt* (pp. 22-37). Bonn.
- Hietel, E., Waldhardt, R., & Otte, A. (2004). Analysing land-cover changes in relation to environmental variables in Hesse, Germany. *Landscape Ecology*, 19(5), 473-489.
- Hietel, E., Waldhardt, R., & Otte, A. (2005). Linking socio-economic factors, environment and land cover in the German Highlands, 1945-1999. *Journal of Environmental Management*, 75(2), 133-143.

- Hietel, E., Waldhardt, R., & Otte, A. (2007). Statistical modeling of land-cover changes based on key socio-economic indicators. *Ecological Economics*, 64, 496-507.
- HLNUG (Hessisches Landesamt für Naturschutz, Umwelt und Geologie). (2016). Umweltatlas Hessen (Environmental atlas of Hesse). Retrieved from <http://atlas.umwelt.hessen.de/atlas/>
- HLUG (Hessisches Landesamt für Umwelt und Geologie). (undated). *Daten des Integrierten Verwaltungs- und Kontrollsystem für Hessen 2004-2010 (IACS data for Hesse 2004-2010)*. Wiesbaden.
- HMUELV (Hessisches Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz). (2011a). Jahresagrarbericht 2011 (Annual report of agriculture 2011). Retrieved from [https://verwaltung1.hessen.de/irj/zentral\\_Internet?rid=zentral\\_15/zentral\\_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26\\_ic\\_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd](https://verwaltung1.hessen.de/irj/zentral_Internet?rid=zentral_15/zentral_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26_ic_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd)
- HMUELV (Hessisches Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz). (2011b). Landwirtschaft in Hessen. Zahlen und Fakten 2011 (Agriculture in Hesse 2011). Retrieved from [https://verwaltung1.hessen.de/irj/zentral\\_Internet?rid=zentral\\_15/zentral\\_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26\\_ic\\_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd](https://verwaltung1.hessen.de/irj/zentral_Internet?rid=zentral_15/zentral_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26_ic_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd)
- Hopkins, A., & Holz, B. (2006). Grassland for agriculture and nature conservation: production, quality and multi-functionality. *Agronomy Research*, 4, 3-20.
- HSL (Hessisches Statistisches Landesamt). (2003). *Hessische Gemeindestatistik 2003. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2002 (Hessian communal statistics 2003)*. Wiesbaden.
- HSL (Hessisches Statistisches Landesamt). (2007). Hessische Gemeindestatistik 2007. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2006 (Hessian communal statistics 2007). Retrieved from <http://www.statistik-hessen.de/publikationen/download/496/index.html>
- HSL (Hessisches Statistisches Landesamt). (2010). Hessische Gemeindestatistik 2010. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2009 (Hessian communal statistics 2010). Retrieved from <http://www.statistik-hessen.de/publikationen/download/496/index.html>
- HSL (Hessisches Statistisches Landesamt). (2012). Hessische Gemeindestatistik 2011. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2010 (Hessian communal statistics 2011). Retrieved from <http://www.statistik-hessen.de/publikationen/download/496/index.html>
- HSL (Hessisches Statistisches Landesamt). (2013). Statistisches Jahrbuch Hessen 2013/14. Band 1: Wirtschaft, Erwerbstätigkeit und Umwelt (Statistical yearbook of Hesse 2013/2014. Volume 1: Economy, employment and environment). Retrieved from <http://www.statistik-hessen.de/publikationen/download/490/index.html>
- HSL (Hessisches Statistisches Landesamt). (2015). Hessische Gemeindestatistik 2014. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2013. (Hessian communal statistics 2014). Retrieved from <http://www.statistik-hessen.de/publikationen/download/496/index.html>
- HVBG (Hessische Verwaltung für Bodenmanagement und Geoinformation). (undated). *Digitales Höhenmodell DHM25 (Digital Elevation Model DEM25)*. Wiesbaden.
- Inan, H. I., Sagris, V., Devos, W., Milenov, P., van Oosterom, P., & Zevenbergen, J. (2010). Data model for the collaboration between land administration systems and agricultural land parcel identification systems. *Journal of Environmental Management*, 91, 2440-2454.
- Jansen, L. J. M., & di Gregorio, A. (2002). Parametric land cover and land-use classifications as tools for environmental change detection. *Agriculture, Ecosystems and Environment*, 91(1-3), 89-100.

- Jongman, R. H. G. (2002). Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. *Landscape and Urban Planning*, 58, 211-221.
- Jungmann, W. W., & Brückner, H. (2005). Die geologisch-geomorphologischen Grundlagen Hessens (Geologic-geomorphic basics of Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 7-11.
- Kandziora, M., Dörnhöfer, K., Oppelt, N., & Müller, F. (2014). Detecting Land Use And Land Cover Changes In Northern German Agricultural Landscapes To Assess Ecosystem Service Dynamics. *Landscape Online*, 35, 1-24.
- Keenleyside, C., Baldock, D., Hjerp, P., & Swales, V. (2009). International perspectives on future land use. *Land Use Policy*, 26S, S14-S29.
- Keenleyside, C., & Tucker, G. (2010). Farmland Abandonment in the EU: an Assessment of Trends and Prospects. *Report Prepared for WWF*. London: Institute for European Environmental Policy.
- Kirchweg, S., & Kantelhardt, J. (2015). The dynamic effects of government-supported farm-investment activities on structural change in Austrian agriculture. *Land Use Policy*, 48, 73-93.
- Köhler, W., Schachtel, G., & Voleske, P. (2012). Biostatistik. Eine Einführung für Biologen und Agrarwissenschaftler (Biostatistics. An introduction for biologists and agronomists) doi:10.1007/978-3-642-29271-2
- Kovacs-Hostyánszki, A., & Baldi, A. (2012). Set-aside fields in agri-environment schemes can replace the market-driven abolishment of fallows. *Biological Conservation*, 152, 196-203.
- Kristensen, S. B. P. (2016). Agriculture and landscape interaction - landowners' decision-making and drivers of land use change in rural Europe. *Land Use Policy*, 57, 759-763.
- Kunes, P., Polánková, B., Chytrý, M., Jankovská, V., Pokorný, P., & Petr, L. (2008). Interpretation of the last-glacial vegetation of eastern-central Europe using modern analogues from southern Siberia. *Journal of Biogeography*, 35, 2223-2236.
- Laggner, B., Orthen, N., Osterburg, B., & Röder, N. (2014). Ist die zunehmende Biogasproduktion die alleinige Ursache für den Grünlandschwund in Deutschland? - Eine Analyse von georeferenzierten Daten zur Landnutzung (Is the increasing production of biogas the sole reason for grassland loss in Germany? - An analysis of georeferenced data of land use). *Raumforschung und Raumordnung*, 73(3), 195-209.
- Lewis, R. J., Pakeman, R. J., Angus, S., & Marrs, R. H. (2014). Using compositional and functional indicators for biodiversity conservation monitoring of semi-natural grasslands in Scotland. *Biological Conservation*, 175, 82-93.
- Lotz, K. (1995). *Einführung in die Geologie des Landes Hessen (Introduction to geology of Hesse)*. Marburg: Hitzeroth.
- Lupp, G., Steinhäuser, R., Starick, A., Gies, M., Bastian, O., & Albrecht, J. (2014). Forcing Germany's renewable energy targets by increased energy crop production: A challenge for regulation to secure sustainable land use practices. *Land Use Policy*, 36, 296-306.
- MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. In L. M. Le Cam & J. Neyman (Eds.), *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability* (pp. 281-297). Berkeley: University of California Press.
- McClure, S. (2013). Domesticated animals and biodiversity: Early agriculture at the gates of Europe and long-term ecological consequences. *Anthropocene*, 4, 57-68.
- Meeus, J. H. A. (1995). Pan-European landscapes. *Landscape and Urban Planning*, 31, 57-79.
- Meeus, J. H. A., Wijermans, M. P., & Vroom, M. J. (1990). Agricultural Landscapes in Europe and their Transformation. *Landscape and Urban Planning*, 18, 289-352.
- Mendoza, M. E., López Granados, E., Geneletti, D., Pérez-Salicrú, D. R., & Salinas, V. (2011). Analysing land cover and land use change processes at watershed level: A multitemporal study in the Lake Cuitzeo Watershed, Mexico (1975 - 2003). *Applied Geography*, 31, 237-250.

- Mollenhauer, K. (2005). Das Klima in Hessen und im rheinland-pfälzischen Rheinhessen (Climate in Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 12-16.
- Monteiro, A. T., Fava, F., Hiltbrunner, E., Della Marianna, G., & Bocchi, S. (2011). Assessment of land cover changes and spatial drivers behind loss of permanent meadows in the lowlands of Italian Alps. *Landscape and Urban Planning*, 100, 287-294.
- Nitsch, H., Osterburg, B., Roggendorf, W., & Laggner, B. (2012). Cross Compliance and the protection of grassland - Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. *Land Use Policy*, 29, 440-448.
- Osterburg, B., Nitsch, H., Laggner, B., & Roggendorf, W. (2009). Auswertung von Daten des Integrierten Verwaltungs- und Kontrollsystems zur Abschätzung von Wirkungen der EU-Agrarreform auf Umwelt und Landschaft: Bericht für das F+E-Vorhaben "Naturschutzfachliche Bewertung der GAP-Effizienzsteigerung durch Nutzung bestehender Datenbestände", gefördert durch das Bundesamt für Naturschutz (BfN) mit Mitteln des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit (Evaluation of IACS data in order to assess the impacts of agricultural reform of the EU on environment and landscape). *Arbeitsberichte aus der vTI-Agrarökonomie, Nr. 07/2009*.
- Otte, A., Donath, T. W., Waldhardt, R., & Schwabe-Kratochwil, A. (2010). Tuexenia. Mitteilungen der Floristisch-soziologischen Arbeitsgemeinschaft. Beiheft Nr. 3. Jahrestagung der Floristisch-soziologischen Arbeitsgemeinschaft (FlorSoz) in Gießen 2010 (Reports of the floristic-sociological working group).
- Pan, D., Domon, G., de Blois, S., & Bouchard, A. (1999). Temporal (1958-1993) and spatial patterns of land use changes in Haut-Saint-Laurent (Quebec, Canada) and their relation to landscape physical attributes. *Landscape Ecology*, 14, 35-52.
- Pedroli, B., Elbersen, B., Frederiksen, P., Grandin, U., Heikkilä, R., Krogh, P. H., . . . Spijker, J. (2013). Is energy cropping in Europe compatible with biodiversity? - Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. *Biomass and Bioenergy*, 55, 73-86.
- Pesch, R., Schmidt, G., Schroeder, W., & Weustermann, I. (2011). Application of CART in ecological landscape mapping: Two case studies. *Ecological Indicators*, 11, 115-122.
- Pinter, M., & Kirner, L. (2014). Strategies of disadvantaged mountain dairy farmers as indicators of agricultural structural change: A case study of Murau, Austria. *Land Use Policy*, 38, 441-453.
- Pletsch, A. (1989). *Hessen. Bundesrepublik Deutschland und Berlin (West). Wissenschaftliche Länderkunden Band 8/III. (Hesse. Federal Republic of Germany and West Berlin)*. Darmstadt: Wissenschaftliche Buchgesellschaft.
- Poudevigne, I., & Baudry, J. (2003). The implication of past and present landscape patterns for biodiversity research: introduction and overview. *Landscape Ecology*, 18, 223-225.
- Prochnow, A., Heiermann, M., Plöchl, M., Linke, B., Idler, C., Amon, T., & Hobbs, P. J. (2009). Bioenergy from permanent grassland - A review: 1. Biogas. *Bioresource Technology*, 100, 4931-4944.
- Reger, B. (2008). *Analysing agricultural landscape change in a marginal European landscape*. Dissertation, Justus-Liebig-Universität, Gießen.
- Reger, B., Otte, A., & Waldhardt, R. (2007). Identifying patterns of land-cover change and their physical attributes in a marginal European landscape. *Landscape and Urban Planning*, 81(1-2), 104-113.
- Reger, B., Sheridan, P., Simmering, D., Otte, A., & Waldhardt, R. (2009). Potential effects of direct transfer payments on farmland habitat diversity in a marginal European landscape. *Environmental Management*, 43(6), 1026-1038.
- Rizzo, D., Martin, L., & Wohlfahrt, J. (2014). Miscanthus spatial location as seen by farmers: A machine learning approach to model real criteria. *Biomass and Bioenergy*, 66, 348-363.

- Rödig, K.-P. (2005). Forstwirtschaft in Hessen (Forestry in Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 38-40.
- Rounsevell, M. D. A., Annetts, J. E., Audsley, E., Mayr, T., & Reginster, I. (2003). Modelling the spatial distribution of agricultural land use at the regional scale. *Agriculture, Ecosystems and Environment*, 95, 465-479.
- Rounsevell, M. D. A., Ewert, F., Reginster, I., Leemans, R., & Carter, T. R. (2005). Future scenarios of European agricultural land use II. Projecting changes in cropland and grassland. *Agriculture, Ecosystems and Environment*, 107, 117-135.
- Rounsevell, M. D. A., Reginster, I., Araujo, M. B., Carter, T. R., Dendoncker, N., Ewert, F., . . . Tuck, G. (2006). A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems and Environment*, 114, 57-68.
- Rudolf, M., & Kuhlisch, W. (2008). *Biostatistik. Eine Einführung für Biowissenschaftler (Biostatistics. An introduction for bioscientists)*. München: Pearson.
- Russi, D., Margue, H., Oppermann, R., & Keenleyside, C. (2016). Result-based agri-environment measures: Market-based instruments, incentives or rewards? The case of Baden-Württemberg. *Land Use Policy*, 54, 69-77.
- Sabel, K.-J. (2005). Die Bodenlandschaften Hessens (Soil landscapes of Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 21-26.
- Sagris, V., Wojda, P., Milenov, P., & Devos, W. (2013). The harmonised data model for assessing Land Parcel Identification Systems compliance with requirements of direct aid and agri-environmental schemes of the CAP. *Journal of Environmental Management*, 118, 40-48. doi: <http://dx.doi.org/10.1016/j.jenvman.2012.12.019>
- Sanderson, F. J., Kucharz, M., Jobda, M., & Donald, P. F. (2013). Impacts of agricultural intensification and abandonment on farmland birds in Poland following EU accession. *Agriculture, Ecosystems and Environment*, 168, 16-24.
- Schaldach, R. (2004). *Räumliche Modellierung der Dynamik von Landnutzung in Hessen und ihrer Wirkung auf die biologische Kohlenstoffspeicherung. Entwicklung eines GIS-basierten Modellsystems (Spatial modelling of the dynamic of land use in Hesse and of its impact on biological carbon sequestration. Development of a GIS-based modelling system)*. Dissertation, Universität Kassel. Retrieved from <http://nbn-resolving.de/urn:nbn:de:hebis:34-1335>
- Schaller, K. (2005). Sonderkultur Wein (Specialised crop wine). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer, Band 105*, 45-48.
- Schmit, C., Rounsevell, M. D. A., & La Jeunesse, I. (2006). The limitations of spatial land use data in environmental analysis. *Environmental Science & Policy*, 9, 174-188.
- Schmitt, T., & Rákossy, L. (2007). Changes of traditional agrarian landscapes and their conservation implications: a case study of butterflies in Romania. *Diversity and Distributions*, 13, 855-862.
- Schneeberger, N., Bürgi, M., & Kienast, F. (2007). Rates of landscape change at the northern fringe of the Swiss Alps: Historical and recent tendencies. *Landscape and Urban Planning*, 80, 127-136.
- Schneider, L. C., & Pontius, G. J. (2001). Modeling land-use change in the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems and Environment*, 85, 83-94.
- Schröder, W., Pesch, R., & Schmidt, G. (2007). Statistical Classification of Terrestrial and Marine Ecosystems for Environmental Planning. *Landscape Online*, 2, 1-22.
- Schulze Steinmann, M., & Holm-Müller, K. (2010). Thünensche Ringe der Biogaserzeugung - der Einfluss der Transportwürdigkeit nachwachsender Rohstoffe auf die Rohstoffauswahl von Biogasanlagen (Thuenen Rings of Biogas Production - the Effect of Differences in Transport Costs of Energy Crops in the Choice of Renewable Resources by Biogas Plants). *GJAE (German Journal of Agricultural Economics)*, 59, 1-12.
- Simmering, D., Waldhardt, R., & Otte, A. (2013). Erfassung und Analyse der Pflanzenartenvielfalt in der "Normallandschaft" - ein Beispiel aus Mittelhessen



- (Registration and analysis of plant species diversity in the "normal landscape" - an example of middle Hesse). *Berichte der Reinhold-Tüxen-Gesellschaft (RTG)*, 25, 73-94.
- Söderberg, C., & Eckerberg, K. (2013). Rising policy conflicts in Europe over bioenergy and forestry. *Forest Policy and Economics*, 33, 112-119.
- Soepboer, W., & Lotter, A. F. (2009). Estimating past vegetation openness using pollen-vegetation relationships: A modelling approach. *Review of Palaeobotany and Palynology*, 153, 102-107.
- StatSoft. Inc. (2011). STATISTICA for Windows. Version 10.0. Tulsa, OK, USA.
- StatSoft. Inc. (2014). STATISTICA for Windows. Version 12.0. Tulsa, OK, USA.
- Stoate, C., Baldi, A., Beja, P., Boatman, N. D., Herzon, I., von Doorn, A., . . . Ramwell, C. (2009). Ecological impacts of early 21st century agricultural change in Europe - A review. *Journal of Environmental Management*, 91(1), 22-46.
- Stoate, C., Boatman, N. D., Borralho, R. J., Rio Carvalho, C., de Snoo, G. R., & Eden, P. (2001). Ecological impacts of arable intensification in Europe. *Journal of Environmental Management*, 63, 337-365.
- Strijker, D. (2005). Marginal lands in Europe - causes of decline. *Basic and Applied Ecology*, 6, 99-106.
- Svenning, J.-C. (2002). A review of natural vegetation openness in north-western Europe. *Biological Conservation*, 104, 133-148.
- Svoboda, N., Taube, F., Kluß, C., Wienforth, B., Kage, H., Ohl, S., . . . Herrmann, A. (2013). Crop production for biogas and water protection - A trade-off? *Agriculture, Ecosystems and Environment*, 177, 36-47.
- Tilman, D., Cassman, K. G., Matsons, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, 418, 671-677.
- Tóth, K., & Kucas, A. (2016). Spatial information in European agricultural data management. Requirements and interoperability supported by a domain model. *Land Use Policy*, 57, 64-79.
- Trubins, R. (2013). Land-use change in southern Sweden: Before and after decoupling. *Land Use Policy*, 33, 161-169.
- Uthes, S., Piorr, A., Zander, P., Bienkowski, J., Ungaro, F., Dalgaard, T., . . . Müller, K. (2011). Regional impacts of abolishing direct payments: An integrated analysis in four European regions. *Agricultural Systems*, 104, 110-121.
- Valbuena, D., Verburg, P. H., Veldkamp, A., Bregt, A. K., & Ligtenberg, A. (2010). Effects of farmers' decisions on the landscape structure of a Dutch rural region: An agent-based approach. *Landscape and Urban Planning*, 97, 98-110.
- Van Eetvelde, V., & Antrop, M. (2004). Analyzing structural and functional changes of traditional landscapes - two examples from Southern France. *Landscape and Urban Planning*, 67, 79-95.
- van Vliet, J., de Groot, H. L. F., Rietveld, P., & Verburg, P. H. (2015). Manifestations and underlying drivers of agricultural land use change in Europe. *Landscape and Urban Planning*, 133, 24-36.
- Waldhardt, R., & Otte, A. (2003). Indicators of plant species and community diversity in grasslands. *Agriculture, Ecosystems and Environment*, 98, 339-351.
- Waldhardt, R., Simmering, D., & Albrecht, H. (2003). Floristic diversity at the habitat scale in agricultural landscapes of Central Europe - summary, conclusions and perspectives. *Agriculture, Ecosystems and Environment*, 98, 79-85.
- Waldhardt, R., Simmering, D., & Otte, A. (2004). Estimation and prediction of plant species richness in a mosaic landscape. *Landscape Ecology*, 19, 211-226.
- Wellstein, C., Otte, A., & Waldhardt, R. (2007). Impact of site and management on the diversity of central European mesic grassland. *Agriculture, Ecosystems and Environment*, 122, 203-210.

- Wiehe, J., von Ruschkowski, E., Rode, M., Kanning, H., & von Haaren, C. (2009). Auswirkungen des Energiepflanzenanbaus auf die Landschaft (Impacts of cultivation of bioenergy crops on landscape). *Naturschutz und Landschaftsplanung*, 41(4), 107-113.
- Wilson, J. B., Peet, R. K., Dengler, J., & Pärtel, M. (2012). Plant species richness: the world records. *Journal of Vegetation Science*, 23, 796-802.
- Wu, J. (2013). Landscape sustainability science: ecosystem services and human well-being in changing landscapes. *Landscape Ecology*, 28, 999-1023. doi: 10.1007/s10980-013-9894-9

## Chapter 2

### **Analysing data of the Integrated Administration and Control System (IACS) to detect patterns of agricultural land-use change at municipality level**

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*Over the last decades, agricultural land use in Europe has changed significantly and is likely to experience ongoing changes in the future. Since land use affect ecosystem functioning, natural resources, biodiversity and others, a thorough understanding of land use and its dynamics is needed. Analysing land use has been a prominent research topic in landscape ecology, but studies of the regional or even sub-regional pattern of agricultural land use are scarce. Thus, the aim of the present chapter was to analyse the (sub)regionally differing spatial and temporal patterns of agricultural land use and land-use change. The research was conducted by the example of Hesse, Germany.*

## **Abstract**

European landscapes have featured considerable changes towards intensification and marginalisation. These major trends are expected to continue in the future. Besides, the cultivation of bioenergy crops has become an important factor in agricultural land use. A thorough understanding of land-use processes for management purposes is needed. In this study, the spatial and temporal pattern of agricultural land use and land-use change was classified at the scale of municipalities from 2005 to 2010. The study region was the German federal state Hesse. By using data of the Integrated Administration and Control System (IACS) of the European Union and with the help of k-means cluster analysis, five types of agricultural land-use patterns and dynamics (TLPDs) were detected. These TLPDs represent different sub-regions. Sub-regions with favourable physical conditions for cultivation are dominated by arable land. A progressive land-use change occurred by conversion of grassland to arable land. In sub-regions, where physical conditions are rather unfavourable, especially in mountainous areas, grassland is the predominant land use. But on the remaining arable land, there is a slight change in favour of maize. The knowledge of sub-regions with spatially and temporally different agricultural land use could be utilised to develop land management instruments like site-specific agri-environmental schemes.

### **Keywords:**

land-use data set, classification, cluster analysis, identification of sub-regions, agri-environmental schemes, Germany

## 1 Introduction

Land use is a central component of the landscape that surrounds us. Changes in land use and land cover are influenced by both human activities and several natural ecological processes, and vary across space and time (Petit & Lambin 2002; Verburg et al. 2010). *Land cover* refers to biophysical attributes (either of natural or anthropogenic origin) of the earth's surface and immediate subsurface. *Land use* refers to human activities that exploit the land cover with the purpose of producing goods and services (Lambin et al. 2000; de Chazal & Rounsevell 2009).

This paper focusses on agricultural land use. Many studies have analysed the dynamics of agricultural land use since it became evident that these dynamics affect the environment (Bürgi et al. 2004), ecosystem functioning, and natural resources like water and soil quality, habitat quality, species richness, biodiversity, and others (Vagstad & Oygarden 2003; Rounsevell et al. 2006; Xiao et al. 2006).

In the last several decades, in Europe two opposing trends can be identified in agricultural land use: intensification and marginalisation (Stoate et al. 2009). Agricultural intensification, characterised by both a comparatively higher output of cultivated products per unit area and time, and a higher level of inputs like agrochemicals (Lambin et al. 2001), has been driven by market demands and agricultural policies with the aim of an increased production and efficiency. Hence, intensive land use is connected to landscapes with rather favourable site conditions for arable cultivation like relatively flat and fertile land. The intensification processes in these regions have caused enlarged field sizes, a removal of boundary vegetation as well as a less diversified crop rotation (Fjellstad & Dramstad 1999). In contrast, landscapes affected by marginalisation are characterised by steep slopes, shallow and/or poor soils and an inferior accessibility. Thus, the process of marginalisation can be found especially in mountain regions (MacDonald et al. 2000). Marginal agricultural landscapes are often characterised by an increased biodiversity and habitat richness due to low intensities of cultivation, crop and grassland rotation, small-parcelled mosaics etc. In these landscapes for about six decades, large portions of arable land have been replaced by plantation forestry, rotational fallows and especially by extensive grassland, so that landscape structure has considerably changed (Waldhardt & Otte 2003). Meanwhile, due to increasingly unfavourable economic conditions these landscapes are in danger of undergoing distinct changes by either abandonment or intensification of the remaining agricultural area (Meeus 1995; Harvolk et al. 2013). Thus, management is needed in order to preserve marginal agricultural landscapes (Waldhardt et al. 2004).

Beside these major trends, a competition between different land-use types has developed in Europe in recent years (Rounsevell et al. 2006). Due to increased commodity prices, especially in the years 2007 and 2008, and a growing demand for land to produce bioenergy crops, the

pressure on limited land resources has increased. One result of these modified conditions was the abolition of the compulsory set-aside fields in the European Union (EU) in the year 2008. In Germany, it is the Renewable Energy Act (German: Erneuerbare-Energien-Gesetz – EEG) which regulates the paying of high incentives for energy production from biomass (Lupp et al. 2014). In 2013, bioenergy crops were cultivated on 2.1 million ha which represented 12.6% of the total agricultural land in Germany (FNR 2014). One of the dominant bioenergy crops was maize (*Zea mays*) which was cultivated for biogas production on ca. 800,000 million ha in 2013 (FNR 2013). Often it is claimed, that the cultivation of bioenergy maize might have negative impacts like reduced landscape aesthetics, increasing soil erosion and decreasing biodiversity. These effects are particularly relevant if permanent grassland is converted to bioenergy maize fields since permanent grassland is important for manifold ecological functions and processes (Lupp et al. 2014). Although the proportion of bioenergy crops differs significantly by region, it was reported in several studies that in recent years the cultivation of bioenergy crops generated an increasing pressure on natural resources. However, as a consequence of European and national energy policies, it is expected that the proportion of bioenergy crops will continue to increase in the coming years (Kovacs-Hostyanszki & Baldi 2012; Nitsch et al. 2012; Lupp et al. 2014).

Finally, since the second half of the twentieth century, agricultural land use in Europe has undergone major changes due to technological advances, urban expansion, market conditions, globalisation, enlargement of the EU and the Common Agricultural Policy (CAP). Given this background, European land use is likely to experience ongoing changes in the future (Rounsevell et al. 2003; Keenleyside et al. 2009; Sanderson et al. 2013). Hence, a thorough understanding of past and recent land-use processes is essential in order to understand how agricultural land use might develop in the future.

The EU is well aware of the impact of the CAP on agricultural land use. By supporting the agricultural sector mainly through transfer payments, the CAP is a strong determining factor (Heißenhuber & Krämer 2011). Transfer payments are divided into direct support payments which all farmers receive per ha of farmland, i.e. an area payment, and agri-environmental payments which are offered if farmers voluntarily obligate themselves to comply with an ecologically beneficial cultivation and/or animal husbandry (Reger et al. 2009b). By giving these payments, farmers can be influenced in their management decisions. Thus, the CAP is an important driver of changes in agricultural land use (Strijker 2005). For specific background to the CAP see for example Erjavec & Erjavec (2015) and Gomez y Paloma et al. (2013). As well as income and risk coverage of the EU's farmers, another important aim of the CAP is to consider environmental issues. In this context, direct support payments are coupled to environmental and further standards what means that farmers only get the payments in full if they comply with these standards. One of the environmental aims of the CAP is the protection of permanent grassland. In the past, EU member states had to ensure that the conversion of permanent grassland must not exceed a 10% threshold, i.e. the ratio of permanent grassland in relation to the total agricultural area must not decrease by more than 10% referred to the

year 2003 (according to Regulation (EC) No 796/2004). But most of the member states applied stricter rules. However, with the latest reform of the CAP, the 10%-requirement for reduction in permanent grassland was tightened. Since 2015, the ratio of permanent grassland in relation to the total agricultural area must not be reduced by more than 5%, but referred to the year 2012 (according to Regulation (EU) No 1307/2013) rather than 2003. Member states of the EU had, and still have, to monitor this requirement. Usually, the spatial basis is at the national level. In Germany, the monitoring of permanent grassland is performed at the level of the federal states which reflects the regional level within the EU (Nitsch et al. 2012). Furthermore, the federal states are also the spatial unit for offering different agri-environmental schemes. But this spatial level may hide differences of land-use patterns within the federal states, i.e. at sub-regional level.

In this context, classification of agricultural land use could serve as a useful method because classification systems allow to detect how land use changed, where land-use changes occurred and to assume future changes (Jansen & di Gregorio 2002). Hence, classification systems are a spatial and temporal reference system and can be used as a monitoring, modelling and planning tool (Schröder et al. 2007; Pesch et al. 2011). Analysing and classifying land use has been a prominent research topic in landscape ecology, but studies describing the regional pattern of agricultural land use, and how this pattern differs within sub-regions, are rare (Mendoza et al. 2011; Pinter & Kirner 2014), but see Rounsevell et al. (2003), Gellrich & Zimmermann (2007). Large-scale drivers of land-use change, like policies and market conditions, are spread at a national or even continental scale. However, their effects are known to vary at lower spatial levels because of different physical site characteristics, like climate, topography, soils, socio-economic and structural conditions, etc. Consequently, the patterns of agricultural land use are (sub-)regionally different (Gallant et al. 2004; Rounsevell et al. 2005; Uthes et al. 2011; Bieling et al. 2013). Thus, methods are needed that incorporate the spatial level of sub-regions into classification systems (Stoate et al. 2009; Mendoza et al. 2011).

A classification of agricultural land use requires data which provide solidly quantitative and spatially differentiated information. However, the collection and the analysis of data should not be time and cost consuming (Jansen & di Gregorio 2002). In the EU, member states have to ensure that direct support payments are carried out accurately, that controls are implemented, and that amounts unduly paid are recovered. Fulfilling these purposes, the Integrated Administration and Control System (IACS) was implemented by regional authorities (EC 2013). Since 2004, in order to achieve direct support payments, farmers have had to register all agricultural parcels of land and the cultivated crops every year. As a result, IACS data provide information on land use at the field level on an annual basis as well as information on field size, farm type, legal structure, livestock etc. Thus, IACS data provide a promising data set for analysing agricultural land use and land-use change. However, until now studies using IACS data are scarce, but see Nitsch et al.(2012), Harvolk et al. (2013), de

Longueville et al. (2007), Trubins (2013), who analysed land use and land-use change processes down to field level or used the IACS parcel plan for their studies.

In this study, we developed a classification method to detect spatial and temporal differences of patterns of agricultural land use at sub-regional level which is based on a solid quantitative data source. Further, we were interested to answer the following questions: Which types of land-use patterns could be identified in the study region? Which areas experienced major, minor or no changes of agricultural land use in recent years? Which areas are probably sensitive to future land-use changes and in what manner? The study region was Hesse, one of the federal states in Germany. Hesse was chosen due to its various biogeographical regions comprising both marginal and intensively used agricultural landscapes. By using data of the Integrated Administration and Control System (IACS), we collected information on agricultural land use for the years from 2005 to 2010 and analysed the data at the municipality level (which is the LAU level 2, i.e. the lower level of the officially defined Local Administrative Units within the EU).

Building upon Reger et al. (2007), who studied past land-use change, the aims of the study were:

- (i) to identify ‘types of agricultural land-use patterns and dynamics (TLPDs)’ at the scale of municipalities for the time period 2005 to 2010, and
- (ii) to characterise the identified types by using physical landscape attributes (elevation, slope, temperature and precipitation) and the intensity of livestock farming (expressed by livestock data, i.e. cattle and pig numbers, and a livestock density index).

## **2 Study region**

The German federal state Hesse (Figure 1) is located in central Germany and comprises 430 municipalities. Hesse covers 21,115 km<sup>2</sup>, the maximum north-south extent amounts to 250 km and the maximum east-west extent to 170 km (HSL 2012).

In Hesse, there is a variety of different landscapes (Pletsch 1989). Hesse is part of the central German mountain threshold which is characterised by a spatial alternation of valleys (<300 m a.s.l., planar to colline altitude level) and mountain ranges (>300 m a.s.l., submontane to montane altitude level). This large-scale pattern stretches in a more or less north-south direction. The highest point lies in the eastern low mountain range, called Rhön (950 m a.s.l.). The valleys of the rivers Rhine and Main in the south are the lowest points (<100-200 m a.s.l.) (Jungmann & Brückner 2005).

The four main biogeographical regions are (i) Rhenish Slate Mountains (Rheinisches Schiefergebirge), (ii) West Hessian Highlands and West Hessian Depression (Westhessisches



Bergland und Westhessische Senke), (iii) East Hessian Highlands and East Hessian Depression (Osthessisches Bergland und Osthessische Senke) and (iv) South Hessian Valleys and Elevations (Südthessische Becken- und Gebirgsländer) (Meynen & Schmithüsen 1953-1962; Klausning 1988; Pletsch 1989).

Soil communities are various. In the highlands, they vary between brown soils and ranker, and tend to podsol soil communities upon a quartz-rich rock. In the lowlands, which are dominated by loess, the soil communities are usually base-poor brown soils, belt brown soils and pararendzina soils. On calcareous windborne sands luvisols and black earth soils are prevailing (Sabel 2005).

Hesse lies in the zone of the warm temperate, rainy climate of the middle latitudes. But the regional climate is characterised by a variety of different climate conditions which can be explained by the orographic heterogeneity (Pletsch 1989). The lowlands are notably warm (mean annual temperature: 9-10 °C), for example in the Rhine-Main area. In contrast, the highlands are notably cold (mean annual temperature: 5 °C). The mean annual precipitation (1971-2000) varies between 500 mm in the south-west of Hesse and 1,200-1,300 mm in the north-western highlands (Mollenhauer 2005).

Land use in Hesse is presented in Table 1. For reason of comparison, land use of Germany as a whole is shown, too. In Hesse, agricultural land use varies between the different landscapes. For example, in the Rhine-Main lowlands land use is characterised by intensive arable farming due to favourable physical conditions like humous soils and the warm climate. Here, the dominant crops are vegetables and sugar beets. Field irrigation is often applied. In some cases, where soils are sandy and nutrient-poor, extensive forest areas appear and asparagus is grown. In the fertile loess areas, mostly wheat, sugar beets, rape seed and barley are grown, in some cases also vines and fruits. In the low mountain ranges and hilly landscapes, there is a mixture between agriculture, forestry and grassland which is dependent on soil quality, relief and climate. Thus, land use is less intensive. Many of these regions belong to the less favoured areas (Harrach 2005).

**Table 1**

Land use in Hesse (HMUELV 2011; HSL 2012) and Germany (DBV 2010; 2012) in 2010

	Land use			Proportion of utilised agricultural land	
	<i>Agriculture (%)</i>	<i>Forestry (%)</i>	<i>Settlement and traffic (%)</i>	<i>Arable land (%)</i>	<i>Grassland (%)</i>
<b>Hesse</b>	42	40	16	62	37
<b>Germany</b>	52	30	14	71	29

In Hesse livestock farming is an important component of agriculture. Nevertheless, pig and cattle stocks are decreasing. In 2010, total livestock comprised 469,750 livestock units (LU), on

an average 0.6 LU per ha utilised agricultural land (in Germany: 1.1 LU/ha on average). Livestock farming is concentrated in the north and the east of Hesse (HMUELV 2011).

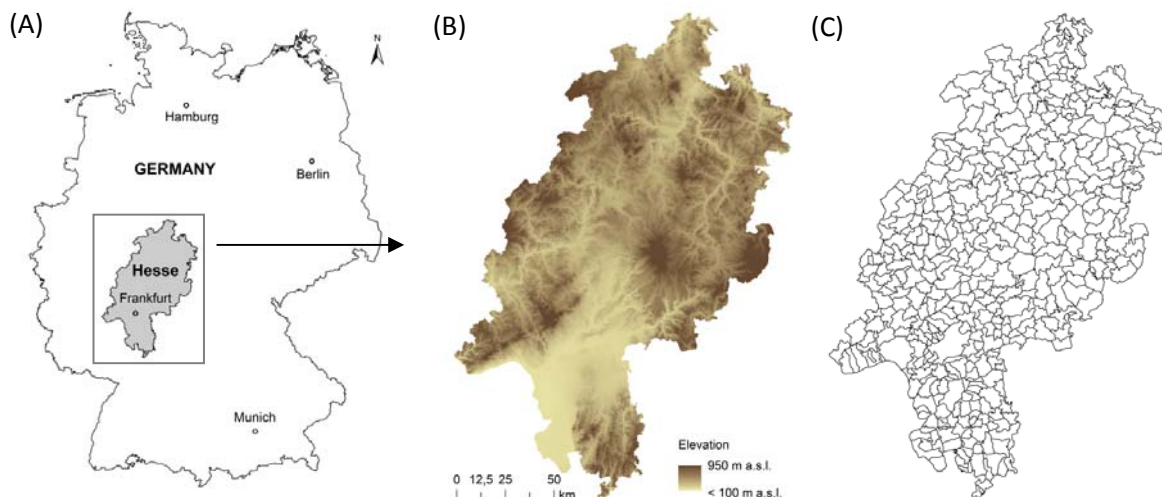
Table 2 shows the structure of the Hessian and, for reasons of comparison, of the German farms. Traditionally, Hesse has been the land of a rather small-scale agriculture, especially in the middle and in the south. Currently, the number of farms is still decreasing and their land is absorbed by the growing farms. Thus, the average farm size increased from 26 to 43 ha between 1999 and 2010 (HMUELV 2011).

**Table 2**

Farm structure in Hesse (HMUELV 2011; HSL 2012) and Germany (DBV 2012) in 2010

	Proportion of farms		Farm size (ha)		
	<i>Full-time farms (%)</i>	<i>Part-time farms (%)</i>	<i>Average (ha)</i>	<i>Full-time farms (ha)</i>	<i>Part-time farms (ha)</i>
<b>Hesse</b>	32	68	43	74	24
<b>Germany</b>	50	50	56	62	20

Owing to relief, climate and soil conditions, the study region Hesse is characterised by a steep gradient of potential agricultural land use comprising marginal agricultural landscapes of the highlands, intensively used agricultural landscapes of the lowlands and a mixture of them. Thus, characterised by areas favourable as well as unfavourable for agricultural use, Hesse is most suitable for analysing types of land use differing in the spatial and temporal pattern.



**Figure 1.** Study area: (A) Hesse in Germany, (B) topography (elevation between <100 and 950 m a.s.l.) (Jungmann & Brückner 2005), (C) 430 municipalities (HSL 2012)

### 3 Methods

#### *3.1 Data set of the Integrated Administration and Control System (IACS)*

The main data used for the analyses were digital polygonal layers of land use at the field level as provided by the Integrated Administration and Control System (IACS). We used IACS data of Hesse for the years from 2005 to 2010, made available for this study by the Hessian Agency for Environment and Geology (HLUG undated). Generally, IACS data are not freely available.

The IACS data set for the Hessian state contained one GIS polygon layer for each year that featured all registered agricultural fields and their land use in the respective year. This layer was intersected with the boundaries of the 430 municipalities, the spatial basis of the study. The boundaries of the Hessian municipalities were provided by the German Federal Office for Cartography and Geodesy (BKG 2011). Land use was grouped according to the land-use classes of the IACS data set: arable land, permanent grassland, permanent crops and non-agricultural area. The sum of the areas of these four land-use classes represents the total utilised agricultural land in each of the municipalities. However, the total area of utilised agricultural land of the municipalities differed considerably between the years 2005 to 2010 irrespective of the area of the municipality. A preceding analysis of the data had revealed this fact, i.e. we identified for each municipality the maximum and the minimum areas of utilised agricultural land which was registered in any one of the years between 2005 and 2010. Then, we calculated the ratio of the difference between the maximum and the minimum area of utilised agricultural land in relation to the maximum agricultural land for each municipality. On average, this ratio was 4.9%. The reason for this variability is that farmers are not obliged to declare their fields for direct support payments, although these fields are still cultivated. If farmers decide not to declare, the fields will not be included in IACS data. As a consequence for the analysis, in order to get a consistent reference value, we decided to take the maximum area of agricultural land and of arable land for each municipality. These maximum areas were assumed as the available areas of utilised agricultural or arable land in the respective municipality.

Since we intended to classify the municipalities according to the patterns of agricultural land use and land-use change, we chose the following four variables (Table 3) based on the IACS data set and calculated them for all 430 municipalities. The aim was to consider variables of agricultural land use which reflect the recent and actual pattern as well as the most important dynamics of recent years. The first variable is calculated as (i) proportion of grassland in 2005 expressed as the percentage (%) of the (maximum) utilised agricultural land. This variable comprises the area of permanent grassland as defined in the IACS data, i.e. the sum of meadows, pasture land, 20-years land set-aside etc. The second and the third variable consider the cultivation of maize. Maize proved to be one of the crops with a strong increase in cultivation in recent years in Hesse. Thus, this crop was chosen to express second variable is

calculated as (ii) proportion of maize area in 2010 expressed as the percentage (%) of the (maximum) arable land. This variable comprises the sum of the area for grain-maize, corn-cob-mix, sweetcorn and silage maize. In this context, we did not know whether maize is used for bioenergy production or not, since IACS data do not provide this information. The third variable is calculated as (iii) expansion of maize area quantified as the average annual expansion rate as the percentage (%) for the proportion of maize area in the time period 2005 to 2010. The latter variable was quantified using the geometric mean, a quantity which calculates the average annual growth rates distributed equally to the respective years (Zeidler 2013), so that the different growth rates of the municipalities are suitable for comparison. Finally, the last variable considers conversion of grassland to arable land. Here, we calculated (iv) the conversion of grassland into arable land between 2005 and 2010 expressed as the percentage (%) of grassland area in 2005. As the protection of grassland against conversion into arable land or other agricultural uses, against loss or decline of its ecological functions is of high importance with respect to several environmental objectives, we included this variable in the study. We considered only the conversion of grassland into arable land, since this direction of conversion seems to be the most dominant (Nitsch et al. 2012).

In order to ensure that these four variables of agricultural land use are not interdependent, i.e. they do not correlate, correlation coefficients among the variables were calculated. The coefficients did not show any relationship between the variables (correlation coefficients between -0.1 and 0.2). Thus, we concluded that the variables are suitable for the analysis.

The analyses of IACS data were conducted using the Geographical Information System ArcGIS 10 (ESRI 2010).

**Table 3**

Variables of agricultural land use used for k-means cluster analysis to detect types of agricultural land-use patterns and dynamics (TLPDs)

Variable	Description	Aim
Grassland area, 2005 (% of util. agr. land)	Proportion of grassland in 2005 as percentage of utilised agricultural land *	Description of status of land use at the beginning of the investigation time
Maize area, 2010 (% of arable land)	Proportion of maize area in 2010 as percentage of arable land **	Description of status of land use at the end of the investigation time
Expansion of maize area, 2005-2010 (%)	Average annual expansion rate as percentage for the proportion of maize area in the time period 2005-2010	Rating of land-use change for the entire time period of investigation
Conversion of grassland 2005 to arable land 2010 (% of grassland 2005)	Grassland converted into arable land between 2005 and 2010, as percentage of grassland area in 2005	Rating of land-use change for the entire time period of investigation

\* Relating to the maximum area of utilised agricultural land from 2005-2010.

\*\* Relating to the maximum area of arable land from 2005-2010; see text for details.

### *3.2 Physical livestock attributes and livestock numbers*

Physical landscape attributes are known to be relevant determinants for agricultural land use and they correlate with land-use change processes (Pan et al. 1999; Schneider & Pontius 2001; Hietel et al. 2004). Hence, we selected four variables to describe the main environmental drivers for agricultural production: (i) elevation, (ii) slope, (iii) temperature, (iv) precipitation. For each municipality, the means of these variables were calculated.

Information on elevation and slope were derived from a digital elevation model (DEM, 25 m resolution), provided by the Hessian State Office for Land Management and Geoinformation (HVBG undated). The underlying raster data set of the DEM was used as the basis to calculate mean elevation (metre a.s.l.) and mean slope (°) within each municipality. Information on climate, with the variables temperature and precipitation, were made available in a 1 km<sup>2</sup>-resolution by the German Weather Service (DWD 2013). For each municipality, we calculated the mean annual temperature (°C) and the mean annual precipitation (mm), both for the time period from 1981-2010.

The processing of physical landscape data was performed also with ArcGIS 10 using the Spatial Analyst tool (ESRI 2010).

To characterise the municipalities regarding the agricultural structure, we quantified livestock numbers. Livestock is known to be relevant for land use because of the fodder needs. Since the degree of self-sufficiency for fodder is very high (in 2010/2011: 89% for fodder corn in Germany), cultivation of fodder is an important part of land use (DBV 2012). Thus, changes in livestock are one reason of land-use changes (Hietel et al. 2007). Livestock data were collected using the Hessian agricultural statistics which is a data set providing detailed information on agriculture. In 2010, the agricultural structure survey (German: Agrarstrukturerhebung) was implemented, thus giving comprehensive and detailed information on agricultural land use. Based on the Hessian agricultural statistics (HSL 2012), for the year 2010 we got information on (i) the number of cattle, (ii) the number of pigs, and (iii) the livestock density index expressed as livestock unit per ha utilised agricultural land (LU/ha) (EC 2011). For reasons of data protection, the data were not available for all of the 430 municipalities. According to agricultural statistics, information on livestock is missing in the case if information could be assigned clearly to a single farm. Concerning the number of cattle, we got information for 384 municipalities, concerning pigs for 326 municipalities and concerning livestock density for 396 municipalities. Nevertheless, we used these data for the analysis. Since the missing data points on livestock are scattered all over Hesse, the data are still representative for the study area.

### 3.3 Statistical analysis

In this study, we performed a k-means cluster analysis, since we aimed to identify types of agricultural land-use patterns and dynamics (TLPDs). As a method of multivariate data analysis, cluster analysis proved to be a suitable method for analysing land-use change, see for example Mendoza et al. (2011), Potashev et al. (2014), Reger et al. (2007) and Stuczynski et al. (2003). The k-means cluster algorithm is a partitioning method (MacQueen 1967). It aims to identify groups or clusters in relatively unknown data sets whereupon the variability between the clusters is maximised and the variability within the clusters is minimised (Hartigan & Wong 1979). Thus, the homogeneity within the clusters allows to characterise these clusters, whereas the heterogeneity between the clusters causes a sharp partitioning (Hartigan 1975).

K-means cluster analysis was performed for the four selected variables of agricultural land use (see Table 3). The statistical process was to allocate the municipalities and accordingly the included variables to different clusters. For each cluster the centroids were defined, i.e. the arithmetic means for the four variables across the clusters were calculated. The k-means algorithm is based on minimising the sum of squared deviations to the centroids. As a result the centroids are as different from each other as possible. For reasons of comparison, we tried also to consider more variables of agricultural land use. For example, the variables proportion of maize area in 2005 and proportion of grassland in 2010 were added. But k-means cluster analysis did not show useful results. Therefore, we chose the four variables as presented before.

In order to find the ‘best’ number of clusters, v-fold cross validation was performed (Janisová et al. 2014; Flanagan & Cerrato 2015; Gumienna et al. 2016). The benefit of v-fold cross validation is that the number of clusters will be determined from the data and must not be known a priori which means prior knowledge about the number of clusters is not essential. V-fold cross validation is an algorithm of repeated calculation. The purpose of this process is to divide the overall sample into a number of v folds (here: 10) which are subgroups (Hastie et al. 2009). One subgroup will be excluded in order to serve as a testing sample. Subsequently, the allocation of the samples to generate clusters will be performed without the testing sample. After the clusters are generated and the samples are allocated, the testing sample is also allocated to these clusters. In this test sample, an error rate will be calculated. The process is repeated according to the number of subgroups. With each repetition another subgroup is excluded and another error rate is determined. The number of clusters with the lowest error rate will be taken as final result.

Hence, in the analysis every cluster contains municipalities with similar characteristics, but well-contrasted to the others. Thus, the derived clusters represent the types of agricultural land-use patterns and dynamics (TLPDs) in Hesse.

In the study, both physical landscape attributes (elevation, slope, temperature, precipitation) and livestock numbers (number of cattle and pigs, livestock density) were considered to check the derived clusters for plausibility. We conducted the non-parametric Kruskal-Wallis one-way ANOVA (analysis of variance) by ranks which is a powerful statistical method for non-normal distributed data. The aim of ANOVA was to test for statistically significant differences between the derived TLPDs by using physical landscape attributes and livestock data. In case of significance, a Median-test for multiple testing ( $p < 0.05$ ) followed.

For all analyses we used Statistica 10.0 software (StatSoft. Inc. 2011).

Figure 2 illustrates the work flow of the applied methodology.

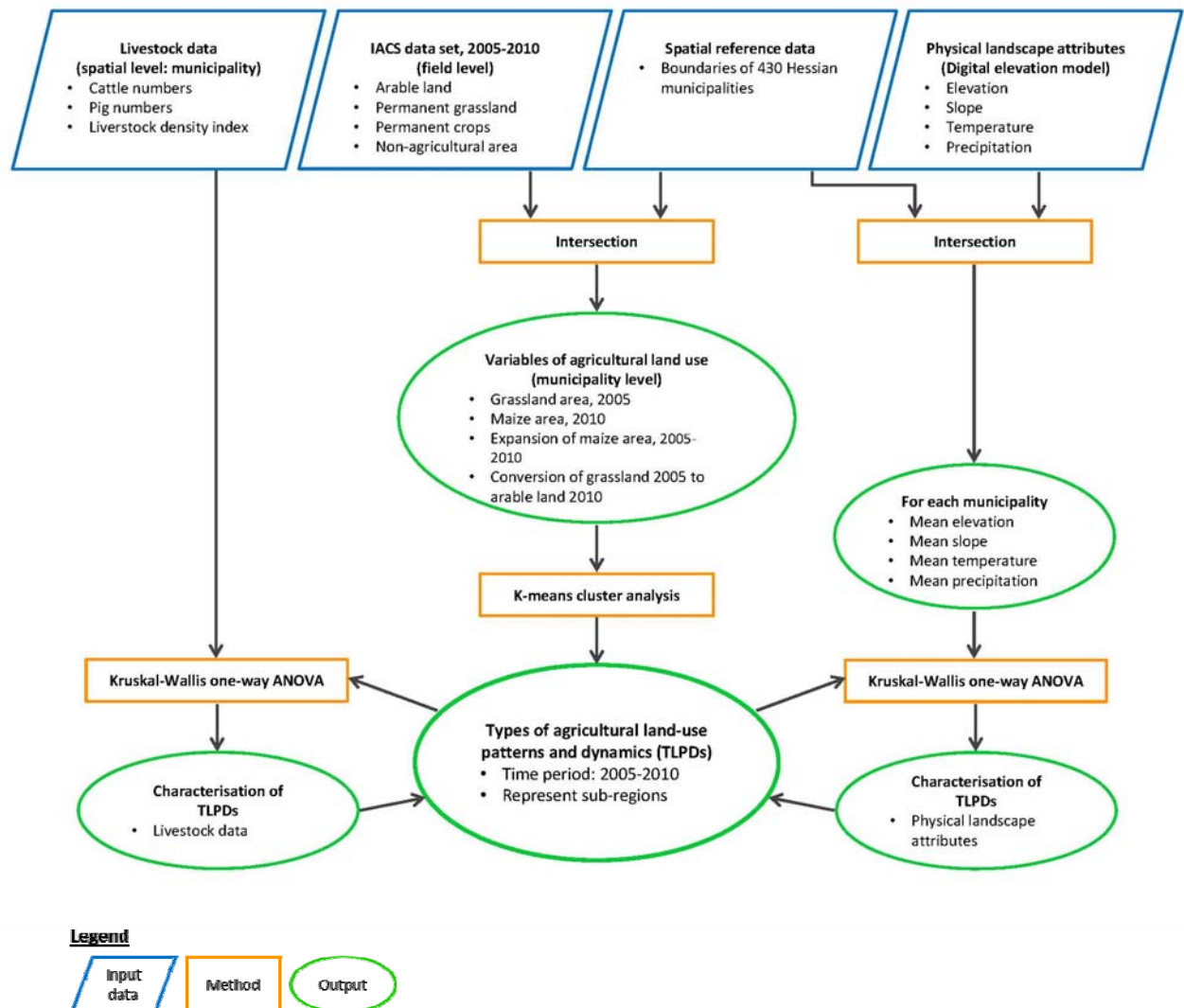


Figure 2. Work flow of the applied methodology

## 4 Results

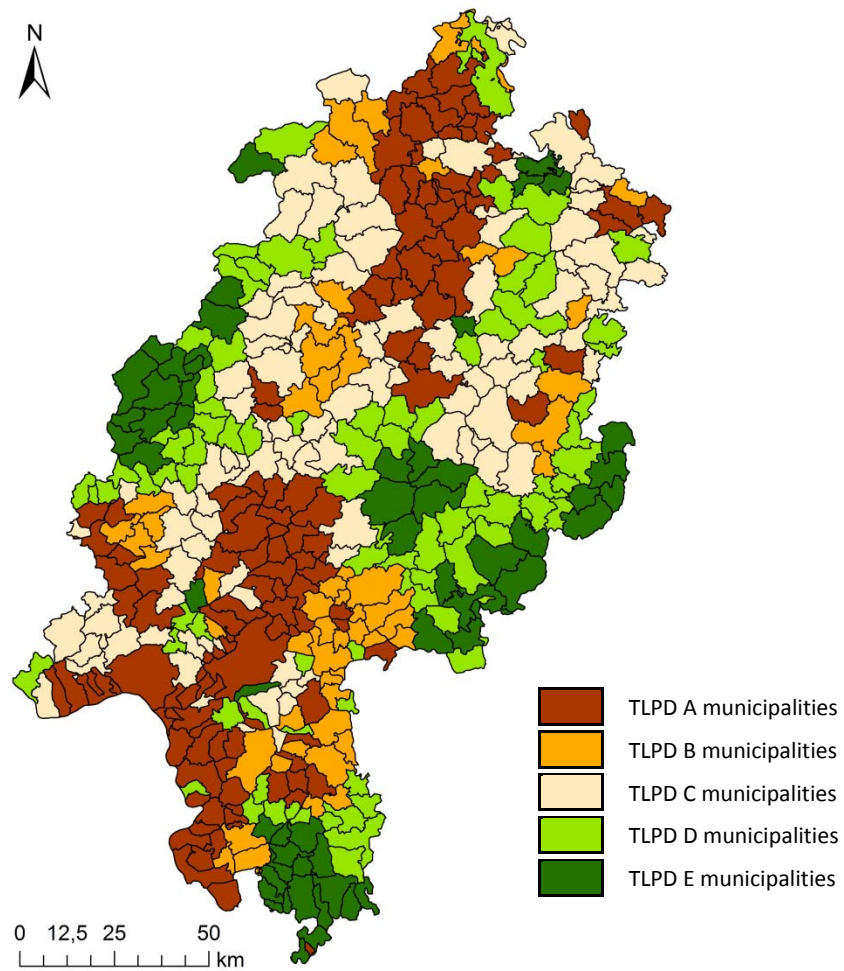
### *4.1 Types of agricultural land-use patterns and dynamics*

The k-means cluster analysis detected five different types of agricultural land-use patterns and dynamics (TLPD A-E, Table 4). They represent the different spatial and temporal patterns of land use and land-use change between the years 2005 to 2010 at the level of municipalities, i.e. at the sub-regional level. For a description of the main characteristics of the types A-E see Table 4, and Figure 3 for their spatial distribution.

TLPD A, the arable land type, ranges from north to south and lies mostly in the centre of Hesse, and thus, represents the lowlands of the Hessian landscape (cf. Figure 1B). Consequently, the proportion of grassland in 2005 was low (14.2%). The proportion of maize area in 2010 was low (6.0%) as well. TLPD A municipalities are characterised by a progressive land-use change in favour of maize to the disadvantage of grassland which means a conversion of grassland. In TLPD B, the maize type, the proportion of maize in 2010 as well as the average annual expansion rate for maize between 2005 and 2010 were the highest of all TLPDs. The latter indicates that TLPD B experienced a distinctive land-use change between 2005 and 2010. The municipalities grouped in TLPD B are scattered throughout the entire study region, but do not occur in the highlands. In contrast, TLPD C, which is the intermediate type, is characterised by a low proportion of maize area (5.0%) and a low average annual expansion rate for maize (1.9%). But the conversion of grassland to arable was the second highest of all clusters (2.8% from 2005 to 2010). TLPD D and E, the grassland and the grassland-maize type, are both dominated by grassland because of their location in the Hessian highlands. The proportion of grassland is traditionally high to very high. These types featured only a slight land-use change regarding grassland loss and maize expansion. However, they differ with respect to the proportion of maize cultivated on the limited arable land.

Despite these agricultural land-use patterns and dynamics at municipality level, we also detected land-use change processes for the entire study area. According to IACS data, in Hesse the proportion of grassland was intermediate (37.0%) in the year 2005 and remained almost stable with 36.5% in the year 2010. The conversion rate of grassland to arable land was 2.3% for the study period. On arable land, in the year 2005 6.5% were covered by maize. The average annual expansion rate for maize was 7.2% from 2005 to 2010 which resulted in an intermediate proportion of maize area (9.2%) in the year 2010.





**Figure 3.** Spatial distribution of types of agricultural land-use patterns and dynamics (TLPD A-E) in the study region Hesse, Germany; see text and Table 4 for details

**Table 4**

Types of agricultural land-use patterns and dynamics (TLPD A-E) characterised by four land-use variables based on IACS data. Results of the k-means cluster analysis are means (with standard deviation). For reasons of comparison, land-use variables of Hesse as a whole are indicated in the last row.

TLPD	Grassland area, 2005 (% of util. agr. land)	Maize area, 2010 (% of arable land)	Expansion of maize area, 2005-2010 (%)	Conversion of grassland 2005 to arable land 2010 (% of grassland 2005)	Description	Area of municipalities (km <sup>2</sup> )	Proportion of Hesse (%)	<i>n</i>
Means								
<b>A</b>	14.2 (± 5.8)	6.0 (± 4.0)	6.9 (± 14.4)	3.2 (± 6.0)	<u>Arable land type</u> : low proportion of grassland and low proportion of maize area, progressive land-use change in favour of maize area and to the disadvantage of grassland	5,465	25.9	127
<b>B</b>	29.6 (± 7.9)	18.7 (± 6.0)	12.1 (± 17.5)	2.2 (± 1.9)	<u>Maize type</u> : intermediate proportion of grassland and high proportion of maize area, strongly progressive land-use change in favour of maize area and to the disadvantage of grassland	2,695	12.8	57
<b>C</b>	34.8 (± 5.8)	5.0 (± 3.6)	1.9 (± 15.7)	2.8 (± 2.1)	<u>Intermediate type</u> : intermediate proportion of grassland and low proportion of maize area, slight land-use change in favour of maize area and to the disadvantage of grassland	5,739	27.2	104
<b>D</b>	55.1 (± 6.7)	10.6 (± 7.3)	5.3 (± 12.8)	1.7 (± 1.4)	<u>Grassland type</u> : high proportion of grassland and intermediate proportion of maize area, progressive land-use change in favour of maize area and to the slight disadvantage of grassland	4,220	20.0	85
<b>E</b>	80.2 (± 8.7)	14.6 (± 14.8)	3.0 (± 9.3)	0.8 (± 1.3)	<u>Grassland-maize type</u> : very high proportion of grassland and high proportion of maize area, slight land-use change in favour of maize area and to the very slight disadvantage of grassland	2,999	14.2	57
Percentages for the total area								
<b>Hesse</b>	37.0	9.2	7.2	2.3		21,118	100	430

*n* = number of municipalities.

## 4.2 Characterisation of types of agricultural land-use patterns and dynamics

The five identified TLPDs reveal distinct differences regarding the four physical landscape attributes (Table 5), which correspond with the variety of Hessian landscapes.

With low elevations, flat slopes and a mild climate, municipalities of TLPD A and B feature physical conditions which are favourable for agricultural production in both areas. As a result, these municipalities are dominated by arable land (see Table 4). According to ANOVA, they do not differ significantly regarding median elevation, slope and temperature. But median precipitation of TLPD B (742 mm) is significantly higher compared to TLPD A (703 mm). Also, physical landscape attributes of both TLPD C and D do not show significant differences among themselves except precipitation (TLPD C: 764 mm, TLPD D: 852 mm). Here, physical conditions are less favourable than before, i.e. median elevations, slopes and temperature differ significantly compared to TLPD A and B. Finally, the physical conditions of municipalities belonging to TLPD E are relatively unfavourable for cultivation which is mirrored by the very high proportion of grassland (see Table 4). All physical landscape attributes differ significantly compared to the ones of TLPD A-D. Elevations are higher (392 m a.s.l.) and the slopes are of middle steepness (6.9°). TLPD E municipalities are exposed to climatic constraints, not so much due to a median temperature of 8.1° C but due to a median precipitation of 1,017 mm.

**Table 5**

Characterisation of types of agricultural land-use patterns and dynamics (TLPD A-E) by physical landscape attributes, results of the analysis of variance

TLPD	Elevation (m a.s.l.)		Slope (°)		Temperature (°C)		Precipitation (mm)		n
	Median	25-75% percentile	Median	25-75% percentile	Median	25-75% percentile	Median	25-75% percentile	
<b>A</b>	195 <sup>a</sup>	133-237	2.3 <sup>a</sup>	1.0-3.4	9.6 <sup>a</sup>	8.9-10.3	703 <sup>a</sup>	664-744	127
<b>B</b>	188 <sup>a</sup>	143-245	3.4 <sup>a</sup>	2.1-4.4	9.5 <sup>a</sup>	8.8-10.1	742 <sup>b</sup>	723-810	57
<b>C</b>	284 <sup>b</sup>	231-324	4.3 <sup>b</sup>	3.3-5.4	8.6 <sup>b</sup>	8.4-9.2	764 <sup>b</sup>	733-807	104
<b>D</b>	311 <sup>b</sup>	246-372	4.7 <sup>b</sup>	3.8-6.1	8.6 <sup>bc</sup>	8.1-9.2	852 <sup>c</sup>	791-912	85
<b>E</b>	392 <sup>c</sup>	332-448	6.9 <sup>c</sup>	5.7-7.9	8.1 <sup>bc</sup>	7.7-9.0	1,017 <sup>d</sup>	970-1,079	57

n = number of municipalities.

Identical letters indicate that differences among the TLPDs are not statistically significant.

In addition to physical landscape attributes, the five TLPDs were also characterised by livestock numbers of the year 2010 (Table 6). Generally, we found a rather low livestock density. Regarding the number of cattle, with 471 altogether only TLPD A municipalities show a difference. Here, the median number of cattle is significantly lower and the lowest of all TLPDs. In contrast, the median number of pigs is the highest one (1,825 altogether). However, with 0.3 LU/ha utilised agricultural land, the median livestock density is significantly the lowest compared to TLPD B-E, which feature a median livestock density of 0.5 to 0.7 LU/ha. Another difference occurred concerning the number of pigs. With a median number of 74 pigs, TLPD E municipalities have a significantly lower number of pigs compared to TLPD A-D (543 to 1,825 pigs).

**Table 6**

Characterisation of types of agricultural land-use patterns and dynamics (TLPD A-E) by livestock numbers for 2010, results of the analysis of variance

TLPD	Cattle (no.)		<i>n</i>	Pigs (no.)		<i>n</i>	Livestock density index (LU/ha)*		<i>n</i>
	Median	25-75% percentile		Median	25-75% percentile		Median	25-75% percentile	
<b>A</b>	471 <sup>a</sup>	166-910	104	1,825 <sup>a</sup>	360-3,831	100	0.3 <sup>a</sup>	0.2-0.5	115
<b>B</b>	910 <sup>b</sup>	394-1,868	54	1,065 <sup>ab</sup>	445-3,347	40	0.6 <sup>bcd</sup>	0.5-0.7	53
<b>C</b>	703 <sup>b</sup>	368-1,759	94	1,363 <sup>ab</sup>	278-4,290	81	0.5 <sup>c</sup>	0.3-0.7	96
<b>D</b>	979 <sup>b</sup>	479-2,136	79	543 <sup>b</sup>	82-1,828	64	0.7 <sup>b</sup>	0.5-0.9	78
<b>E</b>	994 <sup>b</sup>	425-3,036	53	74 <sup>c</sup>	25-289	41	0.7 <sup>bd</sup>	0.5-0.9	54

*n* = number of municipalities.

Identical letters indicate that differences among the TLPDs are not statistically significant.

\* Livestock density index is calculated in relation to the utilised agricultural land in ha.

## 5 Discussion

### 5.1 Discussion of data base and methodological approach

In this study, the applied IACS data represent a data base with very detailed information. Due to their spatial level at field scale and the annual data collection, it is possible to analyse land-use change at a highly disaggregated level (Nitsch et al. 2012). Furthermore, it can be assumed that the collected data are of high quality because sanctions concerning direct support payments loom if farmers do not declare correctly their cultivated crops and field sizes. However, disadvantageous is the fact that not all farmers apply for direct support payments. Consequently their fields are not included in IACS data (Nitsch et al. 2012; Trubins 2013). Furthermore, it is possible that farmers declare their fields in one year, and in another year they do not, although these fields are still in agricultural production. As a result, in IACS data

the registered agricultural land varies every year and not all the agricultural land in use is documented. To answer the question of how many hectares are missing each year is difficult, and would require remote sensing monitoring. However, it is reasonable to assume that, considering the financial disadvantage, the proportion of non-IACS-registered farmland is low. Therefore, IACS data provide currently the most detailed and precise information on agricultural land. In the study, these data have proven to be a most useful data set to identify types of agricultural land-use patterns and dynamics at the municipality level. Thus, IACS data represent an auspicious source for monitoring the patterns and dynamics in agriculture (Corbelle-Rico et al. 2012). Since they are collected almost at a continental scale, IACS data could be the basis for analysing land-use change at sub-regional level for all of the area of the EU. However, there are some differences in IACS datasets within the EU, as every member state has its own system of data collection and interpretation. For example, the spatial identification of the agricultural land-use unit is managed differently (Rizzo et al. 2014). Therefore, there is a need for harmonisation and standardisation of IACS data across the European member states (Sagris et al. 2013).

Identifying types of agricultural land-use patterns and dynamics (TLPDs) requires variables considering both current and past land use, so that information on changes in agricultural production can be derived. We chose variables fulfilling these requirements (see Table 3). In the light of competing demands concerning agricultural land use as well as intensification, specialisation and conversion of permanent grassland (Bruns et al. 2000; Plieninger et al. 2013), the four variables reflect these processes in land use. Although we chose carefully our variables, it is not possible to consider all aspects that could be interesting concerning dynamics in agricultural land use (Hietel et al. 2005).

The applied statistical method for classification of agricultural land use, the k-means algorithm, has been successfully conducted in several studies but for different time periods and at different spatial levels (Stuczynski et al. 2003; Hietel et al. 2004; Simmering et al. 2006; Reger et al. 2007; Mendoza et al. 2011). One weakness of k-means cluster analysis is that the calculated centroids of the clusters are arithmetic means. Since arithmetic means are known to be sensitive to outliers (Rudolf & Kuhlisch 2008), these outliers can considerably influence the arithmetic mean, which means the centroids can be displaced. This possible problem can be solved by using the k-means algorithm only if many data are available, so that the influence of outliers can be balanced.

In this study, the spatial level was the municipality which is the lowest administrative unit in Germany. Analysing IACS data at this spatial level means to aggregate them because originally they were available at polygon level. Since data aggregation always means a loss of information (Schneeberger et al. 2007), the aim to develop a workable method of analysing agricultural land use was accompanied by a quality loss in spatial resolution. However, the results of analysis at this spatial level are clearly defined TLPDs with similar characteristics, i.e. similar patterns of agricultural land use in space and time and with similar physical conditions (Reger et al. 2007). Thus, using k-means clustering at municipality level as a classification

method is a simple and rapid way for identifying agricultural sub-regions. As classifications in landscape ecology serve to group landscapes with similar conditions and characteristics and therefore similar requirements, this method can be used for the formulation of management systems, environmental strategies or possible policy needs (Verburg et al. 2010) as well as for monitoring, modelling and planning purposes (Schröder et al. 2007; Pesch et al. 2011).

## 5.2 Discussion of types of agricultural land-use patterns and dynamics (TLPDs)

In general, the results of the study identified the differences of the agricultural land-use patterns and dynamics at sub-regional level. The five detected TLPDs represent these different agricultural sub-regions. Additionally, the TLPDs could be characterised by different physical landscape attributes and livestock numbers.

Municipalities of TLPD A, the arable land type, are a sub-region where intensification took place and will likely occur in the future. These municipalities are dominated by arable land and consequently the proportion of grassland is low (14.2% in 2005) and beneath the average rate for Hesse (37.0%). The physical attributes are favourable for agriculture, thus this sub-region belongs to the intensively cultivated areas in Hesse. There is a distinct conversion from grassland to arable land, since the conversion of grassland (3.2%) is the highest one for the entire study area. Thus, grassland likely will decrease in the future. These findings are in line with the results of a study conducted in the Rhine-Main area (Wittig et al. 2010). In the sub-region of TLPD A, land use changed in favour of maize. Due to the average annual expansion rate of 6.9% from 2005 to 2010, the maize area is still expected to expand. The livestock density is the lowest (0.3 LU/ha), but the pig stock is the highest one. In this sub-region, pig farming is managed on a relatively intensive level (HMUELV 2011). As biodiversity in agricultural landscapes is highly dependent on the intensity of land use insofar as biodiversity decreases in intensified regions (Reidsma et al. 2006), in municipalities of TLPD A it is essential to lessen the pressure on biodiversity because it can be assumed, that here biodiversity has already decreased (Waldhardt et al. 2010). One possibility could be to get more of the agricultural area in agri-environmental schemes which surely depends on the amount of payments farmers receive (Hampicke 2013). Another possible beneficial development for these regions is reported by Harvolk et al. (2013). They recommend to grow *Miscanthus x giganteus* Greef et Deu. (hereafter: *Miscanthus*), an energy crop mostly used for thermal energy production, in regions which are dominated by arable land and which lack other landscape elements. In these open agricultural landscapes, a conversion from arable land to *Miscanthus* may be advantageous for structural diversity. Furthermore, *Miscanthus* cultivation might enhance biodiversity through mixed-aged plantations, buffer stripes or ecotones.

In the sub-region of TLPD B, which is the maize type, physical conditions for agriculture are similarly favourable as in TLPD A, but land-use patterns and dynamics are different. Here, a distinct land-use change occurred especially on arable land. Both variables, the proportion of maize area (18.7% in 2010) and its average annual expansion rate (12.1% from 2005-2010), are the highest ones of all five TLPDs. It can be assumed that the conversion of arable land is in favour of maize. In consequence, in this sub-region the proportion of maize area is clearly higher than the average for Hesse. Similar developments concerning maize area were also reported for other parts of Germany (Kandziora et al. 2014; Lupp et al. 2014). In TLPD B, grassland is also a part of this conversion. Livestock density is comparatively high due to high cattle numbers. Thus, it can be assumed, that the reason for this relatively high proportion of maize area is both cattle farming and its need for fodder, and biogas production. Maize fields are known to feature relatively few species compared to other crops. Thus, in sub-regions of TLPD B measures should be taken to preserve and promote species richness. In this context, one recommendation is reported by Waldhardt et al. (2011). They suggest that within the maize fields small areas and stripes should be cultivated without crop protection measures since these measures advance the number and variety of species.

Both, TLPD A and TLPD B sub-regions, belong to agricultural production areas with rather flat and fertile land and with an ongoing process of intensification. The developments of TLPD A and B were also reported for other German regions characterised by favourable conditions for agriculture (Bruns et al. 2000; Bender et al. 2005; Nitsch et al. 2012). Drivers of these developments are, for example, market forces and agricultural policies like the CAP. These drivers are known to be continent-wide influencing factors of land-use change but with regionally differentiated consequences (Strijker 2005; Reger et al. 2009b; Klug & Jenewein 2010; Trubins 2013).

Municipalities grouped to TLPD C represent an intermediate type. In this sub-region, livestock density is at an average (0.5 LU/ha), the proportion of grassland (34.8%) is around the Hessian mean. The proportion of maize area (5.0% in 2010) is the lowest compared to the other regions. Noticeable is the fact, that the conversion from grassland to arable land is rather high (2.8%). Land-use change occurred by conversion of grassland. Since grassland is known to be of high importance for a variety of ecological functions concerning nature, soil, water and climate protection (Nitsch et al. 2012) and since grassland features high species-richness compared to other agricultural land uses (Stoate et al. 2009), the loss of grassland should be stopped. Conversion of grassland to arable land could be stopped, for example through pasture management. It is reported from several studies (e.g. Rudmann-Maurer et al. 2008; Wittig et al. 2010), that low intensity grazing and also hay harvesting seem to be a beneficial conservation alternative for grassland.

In sub-regions of both TLPD D and E, the grassland type and the grassland-maize type, physical conditions are unfavourable for agricultural production. They are characterised by a rather cold climate and partly a mountainous relief. Here, arable cultivation is difficult and consequently, the proportion of grassland is very high. Surprisingly however, these sub-regions

feature a land-use change in favour of maize which is indicated by the expansion rates of maize. In TLPD E municipalities, the proportion of grassland is the highest compared to the other sub-regions. But, on the small area of arable land, the proportion of maize is comparatively high (14.6%) and has been moderately increasing in recent years at the expense of arable land. The loss of grassland is rather low. In the sub-region of TLPD D, the conversion to the advantage of maize is still going on which is indicated by an average annual expansion rate of 5.3% (from 2005-2010). In both sub-regions, due to the number of cattle, livestock density is 0.7 LU/ha which is the highest level in the study region (HMUELV 2011).

The marginal landscapes like the ones of TLPD D and E have been subject to several research studies in recent years (MacDonald et al. 2000; Bieling et al. 2013), because these agricultural areas are in danger of either abandonment (Pinter & Kirner 2014) or intensification and homogenisation (Jongman 2002; Reger et al. 2009b), a development which is also reported for other marginal landscapes in Germany (Bruns et al. 2000; Bieling et al. 2013). In this study it is remarkable that distinct conversion processes on the arable land in favour of maize took place and that the livestock density is the highest. This indicates that in these sub-regions where the number of farms decreases, but simultaneously the size of the farms increases, the remaining farms manage the cultivation of arable land and grassland as well as the cattle farming at a more and more intensified level (HMUELV 2011). Since these formerly traditionally managed, marginal landscapes are known to offer a large variety of farmland habitats resulting in a richness of plant and animal species (Reger et al. 2009a; Corbelle-Rico et al. 2012), management for the conservation of these landscapes is needed. This demand should be realised through agri-environmental schemes designed especially for sub-regions of TLPD D and E. By offering agri-environmental schemes with the aim to preserve an extensive way of both arable and grassland cultivation, or even reintroduce it, the site-specific agricultural land-use pattern and the species richness could be maintained, or re-established from local to regional spatial scales (Cousins & Eriksson 2002; Waldhardt et al. 2004).

In summary, the study area features distinct temporal and spatial variations in land use and land-use change at the sub-regional level. In Hesse, the most suitable sub-regions for agricultural cultivation featured an ongoing process of intensification. In these sub-regions, arable land is the main land use, a progressive land-use change occurred to the disadvantage of grassland, i.e. grassland was converted to arable land which will likely continue in the future. In sub-regions with rather unfavourable physical conditions, grassland is the predominant land use, especially in mountainous areas. But on the remaining arable land, there is a slight land-use change in favour of maize. Livestock farming is dominated by cattle farming which is managed on a relatively intensive level. In the study area, the physical landscape attributes considered, i.e. elevation, slope, temperature and precipitation, are in accordance with the pattern of land use. Physical conditions are known to be correlated with land-use change as they can be a limiting factor for agricultural production (Hietel et al. 2004). The results of this study revealed that the pattern and the dynamics of land use and land-use change vary at the spatial level of sub-regions. As a consequence, we recommend that the



design of the political instruments should differ according to different sub-regions, a demand which is especially important for agri-environmental schemes (Corbelle-Rico et al. 2012; Chiron et al. 2013). These programmes aim at preserving nature as well as natural resources, ecosystem functioning and the cultural heritage. Since every political instrument should consider a spatial level generating optimal results, the results of this study confirm that agri-environmental schemes should be carried out at a lower spatial level than until now (Kantelhardt et al. 2003; Stoate et al. 2009).

## 6 Conclusion

We conclude that, although rarely used in studies yet, IACS data proved to be an appropriate and high-quality data source providing information on agricultural land use of the present and the past. The combination of k-means cluster analysis, which has already been shown to deliver useful results, with IACS data is a suitable and valuable method for simply and rapidly analysing the spatial and temporal pattern of agricultural land use and land-use change at the scale of municipalities. Furthermore, since IACS data are available almost continent-wide, they could be the basis for land-use change analysis for nearly the whole area of the EU.

The results of this study proved that changes of land use occur at sub-regional level. At the scale of municipalities, we found five types of agricultural land-use patterns and dynamics, which represent different sub-regions, and characterised them by physical landscape attributes and livestock numbers. By applying the method, it was possible to gain a close insight into the sub-regional differences of agricultural processes between 2005 and 2010 in Hesse, Germany. And as stated by several authors (e.g. Marcucci 2000; Stuczynski et al. 2003; Hietel et al. 2004; Antrop 2005; Mendoza et al. 2011), the knowledge of past and present agricultural processes underpinned by a solid quantitative foundation generates the basis for future management processes like the formulation of agricultural policies. This study indicates that agri-environmental schemes should be formulated at the sub-regional level in order to be site-specific. Since decisions on land use and thus land-use change occur at local scales (Harvolk et al. 2013), with site-specific agri-environmental schemes it would be possible to meet the specific environmental concerns and conditions such as species poverty in areas of intensive cultivation.

In general, future research should be directed towards recommendations for site-specific environmental needs. Furthermore, temporal aspects of changes in agricultural land use should be considered. Therefore, in future studies the question has to be answered in which time intervals the information on sub-regions has to be (re)calculated.

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## References

- Antrop, M. 2005. Why landscapes of the past are important for the future. *Landscape and Urban Planning* 70, 21-34.
- Bender, O.; Boehmer, H.J.; Jens, D. & Schumacher, K.P. 2005. Using GIS to analyse long-term cultural landscape change in Southern Germany. *Landscape and Urban Planning* 70, 111-125.
- Bieling, C.; Plieninger, T. & Schaich, H. 2013. Patterns and causes of land change: Empirical results and conceptual considerations derived from a case study in the Swabian Alb, Germany. *Land Use Policy* 35, 192-203.
- BKG (Bundesamt für Kartographie und Geodäsie) 2011. *Verwaltungsgebiete 1:250.000* (Administration units 1:250,000).
- Bruns, D.; Ipsen, D. & Bohnet, I. 2000. Landscape dynamics in Germany. *Landscape and Urban Planning* 47, 143-158.
- Bürgi, M.; Hersperger, A.M. & Schneeberger, N. 2004. Driving forces of landscape change - current and new directions. *Landscape Ecology* 19, 857-868.
- Chiron, F.; Princé, K.; Paracchini, M.L.; Bulgheroni, C. & Jiguet, F. 2013. Forecasting the potential impacts of CAP-associated land use changes on farmland bird at the national level. *Agriculture, Ecosystems and Environment* 176, 17-23.
- Corbelle-Rico, E.; Crecente-Maseda, R. & Santé-Riveira, I. 2012. Multi-scale assessment and spatial modelling of agricultural land abandonment in a European peripheral region: Galicia (Spain), 1956-2004. *Land Use Policy* 29, 493-501.
- Cousins, S.A.O. & Eriksson, O. 2002. The influence of management history and habitat on plant species richness in a rural hemiboreal landscape, Sweden. *Landscape Ecology* 17, 517-529.
- DBV (Deutscher Bauernverband) 2010. *Situationsbericht 2011. Trends und Fakten zur Landwirtschaft* (Report of situation 2011. Trends and facts concerning agriculture). Deutscher Bauernverband, Berlin.
- DBV (Deutscher Bauernverband) 2012. *Situationsbericht 2012/13. Trends und Fakten zur Landwirtschaft* (Report of situation 2012/3. Trends and facts concerning agriculture). Deutscher Bauernverband, Berlin.
- de Chazal, J. & Rounsevell, M.D.A. 2009. Land-use and climate change within assessments of biodiversity change: A review. *Global Environmental Change* 19, 306-315.

- de Longueville, F.; Tychon, B.; Leteinturier, B. & Ozer, P. 2007. An approach to optimise the establishment of grassy headlands in the Belgian Wallon region: A tool for agri-environmental schemes. *Land Use Policy* 24, 443-450.
- DWD (Deutscher Wetterdienst) 2013. ohne Titel (no title). Offenbach.
- EC (European Commission) 2011. Glossary: Livestock density index - Statistics Explained. [http://epp.eurostat.ec.europa.eu/statistics\\_explained/index.php/Glossary:Livestock\\_density\\_index](http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Livestock_density_index) (Date: 02.12.2013).
- EC (European Commission) 2013. Integrated Administration and Control System (IACS). [http://ec.europa.eu/agriculture/direct-support/iacs/index\\_en.htm](http://ec.europa.eu/agriculture/direct-support/iacs/index_en.htm) (Date: 11.01.2014).
- Erjavec, K. & Erjavec, E. 2015. ‚Greening the CAP‘ - Just a fashionable justification? A discourse analysis of the 2014-2020 CAP reform documents. *Food Policy* 51, 53-62.
- ESRI 2010. ArcGIS 10.
- Fjellstad, W.J. & Dramstad, W.E. 1999. Patterns of change in two contrasting Norwegian agricultural landscapes. *Landscape and Urban Planning* 45, 177-191.
- Flanagan, A.M. & Cerrato, R.M. 2015. An approach for quantifying the efficacy of ecological classification schemes as management tools. *Continental Shelf Research* 109, 55-66.
- FNR (Fachagentur Nachwachsende Rohstoffe) 2013. Maisanbau in Deutschland - Anbaujahr 2013 (Cultivation of maize in Germany 2013). <http://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/biogas/maisbau-in-deutschland.html> (Date: 17.04.2014).
- FNR (Fachagentur Nachwachsende Rohstoffe) 2014. Flächennutzung in Deutschland 2013 (Land utilisation in Germany 2013). <http://mediathek.fnr.de/flachennutzung-in-deutschland.html> (Date: 17.04.2014).
- Gallant, A.L.; Loveland, T.R.; Sohl, T.L. & Napton, D.E. 2004. Using an Ecoregion Framework to Analyse Land-Cover and Land-Use Dynamics. *Journal of Environmental Management* 34, S89-S110.
- Gellrich, M. & Zimmermann, N.E. 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning* 79, 65-76.
- Gomez y Paloma, S.; Ciaian, P.; Cristoiu, A. & Sammeth, F. 2013. The future of agriculture. Prospective scenario and modelling approaches for policy analysis. *Land Use Policy* 31, 102-113.
- Gumienna, M.; Szwengiel, A.; Lasik, M.; Szambelan, K.; Majchrzycki, D.; Adamczyk, J.; Nowak, J. & Czarnecki, Z. 2016. Effect of corn grain variety on the bioethanol production efficiency. *Fuel* 164, 386-392.
- Hampicke, U. 2013. Agricultural Conservation Measures - Suggestions for their Improvement. *GJAE (German Journal of Agricultural Economics)* 62, 203-214.
- Harrach, T. 2005. Die naturräumliche Gliederung und Naturraumtypen Hessens (Biogeographical classification of Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105*, 27-30.
- Hartigan, J.A. 1975. *Clustering algorithms*. Wiley, New York.
- Hartigan, J.A. & Wong, M.A. 1979. Algorithm AS 136: A k-means clustering algorithm. *Journal of the Royal Statistical Society. Series C (Applied Statistics)* 28, 100-108.
- Harvolk, S.; Kornatz, P.; Otte, A. & Simmering, D. 2013. Using existing landscape data to assess the ecological potential of *Miscanthus* cultivation in a marginal landscape. *Global Change Biology (GCB) Bioenergy* 1-15. Retrieved from doi:10.1111/gcbb.12078
- Hastie, T.; Tibshirani, R. & Friedman, J. 2009. *The elements of statistical learning. Data mining, inference, and prediction*. 2. edition. Springer, New York.

- Heißenhuber, A. & Krämer, C. 2011. Analyse agrar- und umweltpolitischer Maßnahmen bezüglich ihrer Auswirkungen auf die Agrobiodiversität (Analysis of agricultural and environmental political measures regarding their impact on agricultural biodiversity). Pages 22-37 In: F. Begemann; S. Schröder; D. Kießling; C. Neßhöver & V. Wolters (eds.): Neue Wege zur Erhaltung und nachhaltigen Nutzung der Agrobiodiversität – Effektivität und Perspektiven von Fördermaßnahmen im Agrarbereich. Schriftenreihe des Informations- und Koordinationszentrums für Biologische Vielfalt, Bonn.
- Hietel, E.; Waldhardt, R. & Otte, A. 2004. Analysing land-cover changes in relation to environmental variables in Hesse, Germany. *Landscape Ecology* 19, 473-489.
- Hietel, E.; Waldhardt, R. & Otte, A. 2005. Linking socio-economic factors, environment and land cover in the German Highlands, 1945-1999. *Journal of Environmental Management* 75, 133-143.
- Hietel, E.; Waldhardt, R. & Otte, A. 2007. Statistical modeling of land-cover changes based on key socio-economic indicators. *Ecological Economics* 64, 496-507.
- HLUG (Hessisches Landesamt für Umwelt und Geologie) undated. Daten des Integrierten Verwaltungs- und Kontrollsystem für Hessen 2004-2010 (IACS data for Hesse 2004-2010). Wiesbaden.
- HMUELV (Hessisches Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz) 2011. Landwirtschaft in Hessen. Zahlen und Fakten 2011 (Agriculture in Hesse 2011). Print Consulting, Gladenbach.
- HSL (Hessisches Statistisches Landesamt) 2012. Hessische Gemeindestatistik 2011. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2010 (Hessian communal statistics 2011).
- HVBG (Hessische Verwaltung für Bodenmanagement und Geoinformation) undated. Digitales Höhenmodell DHM25 (Digital Elevation Model DEM25). Wiesbaden.
- Janisová, M.; Michalcová, D.; Bacaro, G. & Ghisla, A. 2014. Landscape effects on diversity of semi-natural grasslands. *Agriculture, Ecosystems and Environment* 182, 47-58.
- Jansen, L.J.M. & di Gregorio, A. 2002. Parametric land cover and land-use classifications as tools for environmental change detection. *Agriculture, Ecosystems and Environment* 91, 89-100.
- Jongman, R.H.G. 2002. Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. *Landscape and Urban Planning* 58, 211-221.
- Jungmann, W.W. & Brückner, H. 2005. Die geologisch-geomorphologischen Grundlagen Hessens (Geologic-geomorphic basics of Hesse). Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, 7-11.
- Kandziora, M.; Dörnhöfer, K.; Oppelt, N. & Müller, F. 2014. Detecting Land Use And Land Cover Changes In Northern German Agricultural Landscapes To Assess Ecosystem Service Dynamics. *Landscape Online* 35, 1-24.
- Kantelhardt, J.; Osinski, E. & Heissenhuber, A. 2003. Is there a reliable correlation between hedgerow density and agricultural site conditions? *Agriculture, Ecosystems and Environment* 98, 517-527.
- Keenleyside, C.; Baldock, D.; Hjerp, P. & Swales, V. 2009. International perspectives on future land use. *Land Use Policy* 26S, S14-S29.
- Klausing, O. 1988. Die Naturräume Hessens mit einer Karte der naturräumlichen Gliederung 1:200.000 (Biogeographical regions of Hesse with a map 1:200,000). Hessische Landesanstalt für Umwelt, Wiesbaden.
- Klug, H. & Jenewein, P. 2010. Spatial modelling of agrarian subsidy payments as an input for evaluating changes of ecosystem services. *Ecological Complexity* 7, 368-377.

- Kovacs-Hostyanszki, A. & Baldi, A. 2012. Set-aside fields in agri-environment schemes can replace the market-driven abolishment of fallows. *Biological Conservation* 152, 196-203.
- Lambin, E.F.; Rounsevell, M.D.A. & Geist, H.J. 2000. Are agricultural land-use models able to predict changes in land-use intensity? *Agriculture, Ecosystems and Environment* 82, 321-331.
- Lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; Fischer, G.; Folke, C.; George, P.S.; Homewood, K.; Imbernon, J.; Leemans, R.; Li, X.; Moran, E.F.; Mortimore, M.; Ramakrishnan, P.S.; Richards, J.F.; Skanes, H.; Steffen, W.; Stone, G.D.; Svedin, U.; Veldkamp, T.A.; Vogel, C. & Xu, J. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11, 261-269.
- Lupp, G.; Steinhäuser, R.; Starick, A.; Gies, M.; Bastian, O. & Albrecht, J. 2014. Forcing Germany's renewable energy targets by increased energy crop production: A challenge for regulation to secure sustainable land use practices. *Land Use Policy* 36, 296-306.
- MacDonald, D.; Crabtree, J.R.; Wiesinger, G.; Dax, T.; Stamou, N.; Fleury, P.; Gutierrez Lazpita, J. & Gibon, A. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* 59, 47-69.
- MacQueen, J. 1967. Some methods for classification and analysis of multivariate observations. Pages 281-297 In: L. M. Le Cam & J. Neyman (eds.): *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability*. University of California Press, Berkeley.
- Marcucci, D.J. 2000. Landscape history as a planning tool. *Landscape and Urban Planning* 49, 67-81.
- Meeus, J.H.A. 1995. Pan-European landscapes. *Landscape and Urban Planning* 31, 57-79.
- Mendoza, M.E.; López Granados, E.; Geneletti, D.; Pérez-Salicrup, D.R. & Salinas, V. 2011. Analysing land cover and land use change processes at watershed level: A multitemporal study in the Lake Cuitzeo Watershed, Mexico (1975 - 2003). *Applied Geography* 31, 237-250.
- Meynen, E. & Schmithüsen, J. 1953-1962. *Handbuch der naturräumlichen Gliederung Deutschlands* (Handbook of the biogeographical classification of Germany). Bundesanstalt für Landeskunde und Raumforschung Selbstverlag, Bad Godesberg.
- Mollenhauer, K. 2005. Das Klima in Hessen und im rheinland-pfälzischen Rheinhessen (Climate in Hesse). *Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105*, 12-16.
- Nitsch, H.; Osterburg, B.; Roggendorf, W. & Laggner, B. 2012. Cross Compliance and the protection of grassland - Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. *Land Use Policy* 29, 440-448.
- Pan, D.; Domon, G.; de Blois, S. & Bouchard, A. 1999. Temporal (1958-1993) and spatial patterns of land use changes in Haut-Saint-Laurent (Quebec, Canada) and their relation to landscape physical attributes. *Landscape Ecology* 14, 35-52.
- Pesch, R.; Schmidt, G.; Schroeder, W. & Weustermann, I. 2011. Application of CART in ecological landscape mapping: Two case studies. *Ecological Indicators* 11, 115-122.
- Petit, C.C. & Lambin, E.F. 2002. Long-term land cover changes in the Belgian Ardennes (1775-1929): model-based reconstruction vs. historical maps. *Global Change Biology* 8, 616-630.
- Pinter, M. & Kirner, L. 2014. Strategies of disadvantaged mountain dairy farmers as indicators of agricultural structural change: A case study of Murau, Austria. *Land Use Policy* 38, 441-453.

- Pletsch, A. 1989. Hessen. Bundesrepublik Deutschland und Berlin (West). Wissenschaftliche Länderkunden Band 8/III. (Hesse. Federal Republic of Germany and West Berlin). Wissenschaftliche Buchgesellschaft, Darmstadt.
- Plieninger, T.; Bieling, C.; Ohnesorge, B.; Schaich, H.; Schleyer, H. & Wolff, F. 2013. Exploring Futures of Ecosystem Services in Cultural Landscapes through Participatory Scenario Development in the Swabian Alb, Germany. *Ecology and Society* 18, 39.
- Potashev, K.; Sharonova, N. & Breus, I. 2014. The use of cluster analysis for plant grouping by their tolerance to soil contamination with hydrocarbons at the germination stage. *Science of the Total Environment* 485-486, 71-82.
- Reger, B.; Mattern, T.; Otte, A. & Waldhardt, R. 2009a. Assessing the spatial distribution of grassland age in a marginal European landscape. *Journal of Environmental Management* 90, 2900-2909.
- Reger, B.; Otte, A. & Waldhardt, R. 2007. Identifying patterns of land-cover change and their physical attributes in a marginal European landscape. *Landscape and Urban Planning* 81, 104-113.
- Reger, B.; Sheridan, P.; Simmering, D.; Otte, A. & Waldhardt, R. 2009b. Potential effects of direct transfer payments on farmland habitat diversity in a marginal European landscape. *Environmental Management* 43, 1026-1038.
- Reidsma, P.; Tekelenburg, T.; van den Berg, M. & Alkemade, R. 2006. Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union. *Agriculture, Ecosystems and Environment* 114, 86-102.
- Rizzo, D.; Martin, L. & Wohlfahrt, J. 2014. *Miscanthus* spatial location as seen by farmers: A machine learning approach to model real criteria. *Biomass and Bioenergy* 66, 348-363.
- Rounsevell, M.D.A.; Annetts, J.E.; Audsley, E.; Mayr, T. & Reginster, I. 2003. Modelling the spatial distribution of agricultural land use at the regional scale. *Agriculture, Ecosystems and Environment* 95, 465-479.
- Rounsevell, M.D.A.; Ewert, F.; Reginster, I.; Leemans, R. & Carter, T.R. 2005. Future scenarios of European agricultural land use II. Projecting changes in cropland and grassland. *Agriculture, Ecosystems and Environment* 107, 117-135.
- Rounsevell, M.D.A.; Reginster, I.; Araujo, M.B.; Carter, T.R.; Dendoncker, N.; Ewert, F.; House, J.I.; Kankaanpää, S.; Leemans, R.; Metzger, M.J.; Schmit, C.; Smith, P. & Tuck, G. 2006. A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems and Environment* 114, 57-68.
- Rudmann-Maurer, K.; Weyand, A.; Fischer, M. & Stöcklin, J. 2008. The role of landuse and natural determinants for grassland vegetation composition in the Swiss Alps. *Basic and Applied Ecology* 9, 494-503.
- Rudolf, M. & Kuhlisch, W. 2008. *Biostatistik. Eine Einführung für Biowissenschaftler (Biostatistics. An introduction for bioscientists)*. Pearson, München.
- Sabel, K.-J. 2005. *Die Bodenlandschaften Hessens (Soil landscapes of Hesse)*. Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, 21-26.
- Sagris, V.; Wojda, P.; Milenov, P. & Devos, W. 2013. The harmonised data model for assessing Land Parcel Identification Systems compliance with requirements of direct aid and agri-environmental schemes of the CAP. *Journal of Environmental Management* 118, 40-48.
- Sanderson, F.J.; Kucharz, M.; Jobda, M. & Donald, P.F. 2013. Impacts of agricultural intensification and abandonment on farmland birds in Poland following EU accession. *Agriculture, Ecosystems and Environment* 168, 16-24.

- Schneeberger, N.; Bürgi, M. & Kienast, F. 2007. Rates of landscape change at the northern fringe of the Swiss Alps: Historical and recent tendencies. *Landscape and Urban Planning* 80, 127-136.
- Schneider, L.C. & Pontius, G.J. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA. *Agriculture, Ecosystems and Environment* 85, 83-94.
- Schröder, W.; Pesch, R. & Schmidt, G. 2007. Statistical Classification of Terrestrial and Marine Ecosystems for Environmental Planning. *Landscape Online* 2, 1-22.
- Simmering, D.; Waldhardt, R. & Otte, A. 2006. Quantifying determinants contributing to plant species richness in mosaic landscapes: a single- and multi-patch perspective. *Landscape Ecology* 21, 1233-1251.
- StatSoft. Inc. 2011. STATISTICA for Windows. Version10.0.
- Stoate, C.; Baldi, A.; Beja, P.; Boatman, N.D.; Herzon, I.; von Doorn, A.; de Snoo, G.R.; Rakosy, L. & Ramwell, C. 2009. Ecological impacts of early 21st century agricultural change in Europe - A review. *Journal of Environmental Management* 91, 22-46.
- Strijker, D. 2005. Marginal lands in Europe - causes of decline. *Basic and Applied Ecology* 6, 99-106.
- Stuczynski, T.; Kus, J. & Filipiak, K. 2003. The Structure of Landscapes in Poland as a Function of Agricultural Land Quality. Pages 143-156 In: K. Helming & H. Wiggering (eds.): *Sustainable Development of Multifunctional Landscapes*. Springer, Berlin & Heidelberg.
- Trubins, R. 2013. Land-use change in southern Sweden: Before and after decoupling. *Land Use Policy* 33, 161-169.
- Uthes, S.; Piorr, A.; Zander, P.; Bienkowski, J.; Ungaro, F.; Dalgaard, T.; Stolze, M.; Moschitz, H.; Schader, C.; Happe, K.; Sahrbacher, A.; Damgaard, M.; Toussaint, V.; Sattler, C.; Reinhardt, F.-J.; Kjeldsen, C.; Casini, L. & Müller, K. 2011. Regional impacts of abolishing direct payments: An integrated analysis in four European regions. *Agricultural Systems* 104, 110-121.
- Vagstad, N. & Oygarden, L. 2003. Landscape Function in Relation to Agricultural Management in Norway. Pages 191-200 In: K. Helming & H. Wiggering (eds.): *Sustainable Development of Multifunctional Landscapes*. Springer, Berlin & Heidelberg.
- Verburg, P.H.; van Berkel, D.B.; van Doorn, A.M.; van Eupen, M. & van den Heiligenberg, H.A.R.M. 2010. Trajectories of land use change in Europe: a model-based exploration of rural futures. *Landscape Ecology* 25, 217-232.
- Waldhardt, R.; Bach, M.; Borresch, R.; Breuer, L.; Diekötter, T.; Frede, H.-G.; Gäth, S.; Ginzler, O.; Gottschalk, T.; Julich, S.; Krumpholz, M.; Kuhlmann, F.; Otte, A.; Reger, B.; Reiher, W.; Schmitz, K.; Schmitz, P.M.; Sheridan, P.; Simmering, D.; Weist, C.; Wolters, V. & Zörner, D. 2010. Evaluating Today's Landscape Multifunctionality and Providing an Alternative Future: A Normative Scenario Approach. *Ecology and Society* 15: 30. Retrieved from <http://www.ecologyandsociety.org/vol15/iss3/art30/>
- Waldhardt, R. & Otte, A. 2003. Indicators of plant species and community diversity in grasslands. *Agriculture, Ecosystems and Environment* 98, 339-351.
- Waldhardt, R.; Otte, A.; Simmering, D. & Ginzler, O. 2011. Biogas gegen Biodiversität? (Biogas contra biodiversity?). *DLG-Mitteilungen* 3/2011, 20-23.
- Waldhardt, R.; Simmering, D. & Otte, A. 2004. Estimation and prediction of plant species richness in a mosaic landscape. *Landscape Ecology* 19, 211-226.
- Wittig, R.; Becker, U. & Nawrath, S. 2010. Grassland loss in the vicinity of a highly prospering metropolitan area from 1867/68 to 2000 – The example of the Taunus (Hesse, Germany) and its Vorland. *Landscape and Urban Planning* 95, 175-180.

- Xiao, J.; Shen, Y.; Ge, J.; Tateishi, R.; Tang, C.; Liang, Y. & Huang, Z. 2006. Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing. *Landscape and Urban Planning* 75, 69-80.
- Zeidler, E. (ed.) 2013. *Taschenbuch der Mathematik (Pocketbook of mathematics)*. 3. edition. Springer Spektrum, Wiesbaden.



## Chapter 3

### **The impact of biogas plants on regional dynamics of permanent grassland and maize area – The example of Hesse, Germany (2005-2010)**

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*The previous chapter revealed that temporal and spatial changes in land use occur at sub-regional level. In sub-regions with favourable physical conditions, arable land is the predominant land use, the few areas of permanent grassland featured a distinct conversion to arable land. In contrast, in sub-regions with rather unfavourable site-conditions permanent grassland is the prevailing land use. But on the few areas of arable land, there is a slight land-use change in favour of maize. Since Chapter 1 did not analysed the reasons for these developments, but indicated that the increased number of biogas plants can be an influencing factor, this chapter investigated if there is a statistically significant relationship between biogas plants and the changes in land use, at the example of permanent grassland and maize area.*

## **Abstract**

The fostering of bioenergy by European and German energy policies in recent years has led to a strong increase in the cultivation of energy crops, especially maize for biogas production. Contemporaneously, in Germany the area of permanent grassland has significantly decreased. In this context, energy maize is often discussed to affect the conversion of grassland. The aim of this study was to examine the area changes of maize and permanent grassland and to analyse if there is a relationship to biogas plants. For comparison, livestock farming as another possible influencing factor was implemented, too. The study was conducted at two spatial levels: the first was the German federal state Hesse as a whole, the second were five Hessian sub-regions clustered by prevailing agricultural land use and land-use change from 2005 to 2010. Correlation and regression analyses revealed the association of biogas plants and livestock density to three variables of agricultural land use, i.e. maize area, expansion of maize area and conversion of permanent grassland to arable land. Negative correlations between biogas plants and maize area were significant for Hesse and three sub-regions (-0.21 to -0.42). However, the positive correlations between livestock density and maize area were higher (0.33 to 0.66). Biogas plants were considerably negative related to the expansion of maize area on all spatial levels (-0.29 to -0.42). Conversion of grassland was less but still significantly related to biogas plants and livestock density. Biogas plants and livestock density can serve as an indicator for land-use change, especially for permanent grassland and maize area.

## **Keywords:**

agricultural land-use change, permanent grassland loss, bioenergy, livestock density, different spatial scales, correlation and multiple linear regression analysis

## 1 Introduction

The production of renewable energies is politically and consequently financially supported within the European Union with the aim of reducing CO<sub>2</sub> emissions and to achieve climate aims (Troost et al., 2015). Biomethane from anaerobic digestion of crops and manure is a renewable energy source. Hence, electricity production based on biogas is considered a promising way to contribute to environmental protection aims, and therefore has considerably and rapidly increased in recent years (Svoboda et al., 2013). In Germany, the production and utilisation of biogas (and also other renewable energy sources like wind and solar) has been promoted by the Renewable Energy Act (German: Erneuerbare-Energien-Gesetz, EEG). The EEG was passed for the first time in 1991 and then reformed in 2004 and 2008, and gives feed-in tariffs for electricity generated from biogas which are higher than the feed-in tariffs for electricity from fossil fuels and guarantees these subsidies for a fixed time period of 20 years (Lupp et al., 2014). Since the subsidies for biogas production represent a profitable new income possibility for farmers (Amon et al., 2007), this support policy of the EEG has resulted in a considerable increase in the number of biogas plants and also in the average plant size (Delzeit et al., 2012). From 2004-2013, the number of biogas plants in Germany increased from 2,010 to 7,772, and the average electrical power per plant grew from 123 to 454 kW<sub>el</sub> (BMELV, 2013).

Biogas plants represent a good opportunity for farms to dispose of surplus animal manure in an environmentally friendly way which is especially important in areas of intensive livestock farming. Thus, the occurrence of biogas plants correlates with the distribution of livestock farms (Delzeit and Kellner, 2013). However, biogas plants do not only occur in regions where livestock farming is practised. Since maize (*Zea mays*) is the dominant feedstock used for methane production due to its high methane yield during digestion and additionally due to its low soil requirements, good silage ability and high crop yields per area which results in a high profitability compared to other crops (Schulze Steinmann and Holm-Müller, 2010), biogas plants occur in regions where maize is cultivated. Indeed, the biogas boom of recent years coincided with a significant expansion of maize cultivation and the area of silage maize has increased continuously (Britz and Delzeit, 2013). However, it is not clear to what extent biogas plants (and associated financial subsidies) are the causal driver of this development. In Germany, in the year 2012 the area of silage maize grew by 28,000 ha to a total of 2.1 million ha, of which approximately 900,000 ha were used as bioenergy maize (DBV, 2012). The remaining amount was used as fodder and as corn maize. The continuing increase of silage maize area in recent years is considered to be a result of bioenergy production (DBV, 2012; Lupp et al., 2014). Concerning the proportion of silage maize on arable land, there are significant differences by region. In some regions of Germany, the maize area can occupy up to 70% of arable land (Svoboda et al., 2013). Growing controversy attends this development, since the cultivation of maize is known to have some possible negative environmental effects

like soil erosion, high nitrogen inputs followed by nitrogen spill-overs, less biodiversity, habitat loss, reduced landscape aesthetics etc. (Wiehe et al., 2009; Pedroli et al., 2013; Söderberg and Eckerberg, 2013; Lupp et al., 2014; Jomaa et al., 2016). The cultivation of maize has a high relevance not only for biogas production, but also for cattle farming, since silage maize is an important cattle fodder. As a result, cattle farming promotes maize cultivation especially in regions with intensive milk production. However, the number of cattle in Germany has increased by only 0.9% to 12.7 million from 2013 to 2014 (DBV, 2014), therefore cattle farming is considered to be only a minor reason for the rapid increase in maize cultivation (Laggner et al., 2014). Altogether, these indications suggest that there are interactive influences among biogas plants, maize cultivation and livestock farming.

The promoting of biogas plants via financial subsidies is a policy which has surely affected agricultural land use (Britz and Delzeit, 2013). Policy support instruments are known to be important drivers for changes in land use (van Delden et al., 2010). In recent years, the discussion is to what extent the development of biogas plants and the associated cultivation of silage maize has contributed to the conversion and therefore the loss of permanent grassland (Laggner et al., 2014). Permanent grassland can belong to the most species-rich habitat types (Wilson et al., 2012; Lewis et al., 2014) if managed traditionally by non-intensive management practices (Wellstein et al., 2007) which means it has great importance for preserving biodiversity (Bruun et al., 2001). Additionally, permanent grassland is part of the cultural landscape in Europe. It combines ecosystem functions like storage of high carbon stocks, protection from soil erosion, water retention and nutrient holding (Conant et al., 2001; Chen et al., 2009; Prochnow et al., 2009), and it contributes to recreation and tourism (Hopkins and Holz, 2006; Stoate et al., 2009). Hence, permanent grassland is important in terms of nature, environmental protection and recreation (Pykälä, 2003; Rösch et al., 2009), but its quantity and quality are endangered due to intensification of land use and abandonment as well as conversion into arable land (Hopkins and Holz, 2006). These processes were not only reported for Germany but for many European countries, for example Romania (Schmitt and Rákossy, 2007), Hungary (Biró et al., 2013), Scotland (Lewis et al., 2014), Italy (Bracchetti et al., 2012) and Switzerland (Gellrich and Zimmermann, 2007). In Germany from 1993 to 2012, the area of permanent grassland decreased from 5,251,000 ha to 4,631,000 ha, an absolute loss of 620,000 ha (-11.8%). In contrast, the area of arable land has remained rather stable. In 1993, it comprised 11,676,000 ha, and in 2012 11,834,000 ha (BMELV, 2013). The loss of permanent grassland in recent years coincides with the promotion of biogas production and increased maize cultivation. This area loss is also evident in regions with high or constant livestock density, hence it is not clear if biogas plants are a causal driver or a temporal coincidence in the loss of permanent grassland. If permanent grassland was converted into fields for silage maize used as feedstock for biogas plants, this change in land use would mean a causal relationship between development of biogas plants and loss of permanent grassland (Laggner et al., 2014). Another important driver for loss of permanent grassland could be cattle breeding and especially milk production since these sectors of agriculture are known to have

been intensified in recent years (BfN, 2015). The increased milk yield of cattle demands higher requirements on fodder quality. Consequently, permanent grassland has to be mown several times a year which is an intensification of land use. Additionally, dairy cattle farming will be practised in more profitable regions. As a consequence, in Germany the low mountain ranges which were typical regions for dairy production, are in danger of being given up (BfN, 2014). Furthermore, the declining area of permanent grassland could also be the result of better market conditions. Due to increased commodity prices especially since the year 2007, the conversion of permanent grassland to arable land was profitable which was an opportunity farmers made use of (Ericsson et al., 2009; Gillings et al., 2010).

In general, changes in land use have always been and are a basic feature of cultural landscapes, and agricultural cultivation is always a dynamic process (Cabrera, 2015). However, recent developments in agricultural land use are known to cause several negative impacts on ecosystems. Thus, knowledge of dynamics in land use is of crucial importance for decision-making, policy development and the management of agricultural landscapes (Ernault et al., 2003; Van Turnhout et al., 2010; Biró et al., 2013; Kandziora et al., 2014).

Our study focusses on the temporal and spatial dynamics of permanent grassland and maize area. The study region was Hesse, one of Germany's federal states. The analyses were carried out at different spatial levels, considering the time period from 2005 to 2010. Therefore, the specific objectives of the study were to quantify (i) the area changes of permanent grassland and (ii) the changes of maize area, both at the spatial level of the federal state Hesse as a whole and at the level of its 430 municipalities. Additionally, since we were interested in the potential effect of the operation of biogas plants on agricultural land use, we investigated (iii) if there is a statistically reliable association between the existence of biogas plants and maize area as well as biogas plants and the conversion of grassland, here at the spatial level of Hesse as a whole and five sub-regions. The results were compared with the association between livestock density and, again, maize area and the conversion of grassland. Regarding the third aim, our hypothesis was that biogas production is one driver of land-use change of recent years and livestock farming is an enduring driver.

## **2 Material and methods**

### ***2.1 The study region Hesse in Germany***

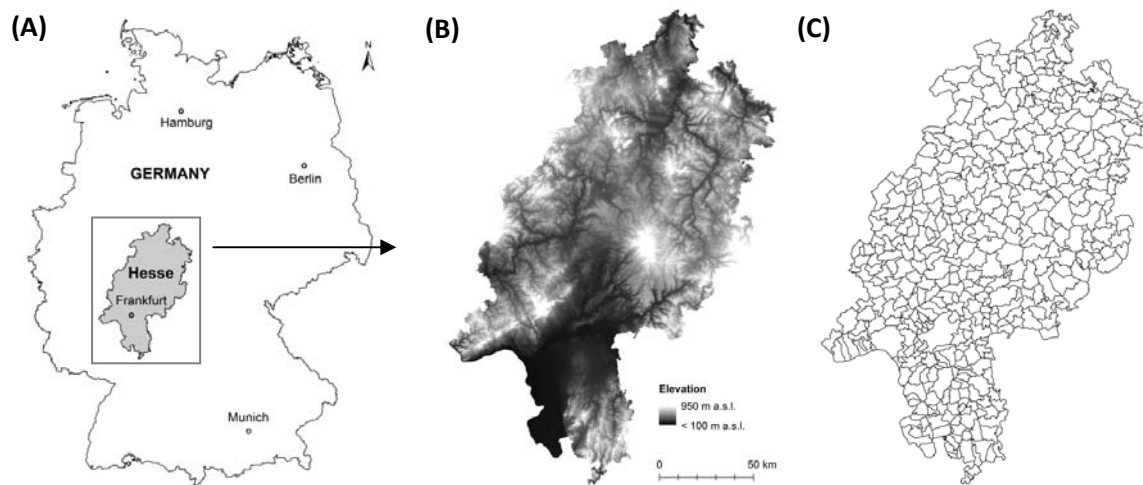
The study region Hesse is one of the German federal states located in central Germany (Fig. 1). It has a size of 21,115 km<sup>2</sup> and is subdivided into 430 municipalities (HSL, 2012). Hesse is characterised by a variety of different landscapes (Pletsch, 1989). Due to various physical site conditions, it comprises areas both favourable and unfavourable for agricultural cultivation.

Thus, Hesse features an agricultural land use ranging from intensively used to marginal agricultural landscapes and a mixture of the two.

The valleys of the lowlands (<100-300 m a.s.l., planar to colline altitude level) alternate with the elevations of the highlands (300-950 m a.s.l., submontane to montane altitude level). These large scale structures are a morphologically structuring axis and extend in a more or less north-south direction (Jungmann and Brückner, 2005). As a result, climate shows distinct regional differences and is divided in two parts. The lowlands feature a mean annual temperature of 9-10 °C and a mean annual precipitation (1971-2000) of 500-700 mm. In the highlands mean annual temperature is about 5 °C and mean annual precipitation (1971-2000) is 1,200-1,300 mm (Mollenhauer, 2005). Due to orographic and climate conditions, soil types are heterogeneous and diverse (Pletsch, 1989; Lotz, 1995). In the lowlands, the main substrate of pedogenesis are loess and windborne sands. In the Rhine-Main area, soil types are usually Umbrisol and Umbrisol Protospodic, and feature a high permeability. Additionally, in this region the average temperatures (1981-2010) are high, especially in late spring (10-11 °C) and summer (18-20 °C) (HLNUG, 2016). Thus, field irrigation has to be used for cultivation. North of the Main river, the lowlands are dominated by loess. Here, the soil types are mainly Umbrisol Protospodic, Phaeozems and Luvisols, which all offer a high agricultural profitability (Schaldach, 2004). In the highlands, the pedogenesis is shaped by a mixture of weathered parent rock material and loess resulting usually in base-poor soil types. Consequently, Umbrisols and Podzols are prevalent and are rather unfavourable for agricultural cultivation. The highlands also have soil types with a high base saturation like Cambisols (Sabel, 2005). These sites are suitable for agricultural cultivation (Schaldach, 2004; Harrach, 2005).

In Hesse in the year 2010, 42% of the total area was used for agriculture, 40% for forestry and 16% for settlement and traffic. Since Hesse is characterised by distinct highlands with rather unfavourable physical conditions for agriculture, the proportion of permanent grassland was 37% in 2010. The proportion of arable land amounted to 62% (HSL, 2012). For comparison, in Germany as a whole the area of permanent grassland comprised 29% and the area of arable land 71% of the utilised agricultural land in 2010 (DBV, 2010). In the Hessian highlands, land use varies between grassland, agriculture and forestry depending on soil quality, relief and climate. Usually, in these regions land use is practised non-intensively (Graß, 2005), and there is a diverse mosaic of habitats and a comparably high number of characteristic species (Simmering et al., 2013). In contrast, due to favourable physical conditions agricultural land use in the lowlands is intensive (Freund, 2002). Here, grain is the dominant crop with a proportion of 64% on arable land in 2010, of which 55% was wheat and 29% barley (HSL, 2012). Other important crops are vegetables, sugar beet and in some cases vines and fruits. In Hesse, both the cultivation of rapeseed (*Brassica napus*), which can be used for the production of biodiesel and blending fossil fuels, and maize (*Zea mays*) have increased in recent years. Especially, silage maize used as a bioenergy crop featured a significant area growth (HMUELV, 2011a). From 2009-2010, the area of silage maize increased by 10% and thus, covered 8% of the arable land (HMUELV, 2011b). In Hesse, pig and cattle stocks and the associated farms

have decreased. In 2010, total livestock added up to 469,750 livestock units (LU), and the average livestock was 0.6 LU per ha of utilised agricultural land (in Germany as a whole: 1.1 LU/ha). Livestock farming is practised predominantly in the northern and eastern regions of Hesse at a rather intensive level (HMUELV, 2011b). In recent decades, agricultural structure has changed (Graß, 2005). The total number of farms decreased from 90,900 in the year 1971 to 17,900 in 2010. Additionally, farm sizes changed. In 1999, the average farm size was 26 ha. It increased to 43 ha in 2010 (74 ha for full-time farms and 24 ha for part-time farms) (HMUELV, 2011b). In Germany as a whole, in 2010 the average farm size was 56 ha (DBV, 2012).



**Figure 1.** Study region: (A) Hesse in Germany, (B) topography of Hesse: elevation from <100-950 m a.s.l., (C) administrative structure: 430 municipalities.

## 2.2 Data set and GIS analysis

We investigated the development of permanent grassland and maize area by using data of the Integrated Administration and Control System (IACS) provided by the Hessian Agency for Environment and Geology (HLUG, undated). The Integrated Administration and Control System is an instrument of the European Common Agricultural Policy (CAP) which all member states were obliged to install. The system assures that financial transactions with the farmers are carried out and implemented correctly. It consists of four parts: an identification system for farmers, a so called Land Parcel Identification System (LPIS) which registers all agricultural fields, an identification system for payment entitlements, and, if member states utilise animal-based measures, an identification and registration system for animals (EC, 2015). IACS data have been collected since 2004 and provide data on an annual basis and for each agricultural parcel. If applying for support payments, every year farmers need to register their fields

including specifications on field size and cultivated crops. Thus, IACS data provide spatially and temporally precise information on agricultural land use and its changes.

For the time period 2005-2010, we created a geodatabase by using the Spatial Analyst tool included in the ArcGIS 10 software (ESRI, 2010). IACS data were digital polygonal layers at the spatial level of agricultural fields. They were intersected with a polygonal layer of the 430 municipalities of Hesse which was made available by the German Federal Office for Cartography and Geodesy (BKG, 2011). IACS data consist of four land-use classes: arable land, permanent grassland, permanent crops and non-agricultural area. Added together, they represent the utilised agricultural land (UAL). In order to show the changes of permanent grassland and maize, we analysed IACS data for each of the 430 municipalities and calculated seven variables (see Table 1 for a detailed description). The selection and calculation of the variables based on a previous study (cf. Lüker-Jans et al., 2016). The proportion of permanent grassland referred to the maximum area of utilised agricultural land, likewise the proportion maize area referred to the maximum area of arable land. We chose these maximum areas as consistent reference values, the areas differed every year which is due to the fact that farmers do not necessarily declare their total area of cultivation. For a more detailed description see Lüker-Jans et al. (2016). We calculated the seven variables and the utilised agricultural land both at the level of the municipalities and at the level of Hesse as a whole.

**Table 1**

Variables used for analysis of changes in permanent grassland and maize area based on IACS data (HLUG, undated).

Variable	Description
<i>Permanent grassland</i>	
1. Permanent grassland area, 2005 (% of util. agr. land)	Proportion of permanent grassland in 2005 as percentage of utilised agricultural land *
2. Permanent grassland area, 2010 (% of util. agr. land)	Proportion of permanent grassland in 2010 as percentage of utilised agricultural land *
3. Expansion of permanent grassland area, 2005-2010 (%)	Average annual expansion rate as percentage for the proportion of permanent grassland area in the time period 2005-2010
4. Conversion of permanent grassland 2005 to arable land 2010 (% of grassland 2005)	Permanent grassland converted into arable land between 2005 and 2010, as percentage of grassland area in 2005
<i>Maize</i>	
5. Maize area, 2005 (% of arable land)	Proportion of maize area in 2005 as percentage of arable land **
6. Maize area, 2010 (% of arable land)	Proportion of maize area in 2010 as percentage of arable land **
7. Expansion of maize area, 2005-2010 (%)	Average annual expansion rate as percentage for the proportion of maize area in the time period 2005-2010

\* Relating to the maximum area of utilised agricultural land from 2005-2010.

\*\* Relating to the maximum area of arable land from 2005-2010. Variables number 4., 6. and 7. were used for statistical analysis.



To check the IACS data for plausibility, we analysed data of agricultural land use published by the Hessian Agency for Statistics (HSL, 2003, 2007, 2010, 2013, 2015). Thereby, the intention was to investigate if the trends in agricultural land use appear in both data sets. These agricultural statistics are the result of a census in which every farm of Hesse has to participate. Data are presented at municipal and at federal state level. In the data set, land use is grouped into the two main land-use classes of arable land and permanent grassland. Additionally, it contains the area of utilised agricultural land (UAL). Data for the cultivated maize area does not exist. We used data of Hesse as a whole. Since these data are collected at irregular time intervals, we possess data for the years 1999, 2003, 2007, 2010 and 2012.

Using the GIS, we created several layers based on our geodatabase and analysed the changes of permanent grassland and maize area both graphically and numerically (Rudolf and Kuhlisch, 2008).

In this study, we also aimed at detecting relationships of changes in agricultural land use to the possible drivers biogas plants and livestock farming. The relevant variables were defined as follows:

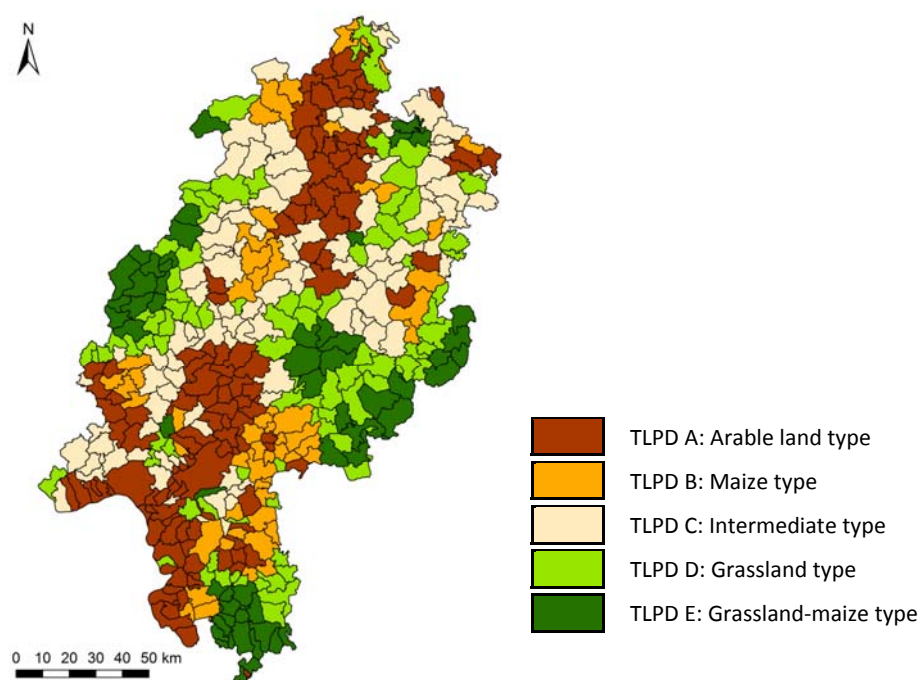
- Our assumption was that land use will change if biogas plants exist since farmers will cultivate subsequently the necessary feedstock. Due to reasons of cost reduction, the feedstock will be cultivated in the immediate vicinity of a biogas plant because costs are lower the shorter the transportation route of the feedstock is. This means that the influence of biogas plants on land use is higher the nearer a biogas plant is. Thus, the corresponding variable was calculated as distance of municipalities to next biogas plant. Data to the location of biogas plants in Hesse were made available by the German Bundesnetzagentur (Bundesnetzagentur, undated). In this data set, we received information about every biogas plant in Hesse, and thus could allocate them to the 430 Hessian municipalities. Due to reasons of data protection, it was not possible to create a map with the number of biogas plants per every municipality. In order to get the distance of municipalities to biogas plants, we calculated the Euclidean distance of every municipality to the next biogas plant with the help of the Spatial Analyst tool of the ArcGIS 10 software (ESRI, 2010). The median value of the Euclidean distance of the Hessian municipalities to the next biogas plant was 2.6 km (25-75% percentile: 1.1-5.0 km).
- Concerning the second variable, we used information on livestock density expressed as livestock unit per ha utilised agricultural land (LU/ha) for the year 2010. We obtained the number of livestock from agricultural statistics (HSL, 2012), and subsequently calculated livestock density by using information on utilised agricultural land per municipality of our IACS data set. In agricultural statistics, the number of livestock is not apparent for every municipality. The statistics miss, if only one farm in a municipality practices livestock farming. This was true for a number of 34 municipalities mainly concentrated in the south of Hesse where livestock farming is of minor relevance for the Hessian agriculture. Livestock farming is practised mainly in the north and the east of Hesse. For these municipalities with missing values, we used livestock density of the corresponding

administrative district (in German: Landkreis) as a kind of mean value. The administrative district is a higher spatial level. We received these data from HMUELV (2011b). Since Hesse is not a region of intensive livestock farming compared to other regions in Germany, livestock densities are generally lower and, additionally do not differ considerably, thus it was possible to take over the livestock density of the higher spatial level in case of the municipalities with missing numbers. In Hesse, the median value of the livestock density of the municipalities was 0.5 LU/ha (25-75% percentile: 0.3-0.7 LU/ha).

For the analysis of the relationships of agricultural land-use changes to bioenergy production and livestock farming, we chose the following three variables of our GIS analysis: (i) maize area in 2010, (ii) expansion of maize area from 2005 to 2010, and (iii) conversion of permanent grassland to arable land from 2005 to 2010 (see Table 1). Maize was chosen as variable, since in Hesse maize is the dominant feedstock of biogas plants (HMUELV, 2011b; LLH, 2012). Additionally, permanent grassland was chosen as a variable, since this study investigated if permanent grassland gets lost through conversion to the feedstock maize.

The data set of the Hessian biogas plants furthermore contained information to the capacity of the biogas plants. The capacity can also be a relevant factor for changes in land use because higher capacities need more feedstock which will lead to an increased production of it. Therefore, we also calculated correlation and regression analysis by considering the capacity as an independent variable. However, the analyses did not deliver useful results. In the year 2010, the average capacities did not vary considerably (median: 250 kW, 25-75% percentile: 195-499 kW), thus the variable capacity of biogas plants was highly intercorrelated to the variable distance to municipalities (correlation coefficient from -0.72 to -0.86). In consequence, the resulting  $R^2$  values were not improved by considering the capacity of biogas plants. Thus, we did not include this variable to our analyses.

The relationships of agricultural land-use changes to bioenergy production and livestock farming were investigated on two spatial levels: the first was Hesse as a whole, the second were five Hessian sub-regions. We identified these sub-regions in our previous study (Lüker-Jans et al., 2016). Using a k-means cluster analysis based on four of our variables of land-use change (cf. Table 1), we revealed five types of agricultural land-use patterns and dynamics (TLPD A-D) which are equivalent to the Hessian sub-regions. The statistical process was to calculate the value of the four variables for each of the 430 municipalities, and subsequently to allocate them to different clusters which represent the TLPDs. The localisation of the five TLPDs of Hesse is visible in Fig. 2, an abbreviated description of the TLPDs is given in Table 2.



**Figure 2.** Spatial distribution of types of agricultural land use patterns and dynamics (TLPD A-E) in the study region Hesse, Germany (after Lüker-Jans et al., 2016). See text and Table 2 for details.

**Table 2**

Characterisation of TLPD A-E using four variables of agricultural land use (see Lüker-Jans et al., 2016)

Region	Permanent grassland area, 2005 (% of UAL)	Maize area, 2010 (% of arable land)	Expansion of maize area, 2005-2010 (%)	Conversion of permanent grassland 2005 to arable land 2010 (% of grassland 2005)	Area of municipalities (km <sup>2</sup> )	Proportion of the total area of Hesse (%)	<i>n</i>
<b>TLPD A</b> <i>Arable land type</i>	14.2	6.0	6.9	3.2	5,465	25.9	127
<b>TLPD B</b> <i>Maize type</i>	29.6	18.7	12.1	2.2	2,695	12.8	57
<b>TLPD C</b> <i>Intermediate type</i>	34.8	5.0	1.9	2.8	5,739	27.2	104
<b>TLPD D</b> <i>Grassland type</i>	55.1	10.6	5.3	1.7	4,220	20.0	85
<b>TLPD E</b> <i>Grassland-maize type</i>	80.2	14.6	3.0	0.8	2,999	14.2	57

*n* = number of municipalities.

### 2.3 Statistics

Correlation and regression analysis were used to analyse the relationships of bioenergy production and livestock farming to land-use changes. These analyses are known from several studies investigating land use, see for example Bürgi and Turner (2002), Iverson (1988), Kantelhardt et al. (2003) and Räsänen et al. (2015).

We applied correlation analysis using Pearson's correlations coefficient (Köhler et al., 2012). A Pearson correlation is the special case of a linear correlation. Since our variables did not show a linear association, prior to the analysis they had to be log-transformed. By use of this transformation it was possible to transfer the non-linear association into a linear one. Additionally, the differences of the lower range of the variables will be emphasized (Leyer and Wesche, 2007) which is reasonable due the assumption that biogas plants influences land use in their immediate vicinity. In the case of variables featuring a zero or negative value, a constant was added to the original value so that the log-transformation was possible (Bruun et al., 2001). Extreme values were excluded from the analysis to reduce an exaggerated influence (Tabachnick and Fidell, 2001). To define extreme values, we used the method implemented in Statistica 12.0 software (StatSoft. Inc., 2014). Extreme values were identified by applying a box-plot analysis of the variables and defined as values which are distant from the end of the box (25% and 75% percentile) by more than 3-fold of the length of the box. The deletion of extreme values resulted in different  $n$  values in the analyses.

In a first step, we checked the relationship between the distance of municipalities to biogas plants and livestock density. We expected a correlation since the animal slurry of livestock breeding farms can be used for bio-methane production. Subsequently, we investigated the relationships between the distance of the municipalities to the next biogas plant and the three variables of agricultural land use. Correlation analysis was also utilised for the relationship between livestock density and the three variables of agricultural land use. By applying these correlation analyses, the aim was a comparison of the two possible drivers of land-use change, i.e. biogas plants and livestock farming.

We also applied a multiple linear regression analysis (Rudolf and Kuhlisch, 2008) to examine the relationship between the independent variables existence of biogas plants as well as livestock density and the three dependent variables. The resulting  $R^2$ , the coefficient of determination, was used as a measure for the quality of the relationship. If  $R^2$  values approach 1.00, then the independent variables existence of biogas plants and livestock density are related to the three variables maize area 2010, expansion of maize area 2005-2010 and conversion of permanent grassland to arable land 2005-2010 which means that the independent variables are sufficient to explain the dependent variables.

For both analyses we used Statistica 12.0 software (StatSoft. Inc., 2014).

### 3 Results

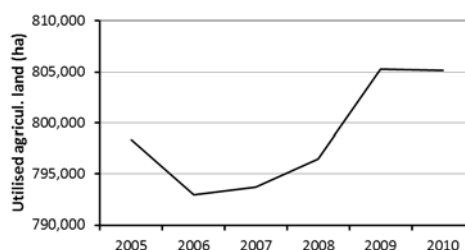
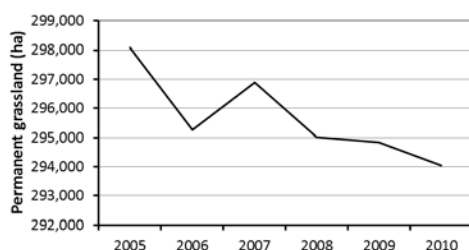
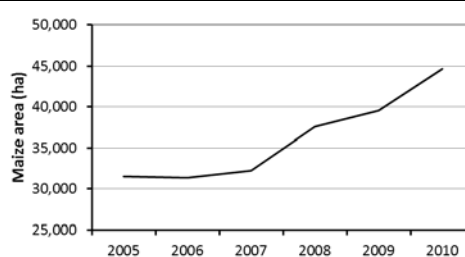
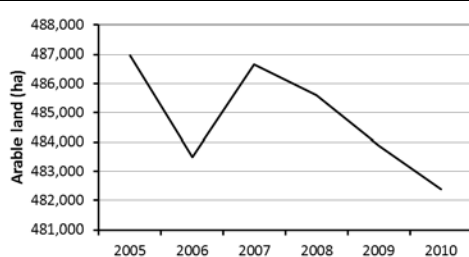
#### 3.1 Changes of permanent grassland and maize area

According to our analysis of IACS data, in Hesse the areas of both arable land and permanent grassland decreased from 2005 to 2010 (Table 3). Arable land decreased by -4,597 ha (-0.9% of arable land in 2005), permanent grassland by -4,026 ha (-1.4% of permanent grassland in 2005). In contrast, the maize area increased significantly from 6.5% to 9.3% of arable land which is an area growth of +13,144 ha (+41.7% of maize area in 2005). In the study period, the utilised agricultural land increased by +6,833 ha (+0.9% of UAL in 2005) which is due to the growth of permanent crops in 2007 and of the non-agricultural area especially in 2009 (both permanent crops and the non-agricultural area are not explicitly mentioned in Table 3). From 2009-2010, the area of utilised agricultural land was slightly reduced to 805,178 ha.

**Table 3**

Changes of agricultural land use, 2005-2010, based on IACS data (HLUG, undated).

	Arable land		Maize area		Permanent grassland		UAL
	ha	% UAL	ha	% arable land	ha	% UAL	ha
<b>2005</b>	486,978	61.0	31,510	6.5	298,078	37.3	798,345
<b>2006</b>	483,483	61.0	31,348	6.5	295,263	37.2	792,962
<b>2007</b>	486,650	61.3	32,257	6.6	296,887	37.4	793,687
<b>2008</b>	485,607	61.0	37,542	7.7	295,008	37.0	796,468
<b>2009</b>	483,871	60.1	39,506	8.2	294,834	36.6	805,304
<b>2010</b>	482,380	59.9	44,654	9.3	294,052	36.5	805,178



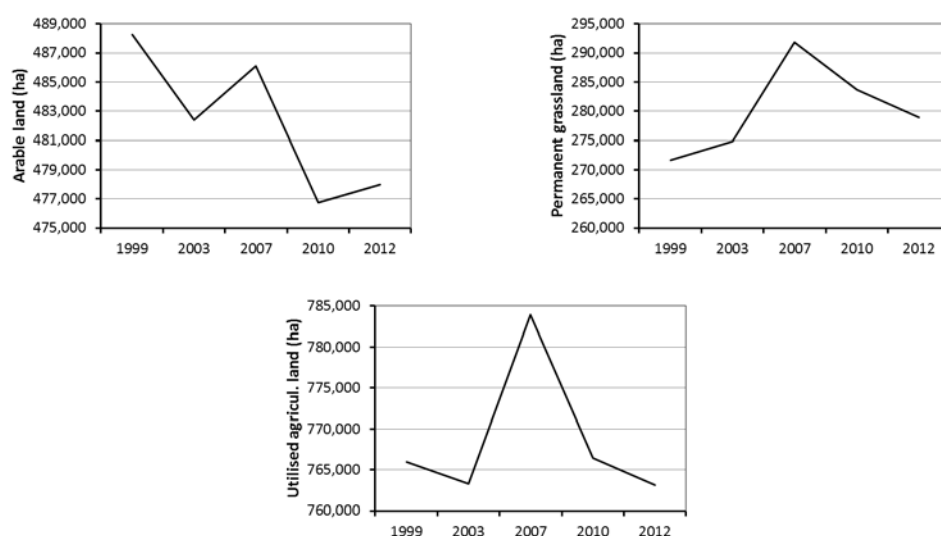
UAL = utilised agricultural land.

The supplementary analysis of the Hessian agricultural statistics, revealed some slight differences to IACS data. According to Hessian agricultural statistics (Table 4), arable land decreased by -10,251 ha from 1999 to 2012 (-2.1% of arable land in 1999). From 2010-2012, it slightly increased by 1,263 ha to a total of 478,000 ha. Also, the utilised agricultural land was reduced. From 1999-2012, it decreased by -2,876 ha (-0.4% of UAL in 1999). The area of permanent grassland increased by +7,271 ha (+2.7% of permanent grassland in 1999) from 1999 to 2012. But remarkable is the fact that permanent grassland has clearly decreased in recent years, i.e. from 2007 to 2012 it decreased from 291,845 to 278,900 ha which is a loss of 12,945 ha.

**Table 4**

Changes of agricultural land use, 1999-2012, based on agricultural statistics (HSL, 2003, 2007, 2010, 2013, 2015).

	Arable land		Permanent grassland		UAL
	ha	% UAL	ha	% UAL	ha
<b>1999</b>	488,251	63.7	271,629	35.5	765,976
<b>2003</b>	482,399	63.2	274,797	36.0	763,299
<b>2007</b>	486,086	62.0	291,845	37.2	783,905
<b>2010</b>	476,737	62.2	283,666	37.0	766,437
<b>2012</b>	478,000	62.6	278,900	36.5	763,100



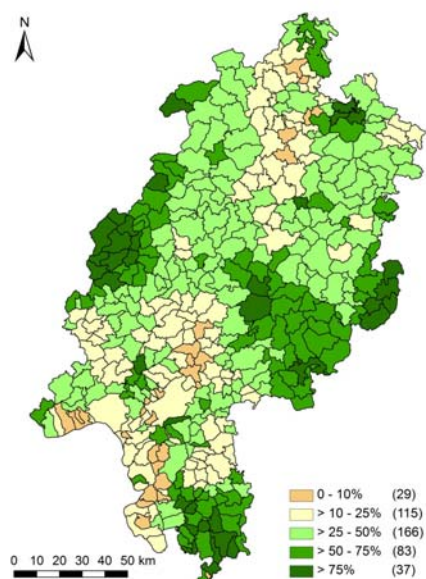
UAL = utilised agricultural land.

The analysis of IACS data at the spatial level of the municipalities showed more differentiated results for permanent grassland and maize area. In the year 2005, 29 of the 430 Hessian municipalities featured a proportion of permanent grassland up to 10% of the utilised agricultural land (Fig. 3A), which is an area of 2,721 ha. In 2010, the number of municipalities slightly increased to 31 (Fig. 3B), which is also indicated by the increase of the grassland area to 3,238 ha. Municipalities with a grassland proportion of >10-25% and >25-50% had no

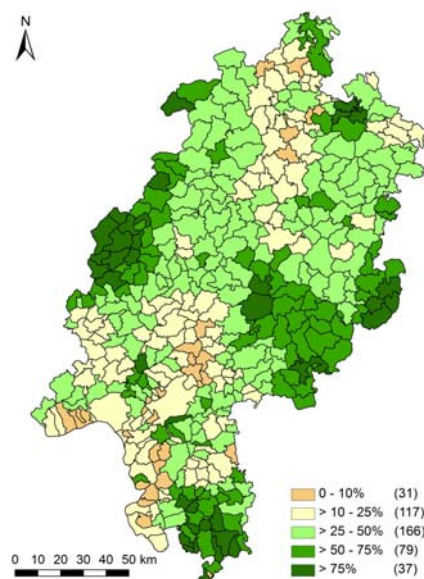
significant changes, the area remained almost stable. Distinct changes of permanent grassland area occurred in municipalities with a middle proportion of grassland. The number of municipalities with a proportion of >50-75% decreased from 83 to 79, the area changed from 90,933 to 87,685 ha. The grassland area of municipalities with a proportion of >75% and more remained nearly stable. The expansion rate of permanent grassland (Fig. 3C) was on average -0.3% for the total area of permanent grassland in Hesse. In 268 municipalities the proportion of permanent grassland decreased, whereas in 162 of the 430 municipalities featured an increase of permanent grassland (Fig. 3C). Concerning the conversion of permanent grassland, the results revealed that the area of permanent grassland of 2005 converted into arable land in 2010 was on an average 2.3% for the total area of Hesse. In 384 municipalities the conversion rate was up to 5%. A conversion rate higher than 5% was featured by 46 municipalities (Fig. 3D).

In Hesse, maize area grew clearly. With just one exception, every class of proportion of maize area featured an increase in the number of municipalities. The number of municipalities with a proportion of maize from 5% and more increased from 220 to 276 (an increase of 56). In the class with a maize area up to 5%, the number of municipalities decreased from 210 to 154 (a reduction of 56) which means an area decrease from 6,688 to 4,148 ha. Accordingly, the expansion rate for maize area was 7.2% for Hesse as a whole from 2005 to 2010. 157 municipalities featured a negative expansion rate, i.e. the maize area decreased from 2005 to 2010. In contrast, with a number of 273 the majority of the 430 Hessian municipalities experienced an increase of maize area (Fig. 4C).

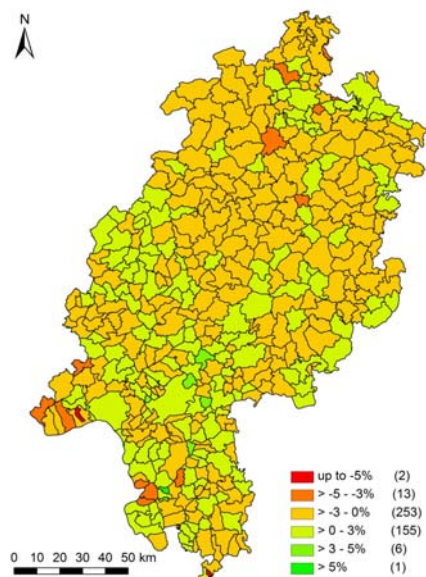
(A) Permanent grassland area, 2005



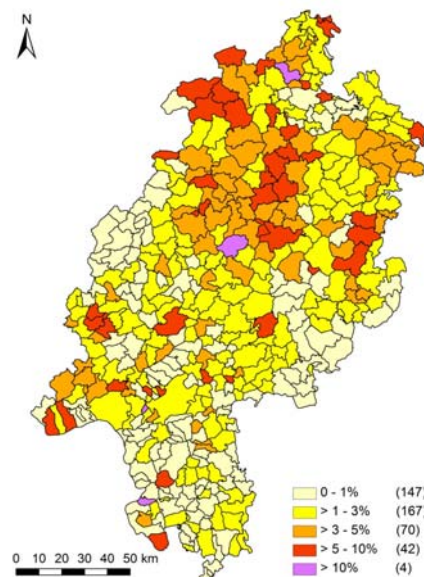
(B) Permanent grassland area, 2010



(C) Expansion of permanent grassland area, 2005-2010



(D) Conversion of permanent grassland into arable land, 2005-2010



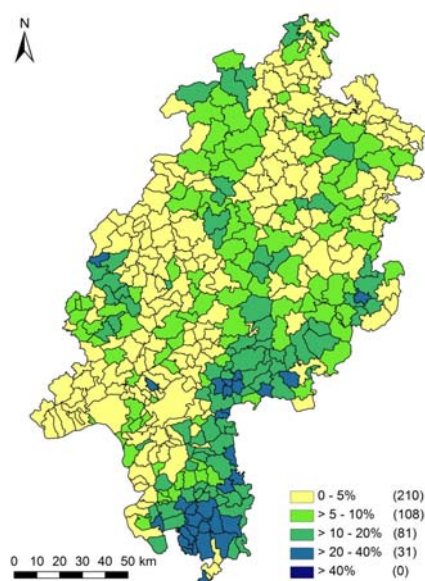
**Figure 3.** Changes of permanent grassland area in Hesse, 2005-2010: (A) proportion of permanent grassland in 2005 as percentage (%) of utilised agricultural land \*, (B) proportion of permanent grassland in 2010 as percentage (%) of utilised agricultural land \*, (C) average annual expansion rate as percentage (%) for the proportion of permanent grassland from 2005 to 2010, and (D) permanent grassland converted into arable land between 2005 and 2010 as percentage (%) of permanent grassland area in 2005.

( ) number of municipalities.  $n = 430$ .

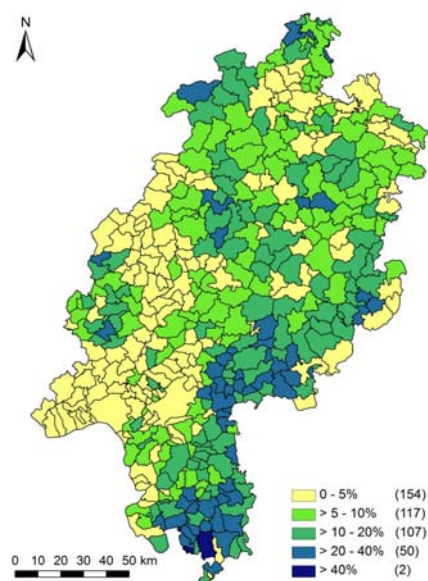
\* Relating to the maximum area of utilised agricultural land from 2005 to 2010. See text for details.



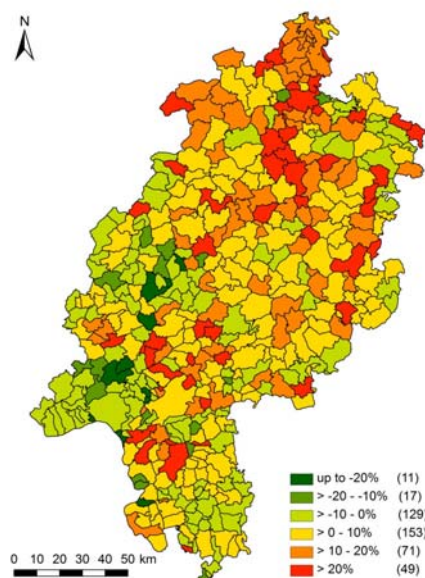
(A) Maize area, 2005



(B) Maize area, 2010



(C) Expansion of maize area, 2005-2010



**Figure 4.** Changes of maize area in Hesse, 2005-2010: (A) proportion of maize area in 2005 as percentage (%) of arable land \*, (B) proportion of maize area in 2010 as percentage (%) of arable land \*, and (C) average annual expansion rate as percentage (%) for the proportion of maize area from 2005 to 2010.

() number of municipalities.  $n = 430$ .

\* Relating to the maximum area of arable land from 2005 to 2010. See text for details.

### 3.2 Associations between variables of agricultural land use and biogas plants or livestock density

In Hesse, a total of 135 biogas plants were installed distributed across 90 municipalities in the year 2010 (Table 5A) which means many municipalities had few and few municipalities had many biogas plants. The distribution of biogas plants per region revealed that the number of biogas plants decreased from TLPD A to E (Table 5B). The locations of the biogas plants concentrate in the north of Hesse and in the eastern highlands. Additional single sites are in the western regions of Hesse and in the lowlands of the south. The total capacity of the biogas plants was 47,860 kW, on average 355 kW per plant.

**Table 5**

Number of biogas plants in Hesse, 2010.

<b>(A) Distribution of biogas plants per municipality</b>	
Number of municipalities	Biogas plants per municipality
340	0
63	1
16	2
8	3
2	4
0	5, 6, 7
1	8
0	9 and more
<b>(B) Distribution of biogas plants per region</b>	
Region	Number of biogas plants
Hesse	135
TLPD A	42
TLPD B	36
TLPD C	26
TLPD D	20
TLPD E	11

The correlation analysis of the association between distance of the municipalities to the next biogas plant and livestock density index showed a negative correlation, this means the more livestock the lower the distance to biogas plants. In our analysis, distance to the next biogas

plant correlated negatively with livestock density for the entire area of Hesse as well as for the four sub-regions (Table 6).

**Table 6**

Correlation between distance of municipalities to the next biogas plant and livestock density index in 2010 (based on Pearson's Correlation Coefficient).

Region	Correlation between
	Distance of municipalities to next biogas plant ----- Livestock density index
Hesse	<b>-0.14</b>
TLPD A	<b>-0.25</b>
TLPD B	<b>-0.35</b>
TLPD C	<b>-0.32</b>
TLPD D	<b>-0.27</b>
TLPD E	-0.10

Figures in **bold** indicate statistical significance ( $p < 0.05$ ).

$n = 430$ .

Correlation analysis between the selected variables of agricultural land use and the distance of the municipalities to the next biogas plant revealed an assortment of significant associations for Hesse as a whole as well as for different sub-regions of Hesse. This was also the case concerning the correlations to livestock density (Table 7). All statistically significant correlations between maize area and distance to biogas plants were negative. In the case of Hesse, the correlation between maize area and distance to biogas plants was with -0.21 weaker than that for the significant sub-regions. In TLPD C, the highest correlation (-0.42) was found. TLPD A (-0.30) and TLPD D (-0.24) featured correlations which were slightly lower. In contrast, the correlations between maize area and livestock density were generally higher. The correlations were positive since a higher livestock density will need more fodder which can be maize. On the spatial level of Hesse, the correlation coefficient was 0.49. This value was exceeded by TLPD C (0.58), D (0.66) and E (0.53).

The correlations between expansion of maize area and distance to biogas plants were statistically significant and furthermore negative on all spatial levels. The negative correlations reached values from -0.29 to -0.42. In contrast, livestock density had just one significant correlation (0.18) to the expansion of maize area.

Furthermore, we analysed the correlations of conversion of grassland to arable land to distance to biogas plants. In the case of Hesse and four sub-regions we found statistically significant correlations. The negative correlation coefficient was maximal in TLPD B (-0.43), closely followed by TLPD D (-0.39). In TLPD A and E as well as in Hesse as a whole, the correlation coefficients were -0.25, -0.27 and -0.31. Therefore, there is a relationship between

the vicinity of biogas plants and the conversion of grassland. In contrast, we found only three significant correlation coefficients, which were positive, concerning the relationship between livestock density and conversion of grassland. TLPD E featured the highest value (0.38). Although two more sub-regions showed significant correlations, our analysis does not reveal a clear correlation between livestock density and conversion of grassland.

**Table 7**

Correlations between variables of agricultural land use and distance of municipalities to the next biogas plant and livestock density index in 2010 (based on Pearson's Correlation Coefficient).

Region	Correlations between					
	Maize area 2010 *		Expansion of maize area 2005-2010 **		Conversion of grassland 2005 to arable land 2010 ***	
	Distance of municipalities to next biogas plant	Livestock density index	Distance of municipalities to next biogas plant	Livestock density index	Distance of municipalities to next biogas plant	Livestock density index
Hesse	<b>-0.21</b>	<b>0.49</b>	<b>-0.31</b>	0.08	<b>-0.31</b>	0.07
TLPD A	<b>-0.30</b>	<b>0.33</b>	<b>-0.29</b>	<b>0.18</b>	<b>-0.25</b>	<b>0.33</b>
TLPD B	0.09	0.03	<b>-0.36</b>	-0.13	<b>-0.43</b>	<b>0.26</b>
TLPD C	<b>-0.42</b>	<b>0.58</b>	<b>-0.30</b>	0.11	-0.07	0.09
TLPD D	<b>-0.24</b>	<b>0.66</b>	<b>-0.36</b>	0.14	<b>-0.39</b>	0.09
TLPD E	0.07	<b>0.53</b>	<b>-0.42</b>	0.07	<b>-0.27</b>	<b>0.38</b>

Figures in **bold** indicate statistical significance ( $p < 0.05$ ).

\*  $n = 430$ .

\*\*  $n = 422$ .

\*\*\*  $n = 426$ . For different  $n$  values see text for details.

Regression analysis confirmed the assumption that the analysed variables of agricultural land use are influenced by the existence of biogas plants and by livestock density. Even though  $R^2$  values were rather low in general, the analysis revealed significant relationships (Table 8).

The variable which was related most significantly was maize area (Table 8A). In the region of TLPD D,  $R^2$  reached a maximum value of 0.44, which means 44% of maize area could be explained by the variables distance to biogas plants and livestock density. In other regions,  $R^2$  reached values between 0.16 and 0.40 in case of significance of the independent variables. When comparing the relative contribution of the independent variables, livestock density had higher values compared to distance to next biogas plants. Additionally, in the two sub-regions with high proportions of permanent grassland (TLPD D and E) livestock density alone is significant. Thus, as expected from the previous correlation analysis, both the factors distance to biogas plants and livestock density serve as an explanation for the increased proportion of maize area, but livestock density is even more strongly related.

In contrast, livestock density had a minor or no influence in the regression analysis for the variable expansion of maize area (Table 8B). The variable was explained better by the variable

distance to next biogas plant. In general,  $R^2$  values were lower than before in case of significance ( $R^2$  between 0.09 and 0.21 for Hesse as a whole and TLPD A-D).

Regression equations for conversion of grassland in 2005 to arable land in 2010 (Table 8C) reached  $R^2$  values which were alike low as before ( $R^2$  between 0.13 and 0.20 for TLPD A, B and D.  $R^2 = 0.10$  for Hesse). The factors, biogas plants and livestock density, could only to a moderate extent explain the conversion of permanent grassland. Furthermore, they were not suitable in two sub-regions (TLPD C and D).

**Table 8**

Results of multiple linear regression analysis for three variables of agricultural land use \*.

<b>(A) Maize area 2010</b>						
Region	R <sup>2</sup>	b*-coefficients of independent variables **		Constant	Significance	n
		Distance of municipalities to next biogas plant	Livestock density index			
Hesse	0.26	<b>-0.14</b>	<b>0.47</b>	<b>0.50</b>	0.000	428
TLPD A	0.16	<b>-0.23</b>	<b>0.27</b>	<b>0.69</b>	0.000	127
TLPD B	0.01	0.12	0.07	<b>1.23</b>	0.701	57
TLPD C	0.40	<b>-0.26</b>	<b>0.49</b>	<b>0.37</b>	0.000	104
TLPD D	0.44	-0.08	<b>0.64</b>	<b>0.27</b>	0.000	85
TLPD E	0.31	0.15	<b>0.55</b>	-0.15	0.000	55

<b>(B) Expansion of maize area 2005-2010</b>						
Region	R <sup>2</sup>	b*-coefficients of independent variables **		Constant	Significance	n
		Distance of municipalities to next biogas plant	Livestock density index			
Hesse	0.10	<b>-0.31</b>	0.03	<b>1.60</b>	0.000	422
TLPD A	0.10	<b>-0.26</b>	0.11	<b>1.57</b>	0.002	125
TLPD B	0.21	<b>-0.47</b>	<b>-0.30</b>	<b>1.75</b>	0.003	55
TLPD C	0.09	<b>-0.30</b>	0.01	<b>1.60</b>	0.008	102
TLPD D	0.13	<b>-0.35</b>	0.03	<b>1.58</b>	0.004	83
TLPD E	0.18	-0.42	0.03	1.58	0.004	57

<b>(C) Conversion of grassland 2005 to arable land 2010</b>						
Region	R <sup>2</sup>	b*-coefficients of independent variables **		Constant	Significance	n
		Distance of municipalities to next biogas plant	Livestock density index			
Hesse	0.10	<b>-0.30</b>	0.03	<b>0.52</b>	0.000	426
TLPD A	0.13	<b>-0.18</b>	<b>0.28</b>	<b>0.37</b>	0.000	124
TLPD B	0.20	<b>-0.38</b>	0.13	<b>0.44</b>	0.002	57
TLPD C	0.01	-0.05	0.10	<b>0.49</b>	0.010	103
TLPD D	0.15	-0.38	-0.02	0.57	0.001	85
TLPD E	0.20	-0.23	<b>0.36</b>	0.09	0.003	57

Figures in **bold** indicate statistical significance (p = see column).

\* Variables of agricultural land use = dependent variables, i.e. variables to explain.

\*\* b\*-coefficients are standardised regression coefficients whose dimension indicate the relative contribution of the independent variables to explain.

For different n values see text for details.

## 4 Discussion

Our analysis shows a clear decline in the area of permanent grassland in Hesse for the investigated time period. This is the case for the IACS data as well as the data from the agricultural statistics. Also, arable land featured a decrease in area, especially since the year 2007.

The development of the UAL is different depending on the two data bases. Whereas in IACS data set, the area of UAL increases from 2006 to 2009 and show only a negligible decrease from 2009 to 2010, in the data set from agricultural statistics the area of UAL shows a clear decrease from 2007 to 2012. One reason for these differences concerning UAL and also the different values of the land-use classes may be that there is no consistent method of data collection. In IACS data, farmers can register every field of their cultivated area, so that they can receive the support payments. If they do not register, these fields miss. As a result, the area of land use varies every year. Additionally, even among the federal states in Germany, there are differences of IACS data concerning the structure and the differentiation of land use as well as information on the farm, its area of cultivation and the reference area for GIS-analyses (Osterburg et al., 2009). In the Hessian agricultural statistics, just as in the IACS data set not all of the fields will be integrated in the data base. But this is a result of the limits of detection (in German: Erfassungsgrenze) which are applied in agricultural statistics and, furthermore, which vary over time. The current limit of detection, i.e. since the year 2010, is a minimum of 5 ha UAL (HSL, 2015). In former years, this value was 1 ha UAL (from 1979 to 1998) or 2 ha UAL (from 1999 to 2009) (HSL, 2010). As a result, the comparability of the two data sets between the analysed years is imperfect (HSL, 2012). Nevertheless, decreases or increases in the areas of different land use are obvious.

The development for the year 2007 is remarkable. In both data sets, there is an area increase for arable land, permanent grassland and thus UAL. The reason for this development were high commodity prices especially in the years 2007 and 2008. Due to this prices increase, farmers began to cultivate again fields which had been fallow land. In Hesse, as a result mainly winter wheat was grown (HSL, 2011), which can be seen in the increase of arable land from 2006 and 2007 (see Table 3). The favourable prices on the agricultural market affected also the set-aside measurement. Compulsory set-aside was a measure of nature protection within the EU (according to meanwhile annulled Council Regulation (EC) No 1782/2003) by which farmers were obliged to take a certain proportion of arable land out of production. This proportion varied over the years, because the percentage of set-aside was defined yearly and regionally new. In 2007, the percentage of set-aside was reduced to 0% for the 2008 harvest season. At the beginning of the year 2009, the set-aside measure was completely abandoned which was a result of the CAP Health Check (according to Council Regulation (EC) No 73/2009) (Gillings et al., 2010). In Hesse, the area of set-aside fields decreased continuously from the year 2003 onwards (HSL, 2009, 2011), this was a development reported also for the whole agricultural

area of Germany (BMELV, 2013). The regulation of 2009 managed also the payments entitlements for the former set-aside fields. In order to maintain the eligibility of support payments for such fields, it was introduced that farmers can receive the payments for certain afforested areas. In Hesse, this resulted in an increase of the non-agricultural area, since this land-use class comprises the afforested area, and thus UAL from 2008 to 2009 (see Table 3).

In our study region, permanent grassland primarily gets lost in the highly productive regions which are the lowlands and the floodplains in the south and the south-west and in the north. Here, intensive cultivation is practiced. Changes in land use are known to affect biodiversity which means agricultural changes towards intensification and abandonment are a driving factor in the loss of biodiversity (Gillings et al., 2010). Since biodiversity and ecosystem functioning are inseparably linked (Butler et al., 2007; BfN, 2015), it is of utmost importance to achieve continuity in the management of permanent grassland, preferably with non-intensive methods of cultivation (Austrheim and Olsson, 1999). Over recent decades, the European Union has installed several regulations to stop or to at least to reduce the loss and decrease of permanent grassland. This recent reform, the so called “greening”, is a measure of protection alongside the still existing agri-environment-climate schemes and contractual nature conservation programmes. Within the greening measures as part of pillar one of the CAP, farmers are obliged to comply with given maximum proportions for cultivated crops, i.e. crop diversification, to reserve at least 5% of the arable land as “ecological focus areas” and to preserve permanent grassland (according to Regulation (EU) No 1307/2013 of the European Parliament and of the Council). The extent to which these measures are suitable for the protection of permanent grassland is controversial and coming years will deliver a final result. The EU has defined 2012 as the reference year for the area of permanent grassland which should not be diminished which means that losses of previous years can most likely not be regained (Pe’er et al., 2014).

As our investigation demonstrates, the development of maize area is a significant factor in land-use change. In the study region, the area of maize increased by 13,144 ha from 2005 to 2010 and holds a proportion of 9.2% of arable land in 2010. Thus, in Hesse maize has become an important arable crop. However, the relevance of maize cultivation depends on the region. This means, in Hesse, depending on the region, the percentage of maize area varies considerably. These findings are confirmed by other studies in Germany which revealed that the proportion of maize area differs not only between the federal state but significantly within them (Wiehe et al., 2009; Breitenfeld, 2012; Kornatz, 2016). In this study, in Hesse maize is cultivated predominantly in municipalities of the south, of the east and in parts of the west. Here, livestock density is comparably low. Thus, livestock farming can not serve as an explanation for the maize area. But maize is also cultivated in municipalities in the north of Hesse which are regions of intensive land use. A possible explanation is that in these municipalities the livestock density is comparably high, but another reason for the increased proportion of maize area is surely the increased number of biogas plants which our study aimed to analyse. Biogas plants are located in regions with a higher percentage of maize area.



Yet, it has to be considered that they are also located in regions with a high livestock density. Since the variables distance to biogas plants as well as livestock density show significant correlations to maize area, our results corroborated the assumption that biogas plants, maize cultivation and livestock farming all affect each other. This means they can be seen like a “triangle” of mutual interaction.

Our study aimed at finding relationships between variables of agricultural land use and biogas plants and livestock density. By use of correlation and regression analysis, we found significant relationships between livestock density and maize area which means that these variables correlate with each other but depending on the region. Livestock density does not significantly correlate with the expansion of maize area. Additionally, we found some minor correlation between livestock density and the variable conversion of grassland. In contrast to the variable livestock density, biogas plants featured different relationships to the variables of agricultural land use. The correlations between biogas plants and maize area were weaker than the correlations between livestock density and maize. But the correlations of biogas plants to the expansion of maize area were significant and apparent at all spatial scales. Biogas plants also correlated significantly with the variable conversion of permanent grassland.

Thus, the hypothesis that biogas plants and livestock farming are drivers of land-use change but depending on the region could thus be confirmed as the results of correlation and multiple linear regression analysis revealed. The two independent variables could reliably describe the dependent variables maize area, expansion of maize area and conversion of grassland, but differing in its extent and in the spatial scale. Biogas plants could be used as an indicator for the proportion of maize area, yet livestock density is more suitable as a causal explanation due to higher  $b^*$ -coefficients in the regression equation. In contrast, the increase in biogas plants is more strongly associated with the expansion of maize. Therefore, the development of biogas plants in recent years contributed to the increase in maize area in Hesse. Additionally, biogas plants are often discussed in the context of effecting the conversion of grassland. In our study, this assumption could be proved, but only to a lower extent than expected. This finding is in line with another study conducted in German federal states (Laggner et al., 2014).

Maize cultivation has often been a matter of debate since maize cultivation might contribute to environmental decline, for example it causes erosion, can negatively affect the landscape scenery and requires high amounts of fertiliser. Especially the use of mineral fertiliser can be problematic like Jomaa et al. (2016) have revealed. The results of their study have shown that, by using a water quality model, the instream nitrogen loads will increase if the arable crops were converted to maize or if the amount of the applied mineral fertiliser will be risen. Thus, an increased maize cultivation in order to produce feedstock for biogas production might lessen the quality of water resources. Hence, the goal of a renewable energy production, motivated by environmental protection, can cause in return some environmental problems as the example of biogas production demonstrates. Thus, the fostering of energy crops by law is in contradiction to other regulations, for instance to the European Water Framework Directive (Directive 2000/60/EC) which aims at protecting waters and preventing them from further

deterioration by means of an effective water policy. However, maize cultivation can also have some positive effects on the environment. The existence of maize fields can also contribute to a greater crop diversity, for example on arable fields with a hitherto minor crop rotation (Wiehe et al., 2009). Furthermore, maize fields can be an alternative to abandoned fields which means maize cultivation can prevent agricultural landscapes from marginalisation. Thus, the effects of maize cultivation cannot be evaluated as positive or negative, but are site specific. Nevertheless, for maintaining high biodiversity the cultivation of maize or bioenergy crops in general is not a suitable substitute for natural and semi-natural habitats (Rowe et al., 2009). Bearing in mind that biodiversity targets which were set for 2010 were not achieved (CBD, 2010) and that the EU 2020 biodiversity strategy targets are strongly in danger of being missed (Admiraal et al., 2016; Cormont et al., 2016), it is necessary that changes in land use will be managed with explicit consideration of ecological compatibility.

Including ecological compatibility in the use of energy provided by biogas plants will be certainly necessary, since maize will be also in the future the dominant feedstock. As mentioned before, for the time period of our study in Hesse biogas plants were predominantly run by using silage maize (HMUELV, 2011b), and this was also the case in the following years. Currently, in Hesse 62% of the biogas is produced through silage maize (LLH, 2012). Other substrates like whole-crop-silage or sugar beets as well as municipal waste were utilised for the remaining proportion which comprises a lower extent. The usage of grass as a substrate is of a minor importance in Hesse since it is used very rarely and, if so, only the third or fourth cut (LLH, 2012). These conditions concerning biogas plants are reported in general for Germany (Lupp et al., 2014).

Another aspect concerning the ecologically compatible use of biogas plants is that both the number of biogas plants and their capacities have increased in recent years and will surely do so in the future. In our study, we found that a number of 135 biogas plants with a total capacity of 47,860 kW were installed. Their average capacity was 355 kW. In 2015, this number has increased to a total of 215 biogas plants with a total capacity of 101,064 kW, which means an average capacity of 470 kW (LLH, 2016). Contemporaneously, the area of silage maize reached 44,400 ha in 2015, and further increased to an area of 46,400 ha in the year 2016 (HSL, 2016a). Thereby, the former peak of the 1980s, in 1985 maize was cultivated on 42,900 ha in Hesse (HMUELV, 2011b), is exceeded. Since the number of cattle decreased for this time period, the numbers were 480,400 in May 2010 and 467,100 in May 2015 and 2016 (HSL, 2016b), it is reasonable to assume that the increase in the area of silage maize is due to the development of biogas plants. Thus, a higher number of biogas plants and additionally an increased average capacity will result in an increased feedstock production, which is especially maize. Consequently, the cultivation of silage maize will need management plans concerning environmental compatibility, for example to answer the question how much area of maize a region can tolerate?

The increase of the average capacity of biogas plants is not only related to possible environmental problems but should be considered as a further indicator for changes in maize

area. In our analysis, the relevant indicators for changes in land use were the distance to biogas plants and livestock densities. Considering the capacity of biogas plants did not further explain the dependent variables maize area, its expansion and conversion of permanent grassland. However, since the average capacity of biogas plants currently increases, it will be an important factor for land-use changes. Thus, future studies should investigate if the capacity of biogas plants can serve as an explanatory variable, too.

The data set of this study were data of the Integrated Administration and Control System (IACS). IACS data provide information on agricultural land use and also information on animal breeding. Thus, the thematic content of IACS data is rich (de Longueville et al., 2007). Since these data are collected annually and at field level, information on land use is up-to-date and at a highly disaggregated level (Nitsch et al., 2012). However, there are some limitations in the IACS data. Within the member states of the European Union, IACS data are collected differently. Every member state has its own system. For example, the spatial identification of the agricultural land-use unit is managed differently (Sagris et al., 2013). Another limitation of IACS data is that not all farmers apply for direct support payments. Consequently these fields are not included in IACS data which means that the actually utilised agricultural area is not completely recorded. Furthermore, it is possible that farmers declare their fields in the one year, and in another year they do not, although these fields are still cultivated. As a result, in IACS data the registered fields vary each year (Nitsch et al., 2012). However, it is reasonable to assume that IACS data mirror the major proportion of the utilised agricultural land because farmers need the direct support payments for an economic survival. In summary, until now IACS data represent the most complete and most current data set for agricultural land use concerning space and time as well as content. Therefore, despite the mentioned limitations, IACS data are unique in order to be used as an up-to-date time series of land use at field level which, consequently, enables them to be a basis for policy decisions in the future (Corbelle-Rico et al., 2012; Trubins, 2013; Rizzo et al., 2014). For example, IACS data could be used as the basis for offering targeted agri-environment-climate schemes (Lüker-Jans et al., 2016). Thus, the use of IACS data can be far beyond its originally planned intent (Tóth and Kucas, 2016).

The methodological concept of our study proved to be appropriate for analysing the relationships between the two independent variables and the three variables to explain since correlation analysis and multiple regression analysis are a suitable approach (Bürgi and Turner, 2002). Although  $R^2$  of the regression analyses are generally on a lower extent, which means that biogas plants and livestock farming are not of such a strong influence as we expected prior to our study, they are significantly associated with maize cultivation and conversion of permanent grassland. On the other hand,  $R^2$  will be always lower if the independent variables are distinctly correlated (Leyer and Wesche, 2007; Rudolf and Kuhlisch, 2008) which was the case in our study. Thus, the results of the regression analysis confirmed our assumption that biogas plants, maize cultivation and livestock breeding all affect each other. Nevertheless, for explaining land-use changes, additional factors might play an important role, too. In summary, this study revealed that biogas plants and livestock farming can be used as reliable indicators

for changes in land use, especially maize area and its expansion as well as conversion of permanent grassland.

## **4 Conclusion**

The purpose of our study was to analyse the temporal and spatial dynamics of permanent grassland and maize area and to find possible significant relationships between these two forms of land use and the existence of biogas plants as well as livestock density at different spatial scales. The example of our study region Hesse confirmed the general trends of intensification and marginalisation in agricultural land use as described for Europe. Our analysis revealed a decrease in permanent grassland while the area of maize increased contemporaneously. The correlations between maize area and its expansion as well as the conversion of permanent grassland to the existence of biogas plants were of a lower dimension but still significant. This was also true for livestock density. Thus, biogas plants feature a relationship especially to the increase of maize area of the recent years, whereas the relationship to the conversion of permanent grassland is only low. In contrast, livestock farming has a distinct relationship to maize area but not to its expansion, the relationship to converted grassland is also low. We conclude that biogas plants and livestock farming can serve as one potential indicator for land-use change.

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## References

- Admiraal, J.F., Musters, C.J.M., de Snoo, G.R., 2016. The loss of biodiversity conservation in EU research programmes: thematic shifts in biodiversity wording in the environment themes of EU research programmes FP7 and Horizon 2020. *J. Nat. Conserv.* 30, 12-18.
- Amon, T., Amon, B., Kryvoruchko, V., Zolltisch, W., Mayer, K., Gruber, L., 2007. Biogas production from maize and dairy cattle manure – Influence of biomass composition on the methane yield. *Agric. Ecosyst. Environ.* 118, 173-182.
- Austrheim, G., Olsson, E.G.A., 1999. How does continuity in grassland management after ploughing affect plant community patterns? *Plant Ecol.* 145, 59-74.
- Bürgi, M., Turner, M.G., 2002. Factors and processes shaping land cover and land cover changes along the Wisconsin River. *Ecosystems* 5, 184-201.
- BKG (Bundesamt für Kartographie und Geodäsie), 2011. Verwaltungsgebiete 1:250.000 (Administration Units 1:250,000). (accessed 15.09.2011) [http://www.geodatenzentrum.de/geodaten/gdz\\_rahmen.gdz\\_div](http://www.geodatenzentrum.de/geodaten/gdz_rahmen.gdz_div).
- BMELV (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz), 2013. Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland 2013 (Statistical Yearbook Concerning Feeding, Agriculture and Forest of the Federal Republic of Germany 2013). Landwirtschaftsverlag GmbH, Münster-Hiltrup. (accessed 03.12.2015) <http://www.bmelv-statistik.de/de/statistisches-jahrbuch/>.
- BfN (Bundesamt für Naturschutz), 2014. Grünland-Report. Alles im Grünen Bereich? (Grassland Report) Bundesamt für Naturschutz, Bonn. (accessed 02.07.2014) [http://www.bfn.de/0405\\_hintergrundinfo.html](http://www.bfn.de/0405_hintergrundinfo.html).
- BfN (Bundesamt für Naturschutz), 2015. Artenschutz-Report 2015. Tiere und Pflanzen in Deutschland (Species Conservation Report 2015. Animals and Plants in Germany). Bundesamt für Naturschutz, Bonn. (accessed 23.06.2015) [http://www.bfn.de/0302\\_artenschutz.html](http://www.bfn.de/0302_artenschutz.html).
- Biró, M., Czúcz, B., Horváth, F., Révész, A., Csátri, B., Molnár, Z., 2013. Drivers of grassland loss in Hungary during the post-socialist transformation (1987-1999). *Landscape Ecol.* 28, 789-803.
- Bracchetti, L., Carotenuto, L., Catorci, A., 2012. Land-cover changes in a remote area of central Apennines (Italy) and management directions. *Landscape Urban Plann.* 104, 157-170.
- Breitenfeld, J., 2012. Maisanbau 2010 (Cultivation of maize). *Statistische Monatshefte Rheinland-Pfalz* 02/2012, pp. 129-134. (accessed 27.11.2012) [http://www.statistik.rlp.de/no\\_cache/veroeffentlichungen/statistische-monatshefte/](http://www.statistik.rlp.de/no_cache/veroeffentlichungen/statistische-monatshefte/).
- Britz, W., Delzeit, R., 2013. The impact of German biogas production on European and global agricultural markets, land use and the environment. *Energ. Policy* 62, 1268-1275.
- Bruun, H.H., Fritzboeger, B., Rindel, P.O., Hansen, U.L., 2001. Plant species richness in grasslands: the relative importance of contemporary environment and land-use history since the Iron Age. *Ecography* 24, 569-578.
- Bundesnetzagentur, 2017. Biogasanlagen in Hessen 2010 (Biogas Plants in Hesse 2010). Bundesnetzagentur, Bonn (undated).
- Butler, S.J., Vickery, J.A., Norris, K., 2007. Farmland biodiversity and the footprint of agriculture. *Science* 315, 381-384.
- CBD (Secretariat of the Convention on Biological Diversity), 2010. Global Biodiversity Outlook 3., Montréal. (accessed 30.04.2016) <https://www.cbd.int/gbo3/>.
- Cabrera, A.P., 2015. The landscape of the dehesa in the Sierra Morena of Jaén (Spain) – the transition from traditional to new land uses. *Landscape Online* 43, 1-15.

- Chen, H., Marhan, S., Billen, N., Stahr, K., 2009. Soil organic-carbon and total nitrogen stocks as affected by different land uses in Baden-Württemberg (southwest Germany). *J. Plant Nutr. Soil Sci.* 172, 32-42.
- Conant, R.T., Paustian, K., Elliott, E.T., 2001. Grassland management and conversion into grassland: effects on soil carbon. *Ecol. Appl.* 11, 343-355.
- Corbelle-Rico, E., Crecente-Maseda, R., Santé-Riveira, I., 2012. Multi-scale assessment and spatial modelling of agricultural land abandonment in a European peripheral region: Galicia (Spain), 1956-2004. *Land Use Policy* 29, 493-501.
- Cormont, A., Siepel, H., Clement, J., Melman, T.C.P., WallisDeVries, M.F., van Turnhout, C.A.M., Sparrius, L.B., Reemer, M., Biesmeijer, J.C., Berendse, F., de Snoo, G.R., 2016. Landscape complexity and farmland biodiversity: evaluating the CAP target on natural elements. *J. Nat. Conserv.* 30, 19-26.
- DBV (Deutscher Bauernverband), 2010. Situationsbericht 2011. Trends und Fakten zur Landwirtschaft (Report of Situation 2011. Trends and Facts Concerning Agriculture). Deutscher Bauernverband, Berlin.
- DBV (Deutscher Bauernverband), 2012. Situationsbericht 2012/13. Trends und Fakten zur Landwirtschaft (Report of Situation 2012/13. Trends and Facts Concerning Agriculture). Deutscher Bauernverband, Berlin.
- DBV (Deutscher Bauernverband), 2014. Situationsbericht 2014/15. Trends und Fakten zur Landwirtschaft (Report of Situation 2014/15. Trends and Facts Concerning Agriculture). Deutscher Bauernverband, Berlin.
- de Longueville, F., Tychon, B., Leteinturier, B., Ozer, P., 2007. An approach to optimise the establishment of grassy headlands in the Belgian Wallon region: a tool for agri-environmental schemes. *Land Use Policy* 24, 443-450.
- Delzeit, R., Kellner, U., 2013. The impact of plant size and location on profitability of biogas plants in Germany under consideration of processing digestates. *Biomass Bioenergy* 52, 43-53.
- Delzeit, R., Britz, W., Holm-Müller, K., 2012. Modelling regional input markets with numerous processing plants: the case of green maize for biogas production in Germany. *Environ. Modell. Software* 32, 74-84.
- EC (European Commission), 2015. Integrated Administration and Control System (IACS). (accessed 02.11.2015) [http://ec.europa.eu/agriculture/direct-support/iacs/index\\_en.htm](http://ec.europa.eu/agriculture/direct-support/iacs/index_en.htm).
- ESRI, 2010. ArcGIS 10.0. ESRI, Redlands, CA, USA.
- Ericsson, K., Rosenqvist, H., Nilsson, L.J., 2009. Energy crop production costs in the EU. *Biomass Bioenergy* 33, 1577-1586.
- Ernault, A., Bureau, F., Poudevigne, I., 2003. Patterns of organisation in changing landscapes: implications for the management of biodiversity. *Landscape Ecol.* 18, 239-251.
- Freund, B., 2002. Hessen (Hesse). Klett-Perthes, Gotha, Stuttgart.
- Gellrich, M., Zimmermann, N.E., 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: a spatial statistical modelling approach. *Landscape Urban Plann.* 79, 65-76.
- Gillings, S., Henderson, I.G., Morris, A.J., Vickery, J.A., 2010. Assessing the implications of the loss of set-aside for farmland birds. *Ibis* 152, 713-723.
- Graß, K., 2005. Landwirtschaft in Hessen (Agriculture in Hesse). Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, pp. 41-44.
- HLNUG (Hessisches Landesamt für Naturschutz, Umwelt und Geologie), 2016. Umweltatlas Hessen (Environmental Atlas of Hesse). (accessed 31.07.2016) <http://atlas.umwelt.hessen.de/atlas/>.

- HLUG (Hessisches Landesamt für Umwelt und Geologie), Daten des Integrierten Verwaltungs- und Kontrollsystem für Hessen 2004-2010 (IACS Data for Hesse 2004-2010). Wiesbaden, Undated.
- HMUELV (Hessisches Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz), 2011a. Jahresagrarbericht 2011 (Annual Report of Agriculture 2011). HMUELV, Wiesbaden. (accessed 11.12.2013) [https://verwaltung1.hessen.de/irj/zentral\\_Internet?rid=zentral\\_15/zentral\\_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26\\_ic\\_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd](https://verwaltung1.hessen.de/irj/zentral_Internet?rid=zentral_15/zentral_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26_ic_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd).
- HMUELV (Hessisches Ministerium für Umwelt, Energie, Landwirtschaft und Verbraucherschutz), 2011b. Landwirtschaft in Hessen. Zahlen und Fakten 2011 (Agriculture in Hesse 2011) Print Consulting, Gladenbach. (accessed 11.12.2013) [https://verwaltung1.hessen.de/irj/zentral\\_Internet?rid=zentral\\_15/zentral\\_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26\\_ic\\_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd](https://verwaltung1.hessen.de/irj/zentral_Internet?rid=zentral_15/zentral_Internet/presse.jsp%3FuMen=9154bcb5-f8c9-6013-3e2d-c44e9169fccd%26_ic_menu=true%26all=true&uid=9154bcb5-f8c9-6013-3e2d-c44e9169fccd).
- HSL (Hessisches Statistisches Landesamt), 2003. Hessische Gemeindestatistik 2003. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2002 (Hessian Communal Statistics 2003). HSL, Wiesbaden.
- HSL (Hessisches Statistisches Landesamt), 2007. Hessische Gemeindestatistik 2003. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2002 (Hessian Communal Statistics 2003). HSL, Wiesbaden. (accessed 24.04.2014) <http://www.statistik-hessen.de/publikationen/download/496/index.html>.
- HSL (Hessisches Statistisches Landesamt), 2009. Statistisches Jahrbuch Hessen 2009/10. Band 1: Wirtschaft, Erwerbstätigkeit und Umwelt (Statistical Yearbook of Hesse 2009/2010. Volume 1: Economy, Employment and Environment). HSL, Wiesbaden. (accessed 19.05.2015) <http://www.statistik-hessen.de/publikationen/download/490/index.html>.
- HSL (Hessisches Statistisches Landesamt), 2010. Hessische Gemeindestatistik 2010. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2009 (Hessian Communal Statistics 2010). HSL, Wiesbaden. (accessed 24.04.2014) <http://www.statistik-hessen.de/publikationen/download/496/index.html>.
- HSL (Hessisches Statistisches Landesamt), 2011. Statistisches Jahrbuch Hessen 2011/ 12. Band 1: Wirtschaft, Erwerbstätigkeit und Umwelt (Statistical Yearbook of Hesse 2011/2012. Volume 1: Economy, Employment and Environment). HSL, Wiesbaden. (accessed 20.05.2015) <http://www.statistik-hessen.de/publikationen/download/490/index.html>.
- HSL (Hessisches Statistisches Landesamt), 2012. Hessische Gemeindestatistik 2011. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2010 (Hessian Communal Statistics 2011). HSL. (accessed 11.12.2013) <http://www.statistik-hessen.de/publikationen/download/496/index.html>.
- HSL (Hessisches Statistisches Landesamt), 2013. Statistisches Jahrbuch Hessen 2013/14. Band 1: Wirtschaft, Erwerbstätigkeit und Umwelt (Statistical Yearbook of Hesse 2013/2014. Volume 1: Economy, Employment and Environment). HSL, Wiesbaden. (accessed 19.01.2015) <http://www.statistik-hessen.de/publikationen/download/490/index.html>.
- HSL (Hessisches Statistisches Landesamt), 2015. Hessische Gemeindestatistik 2014. Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2013. (Hessian Communal Statistics 2014). HSL, Wiesbaden. (accessed 30.04.2015) <http://www.statistik-hessen.de/publikationen/download/496/index.html>.

- HSL (Hessisches Statistisches Landesamt), 2016a. Land- und Forstwirtschaft. Anbau ausgewählter Feldfrüchte auf dem Ackerland 2010 bis 2016. (Agriculture and forestry. Cultivation of selected crops on arable land 2010-2016). HSL, Wiesbaden. (accessed 05.02.2017) <https://statistik.hessen.de/zahlen-fakten/land-und-forstwirtschaft/land-und-forstwirtschaft>.
- HSL (Hessisches Statistisches Landesamt), 2016b. Land- und Forstwirtschaft. Rinderbestände der hessischen Rinderhalter 2010-2016. (Agriculture and Forestry. Cattle Stock of the Hessian Cattle Farmers 2010-2016). HSL, Wiesbaden. (accessed 05.02.2017) <https://statistik.hessen.de/zahlen-fakten/land-und-forstwirtschaft/land-und-forstwirtschaft>.
- Harrach, T., 2005. Die naturräumliche Gliederung und Naturraumtypen Hessens (Biogeographical Classification of Hesse). Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, pp. 27-30.
- Hopkins, A., Holz, B., 2006. Grassland for agriculture and nature conservation: production, quality and multi-functionality. *Agronomy Res.* 4, 3-20.
- Iverson, L.R., 1988. Land-use changes in Illinois, USA: The influence of landscape attributes on current and historic land use. *Landscape Ecol.* 2, 45-61.
- Jomaa, S., Jiang, S., Thraen, D., Rode, M., 2016. Modelling the effect of different agricultural practices on stream nitrogen load in central Germany. *Energy, Sustain. Soc.* 6, 1-16.
- Jungmann, W.W., Brückner, H., 2005. Die geologisch-geomorphologischen Grundlagen Hessens (Geologic-geomorphic basics of Hesse). Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, 7-11.
- Köhler, W., Schachtel, G., Voleske, P., 2012. Biostatistik. Eine Einführung für Biologen und Agrarwissenschaftler (Biostatistics. An Introduction for Biologists and Agronomists). Springer Spektrum, Berlin, Heidelberg.
- Kandziora, M., Dörnhöfer, K., Oppelt, N., Müller, F., 2014. Detecting Land Use And Land Cover Changes In Northern German Agricultural Landscapes To Assess Ecosystem Service Dynamics. *Landscape Online* 35, 1-24.
- Kantelhardt, J., Osinski, E., Heissenhuber, A., 2003. Is there a reliable correlation between hedgerow density and agricultural site conditions? *Agric. Ecosyst. Environ.* 98, 517-527.
- Kornatz, P., 2016. Ackerbauliche Landnutzungsänderung durch die Biogasproduktion in Deutschland. Eine quantitative, räumlich explizite Analyse der Wettbewerbsfähigkeit des Silo- und Körnermaisbaus unter Anwendung des Modells ProLand 2.0 (Agricultural Land-Use Change Through Biogas Production in Germany. A Quantitative, Spatially Explicit Analysis of the Competitiveness of the Cultivation of Silage and Grain Maize by Use of the Model ProLand 2.0). Dissertation. Justus-Liebig-Universität Gießen.
- Lüker-Jans, N., Simmering, D., Otte, A., 2016. Analysing Data of the Integrated Administration and Control System (IACS) to Detect Patterns of Agricultural Land-Use Change at Municipality Level. *Landscape Online* 48, 1-24.
- LLH (Landesbetrieb Landwirtschaft Hessen), 2012. Stand und Perspektiven des Energiepflanzenanbaus in Hessen. Bedeutung, Anbauverfahren, Nachhaltigkeit. (Situation and perspectives of the cultivation of energy plants in Hesse. Relevance, cultivation methods, sustainability). (accessed 30.04.2015) [https://verwaltung.hessen.de/irj/HMULV\\_Internet?rid=HMULV\\_15/HMULV\\_Internet/presse.jsp%3fuMen=7a9c53a0-9a47-01be-5926-3b5005ae75d5%26page=4%26pagesize=5%26attr\\_attributfilter\\_id=f3c702a0-a04a-0421-79cd-aad49d576194%26attr\\_attributfilter\\_val=%26getAttrValues=f3c702a0-a04a-0421-79cd-aad49d576194%26getAttrValuesCls=04b409f6-89c5-5401-e76c-d1505eb31b65&uid=7a9c53a0-9a47-01be-5926-3b5005ae75d5](https://verwaltung.hessen.de/irj/HMULV_Internet?rid=HMULV_15/HMULV_Internet/presse.jsp%3fuMen=7a9c53a0-9a47-01be-5926-3b5005ae75d5%26page=4%26pagesize=5%26attr_attributfilter_id=f3c702a0-a04a-0421-79cd-aad49d576194%26attr_attributfilter_val=%26getAttrValues=f3c702a0-a04a-0421-79cd-aad49d576194%26getAttrValuesCls=04b409f6-89c5-5401-e76c-d1505eb31b65&uid=7a9c53a0-9a47-01be-5926-3b5005ae75d5).



- LLH (Landesbetrieb Landwirtschaft Hessen), 2016. Anlagenübersicht und -entwicklung Hessen 2015. (General view and development of biogas plants in Hesse 2015). (accessed 05.02.2017) <https://www.llh.hessen.de/nachwachsende-rohstoffe-bioenergie/energetische-nutzung.html>.
- Laggner, B., Orthen, N., Osterburg, B., Röder, N., 2014. Ist die zunehmende Biogasproduktion die alleinige Ursache für den Grünlandschwund in Deutschland? – Eine Analyse von georeferenzierten Daten zur Landnutzung (Is the increasing production of biogas the sole reason for grassland loss in Germany? – An analysis of georeferenced data of land use). *Raumforschung und Raumordnung* 73, 195-209.
- Lewis, R.J., Pakeman, R.J., Angus, S., Marrs, R.H., 2014. Using compositional and functional indicators for biodiversity conservation monitoring of semi-natural grasslands in Scotland. *Biol. Conserv.* 175, 82-93.
- Leyer, I., Wesche, K., 2007. *Multivariate Statistik in der Ökologie. Eine Einführung (Multivariate Statistics in Ecology. An Introduction)*. Springer-Verlag, Berlin, Heidelberg.
- Lotz, K., 1995. *Einführung in die Geologie des Landes Hessen (Introduction to Geology of Hesse)*. Hitzeroth, Marburg, pp. p267.
- Lupp, G., Steinhäuser, R., Starick, A., Gies, M., Bastian, O., Albrecht, J., 2014. Forcing Germany's renewable energy targets by increased energy crop production: a challenge for regulation to secure sustainable land use practices. *Land Use Policy* 36, 296-306.
- Mollenhauer, K., 2005. *Das Klima in Hessen und im rheinland-pfälzischen Rheinhessen (Climate in Hesse)*. Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, 12-16.
- Nitsch, H., Osterburg, B., Roggendorf, W., Laggner, B., 2012. Cross Compliance and the protection of grassland – Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. *Land Use Policy* 29, 440-448.
- Osterburg, B., Nitsch, H., Laggner, B., Roggendorf, W., 2009. Auswertung von Daten des Integrierten Verwaltungs- und Kontrollsystems zur Abschätzung von Wirkungen der EU-Agrarreform auf Umwelt und Landschaft: Bericht für das F+E-Vorhaben "Naturschutzfachliche Bewertung der GAP-Effizienzsteigerung durch Nutzung bestehender Datenbestände", gefördert durch das Bundesamt für Naturschutz (BfN) mit Mitteln des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit (Evaluation of IACS data in order to assess the impacts of agricultural reform of the EU on environment and landscape). *Arbeitsberichte aus der vTI-Agrarökonomie* Nr. 07/2009.
- Pe'er, G., Dicks, L.V., Visconti, P., Arlettaz, R., Báldi, A., Benton, T.G., Collins, S., Dieterich, M., Gregory, R.D., Hartig, F., Henle, K., Hobson, P.R., Kleijn, D., Neumann, R.K., Robijns, T., Schmidt, J., Schwartz, A., Sutherland, W.J., Turbé, A., Wulf, F., Scott, A.V., 2014. EU agricultural reform fails on biodiversity. *Science* 344, 1090-1092.
- Pedroli, B., Elbersen, B., Frederiksen, P., Grandin, U., Heikkilä, R., Krogh, P.H., Izakovicová, Z., Johansen, A., Meiresonne, L., Spijker, J., 2013. Is energy cropping in Europe compatible with biodiversity? – Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. *Biomass Bioenergy* 55, 73-86.
- Pletsch, A., 1989. *Hessen. Bundesrepublik Deutschland und Berlin (West). Wissenschaftliche Länderkunden Band 8/III. (Hesse. Federal Republic of Germany and West Berlin)*. Wissenschaftliche Buchgesellschaft, Darmstadt.
- Prochnow, A., Heiermann, M., Plöchl, M., Linke, B., Idler, C., Amon, T., Hobbs, P.J., 2009. Bioenergy from permanent grassland – a review: 1. Biogas. *Bioresour. Technol.* 100, 4931-4944.
- Pykälä, J., 2003. Effects of restoration with cattle grazing on plant species composition and richness of semi-natural grasslands. *Biodivers. Conserv.* 12, 2211-2226.

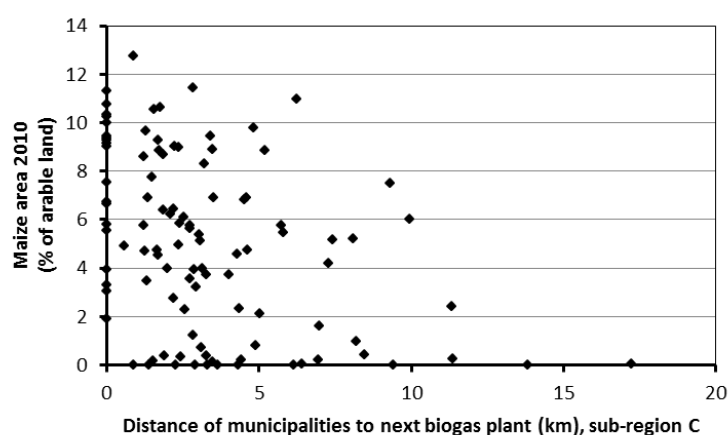
- Räsänen, A., Lensu, A., Tomppo, E., Kuitunen, M., 2015. Comparing conservation value maps and mapping methods in a rural landscape in southern Finland. *Landscape Online* 44, 1-21.
- Rösch, C., Skarka, J., Raab, K., Stelzer, V., 2009. Energy production from grassland – Assessing the sustainability of different process chains under German conditions. *Biomass Bioenergy* 33, 689-700.
- Rizzo, D., Martin, L., Wohlfahrt, J., 2014. *Miscanthus* spatial location as seen by farmers: a machine learning approach to model real criteria. *Biomass Bioenergy* 66, 348-363.
- Rowe, R.L., Street, N.R., Taylor, G., 2009. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renew. Sustain. Energy Rev.* 13, 271-290.
- Rudolf, M., Kuhlisch, W., 2008. *Biostatistik. Eine Einführung für Biowissenschaftler (Biostatistics. An Introduction for Bioscientists)*. Pearson, München.
- Söderberg, C., Eckerberg, K., 2013. Rising policy conflicts in Europe over bioenergy and forestry. *Forest Policy Econ.* 33, 112-119.
- Sabel, K.-J., 2005. *Die Bodenlandschaften Hessens (Soil landscapes of Hesse)*. Deutsche Bodenkundliche Gesellschaft. Exkursionsführer Band 105, 21-26.
- Sagris, V., Wojda, P., Milenov, P., Devos, W., 2013. The harmonised data model for assessing Land Parcel Identification Systems compliance with requirements of direct aid and agri-environmental schemes of the CAP. *J. Environ. Manage.* 118, 40-48.
- Schaldach, R., 2004. *Räumliche Modellierung der Dynamik von Landnutzung in Hessen und ihrer Wirkung auf die biologische Kohlenstoffspeicherung. Entwicklung eines GIS-basierten Modellsystems (Spatial Modelling of the Dynamic of Land Use in Hesse and of Its Impact on Biological Carbon Sequestration. Development of a GIS-based Modelling System)*. Dissertation. Universität Kassel.
- Schmitt, T., Rákossy, L., 2007. Changes of traditional agrarian landscapes and their conservation implications: a case study of butterflies in Romania. *Divers. Distrib.* 13, 855-862.
- Schulze Steinmann, M., Holm-Müller, K., 2010. Thünensche Ringe der Biogaserzeugung – der Einfluss der Transportwürdigkeit nachwachsender Rohstoffe auf die Rohstoffauswahl von Biogasanlagen (Thuenen rings of biogas production – the effect of differences in transport costs of energy crops in the choice of renewable resources by biogas plants). *GJAE (German J. Agric. Econ.)* 59, 1-12.
- Simmering, D., Waldhardt, R., Otte, A., 2013. Erfassung und Analyse der Pflanzenartenvielfalt in der "Normallandschaft" – ein Beispiel aus Mittelhessen (Registration and analysis of plant species diversity in the 'normal landscape' – an example of middle Hesse). *Berichte der Reinhold-Tüxen-Gesellschaft (RTG)* 25, 73-94.
- StatSoft. Inc., 2014. *STATISTICA for Windows. Version 12.0*. StatSoft. Inc., Tulsa, OK, USA.
- Stoate, C., Baldi, A., Beja, P., Boatman, N.D., Herzon, I., von Doorn, A., de Snoo, G.R., Rakossy, L., Ramwell, C., 2009. Ecological impacts of early 21st century agricultural change in Europe – A review. *J. Environ. Manage.* 91, 22-46.
- Svoboda, N., Taube, F., Kluß, C., Wienforth, B., Kage, H., Ohl, S., Hartung, E., Herrmann, A., 2013. Crop production for biogas and water protection – A trade-off? *Agric. Ecosyst. Environ.* 177, 36-47.
- Tóth, K., Kucas, A., 2016. Spatial information in European agricultural data management: requirements and interoperability supported by a domain model. *Land Use Policy* 57, 64-79.
- Tabachnick, B.G., Fidell, L.S., 2001. *Using Multivariate Statistics*. Allyn and Bacon, Boston.

- Troost, C., Walter, T., Berger, T., 2015. Climate, energy and environmental policies in agriculture: simulating likely farmer responses in southwest Germany. *Land Use Policy* 46, 50-64.
- Trubins, R., 2013. Land-use change in southern Sweden: before and after decoupling. *Land Use Policy* 33, 161-169.
- van Delden, H., Stuczynski, T., Ciaian, P., Paracchini, M.L., Hurkend, J., Lopatka, A., Shi, Y., Prieto, O.G., Calco, S., van Vliet, J., Vanhout, R., 2010. Integrated assessment of agricultural policies with dynamic land use change modelling. *Ecol. Modell.* 221, 2153-2166.
- Van Turnhout, C.A.M., Foppen, R.P.B., Leuven, R.S.E.W., Van Strien, A., Siepel, H., 2010. Life-history and ecological correlates of population change in Dutch breeding birds. *Biol. Conserv.* 143, 173-181.
- Wellstein, C., Otte, A., Waldhardt, R., 2007. Impact of site and management on the diversity of central European mesic grassland. *Agric. Ecosyst. Environ.* 122, 203-210.
- Wiehe, J., von Ruschkowski, E., Rode, M., Kanning, H., von Haaren, C., 2009. Auswirkungen des Energiepflanzenanbaus auf die Landschaft (Impacts of cultivation of bioenergy crops on landscape). *Naturschutz Landschaftsplan.* 41, 107-113.
- Wilson, J.B., Peet, R.K., Dengler, J., Pärtel, M., 2012. Plant species richness: the world records. *J. Veg. Sci.* 23, 796-802.

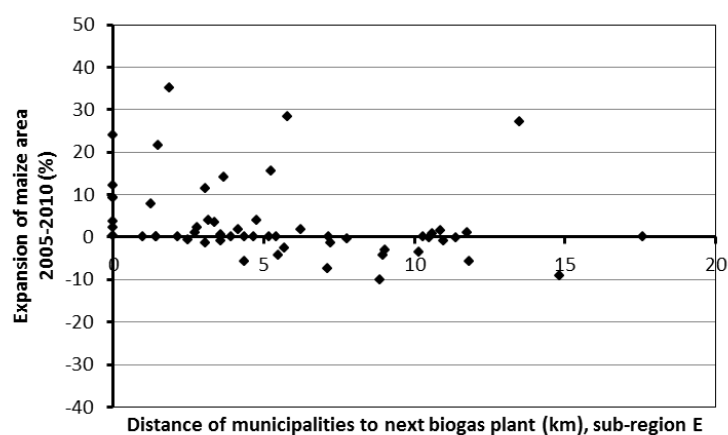
## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.agee.2017.02.023>.

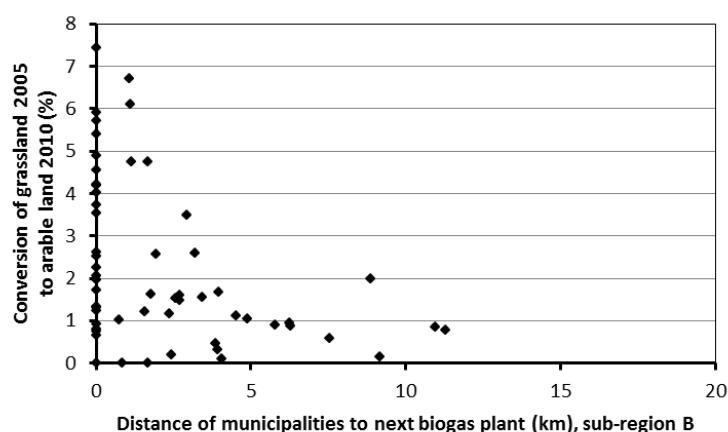
The following figures A1 to A6 show the relationships of biogas plants and livestock density to three variables of agricultural land use with the highest correlation coefficients.



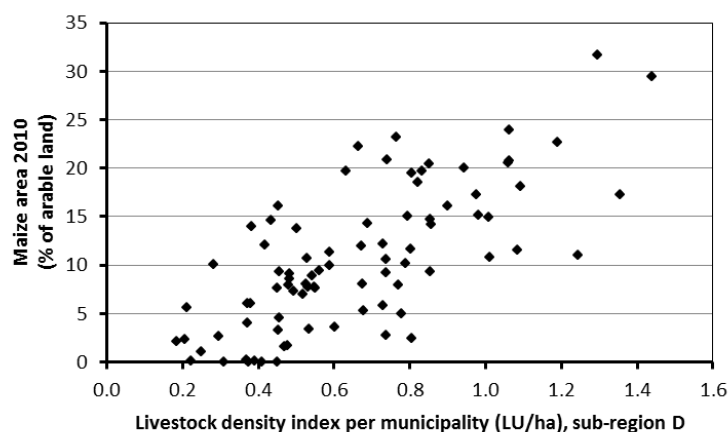
**Figure A1.** Relation between maize area and biogas plants for the year 2010 in the Hessian sub-region C (intermediate type).  $R = -0.42$  ( $p < 0.05$ ), based on Pearson's Correlation Coefficient.  $n = 104$ . The figure is based on non-log-transformed data.



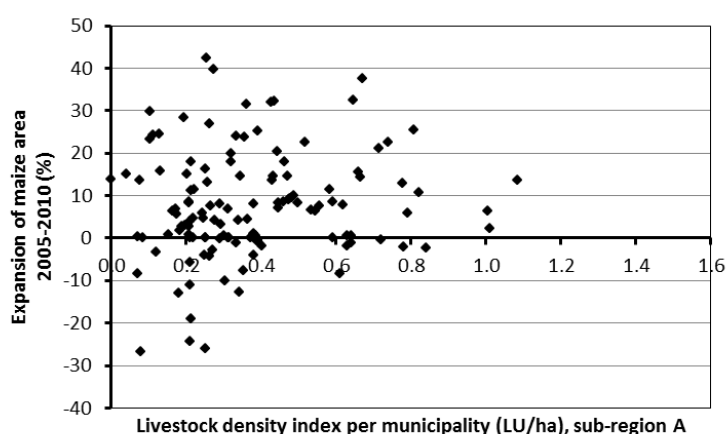
**Figure A2.** Relation between expansion of maize area and biogas plants for the years 2005 to 2010 in the Hessian sub-region E (grassland-maize type).  $R = -0.42$  ( $p < 0.05$ ), based on Pearson's Correlation Coefficient.  $n = 57$ . The figure is based on non-log-transformed data.



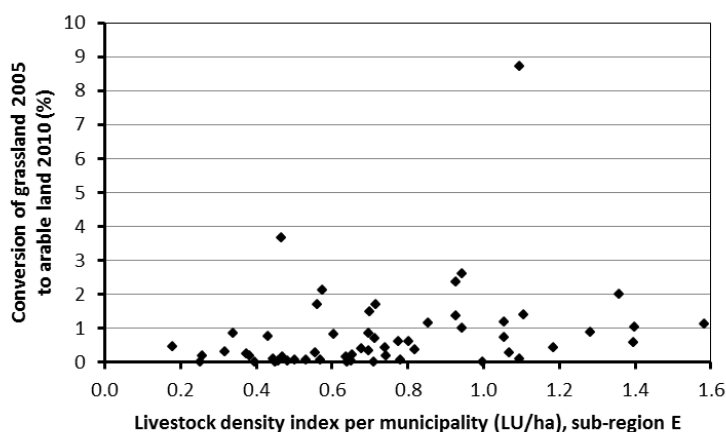
**Figure A3.** Relation between conversion of grassland to arable land and biogas plants for the years 2005 to 2010 in the Hessian sub-region B (maize type).  $R = -0.43$  ( $p < 0.05$ ), based on Pearson's Correlation Coefficient.  $n = 57$ . The figure is based on non-log-transformed data.



**Figure A4.** Relation between maize area and livestock density for the year 2010 in the Hessian sub-region D (grassland type).  $R = 0.66$  ( $p < 0.05$ ), based on Pearson's Correlation Coefficient.  $n = 85$ . The figure is based on non-log-transformed data.



**Figure A5.** Relation between expansion of maize area and livestock density for the years 2005 to 2010 in the Hessian sub-region A (arable land type).  $R = 0.18$  ( $p < 0.05$ ), based on Pearson's Correlation Coefficient.  $n = 125$ . The figure is based on non-log-transformed data.



**Figure A6.** Relation between conversion of grassland to arable land and livestock density for the years 2005 to 2010 in the Hessian sub-region E (grassland-maize type).  $R = 0.38$  ( $p < 0.05$ ), based on Pearson's Correlation Coefficient.  $n = 57$ . The figure is based on non-log-transformed data.

## Summary

Agricultural land use does not only produce agricultural goods, it also creates landscapes. Although natural factors are determining influences, it is the cultivation of land, especially the agricultural cultivation, which has caused a variety of heterogeneous landscapes. Naturally, central Europe would be a natural landscape with mainly forests. Since sedentism and the beginning agricultural cultivation, the forests were stubbed which created an open landscape. Subsequently, the species number of flora and fauna increased since the newly formed cultural landscape provided more habitats. Although some species became extinct, all in all biodiversity as well as the number of habitats and the genetic diversity grew significantly.

This positive effect lasted about till the beginning of the twentieth century. Afterwards, especially from the middle of the century onwards, modern intensive agricultural land use provoked serious concerns which is due to the usage of fertilisers, pesticides, irrigation as well as high-yield crops, a less diversified crop rotation, enlarged fields and the removal of boundary vegetation. Concurrently, many sites are threatened by abandonment. Both trends in agriculture, marginalisation and intensification, feature rather negative consequences for biotic and abiotic resources. Additionally, in Europe in the past years the cultivation of bioenergy crops has become an important component of agriculture. Due to the political and financial fostering, the agricultural area used for bioenergy crops has grown. Especially the production of biogas increased significantly. Since the biogas boom coincided with an expansion of the area of maize, it has to be analysed if biogas production is the causal reason for this expansion, and if biogas production contributes to the conversion of grassland.

Agricultural land use has always been a matter of change and, thus, will always be dynamic. Since European land use is expected to experience ongoing changes in the coming decades, a thorough understanding of past and recent land-use dynamics is essential in order to understand how agricultural land use might develop in the future, which consequently generates the basis for future management processes like agricultural policies.

Given this background, the present thesis analysed the regional differences of agricultural land use and land-use change. As described in two separate papers, this thesis aims at (i) developing a classification method to detect spatial and temporal differences of the patterns of agricultural land use (Chapter 2), and (ii) examining the area changes of permanent grassland and maize as well as analysing if there is a relationship of biogas plants and, for comparison, livestock farming to the changes in agricultural land use (Chapter 3).

The main data set were data of the Integrated Administration and Control System (IACS) containing information on agricultural land use for the years 2005 to 2010. The study region was the federal state Hesse which was chosen due to its various biogeographical regions comprising both marginal and intensively used agricultural landscapes.

The results of the first substudy (Chapter 2) revealed that changes in land use are obvious at the spatial level of sub-regions. With the help of k-means cluster analyses, five types of

agricultural land use patterns and dynamics (TLPDs) were detected which represent the different sub-regions. The TLPDs were characterised by physical landscape attributes (elevation, slope, temperature and precipitation) as well as by the intensity of livestock farming (expressed by livestock data, i.e. cattle and pig number, and livestock density index). In Hesse, the general trends of intensification and marginalisation were evident. The first two TLPDs A and B, which are the arable land type and the maize type, represent sub-regions with favourable physical conditions and therefore an intensive land use. They are dominated by arable land, in return the proportion of grassland is low. TLPD B additionally features a high proportion of maize area. The next sub-region, TLPD C, represents an intermediate type which means that the investigated variables of land use are at an average compared to the other sub-regions. In sub-regions of both TLPD D and E, the grassland type and the grassland-maize type, physical conditions are unfavourable for agricultural cultivation. Thus, these sub-regions belong to the marginal landscapes. Grassland is the predominant land use, and, consequently, the proportions of arable land are low. Surprisingly, these sub-regions feature a land-use change in favour of maize on arable land.

The analyses of the second substudy (Chapter 3) detected in a first step the area changes of permanent grassland and maize, both at the spatial level of Hesse as a whole and at the level of its 430 municipalities. In Hesse, permanent grassland has decreased, especially since 2007 this decrease is continuous. It primarily gets lost in the highly productive regions with intensive agricultural cultivation. In contrast, the maize area increased significantly. However, since the percentage of maize area differs considerably, its relevance for land-use change depends on the sub-region. Furthermore, the results of the second substudy also proved that there are statistically significant correlations between the existence of biogas plants to the exemplarily analysed variables of agricultural land use, i.e. maize area in 2010, expansion of maize area from 2005 to 2010, and conversion of grassland 2005 to arable land 2010. The relationships between maize area and its expansion as well as the conversion of permanent grassland to biogas plants were significant but only in some sub-regions and at a rather low level. In summary, biogas plants are drivers of land-use change but depending on the sub-region.

The underlying data set of this thesis, which are IACS data, proved to be most useful in analysing changes of agricultural land use. Since these data are collected annually and at field level, information on land use is at a highly disaggregated level. Furthermore, the thematic content is rich since they feature the cultivated crops as well as livestock numbers. Thus, despite some limitations like a low percentage of missing utilised agricultural area due to non-declaration, until now IACS data represent the most complete and most up-to-date data set for agricultural land use concerning space and time as well as content. Due to this fact, IACS data are predestinated as time series of land use, and which, consequently, could be used as a basis for policy decisions. Since a sustainable agricultural land use represents the demand as well as the challenge of the future, appropriate management schemes are definitely needed.



## Zusammenfassung

Die Landwirtschaft produziert nicht nur landwirtschaftliche Güter, sondern sie schafft auch Landschaft. Obwohl natürliche Faktoren von entscheidendem Einfluss sind, ist es die Landnutzung und insbesondere die Landwirtschaft, die eine Vielfalt von heterogenen Landschaften hervorgebracht hat. Natürlicherweise wäre Mitteleuropa eine vom Wald dominierte Naturlandschaft. Diese Wälder wurden seit der Sesshaftwerdung und der beginnenden Landwirtschaft gerodet, was zu einer Offenlandschaft führte. Das Artenspektrum von Flora und Fauna stieg daraufhin an, da die neu geformte Kulturlandschaft mehr Habitate aufwies. Obwohl einige Arten ausstarben, nahmen sowohl die Biodiversität als auch die Habitatanzahl und die genetische Vielfalt zu.

Dieser positive Effekt hielt bis zum Beginn des zwanzigsten Jahrhunderts an. Danach, insbesondere ab der Mitte des Jahrhunderts, verursachte die moderne intensive Landwirtschaft ernsthafte Bedenken hinsichtlich des Einsatzes von Düngern, Pestiziden, Bewässerung und auch aufgrund von hohen Erntemengen, einer reduzierten Fruchtvielfalt und der Beseitigung der Begleitvegetation. Gleichzeitig wurden viele Standorte von einer Nutzungsaufgabe bedroht. Beide Trends in der Landwirtschaft, Marginalisierung und Intensivierung, erzeugen eher negative Folgen für biotische und abiotische Ressourcen. Dazu kam, dass in letzter Zeit der Anbau von Bioenergiepflanzen ein wichtiger Bestandteil der Landwirtschaft in Europa wurde. Aufgrund der politischen und finanziellen Förderung ist die Fläche für Bioenergiepflanzen angestiegen. Insbesondere hat sich die Produktion von Biogas deutlich erhöht. Da der Biogasboom mit einer Zunahme der Maisflächen zeitlich zusammenfiel, muss analysiert werden, inwieweit die Produktion von Biogas die kausale Ursache für diesen Flächenzuwachs darstellt und ob sie zum Grünlandumbruch beiträgt.

Die Landwirtschaft war schon immer dem Wandel ausgesetzt und wird deshalb immer dynamisch sein. Zudem wird erwartet, dass die europäische Landwirtschaft in den kommenden Jahrzehnten anhaltende Änderungen erfahren wird, so dass ein tiefgreifendes Verständnis der vergangenen und jüngeren Landnutzungsänderungen notwendig ist, um zu verstehen, wie sich die Landwirtschaft in der Zukunft entwickeln könnte. Dies wiederum schafft die Grundlage für zukünftige Managementprozesse wie beispielsweise agrarpolitische Maßnahmen.

Vor diesem Hintergrund wurden in der vorliegenden Arbeit eine regional differenzierte Analyse der Landnutzung sowie deren Änderungen erstellt. Basierend auf zwei unterschiedlichen Publikationen war es Ziel dieser Arbeit, (i) eine Klassifikationsmethode zu entwickeln, mit Hilfe derer räumliche und zeitliche Unterschiede im Muster der Landnutzung bestimmt werden können (Kapitel 2) und (ii) sowohl die Flächenveränderungen von Dauergrünland und Mais zu untersuchen als auch zu analysieren, ob es eine Beziehung zwischen Biogasanlagen – und zum Vergleich zwischen der Viehwirtschaft – und den Veränderungen in der Landnutzung gibt (Kapitel 3).

Der Hauptdatensatz waren Daten des Integrierten Verwaltungs- und Kontrollsystems (InVeKoS), welches Daten zur Landnutzung für die Jahre 2005 bis 2010 enthielt. Untersuchungsgebiet war das Bundesland Hessen, das ausgewählt wurde aufgrund seiner vielfältigen geographischen Regionen, die sowohl marginale als auch intensiv genutzte Agrarlandschaften aufweisen.

Die Ergebnisse der ersten Teilstudie (Kapitel 2) zeigten, dass Veränderungen der Landnutzung auf der räumlichen Ebene von Subregionen nachweisbar sind. Mit Hilfe der k-means Clusteranalyse konnten fünf Typen der Landnutzungsmuster und der Landnutzungsdynamik (englische Abkürzung: TLPD) identifiziert werden. Diese fünf Typen entsprechen Subregionen. Die TLPDs wurden anhand von Standortparametern (Höhe, Neigung, Temperatur und Niederschlag) charakterisiert und auch anhand von Daten zur Intensität der Viehwirtschaft (Rinder- und Schweineanzahl, Viehdichte). In Hessen setzt sich der generelle landwirtschaftliche Trend von Intensivierung und Marginalisierung fort. Die ersten beiden TLPDs A und B, der Landnutzungstyp „Acker“ und der Landnutzungstyp „Mais“, sind Subregionen mit günstigen Standortbedingungen und deshalb einer intensiven Landwirtschaft. Ackerbau ist die vorherrschende Nutzungsart. Im Umkehrschluss ist der Anteil von Dauergrünland niedrig. TLPD B weist zusätzlich noch einen hohen Maisanteil am Ackerland auf. Die nächste Subregion TLPD C ist eine Art Zwischentyp, der sogenannte „durchschnittliche Landnutzungstyp“. Dies bedeutet, dass die untersuchten Landnutzungsvariablen im Vergleich zu den anderen Subregionen einen Mittelwert aufweisen. Weiterhin stellen die Subregionen von TLPD D als auch TLPD E den Landnutzungstyp „Dauergrünland“ und den Landnutzungstyp „Dauergrünland-Mais“ dar. Hier sind die Standortparameter ungünstig, weshalb diese Subregionen zu den marginalen Kulturlandschaften gehören. Die vorherrschende Landnutzung ist Dauergrünland. Folglich sind die Ackerflächenanteile niedrig. Überraschenderweise hat sich in diesen Subregionen die Landnutzung auf den Ackerflächen zugunsten von Mais gewandelt.

Die zweite Teilstudie (Kapitel 3) untersuchte in einem ersten Schritt die Flächenveränderungen von Dauergrünland und Mais und zwar auf der räumlichen Ebene sowohl von Hessen als auch von seinen insgesamt 430 Gemeinden. Die Ergebnisse zeigen, dass in Hessen die Dauergrünlandfläche abgenommen hat, insbesondere handelt es sich seit dem Jahr 2007 um eine kontinuierliche Abnahme. Vor allem in den hochproduktiven Regionen mit der intensiven Landwirtschaft geht Dauergrünland verloren. Im Gegensatz dazu hat die Maisfläche deutlich zugenommen. Dennoch unterscheidet sich der Flächenanteil von Mais erheblich, so dass seine Bedeutung je nach Subregion unterschiedlich ist. In einem zweiten Schritt wurde dargestellt, dass es statistisch signifikante Korrelationen gibt zwischen dem Vorhandensein von Biogasanlagen und den beispielhaft untersuchten Variablen der Landnutzung, d.h. Maisflächenanteil für 2010, Wachstum des Maisflächenanteil von 2005 bis 2010 und Umbruch von Dauergrünland aus 2005 zu Ackerland im Jahr 2010. Die statistischen Beziehungen von dem Maisflächenanteil und dessen Wachstum und von Dauergrünlandumbruch zu den Biogasanlagen waren signifikant aber nur in wenigen Subregionen vorhanden und zudem auf einem eher niedrigen Niveau. Zusammenfassend kann man sagen, dass Biogasanlagen

durchaus Veränderungen in der Landnutzung verursachen, was aber abhängig ist von der jeweiligen Subregion.

Der InVeKoS-Datensatz, auf welcher diese Studie basierte, war bestens geeignet, um Veränderungen der Landnutzung zu analysieren. Diese Daten werden jährlich und auf der Schlagebene erhoben, so dass die Informationen zur Landnutzung disaggregiert sind. Außerdem verfügen die Daten über einen umfassenden thematischen Inhalt, da sie Angaben zu Anbaufrucht und zu den Viehzahlen enthalten, so dass bis zum jetzigen Zeitpunkt die InVeKoS-Daten – trotz einiger Unschärfen wie beispielsweise eines niedrigen Prozentsatzes von nicht gemeldeten Flächen – der umfassendste und aktuellste Datensatz zur Landnutzung hinsichtlich räumlicher Bezugsebene, Zeit und Inhalt sind. Aufgrund dieser Tatsache sind InVeKoS-Daten hervorragend geeignet, um eine Abfrage des zeitlichen Verlaufs der Landnutzung zu erstellen, welche als Grundlage für Entscheidungen in der Politik genutzt werden könnte. Da eine nachhaltige Landwirtschaft sowohl Anforderung als auch Herausforderung für die Zukunft darstellt, sind hierfür geeignete Managementmaßnahmen eindeutig gefordert.

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