Land Use Policy 49 (2015) 53–64

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Transitions in European land-management regimes between 1800 and 2010

Martin Rudbeck Jepsen[a,*], Tobias Kuemmerle[b,c], Daniel Müller[b,c,d], Karlheinz Erb[e], Peter H. Verburg[f], Helmut Haberl[c,e], Jens Peter Vesterager[a], Maja Andrič[g], Marc Antrop[h], Gunnar Austrheim[i], Ismo Björn[j], Alberte Bondeau[k], Matthias Bürgi[l], Jessica Bryson[m], Gilles Caspar[n], Louis F. Cassar[o], Elisabeth Conrad[o], Pavel Chromý[p], Vidmantas Daugirdas[q], Veerle Van Eetvelde[h], Ramon Elena-Rosselló[r], Urs Gimmi[l], Zita Izakovicova[s], Vít Jančák[p], Ulf Jansson[t], Drago Kladnik[u], Jacek Kozak[v], Eva Konkoly-Gyuró[w], Fridolin Krausmann[d], Ülo Mander[x], John McDonagh[y], Jaan Pärn[x], Maria Niedertscheider[d], Olgerts Nikodemus[z], Katarzyna Ostapowicz[v], Marta Pérez-Soba[A], Teresa Pinto-Correia[B], Gintaras Ribokas[q], Mark Rounsevell[m], Despoina Schistou[C,D], Claude Schmit[D], Theano S. Terkenli[D], Aud M. Tretvik[E], Piotr Trzepacz[v], Angheluta Vadineanu[F], Ariane Walz[G,H], Edvin Zhllima[I], Anette Reenberg[a]

[a] Section of Geography, Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, DK-1350, Copenhagen K, Denmark
[b] Geography Department, Humboldt-University Berlin, Unter den Linden 6, 10099 Berlin, Germany
[c] Integrative Research Institute on Transformation of Human- Environment Systems (IRI THESys), Humboldt-Universität zu Berlin, Friedrichstraße 191, 10117 Berlin, Germany
[d] Leibniz-Institut für Agrarentwicklung in Transformationsökonomien (IAMO), Theodor-Lieser-Str. 2, 06120 Halle (Saale), Germany
[e] Institute of Social Ecology, Alpen-Adria Universität Klagenfurt, Schottenfeldgasse 29, 1070 Wien, Austria
[f] Faculty of Earth and Life Sciences, VU University Amsterdam, de Boelelaan 1087, 1081HV Amsterdam, The Netherlands
[g] Institute of Archaeology, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Ljubljana, Slovenia
[h] Department of Geography, Ghent University, Ghent, Belgium
[i] Norwegian University of Science and Technology, Museum of Natural History and Archaeology, Trondheim, Norway
[j] Karelian Institute, University of Eastern Finland, PL 111 80101 Joensuu, Finland
[k] Institut Méditerranéen de Biodiversité et d'Ecologie Marine et Continentale (IMBE), Aix Marseille Université, CNRS, IRD, Avignon Université, Aix-en-Provence, France
[l] Landscape Ecology Group, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
[m] Institute of Geography & The Lived Environment, School of Geosciences, University of Edinburgh, UK
[n] Institute of Geography and Spatial Planning, University of Luxembourg, Walferdange, Luxembourg
[o] Institute of Earth Systems, University of Malta, Malta
[p] Department of Social Geography and Regional Development, Charles University in Prague, Faculty of Science, Albertov 6, 128 43 Praha 2, Czech Republic
[q] Lithuanian Social Research Centre, Institute of Sociology, Department of Human Geography, Vilnius, Lithuania
[r] Universidad Politécnica de Madrid, Spain
[s] Institute of Landscape Ecology, Slovak Academy of Sciences, Stefanikova 3, P.O. Box 254, 814 99 Bratislava, Slovak Republic
[t] Department of Human Geography, Stockholm University, Sweden
[u] Anton Melik Geographical Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Ljubljana, Slovenia
[v] Department of GIS, Cartography and Remote Sensing, Institute of Geography and Spatial Management, Jagiellonian University, Krakow, Poland
[w] Institute of Forest Management and Rural Development, Faculty of Forestry, University of West Hungary, 9400 Sopron, Cházár András tér 1, Hungary
[x] Department of Geography, Institute of Ecology and Earth Sciences, University of Tartu, Estonia
[y] Discipline of Geography, School of Geography & Archaeology, Galway, Ireland
[z] Faculty of Geography and Earth Sciences, University of Latvia, Riga, Latvia

* Corresponding author.
E-mail addresses: mrj@geo.ku.dk (M.R. Jepsen), mueller@iamo.de (D. Müller), peter.verburg@vu.nl (P.H. Verburg), zita.izakovicova@savba.sk (Z. Izakovicova), egyuro@emk.nyme.hu (E. Konkoly-Gyuró), cschmit3@education.lu (C. Schmit), angheluta.vadineanu@g.unibuc.ro (A. Vadineanu).

http://dx.doi.org/10.1016/j.landusepol.2015.07.003

[A] Iterra, Wageningen University and Research Centre, The Netherlands
[B] ICAAM – Instituto de Ciências Agrárias e Ambientais Mediterrânica, Universidade de Évora, Portugal
[C] Directorate of Tourism Ports, Ministry of Tourism, 21 Andreou Dimitriou St., 17341 Athens, Greece
[D] epartment of Geography, University of the Aegean, University Hill, Mitiline 81100, Lesvos, Greece
[E] Department of History and Classical studies, Norwegian University of Science and Technology, Trondheim, Norway
[F] Department of Systems Ecology and Sustainability, Research Centre in Systems Ecology, Eco-diversity and Sustainability, University of Bucharest, Splaiul Independentei 91-95, 050095, Romania,
[G] Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany
[H] University of Potsdam, Potsdam, Germany
[I] Faculty of Economics and Agribussines, Department of Rural Development Policy and Economics, Agriculture University of Tirana, Koder Kamez, Tirana, Albania

ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form 20 May 2015
Accepted 3 July 2015

Keywords:
Land-use change
Long-term socio-ecological research
Land-management regimes
Institutional change
Technological innovation
Policy
Path dependency

ABSTRACT

Land use is a cornerstone of human civilization, but also intrinsically linked to many global sustainability challenges—from climate change to food security to the ongoing biodiversity crisis. Understanding the underlying technological, institutional and economic drivers of land-use change, and how they play out in different environmental, socio-economic and cultural contexts, is therefore important for identifying effective policies to successfully address these challenges. In this regard, much can be learned from studying long-term land-use change. We examined the evolution of European land management over the past 200 years with the aim of identifying (1) key episodes of changes in land management, and (2) their underlying technological, institutional and economic drivers. To do so, we generated narratives elaborating on the drivers of land use-change at the country level for 28 countries in Europe. We qualitatively grouped drivers into land-management regimes, and compared changes in management regimes across Europe. Our results allowed discerning seven land-management regimes, and highlighted marked heterogeneity regarding the types of management regimes occurring in a particular country, the timing and prevalence of regimes, and the conditions that result in observed bifurcations. However, we also found strong similarities across countries in the timing of certain land-management regime shifts, often in relation to institutional reforms (e.g., changes in EU agrarian policies or the emergence and collapse of the Soviet land management paradigm) or to technological innovations (e.g., drainage pipes, tillage and harvesting machinery, motorization, and synthetic fertilizers). Land reforms frequently triggered changes in land management, and the location and timing of reforms had substantial impacts on land-use outcomes. Finally, forest protection policies and voluntary cooperatives were important drivers of land-management changes. Overall, our results demonstrate that land-system changes should not be conceived as unidirectional developments following predefined trajectories, but rather as path-dependent processes that may be affected by various drivers, including sudden events.

1. Introduction

The past 150 years have witnessed drastic expansion and intensification of land use (Ramankutty and Foley, 1999; Rudel et al., 2009; Vitousek et al., 1997), providing societies with essential ecosystem services. At the same time, the stark environmental trade-offs between land-based production and environmental protection are increasingly becoming apparent, from climate change, to land degradation and biodiversity loss (Foley et al., 2005; Millennium Ecosystem Assessment, 2005). Designing and implementing effective policies to mitigate unwanted land-use outcomes and to navigate land systems towards more sustainable modes is a key challenge (Smith et al., 2014). Understanding the underlying technological, institutional and economic drivers of land-use change, and how they play out differently against the background of varying environmental, socio-economic and cultural contexts are pivotal in this regard.

Yet our understanding of the underlying drivers of land-system change remains partial, with three factors contributing to existing knowledge gaps. First, land-change science has so far focused mainly on analyzing the spatial determinants of land-use change, such as topography, soil quality, market access, and infrastructure development, which typically only provide indirect insights into peoples' land use decisions (Müller et al., 2013; Munroe and Müller, 2007; Gellrich et al., 2007; Mertens and Lambin 2000). Conversely, assessments exploring land-use decisions, such as agent-based models (Gaube et al., 2009; Jepsen et al., 2006; Parker et al., 2003), are usually data-hungry and constrained to small regions and predefined actors.

Second, land-change science has been biased towards analyzing conversions among broad land-cover classes, such as agricultural expansion or urban growth (Kuemmerle et al., 2013; Rounsevell et al., 2012). Changes in management intensity, such as in fertilizer use, machinery, labor, increases in yields, changing grazing pressure, or varying forest harvesting intensity have received less attention, in part because spatially distributed information is limited (Erb, 2012). This is problematic, because much change in land systems occurs along intensification pathways (Rudel et al., 2009; Ellis et al., 2013; Erb et al., 2013), and intensification is expected to become the dominant future land change (Tilman et al., 2011; Garnett et al., 2013).

Third, most studies assessing land-use change and its drivers have focused on relatively short time spans (i.e., a few decades), mainly because most studies rely on satellite images to map land changes as historical statistics are often unavailable (Singh et al., 2013). This is unfortunate, because many underlying drivers of land change tend to change in parallel when observed over short time periods, making attribution difficult (Geist et al., 2006; Jones et al., 2011). Likewise, the location, timing and character of drivers determine the pace of land-use change. For example, population growth typically changes slowly, causing gradual land transformations (Whitmore et al., 1990; Ellis et al., 2013), whereas economic crises (Sunderlin et al., 2001; Gasparri, et al., 2013), policy shifts (Müller and Munroe, 2008), institutional shocks (Niedertscheider et al., 2012), environmental disasters (Hostert et al., 2011) or warfare (Rudel et al., 2005) can alter land systems rapidly (Lambin and Meyfroidt, 2010; Dearing et al., 2010).

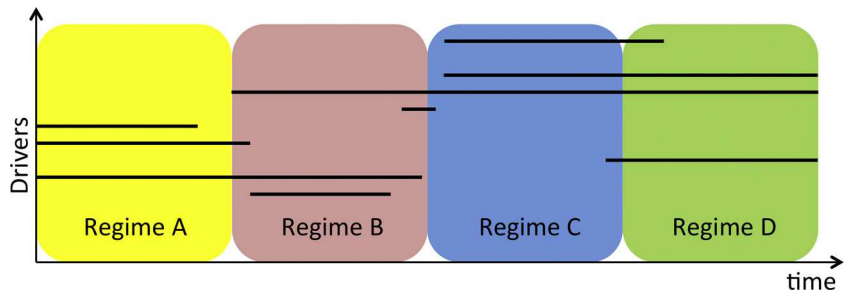

Fig. 1. Temporal co-occurrence of drivers of land-system change for a hypothetical country. Characteristic land-management regimes (colored boxes) were identified based on qualitative heuristic text analysis of the country narratives combined with information on the co-occurring sets of drivers (black lines).

Overall, limited generic knowledge is available on the pathways of land- use change and the role of land management (GLP, 2005; Turner et al., 2007). Longitudinal studies could therefore provide useful insights for revealing generic traits of the complex interplay of sudden and gradual drivers of land-system change.

We studied drivers of long-term agricultural land-use change at the country scale by constructing and analyzing national-level narratives of land-use change. Subsequently, we classified co-occurring drivers of change into broad prototypes of land management, referred to here as 'land-management regimes' (Fig. 1). We deliberately distinguished between *land use* and *land management:* Land use encompasses all socio-economic activities that control or alter flows of energy and matter on a given piece of land (e.g., agriculture, forestry and urban usage). We define land management by the combined legal, fiscal, and political or other institutional arrangements (e.g., land reforms, protection scheme, subsidies) that affect land use, as well as inputs of land, labor, and capital. The co-occurrence of certain levels of these aspects thus constitutes a certain land-management regime. Shifts between land-management regimes may result in typical land-use change processes, such as scale- enlargement, agricultural expansion, increasing agricultural outputs or afforestation. Likewise, a management regime may result in stability in land use, for instance, through environmental protection or subsidies. Methodologically, our approach thus resembles earlier analyses of trajectories of land-cover change (see, e.g., Mertens and Lambin 2000; Munroe and Müller 2007; Müller et al., 2011), but differs in (a) our focus on land use (as opposed to cover), (b) a much longer time scale, and (c) our qualitative narrative approach which allows to consider a much broader range of drivers to establish regimes.

Our overarching goal here was to examine the evolution of European land- management regimes for the past 200 years at the country-scale with the specific aims of (1) identifying major land-management regimes and shifts between them, (2) reveal important technological, institutional, and economic drivers of such shifts, and (3) elucidate spatial and temporal variations in land-management regimes. Europe is an interesting case for such analyses because of (a) the long and well-documented land use history, (b) the various shock events during the past 200 years, including changes in political settings, changing land ownership and warfare, (c) the exposure to common sets of policies during the past 60 years both in Western and Eastern Europe, and (d) the strong biophysical gradients from Boreal to Mediterranean, mountains to lowlands, and oceanic to continental climates. Our study was based on systematically compiled narratives on land-system developments which allowed us to identify drivers of land-use change, discern slow from fast drivers, and understand long-term, systemic changes in land management. While the land-cover history and landscape patterns of Europe have been described elsewhere (e.g., Meeus (1995) Gerard et al. (2010), Bakker et al. (2011), Fuchs et al. (2015)), we are not aware of a systematic analysis of long-term trends in drivers of land-system change across larger areas in Europe or elsewhere.

2. Methods

With a scope covering 200 years for 28 European countries and a focus on the ways in which society utilizes or transforms land, a key methodological challenge of our study was to identify the predominant drivers of land-use change at the national level. We obtained information on these predominant drivers by producing and analyzing narratives of major changes in land systems with regards to land-use change, including management changes, and their respective drivers. For each country, land-use experts were invited to compile a narrative, following the procedure outlined below. The complete narratives are available as supplementary information to this paper.

The core focus of the narratives was on understanding the main technological, institutional, and economic driving forces of land use through time, not on a detailed, data-rich account of the land-use changes that had happened throughout the study period. The use of narratives is well-suited for that purpose because they serve to standardize country-specific information along a common story line. Further, the narrative allows constructing a story with a beginning, middle and an end, with a focus not only on historical events but also on underlying causes (White, 1987), which we anticipated to be useful for revealing trajectories in land management. The literature contains numerous calls for exploring narratives for understanding historical changes in land systems (Costanza et al., 2007; Young et al., 2006), and some interesting examples of such research exist for smaller study regions (e.g. Burgos and Maass, 2004; Klepeis and Turner, 2001). However, we have not come across a single study synthesizing land change across larger areas using a narratives approach.

To obtain, analyze, and synthesize country-level narratives, we followed a five-step, iterative approach (Fig. 2):

1. We produced a sample narrative to illustrate the envisioned narrative style and structure. This sample summarized land management in Denmark for the last 200 years and was divided into sub-sections, reflecting periods when one or more underlying drivers of land change were dominant (e.g., "1880–1920: Transformation to the family farm"; "1920–1960: Intensification and consolidation of the family farm", and "1960—today: Specialization, European management and gradual, local extensification").
2. We used this template, along with a description of our research questions and the conceptual definition of land management regimes, to invite national land-use experts to author a narrative for their respective country, with sub-sections dividing the history into characteristic periods.

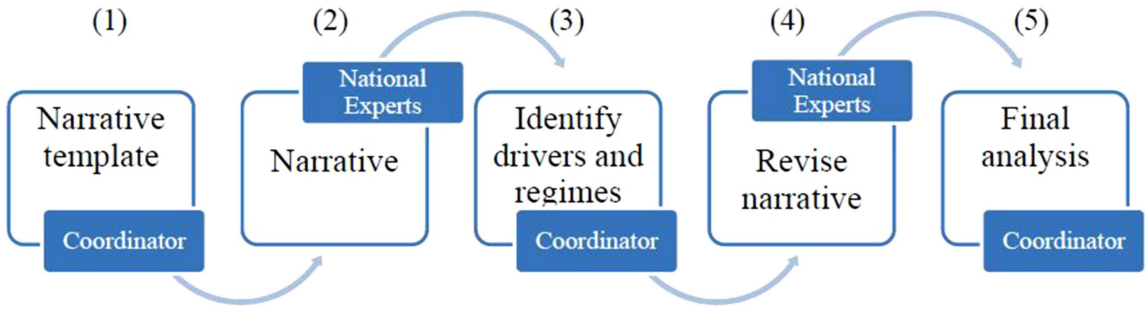

Fig. 2. Iterative data processing. A template narrative was sent out to the national land-use experts (1), who produced narratives for their respective countries (2). These narratives were analyzed for drivers of land-use change and land-management regimes (3). The authors revised their narratives according to the identified regimes (4), and a final analysis was done to synthesize drivers and regimes across countries (5).

3. The national narratives were then analyzed on two levels based on Qualitative Comparative Analysis (Rudel, 2008; Ragin, 1987; Young et al., 2006): (1) a driver-centered analysis, focusing on trends in major drivers, and (2) a regime-centered analysis identifying groupings of countries that represented similar land-management transitions. For the driver-centered analysis, a list of all drivers mentioned in the narratives was created, all narratives were then re-examined and the occurrence of drivers by country was noted in a cross-table. A driver was counted each time it was mentioned in different time periods within the same narrative (e.g., if the development of railways was mentioned several times as a driver in the period 1870–1920 for a given country, it was only counted once—but if railway development was mentioned again as a driver for the period 1950–1970 it was counted twice). This produced a frequency table of drivers across all narratives from which sets of temporally co-occurring drivers were identified (Table 1). Land-management regimes were then identified by combining information on these sets of drivers with a qualitative heuristic text analysis of the narratives, where all narratives were read, and direct or indirect mentioning of periods with particular land management were noted.
4. The major drivers and land-management regimes identified were distributed to the authors, asking them to align their narratives with these drivers and regimes. Specifically, authors were asked to apply regime names as section titles and to update the section texts to include information on the drivers related to the regimes, if relevant. In addition, authors were asked to supply quantitative information on the prevalence or timing of the drivers such as fertilizer use or the development of the number of tractors over time in a spreadsheet template. This quantitative information supported the delineation of regimes for the individual countries by revealing when and how fast changes in drivers occurred.
5. Finally, the revised narratives were re- analyzed as in step 3 to accommodate for new information emerging in the second round of narrative writing. This caused the identification of an additional land-management regime and inclusion of new drivers.

3. Results

A major result of our study was the compilation of 28 national narratives that were the basis for our subsequent analyses of drivers and land-management regimes. While too extensive to be shown here, this compilation provides a unique resource for exploring land-system change in Europe (see http://dx.doi.org/10.1016/j.

Table 1
Results of the driver-centered analysis. Numbers refer to the frequency with which the drivers were mentioned in the narratives. Drivers can be counted multiple times in a single narrative if mentioned in more than one time period.

Institutional		Technological		Economic	
Land reforms	58	Mineral Fertilizer	48	Demand for wood	24
Forest protection	39	Tractors	47	Production for the market	22
Voluntary cooperatives[a]	24	Drainage	37		21
Land reclamation	21	New crops (clover, potatoes,	33		
Subsidies, guaranteed prices	21	beets, feed crops in rotation)[c]		Specialization of agriculture	13
Protectionist policies	17				
Forced collectivization	17				
Nature conservation[b]	17	Roads	26	Shift from grain to dairy	10
Abolition of serfdom	15	Railroads	24	Cash cropping of certain crops[e]	9
Freeholders right to buy land	11	Irrigation	20		
Military operations	8	New plough types[d]	9		
Set-aside programs, agro-environmental schemes	8				
Shift from production to area based subsidies	8				
Land consolidation schemes	6				
Subsidies for organic farming	4				
Marshall plan, European recovery plan	4				
Tax on agricultural inputs	1				
Fascist land use paradigm	1				

[a] Includes establishment of cooperatives following political revolution in Portugal.
[b] 10 of these are from Lithuania.
[c] Includes introduction of higher quality seeds.
[d] This dominantly covers the iron-plated plough, but also the seed drill (UK).
[e] Wine, hops, fruits, vegetables, flowers, livestock.

landusepol.2015.07.003). Below, we summarize key insights from the synthesis analyses across all narratives. We first present the identified drivers of land-use change and their spatio-temporal occurrences. Next, quantitative data are displayed for those drivers where statistics were available. Finally, the land-management regimes identified are presented, followed by an analysis of their spatio-temporal patterns.

3.1. Drivers of land-use change

The analysis of drivers of land-use change mentioned in our narratives resulted in a total of 34 drivers that were mentioned in at least one narrative. We identified three groups of main drivers: technological (i.e., pertaining to agricultural production modes), institutional (i.e., drivers enforced by organizations at various levels), and economic (i.e., drivers with a direct impact on prices or mode of production) (Table 1). The choice of these driver groups was based on Geist and Lambin (2001). Within the group of technological drivers, mineral fertilizer was mentioned most frequently, followed by tractors, drainage and introduction of new crops. Land reforms were the most frequently mentioned driver in the institutional group, followed by forest protection policies and establishment of voluntary cooperatives. Land reforms included laws regulating privatization of land and (re) distributing land, often from clerical land, state land, or large private landholders to landless peasants or persons resettled due to changing borders. Finally, within the group of economic drivers, demand for wood, market integration and specialization of agriculture were ranked highest.

Some drivers where confined to distinct periods whereas others occurred throughout the entire study period. An illustrative example of the latter is the adoption of drainage: At the onset of the study period (1800–1850), drainage by traditional means (open ditches) was mentioned for Czechia, Finland, Italy, Norway, Poland, Slovakia and the UK. Around 1850, following the invention of the clay drain pipe which allowed subsurface drainage, application of this technology was mentioned in Austria, Czechia, Denmark, Estonia, Finland, France, Germany, Hungary Ireland, Italy, Lithuania, Luxembourg, Poland, Romania, Slovakia and Sweden. After 1945, drainage remained a driver in Albania, Estonia, Finland, Hungary, Latvia, Lithuania, the Netherlands, Romania, Slovakia, Slovenia and Switzerland. A contrasting example was the number of tractors, which were adopted in a confined period from 1910 to 1970 in all countries. A full cross-tabulation of drivers by country and period is available in the supplementary data (http://dx.doi.org/10.1016/j.landusepol.2015.07.003).

Our result also revealed temporally co-occurring drivers. A first cohort of drivers of land-use change (<1800–1850) comprised the introduction of new crops, drainage and land reforms. The land reforms included abolition of serfdom and rights for peasants to own land (often related to enclosure of former communal land) in Denmark, Belgium, France, Germany, parts of Latvia, the Prussian parts of Poland and Lithuania, Luxembourg and Norway. The new crops referred to the introduction of roots, tubers and leguminous fodder (beets, turnips, potatoes, clover) in a four-field rotational system, diffusing through Europe from Flanders (1500s) and England (1700s). Both these drivers were labor-intensive means of increasing production prior to introduction of mechanization and mineral fertilizers. Demand for wood products was also mentioned as an early driver of change.

A later cohort of coinciding drivers was the combination of drainage, mechanization, and mineral fertilizers. This wave of technological progress marked a new period, where capital became an important production factor. Open ditch drainage was supplemented with underground drainage by the invention of the clay drain pipe, phosphorous fertilizers such as Thomas phosphate and guano where marketed and horse-drawn reapers and threshing machines became available, soon to be challenged by machinery powered by fossil fuels. These capital inputs were adopted by manors or by small-holders forming voluntary cooperatives. In the period 1850–1900 this is exemplified by Denmark, France, Germany, Latvia and Luxembourg, while Austria, Czechia, Finland and Lithuania experienced this in the period 1900–1950. After 1945, tractors and mineral fertilizers were described in almost all narratives.

In addition to the identification of drivers, consistent time series data were obtained for (1) number of tractors per agricultural area (16 countries), (2) length of railroads per agricultural land (15 countries), and (3) consumption of mineral nitrogen per agricultural land (14 countries). Tractor density on agricultural land was used as a proximate indicator of input intensity in agriculture, reflecting capital investments. A group of mainly mountainous countries reported introduction of the tractor in the early 20th century, with a steep adaptation rate after 1950 and a persistent increase until present (Fig. 3a). These statistical data are in general agreement with the development described in the narratives and presented in the supplementary data. A set of former Eastern Bloc countries had substantially lower tractor densities, slower rates, and experienced the peak in tractor density around 1990 (Fig. 3b). For this group of countries, the narratives generally indicated importance of tractors earlier than the quantitative drivers reveal. Finally, Germany, Luxembourg and Denmark showed almost similar trends and levels of tractor densities over time, with uptake beginning around 1950 and a peak in tractor density around 1980 (Fig. 3c).

Railroad density was interpreted as an indicator of access to urban markets for agricultural producers and for the rural population to migrate to urban centers. A group of early adopters spanned across Europe with highest uptake rates until the 1920s, followed by slight increases or even decrease in the rail density (Fig. 3d). Fig. 3e depicts five late-starter countries (Albania, Latvia, Lithuania, Poland and Slovakia), while the last group exhibits a rapid rate of construction and early stagnation (around 1920) (Fig. 3f). No clear relation was found between the groups of early/late adopters of railroads and the countries reporting early or late engagement in the market economy in the narratives.

Like tractor density, mineral nitrogen (N) fertilizer use per hectare of agricultural land is an indicator of input. The use of mineral N took off after 1945 when particularly the countries of the former Eastern Bloc showed high rates of adoption, reaching an application of approximately 100 kg/ha around 1965, peaked in the late 1970s and declined strongly towards 1990–2000 (Fig. 3g). Curiously, this group overlaps with the countries in Fig. 3b that had low uptake of tractors per agricultural land.

3.2. Land-management regimes

The analysis of the 28 narratives allowed identifying seven distinct land-management regimes characterized by particular land-system changes and the prevalence of specific drivers of change (Table 2).

3.2.1. Era of Peasantry

Most of the narratives depart in the description of a 'traditional' land use system. We identified this period as a land-management regime dominated by feudal structures, low technological input and often some version of usufruct rights to village land. This regime was characterized by limited market access (due to lacking infrastructure, but also because urbanization had not taken off) and production was mainly oriented towards subsistence. This regime also covers the *latifundia* found in Southern Italy, Spain, and Portugal, where vast tracts of land where owned by few landlords

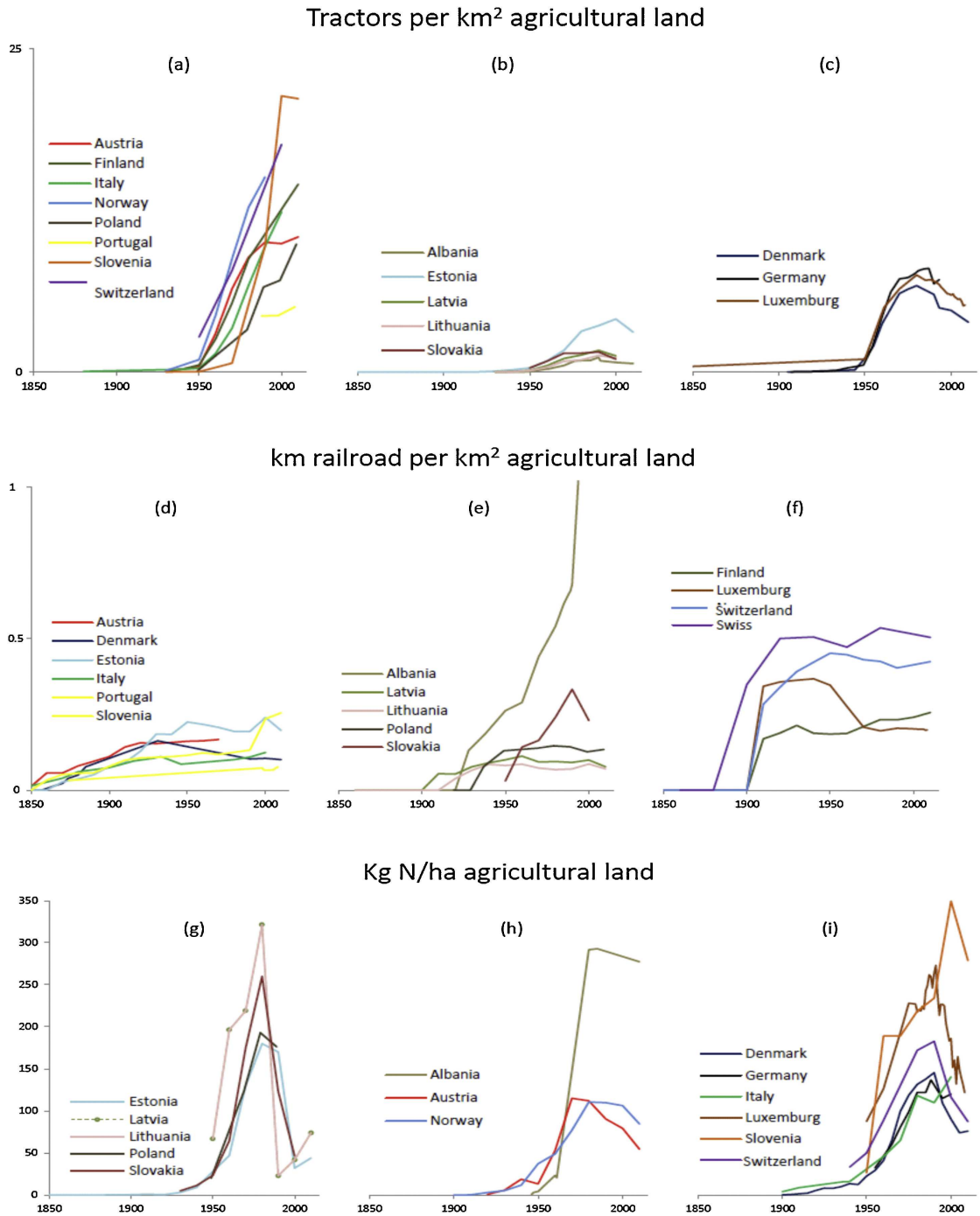

Fig. 3. Statistical data on technological drivers of land-use change, standardized by agricultural area. Number of tractors and kilograms of synthetic nitrogen are indicators of input intensity. Railroad length is a proxy of market accessibility. Countries are grouped to document relatively homogeneous patterns of change for each indicator across groups of countries.. (a) Mainly montane countries where tractor densities are still increasing. (b) Former eastern European countries with relatively low tractor densities, which stabilized during the 1970s and have decreased since the 1990s. (c) Western European countries where tractor densities have decreased since the 1980s, perhaps due to structural adjustment. (d) Early establishers of railroads. (e) Countries where railways were established relatively late, mostly Eastern European countries. (f) Mainly montane countries with early and rapid railway development followed by stagnation. (g) Eastern European countries where nitrogen (N) used peaked around 1980. (H) Austria's use of N peaked early, around 1960, while Norway followed around 1980, similar to Albania. (i) Western European countries where N use peaked around 1990.

and managed with very low inputs, or left unmanaged. Labor was abundant and labor costs were low due to a large group of landless peasantry.

3.2.2. *Innovations and Rights*

With the abolition of serfdom, rights of peasants to own land were established. Often, land reforms also granted land from the state, monasteries, churches and manors to landless peasants. In countries where agricultural production was based on three-field rotation systems coordinated by village institutions, privatization of land led to enclosure of fields and to the introduction of new crops such as alfalfa, clover, beets and turnips in a multi-field rotation. Increasing use of fossil fuels allowed for better steel manufacturing and the iron-plated plough was introduced.

Table 2
Drivers and characteristics of the identified land-management regimes

Regime	Characteristics	Drivers and/or conditions		
		Technological	Institutional	Economic
Era of Peasantry	Land owned by crown, nobility, state and religious organizations Feudal structures Tenants farm village land using three-field rotation with fallowing Commons for grazing Subsistence production	Low-tech	Feudal society Lack of private land rights	Few urban centers—low demand for agricultural products Limited access to markets
Innovations and Rights	Enclosure of fields Multi-field rotation Agricultural expansion Subsistence production	Improved ploughs New crops	Private land rights Land reforms	Few urban centers – low demand for agricultural products Limited access to markets
Intensification	Industrial processing (dairy, meat) Specialization (in some countries) Land reclamation Agricultural expansion Agricultural intensification	Centrifugal separator Cool storage rooms Threshers Harvesters Improved ploughs Motorization Clay drainage pipe Mineral fertilizer	Private land rights Land reforms Voluntary cooperatives Protectionism in some countries	Urban markets create demand for agricultural products Increased access to markets Emerging (world) market integration
Industrialization	Commercial farming Specialization Larger fields, fewer borders Agricultural intensification	Motorization Mineral fertilizers Irrigation	EU policies to ensure self-sufficiency Guaranteed prices – production-based subsidies	World market integration
Collectivization	Commercial farming Specialization Larger fields, fewer borders Agricultural intensification	Motorization Mineral fertilizers	Land reforms Collectivization Guaranteed prices – production-based subsidies	Centrally planned economy
De-intensification and Commercialization	Polarization of land uses Commercial farming Specialization Larger fields, fewer borders Agricultural de-intensification Abandonment	Motorization Mineral fertilizers Irrigation	Land reforms	Market economy
Environmental Awareness	Polarization of land uses Intensive vs. extensive/ abandonment/ organic farming Larger fields, fewer borders Declining agricultural work force Goal-oriented land management	Motorization Mineral fertilizers Precision farming Irrigation	Agro-environmental schemes Limits on fertilizer applications Area-based subsidies	World market integration

3.2.3. *Intensification*

This land-management regime is characterized by the introduction and uptake of new technologies (i.e., new machinery, clay drainage pipe). Mineral fertilizers such as Chilean nitrate, potash, basic slag, superphosphate, and later urea were developed and spurred processes of agricultural expansion and intensification. This development coincided with industrialization and urbanization, creating a market for surplus production of smallholder farms and contributing to the shift to market-orientated production. To meet demands from urban markets, which were now accessible due to railroad and road expansion, farmers in many countries shifted from producing grain to higher-value farming systems based on livestock and dairy production. Investments in modern technology were sometimes facilitated through participation in voluntary cooperatives, for instance dairy plants, abattoirs and shared cool storage rooms. The land reforms of *Innovations and Rights* continued with clerical and manorial land being seized by the state and granted, rented or sold to smallholders, often in parcels <10 hectares. In some cases (e.g., in Germany), the rural exodus led to arable land being converted to more extensive uses or abandoned.

3.2.4. *Industrialization*

This regime is in all aspects a full implementation of the management practices initiated in the *Intensification* regime. The *Industrialization* regime represents full adoption of commercial farming specialized in crop or livestock production, including structural changes in agriculture towards fewer, but larger farms and larger fields, which led to drastic changes in the agricultural landscapes. Farms were increasingly oriented towards the world market for both imports of inputs and technology and exports of agricultural produce. While mineral fertilizers and motorization were gradually introduced during *Intensification*, the uptake of both drivers increased dramatically during *Industrialization* (Fig. 3).

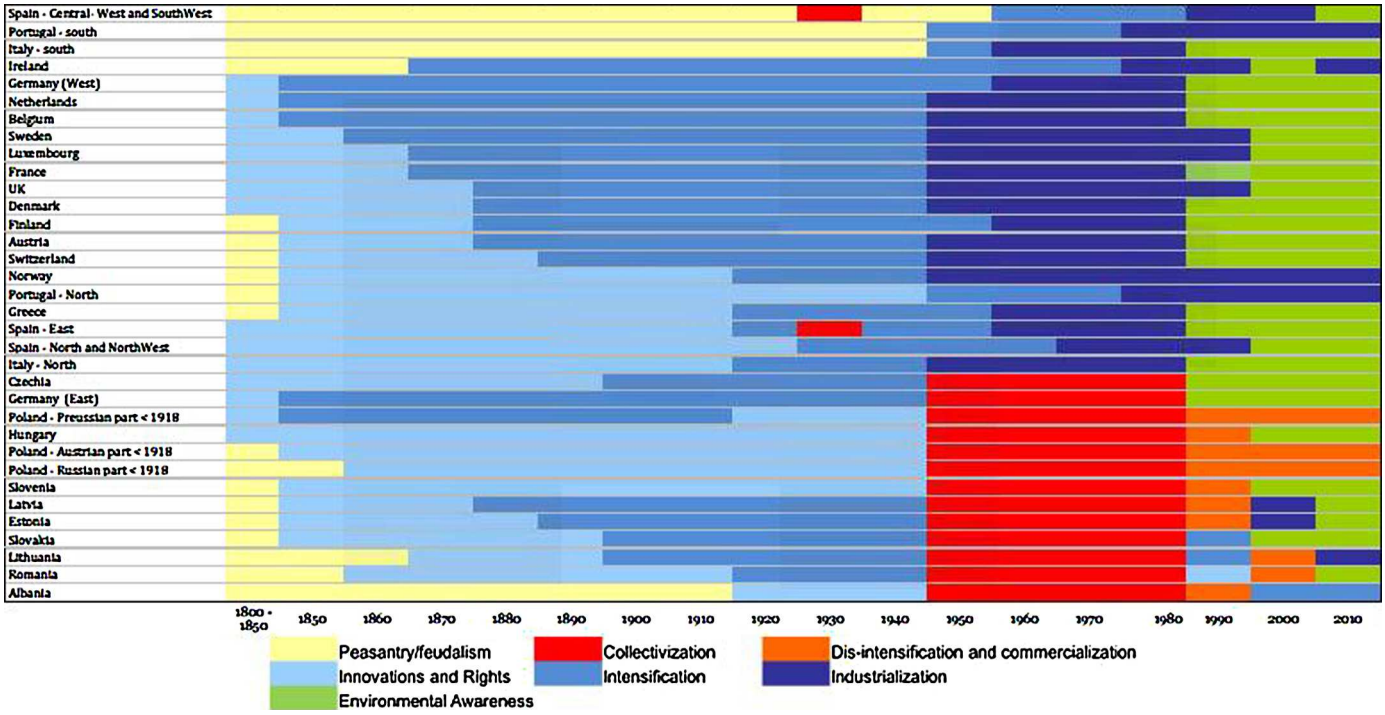

Fig. 4. Spatio-temporal distribution of land management regimes across Europe from 1800 to 2010. Countries are ordered to highlight similarities in regime shift patterns between countries. Due to large internal biophysical variation, Spain, Portugal, and Italy were split into distinct regions. For historical reasons, Poland was divided into an Austrian, a Prussian, and a Russian region until 1920.

3.2.5. Collectivization

Between 1945 and 1991, the land management regime in the Eastern Bloc (including the communist states of Albania and Slovenia as part of former Yugoslavia) shared some of the characteristics of the *Industrialization* regime described above: throughout this period, agricultural technologies were motorized, the use of mineral fertilizers exploded, and farm and field sizes increased. However, while this development in Western Europe was driven by a combination of market forces and institutionally determined economic incentives, in the Eastern bloc it was driven by a centrally-planned economy through land reforms seizing and redistributing farmland—in particular from larger landowners—and the establishment of large collective and state farms.

3.2.6. De-intensification and commercialization

The collapse of the Eastern Bloc after 1989 caused considerable changes in the land management of the former socialist countries. State farms and collectives were dissolved; land reforms were enacted to reinstate private property rights to land either through distribution of the land to persons working in agriculture or through restitution to historical owners. Many original owners, however, were absent (living in cities), old or without funds or know-how to operate, maintain or invest in modern machinery. This led to a bifurcation in land use: intensive cultivation continued, but on commercial premises, with large agro-companies buying former collectives or state farms on the one hand, alongside an expansion of low-intensity, mainly subsistence-oriented farming as well as widespread agricultural abandonment of marginal land on the other hand. The management of the low-intensity farms resembled the *Innovations and Rights* regime as well as the *Intensification* regimes: land reforms granted land to smallholders focusing on subsistence farming with low degrees of mechanization and mineral fertilizer inputs.

3.2.7. Environmental awareness

The development since 1990 has been influenced by an increasing awareness of the environmental impacts of agricultural production, in particular emissions of nutrients to the aquatic environment and the use of pesticides. Agro-environmental policies to curb emissions and reduce surplus production were implemented, and area-based subsidies replaced production-based subsidies in the Common Agricultural Policy of the EU. However, even though this trend is important, high-input, intensive agriculture continuous to dominate. Together, this often leads to a process of polarization, with intensifying land use co-occurring with de-intensification or even abandonment in the same landscape.

3.3. Distribution of regimes in space and time

All countries we studied progressed through sequences of land management regimes (Fig. 4). From the onset of the 19th century, the *Era of Peasantry* gradually yielded to the *Innovations and Rights* regime (Fig. 5a). In montane regions, as well as in many of the countries associated with the Austro-Hungarian Empire, the shift from the *Era of Peasantry* to *Innovations and Rights* took place around 1850 (Fig. 5b). In Southern Europe and areas under Ottoman influence, *latifundia* or *chiftlik* systems sustained the *Era of Peasantry* regime well into the 20th century.

The *Innovations and Rights* regime was gradually replaced by the Intensification regime in most countries, with the first adopters of the *Innovations and Rights* regime typically being the first to transit to *Intensification* (Fig. 5c). Later adopters tended to be found at the geographical periphery of the study area (Fig. 5d). By 1945, most countries fell under the Intensification regime, except Poland (characterized by traditional farming methods and low agricultural yields), Hungary (where agricultural intensification stagnated after the collapse of the Austro-Hungarian Monarchy in 1918), Albania (where land reforms and agricultural expansion occurred at a slow

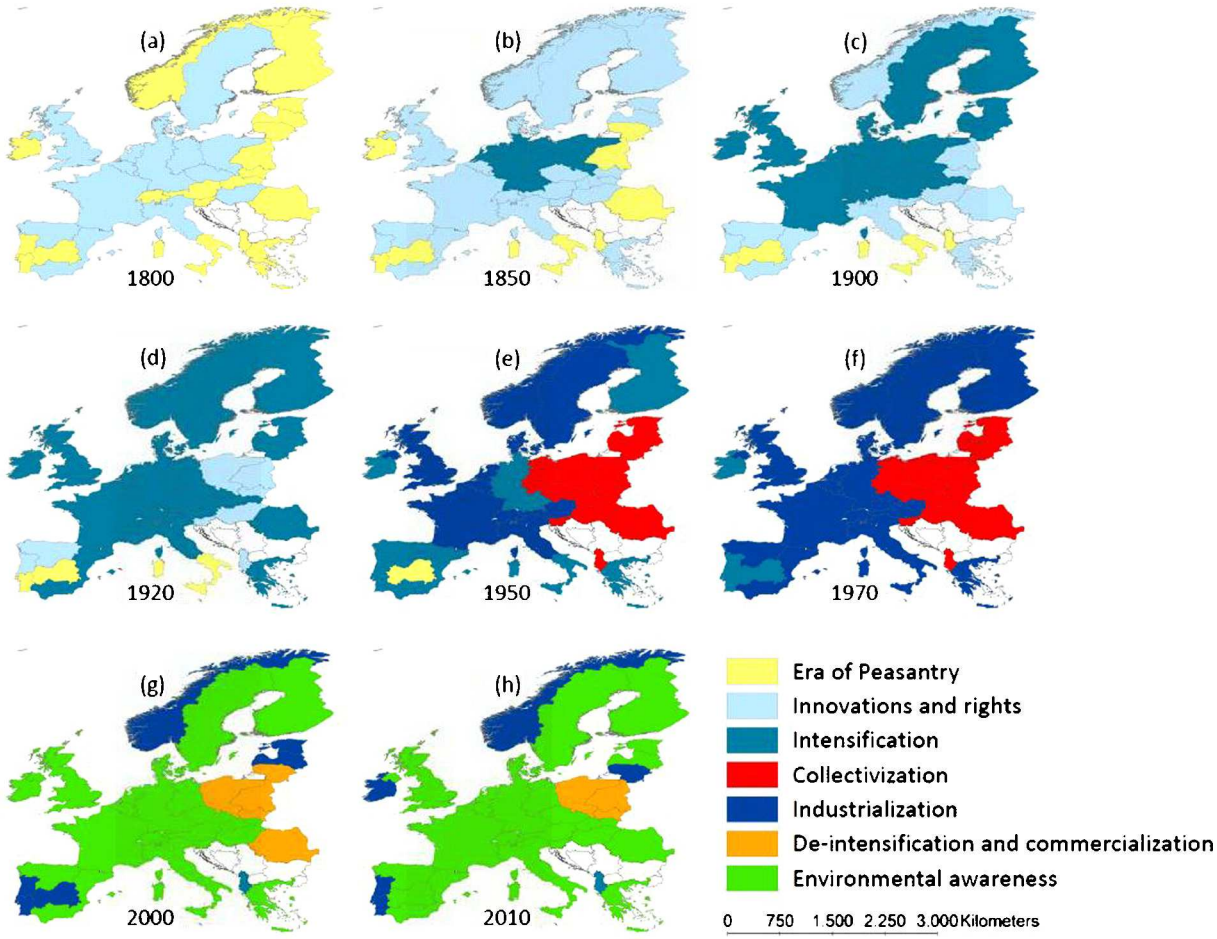

Fig. 5. Distribution of land-management regimes in different years between 1800 and 2010. See text for description of regimes.

pace), North Portugal (where traditional, mixed farming persisted), and Central and Western Spain (where latifundia still dominated).

With the end of World War II, land-management regimes changed markedly. Large parts of Western Europe entered the *Industrialization* regime, and only Ireland, Portugal and Central Spain had not made the transit from *Intensification* to *Industrialization* by 1970 (Fig. 5f).

Throughout the Eastern Bloc, the emergence of socialism resulted in the *Collectivization* regime (Fig. 5e). Yet, despite differences in land tenure and economic systems between Europe's East and West, policies on both sides of the Iron Curtain aimed to increase production by intensifying land use and farm specialization into either livestock or plant production took place at the expense of mixed farming. Only Portugal, Ireland, and Central Spain remained in the *Intensification* regime until 1980 or even 1990.

The *Collectivization* regime came to a sudden end in 1990 when the Soviet Union broke down. The collapse of socialism also had diverse effects such as in Romania where many areas de-intensified and are to date dominated by small semi-subsistence holdings, lacking incentives for investing into mechanization, intermediate inputs, and into maintenance of irrigation systems. Although commercial and agricultural societies emerged, the country characteristics and management drivers resembled those of the *Innovations and Rights* regime. Lithuania and Slovakia shifted to the *Intensification* regime. In Lithuania, stock companies were allowed in 1993, but with a very low rate of adoption. Albania, Estonia, Latvia, Slovenia, Poland, and Hungary entered a dualistic regime, where *De-intensification and Commercialization* co-existed, allowing private companies to acquire collectives or state farms, while smallholders worked the many small, fragmented farm holdings. After a decade, Romania and Lithuania entered the *De-intensification and Commercialization* regime in 2000, Latvia and Estonia shifted to *Industrialization*, Albania shifted from *Innovations and Rights* to *Intensification,* Poland remained in the *De-intensification and Commercialization* regime and Hungary, Slovenia and Slovakia entered *Environmental Awareness* (Fig. 5g).

With the exceptions of Portugal, Greece, and Ireland, the *Industrialization* regime ceased around 1990 across Western Europe, and *Environmental Awareness* increasingly shaped land use (Fig. 5g and h). Note, however, that negative environmental effects of agriculture are not necessarily absent in the *Environmental Awareness* regime. Likewise, the environmental awareness regime was often also characterized by an increasing displacement of land use outside the EU's boundaries (Kastner et al., 2014), thereby outsourcing environmental footprints.

4. Discussion

Understanding the underlying technological, institutional, and economic drivers of land-use change, and how they play out differently in different environmental, socio-economic and cultural contexts, is essential for identifying effective policies to navigate land systems towards more sustainable futures. We compiled a unique set of narratives on 200 years of land-system change in 28 European countries to identify seven dominating land-management regimes. We found substantial spatiotemporal heterogeneity in the prevalence of regimes across Europe as well as

shifts among them, yet also marked commonalities in the drivers explaining these transitions with a general tendency of diffusion of emerging regimes from Europe's Northwest to its Southeast. Regime shifts were often related to supra-national institutional reforms (e.g., changes in EU agrarian policies or the emergence and disappearance of Soviet land management), technological innovations and their diffusion across Europe (e.g., drainage pipes, tillage and harvesting machinery, motorization, and synthetic fertilizer), and land reforms. While land-system change was often gradual or unidirectional, our results highlight that abrupt transformation in land systems can occur, including reversal to a previous regime. Our results strongly suggest that land-system change should not be conceived as a unidirectional process following predefined pathways, but is better understood as a sequence of management regimes, with inertia and path-dependency, but also potential leapfrogging. Our findings have major implications for policy making, because they demonstrate the strong influence of political and institutional factors, but also highlight the spatial heterogeneity of land-management regimes across Europe and thus a need for diversified, spatially-targeted land-use policies.

4.1. Shifts in land-management regimes across Europe

At the European level, we observed both gradual transitions between regimes and abrupt shifts. Gradual transitions were more frequent in the 19th century. For instance, the *Era of Peasantry* persisted in Europe for 150 years after the first group of countries shifted to *Innovations and Rights* around year 1800. Feudal structures persisted in the Southern parts of the Mediterranean countries because of a combination of land ownership structures and relative low agricultural potential due to water constraints. Similarly, the transition from *Innovations and Rights* to *Intensification* began in 1850 in the present Germany while this shifting occurred up to 100 years later in Albania, Greece, Hungary, Poland and Slovenia.

Abrupt shifts occurred predominately around World War II: the Western European countries all entered the Industrialization regime within 20 years after the war and countries in the Eastern Bloc where forced into Collectivization to varying degrees. Both regimes were rapidly introduced, and with comparable land management in terms of means of intensification (driven by motorization, use of mineral fertilizers, field enlargements, production subsidies). Interestingly, both regimes endured for 40 years. Collectivization came to a sudden end due to political shocks, whereas the Industrialization regime is currently in slow transition towards reduced local environmental impacts. The impacts on the land system of the two transitions are thus substantially different: while the former Eastern Bloc experienced rapid de-intensification or complete abandonment of agriculture, Western Europe is still undergoing a gradual change towards decreasing the pressure exerted by land use on Europe's ecosystems.

Compared to the gradual changes between regimes at the European level, regime shifts tended to occur more swiftly at national levels. This is particularly obvious for regime shifts with a strong relation to institutional drivers, for instance shifts from the *Era of Peasantry* to *Innovations and Rights* (e.g., in the last decade of the 18th century in France and Denmark or around 1848 for the Austro-Hungarian Empire with the abolition of serfdom). Some regime shifts, however, also occurred gradually at national levels. For instance, the shift from *Innovations and right* to *Intensification* happened over several decades for a group of countries where the emerging intensification process was stalled by agrarian crisis (see, for instance, the narratives for France and Slovakia). Gradual shifts also occurred towards the *Environmental Awareness* regime, where land management practices associated with the *Industrialization* regime persist at national levels. This can partly be explained by agro-environmental schemes and policies being voluntary.

4.2. Drivers of land management change in Europe

Our narratives revealed major trends in dominant drivers of land-use change for Europe in the period 1800–2010. Of all 34 drivers identified, the most frequently mentioned driver of change in land management was land reforms, followed by mineral fertilizer and tractors. Other institutional and in particular economic drivers seem to play a relatively minor role in the national narratives. This indicates that regime shifts were mainly brought about by fundamental structural changes and technological innovation, a finding that is interesting in the perspective of identifying pathways to sustainable land systems. It also demonstrates that land-management change was driven by factors from very different organizational levels, from land reforms being implemented by nation states (e.g., seizure of land from large land owners), to individuals deciding on the uptake of technological innovations in response to variations in input and output prices.

Particular drivers were not confined to specific periods or particular countries and can produce similar land-use changes. For example, in all the narratives mentioning drainage, it caused agricultural and forestry expansion and/or conversions from meadows to cultivated fields, whether initiated by private entities or institutions. In contrast, some drivers also led to different outcomes. This is illustrated by the effects of establishing private land rights and granting or renting of land to smallholders, which during the *Innovations and Rights* regime in Denmark enabled peasants to invest their labor in production, ensure their livelihoods and produce a surplus which they could invest in the farm. In Ireland in the late 1880s, a public rural development program bought land from large estates and distributed it to smallholders, resulting in small and fragmented, uncompetitive on the modern European market. In other countries, granting of smaller (<10 ha) parcels of land took place after the *Intensification* regime became dominant in Europe, but these newly established farms could not compete by investing labor alone; for that, they needed mineral fertilizer and mechanization as well. These inputs required larger investments than the small parcels could recoup, leaving the peasants partially outside the market economy. In Austria, the price of acquiring land after land privatization reforms was so high that peasants struggled to pay back loans, thus hampering agricultural modernization. Finally, re-establishing private property rights after the collapse of the communist regimes in the Eastern Bloc caused both intensification and land abandonment (see the individual narratives in the SI).

4.3. Uncertainty

The analyses presented in this study are based on narratives of changes in land use and land management, supplemented with quantitative information on technological drivers of land-use change.

Relying on narratives for obtaining information through an iterative process has helped authors focus on generic trends in land management, often related to major historical events. For example, time periods where often used as section headings in the first versions of the narratives. But this approach also exposes the study to some uncertainties. First, narratives represent a discourse, potentially deviating from a neutral veridical historical representation (White, 1987; Bryant, 2000). In our case, the variation in narrative structure and content was large and can be attributed to many factors including differences in land cover, land use, climate, politics and the dominant national narratives of individual countries, as well as the personal reflections of authors. The narratives thus expose a national understanding of causal drivers of

land-use change, conveyed by national experts for each of the 28 countries. Second, while we supplemented the drivers identified in the narratives with statistical data, no triangulation was made to verify the causality between land-use change and the drivers mentioned in the narratives because (a) the historical statistical data is scarce; (b) it is subject to statistical uncertainties and (c) it served as proxy variables of indicators of driving forces. Third, causal relations between drivers and land-use changes are also obscured by time lags between the onset of a driver and its spatial impacts. For further discussion on the use of narratives, see, e.g., Goldthorpe (1991), in addition to Leach and Fairhead (2000) and Clement and Amazaga (2008) who both confront dominant deforestation narratives with local and historical sources.

We used the concept of management regimes to obtain an overview of major states of and shifts in agricultural management regimes at national level and with a decadal temporal resolution. This generalized overview comes at the expense of detailed information, e.g., on differences in management and change trajectories within countries and between single years. If Europe was studied at finer spatial and temporal resolution our results would be more nuanced but would likely not include significantly more drivers and regimes. However, adding more land-use sectors to the analysis, such as forestry, could increase the number of regimes if (a) forestry is influenced by other drivers than agriculture or (b) the regime shifts in the two sectors are not synchronized. This would provide a more complete picture of management of the land system.

An alternative approach to our study could be to obtain characteristics of the land systems from historical land-use data and categorize this information into sequences of distinct land systems. Next, the analysis of drivers of change from the narratives could be based on formal Qualitative Comparative Analysis (Ragin 1987) or alternative rigorous text analysis approaches, coding drivers as variables with temporal information. Finally, the land system sequences could be regressed against the coded drivers. Such approach would build strongly on the trajectories of land-cover change tradition (Mertens and Lambin 2000; Munroe and Müller 2007) and allow a quantitative analysis of the relationships of the determinants of land system changes, including path dependencies. This approach would potentially also facilitate inclusion of the forestry sector which is not systematically addressed in the narratives, and hence note represented in any of the seven management regimes.

5. Conclusion

During the past 200 years, agricultural expansion and intensification have shaped European land systems, driven by land reforms, market access and availability of technology. This was reflected by a seemingly deterministic progression through land-management regimes, from *Era of Peasantry* through *Innovations and Rights* and *Intensification* to *Industrialization* and *Collectivization*. However, until around 1950, Europe was also characterized by marked spatial heterogeneity in land-management regimes, where single countries or groups of countries followed idiosyncratic pathways, influenced by path-dependencies (for instance, focus on livestock production), lock-ins (land reforms that created a large number of rural smallholdings) or external shocks (the agrarian crisis in the late 19th century due to grain imports from Ukraine and the United States).

In the aftermath of World War II, Europe became more homogeneous and was dominated by two distinct land-management regimes by 1970; the *Industrialization* regime in Western Europe and the *Collectivization* regime in Eastern Europe. Despite their political and geographical differences, both regimes were driven by motivations of self-sufficiency in agricultural products and sharing adverse environmental outcomes of intensive, large-scale agricultural production. This homogeneity was soon to end; environmental concerns in Western Europe spurred the *Environmental Awareness* regime while the breakdown of communism in Eastern Europe caused the replacement of the *Collectivization* regime with a diversity of land-management regimes.

Both historical and recent transitions in European land-management regimes demonstrate that pathways are neither unidirectional, as some countries re-entered previously experienced regimes, nor can they be applied as projections for future development. Regime shifts can occur suddenly or as results of incremental changes and change pathways are generally influenced by spatial variations in biophysical, institutional and economic settings. This implies that future policies on sustainable land use in Europe should carefully consider the spatial variation in both environmental conditions and land-use legacies, while acknowledging that land-management regimes can be changed quickly, in intended and unintended directions, depending on the policy instruments.

Acknowledgements

This research was partly funded by the European Commission (VOLANTE FP7 -ENV-2010-265104, HERCULES FP7-ENV-2013-603447, LUISE ERC-2010-STG-263522), the Einstein Foundation Berlin, the Austrian proVISION programme, the Austrian Academy of Sciences (Global Change Programme), the Austrian Science Fund FWF (project P20812-G11), the Czech Science Foundation (project P410/12/G113), and the Social Science and Humanities Research Council of Canada. This research contributes to the Global Land Project (www.globallandproject.org).

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.landusepol.2015.07.003

References

Bakker, M.M., Hatna, E., Kuhlman, T., Mücher, C.A., 2011. Changing environmental characteristics of European cropland. Agric. Syst. 104, 522–532.
Bryant, J.M., 2000. On sources and narratives in historical social science: a realist critique of positivist and postmodernist epistemologies*. Br. J. Sociol. 51, 489–523.
Burgos, A., Maass, J.M., 2004. Vegetation change associated with land-use in tropical dry forest areas of Western Mexico. Agric. Ecosyst. Environ. 104, 475–481.
Costanza, R., Graumlich, L., Steffen, W., Crumley, C., Dearing, J., Hibbard, K., Leemans, R., Redman, C., Schimel, D., 2007. Sustainability or collapse: What can we learn from integrating the history of humans and the rest of nature? AMBIO: J. Hum. Environ. 36, 522–527.
Dearing, J.A., Braimoh, A.K., Reenberg, A., Turner, B.L., van der Leeuw, S., 2010. Complex land systems: the need for long time perspectives to assess their future. Ecol. Soc., 15.
Ellis, E.C., Kaplan, J.O., Fuller, D.Q., Vavrus, S., Goldewijk, K.K., Verburg, P.H., 2013. Used planet: a global history. Proc. Nat. Acad. Sci. U. S. A. 110, 7978–7985.
Erb, K.-H., 2012. How a socio-ecological metabolism approach can help to advance our understanding of changes in land-use intensity. Ecol. Econ. 76, 8–14.
Erb, K.H., Haberl, H., Jepsen, M.R., Kuemmerle, T., Lindner, M., Müller, D., Verburg, P.H., Reenberg, A., 2013. A conceptual framework for analysing and measuring land-use intensity. Curr. Opin. Environ. Sustain. 5, 464–470.
Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574.
Fuchs, R., Herold, M., Verburg, P.H., Clevers, J.G.P.W., Eberle, J., 2015. Gross changes in reconstructions of historic land cover/use for Europe between 1900 and 2010. Glob. Change Biol. 21 (1), 299–313.
Garnett, T., Appleby, M., Balmford, A., Bateman, I., Benton, T., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P., Toulmin, C., Vermeulen, S., Godfray, H., 2013. Sustainable intensification in agriculture: premises and policies. Science 341, 33–34.

Gasparri, N.I., Grau, H., Gutierrez Angonese, J., 2013. Linkages between soybean and neotropical deforestation: Coupling and transient decoupling dynamics in a multi-decadal analysis. Glob. Environ. Change-Hum. Policy Dimensions 23, 1605–1614.
Gaube, V., Kaiser, C., Wildenberg, M., Adensam, H., Fleissner, P., Kobler, J., Lutz, J., Schaumberger, Andreas, Schaumberger, Jakob, Smetschka, Barbara, Wolf, Angelika, Richter, Andreas, Haberl, Helmut, 2009. Combining agent-based and stock-flow modelling approaches in a participative analysis of the integrated land system in Reichraming, Austria. Landsc. Ecol. 24, 1149–1165.
Geist, H.J., Lambin, E.F., 2001. What Drives Tropical Deforestation? LUCC Report Series 4. Louvain-la-Neuve: LUCC International Project Office1–116.
Geist, H.J., McConnell, W.J., Lambin, E.F., Moran, E., Alves, D., Rudel, T., 2006. Causes and trajectories of land use/cover change. In: Lambin, E.F., Geist, H.J. (Eds.), Land Use and Land Cover Change. Local Processes and Global Impacts. Springer Verlag, Berlin, Heidelberg, New York, pp. 41–70.
Gellrich, M., Baur, P., Koch, B., Zimmermann, N.E., 2007. Agricultural land abandonment and natural forest re-growth in the Swiss mountains: s spatially explicit economic analysis. Agric. Ecosyst. Environ. 118, 93–108.
Gerard, F., Petit, S., Smith, G., Thomson, A., Brown, N., Manchester, S., Wadsworth, R., Bugar, G., Halada, L., Bezak, P., Boltiziar, M., De badts, E., Halabuk, A., Mojses, M., Petrovic, F., Gregor, M., Hazeu, G., Mücher, C.A., Wachowicz, M., Huitu, H., Tuominen, S., Köhler, R., Olschofsky, K., Ziese, H., Kolar, J., Sustera, J., Luque, S., Pino, J., Pons, X., Roda, F., Roscher, M., Feranec, J., 2000. Land cover change in Europe between 1950 and 2000 determined employing aerial photography. Prog. Phys. Geogr. 34, 183–205.
GLP. Science Plan and Inplementation Strategy Ojima, Dennis, Moran, Emilio F., McConnell, William, Smith, Mark Stafford, Laumann, Gregor, Morais, João, and Young, Bill. 53, 1-64. 2005. Stockholm, IGBP Secretariat. IGBP reports.
Hostert, P., Kuemmerle, T., Prishchepov, A., Sieber, A., Lambin, E.F., Radeloff, V.C., 2011. Rapid land-use change after socio-economic disturbances: the collapse of the Soviet Union versus Chernobyl. Environ. Res. Lett. 6.
Jepsen, M.R., Leisz, S., Rasmussen, K., Jakobsen, J., Moller-Jensen, L., Christiansen, L., 2006. Agent-based modelling of shifting cultivation field patterns, Vietnam. Int. J. Geog. Inf. Sci. 20, 1067–1085.
Nádia, Jones N., de Graaff, J., Rodrigo, Duarte, I.F., 2011. Historical review of land use changes in Portugal (before and after EU integration in 1986 and their implications for land degradation and conservation, with a focus on Centro and Alentejo region. Appl. Geogr. 31, 1036–1048.
Kastner, T., Erb, K.-H., Haberl, H., 2014. Rapid growth in agricultural trade: effects on global area efficiency and the role of management. Environ. Res. Lett. 9 (3), 034015 (10pp).
Klepeis, P., Turner II, B.L., 2001. Integrated land history and global change science:: the example of the Southern Yucat + in Peninsular Region project. Land Use Policy 18, 27–39.
Kuemmerle, T., Erb, K., Meyfroidt, P., Müller, D., Verburg, P.H., Estel, S., Haberl, H., Hostert, P., Jepsen, M.R., Kastner, T., Levers, C., Lindner, M., Plutzar, C., Verkerk, P.J., van der Zanden, E.H., Reenberg, A., 2013. Challenges and opportunities in mapping land use intensity globally. Curr. Opin. Environ. Sustain. 5 (5), 484–493.
Lambin, E.F., Meyfroidt, P., 2010. Land use transitions: socio- ecological feedback versus socio-economic change. Land Use Policy 27, 108–118.
Leach, M., Fairhead, J., 2000. Challenging neo-malthusian deforestation analyses in West Africa's dynamic forest landscapes. Popul. Dev. Rev. 26, 17–43.
Meeus, J.H.A., 1995. Pan-European landscapes. Landsc. Urban Plann. 31, 57–79.
Mertens, B., Lambin, E.F., 2000. Land-cover-change trajectories in Southern Cameroon. Ann. Assoc. Am. Geographers 90 (3), 467–494.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, D.C, pp. 1–137.
Müller, D., Leitao, P.J., Sikor, T., 2013. Comparing the determinants of cropland abandonment in Albania and Romania using boosted regression trees. Agric. Syst. 117, 66–77.
Müller, D., Munroe, D.K., 2008. Changing rural landscapes in Albania: cropland abandonment and forest clearing in the postsocialist transition. Ann. Assoc. Am. Geographers 98, 855–876.
Müller, R., Müller, D., Schierhorn Gerold, F.G., 2011. Spatiotemporal modeling of the expansion of mechanized agriculture in the Bolivian lowland forests. Appl. Geogr. 31 (2), 631–640.
Munroe, D.K., Müller, D., 2007. Issues in spatially explicit statistical land-use/cover change (LUCC) models: examples from western Honduras and the Central Highlands of Vietnam. Land Use Policy 24, 521–530.
Niedertscheider, M., Gingrich, S., Erb, K.-H., 2012. Changes in land use in South Africa between 1961 and 2006: an integrated socio-ecological analysis based on the human appropriation of net primary production framework. Reg. Environ. Change 12, 715–727.
Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., Deadman, P., 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. Ann. Assoc. Am. Geographers 93, 314–337.
Ragin, Charles C., 1987. The Comparative Method: Moving Beyond Qualitative and Quantitative Strategies. University of California Press, Berkeley.
Ramankutty, N., Foley, J.A., 1999. Estimating historical changes in global land cover: Croplands from 1700 to 1992. Glob. Biogeochem. Cycles 13, 997–1027.
Rounsevell, M.D.A., Pedroli, B., Erb, K.H., Gramberger, M., Busck, A.G., Haberl, H., Kristensen +, S., Kuemmerle, T., Lavorel, S., Lindner, M., Lotze-Campen, H., Metzger, M.J., Murray- Rust, D., Popp, A., Pérez-Soba, M., Reenberg, A., Vadineanu, A., Verburg, P.H., Wolfslehner, B., 2012. Challenges for land system science. Land Use Policy 29, 899–910.
Rudel, T.K., 2008. Meta-analyses of case studies: A method for studying regional and global environmental change. Glob. Environ. Change 18, 18–25.
Rudel, T.K., Coomes, O.T., Moran, E., Achard, F., Angelsen, A., Xu, J., Lambin, E., 2005. Forest transitions: towards a global understanding of land-use change. Glob. Environ. Change 15, 23–31.
Rudel, T.K., Schneider, L., Uriarte, M., Turner, B.L., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E.F., Birkenholtz, T., Baptista, S., Grau, R., 2009. Agricultural intensification and changes in cultivated areas, 1970–2005. PNAS 106, 20675–20680.
Singh, Simron J., Haberl, H., Chertow, M., Mirtl, M., Schmid, M. (eds.), 2013. Long-Term Socio-Ecological Research. Studies in Society-Nature Interactions Across Spatial and Temporal Scales. Springer, Dordrecht, Heidelberg, New York, London.
Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N.H., Rice, C., Robledo Abad, C., Romanovskaya, A., Sperling, F., Tubiello, F.N., 2014. Agriculture, Forestry and Other Land Use (AFOLU), in: Edenhofer, O., R. Pichs-Madruga, Y., Sokona, E., Farahani, S., Kadner, K.
Sunderlin, W.D., Angelsen, A., Resosudarmo, D.P., Dermawan, A., Rianto, E., 2001. Economic crisis, small farmer well-being, and forest cover change in Indonesia. World Dev. 29, 767–782.
Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad Sci. U. S. A. 108, 20260–20264.
Turner, B.L., Lambin, E.F., Reenberg, A., 2007. The emergence of land change science for global environmental change and sustainability. Proc. Natl. Acad. Sci. U. S. A. 104 (20), 666–20671.
Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science 277, 494–499.
White, Hayden, 1987. The content of the form narrative discourse and historical representation. John Hopkins University Press, Baltimore.
Whitmore, T.M., Turner II, B.L., Johnson, D.L., Kates, R.W., Gottshang, T.S., 1990. Long-Term Population Change. In: Turner II, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T., Meyer, W.B. (Eds.), The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 years. Cambridge University Press, Cambridge, New York, Port Chester, Melbourne, Sydney, pp. 25–40.
Young, O.R., Lambin, E.F., Alcock, F., Haberl, H., Karlsson, S.I., McConnell, W.J., Myint, T., Pahl-Wostl, C., Polsky, C., Ramakrishnan, P., Schroeder, H., Scouvart, M., Verburg, P.H., 2006. A portfolio approach to analyzing complex human-environment interactions: Institutions and land change. Ecology and Society 11.