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The driving forces of landscape change in Europe: A systematic review of the evidence

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ABSTRACT

Over the past decades, landscapes worldwide have experienced changes (e.g., urbanization, agricultural intensification, expansion of renewable energy uses) at magnitudes that put their sustainability at risk. The understanding of the drivers of these landscape changes remains challenging, partly because landscape research is spread across many domains and disciplines. We here provide a systematic synthesis of 144 studies that identify the proximate and underlying drivers of landscape change across Europe. First, we categorize how driving forces have been addressed and find that most studies consider medium-term time scales and local spatial scales. Most studies assessed only one case study area, one spatial scale, and less than four points in time. Second, we analyze geographical coverage of studies and reveal that countries with a non-European Union/European Free Trade Association membership; low Gross Domestic Product; boreal, steppic, and arctic landscapes; as well as forestland systems are underrepresented in the literature. Third, our review shows that land abandonment/extensification is the most prominent (62% of cases) among multiple proximate drivers of landscape change. Fourthly, we find that distinct combinations of mainly political/institutional, cultural, and natural/spatial underlying drivers are determining landscape change, rather than single key drivers. Our systematic review indicates knowledge gaps that can be filled by: (a) expanding the scope of studies to include underrepresented landscapes; (b) clarifying the identification and role of actors in landscape change; (c) deploying more robust tools and methods to quantitatively assess the causalities of landscape change; (d) setting up long-term studies that go beyond mapping land-cover change only; (e) strengthening cross-site and cross-country comparisons of landscape drivers; (f) designing multi-scale studies that consider teleconnections; (g) considering subtle and novel processes of landscape change.

1. Introduction

Landscapes have been shaped and maintained by people and their activities over millennia (Ellis, 2015; Farina, 2000) and have undergone fundamental changes, both today and in their history (Levers et al., 2016; van der Sluis et al., 2015; Verburg et al., 2010). Partly reflecting global trends, partly exhibiting regional particularities, multiple causes are influential in reshaping European landscapes, though their magnitude has not been quantified yet. Among the causes of landscape change are urbanization, agricultural intensification, land abandonment and forest expan-

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sion, international commerce and trade, new demands of land for nature conservation, and development of renewable energy uses (Plieninger and Bieling, 2012). Depending on prevailing social-ecological conditions, these trends find strongly varying regional expression, exhibiting diverse directions and pace (Pinto-Correia and Kristensen, 2013). For example, hotspots of land abandonment occur in Eastern Europe (Estel et al., 2015), the Mediterranean parts of Europe (Sluiter and de Jong, 2007), and many European upland areas (MacDonald et al., 2000). In contrast, agricultural intensification is most expressed in those European regions where biophysical and structural conditions for agriculture are favorable, e.g. in many areas of Northwestern Europe (Pinto-Correia and Kristensen, 2013).

The magnitude of these changes has given rise to concerns that landscape sustainability – the capacity of a landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improving human well-being (Wu, 2013) – is currently at risk (Selman, 2012). The understanding of the reasons behind landscape changes has been at the center of recent landscape research, and the "driving forces", i.e. the forces that drive changes in and of a landscape (Bürgi et al., 2004), have developed into a fundamental concept. Initially introduced in the late 1990s as an indicator framework for environmental policy (OECD, 1999), the concept of driving forces is now used as a framework for understanding the causes, processes, and outcomes of landscape change and has become indispensable for the evaluation of policy interventions (Klijn, 2004). Knowledge on drivers of landscape change is becoming more important, as attention is moving away from traditional sectorial policies toward integrated "landscape approaches" in natural resources management (Sayer et al., 2013). In the European context, this view has been reflected in the cross-sectoral approach of the European Landscape Convention that calls for the integration of protection, planning, and management of landscapes (Jones et al., 2007).

The concept of driving forces distinguishes between proximate and underlying drivers of change. Proximate drivers refer to human activities at the local level that result in landscape change, such as agricultural expansion or extension of settlements (Geist and Lambin, 2002). Underlying drivers comprise the fundamental social and natural processes (e.g. human population dynamics, agricultural policies, markets, or culturally embedded attitudes and beliefs) that underpin the proximate drivers and either operate at the local level or have a more indirect impact from the national or global level (Geist and Lambin, 2001; Geist and Lambin, 2002). Underlying drivers can comprise political, economic, cultural, technological, and natural factors (Brandt et al., 1999; Bürgi et al., 2004).

Since the turn of the millennium, the number of case studies on driving forces of landscape change in Europe has grown (e.g., Bieling et al., 2013; Hersperger and Bürgi, 2009; Mottet et al., 2006; Serra et al., 2008), and important conceptual contributions have been made, e.g. directed towards enhancing the understanding of the interplay between driving forces and actors (Hersperger et al., 2010). However, the understanding of the drivers of landscape changes remains poor, among other reasons due to the strong variation of existing case studies over disparate spatial and temporal scales (Bürgi et al., 2004) and the current spread of landscape research across many domains and disciplines within the human, social, and natural sciences (ESF, 2010). Case study research at local level is on the one hand needed to foster a "place-based culture" in landscape ecology (Fischer et al., 2011), because the landscape is the most relevant scale to address real-world sustainability problems (Crumley, 2012). On the other hand, local-level studies are highly specific in contexts, actors, main processes, scale, and resolution (Bürgi et al., 2004). But despite the unique context of most local landscapes and their drivers, the application of a comparative framework can allow more generalized insight that can be transferred across places (Kinzig, 2012; Rindfuss et al., 2007). Systematic review and meta-analyses techniques are particularly promising approaches to synthesize and upscale local-level insights on environmental changes to a more general level (Rudel, 2008). While recent years have brought significant developments in all corners of landscape research, these have hardly been synthesized, so that Pan-European perspectives on landscape change – as informed by local case studies – are under-developed (ESF, 2010).

Several meta-analyses have provided valuable insights into drivers and patterns of land-use change (Magliocca et al., 2015; van Vliet et al., 2015b). Previous studies reviewed individual land-cover changes (e.g., deforestation, Geist and Lambin, 2002; Robinson et al., 2014; or urban land expansion, Seto et al., 2011), land-use sectors (e.g., agriculture, Keys and McConnell, 2005; van Vliet et al., 2015a), or natural ecosystems (e.g., wetlands, van Asselen et al., 2013). However, studies that synthesize broader landscape change at continental scale, including the interactions among multiple change processes, have not been carried out.

The aim of this study is to provide a synthesis of the proximate and underlying drivers of landscape change across Europe. Our systematic review of the literature on landscape change identifies and catalogues the available knowledge from a wide variety of sources. In particular, our review has the following objectives: (1) to broadly characterize how proximate and underlying drivers of landscape change have been addressed in empirical case studies; (2) to examine coverage of particular socio-economic, biogeographical, and land systems attributes in the scientific literature; (3) to identify and classify the most important proximate drivers of change in European landscapes; and (4) to reveal the underlying drivers of landscape change and the interactions between proximate and underlying drivers. By this, we identify knowledge gaps that put barriers to the understanding and management of landscape change. We follow the understanding of the European Landscape Convention of landscape being "an area, as perceived by people, whose character is the result of action and interaction of natural and/or human factors" (ELC, 2000: 3).

2. Methods

Our method followed established guidelines for systematic review and systematic mapping (Centre for Evidence-Based Conservation, 2010) and was inspired by previous systematic review exercises in comparable fields (Geist and Lambin, 2002; Rudel, 2008; van Asselen et al., 2013; van Vliet et al., 2012).

2.1. Study selection

Scoping was performed to find useful keywords and to get a first overview about the availability of landscape studies. The scoping exercise was performed in the ISI Web of Science and revealed that many landscape studies did not use terms such as "driving forces", "drivers", or "causes" in the abstracts, though they offered explanations on these. Therefore, we decided to perform an inclusive search based on the following search string: "*Landscape change*" *OR* "*landscape dynamics*". To select only case studies from Europe, the search was refined by adding the names of each European country as search terms. We searched the following databases for relevant documents: ISI Web of Science, GEOBASE (Ovid), CABI: CAB Abstracts (Ovid), and Scopus. To locate grey literature, we additionally considered the first 50 pdf and word documents that were provided by the Google Scholar and Dogpile search engines. We stored titles and abstracts in a single reference database and removed all duplicates. Our review considered studies in English, French, and German language.

Building on Rudel (2008) and Geist and Lambin (2002), we specified the following four inclusion criteria: A study had to

(1) cover a landscape that is exposed to anthropogenic change, (2) be based on in-depth field investigations, (3) provide some form of measurement of landscape change processes at regional to local scale within Europe, and (4) offer explanations about the forces driving landscape change in the study areas. In particular, we included studies focusing on landscapes in Europe at local to regional scales (1–10,000 km^2). Observations of multiple landscapes that were situated more than 200 km apart, but appeared within one paper were included separately in the dataset and considered independently. We used six categories of proximate drivers of change, comprising urban/infrastructure development, agricultural expansion/intensification, expansion/intensification of forestry, extraction of nonrenewable resources, land abandonment/extensification, and nature/heritage conservation activities. We covered policy/institutional, economic, technological, cultural, or natural/spatial factors as underlying drivers. Political/institutional factors comprise formal policies, but also the informal policy climate and property rights. Economic factors relate to markets and commercialization (e.g. of agricultural commodities), economic structures, urbanization, and industrialization. Technological factors refer to the appearance and spread of new technologies. Cultural factors represent public attitudes, values and beliefs as well as individual and household behavior (Geist and Lambin, 2002). Natural/spatial drivers include climate, topography, natural disturbances, soil characteristics, and the spatial configuration of landscape patches.

We performed the search in August 2014 and initially obtained 4034 papers. After removal of duplicates, 2190 papers remained. The selection of studies relevant for this review took place in a three-stage process. First, we selected 606 papers on the basis of study titles on the basis of the four inclusion criteria. Second, after further selecting studies on the basis of their abstracts, we retained 174 papers. The third stage, in which we assessed the content of the full papers, left 96 papers. In cases of doubt, we included studies to the next phase of the selection process. We checked the repeatability of study inclusion through a random subset of about 10% of the references whose titles (201 studies) and abstracts (60 studies) were assessed by a second reviewer independently. Inclusion consistency was calculated through kappa statistics (Cohen, 1960). The agreement between reviewers was good in both steps (k = 0.57 in the first stage and k = 0.63 in the second stage). In parallel, we asked experts on landscape change to provide additional publications that were not part of our list and that should be considered (c.f. van Vliet et al., 2012). Our sample of 125 papers comprised 144 independent case studies, which form the basis of this review (the full list of studies is found in supplementary material 1).

We coded all information extracted from the studies in spreadsheets. Spreadsheet categories were pretested to assure repeatability. In the course of that process the initially intended identification of actors and their role in landscape change had to be given up, since the studies provided no systematic information and a differentiation between actors and driving forces was not possible. From the 144 studies that met the inclusion criteria, we extracted the following information:

- What were the characteristics of the study (e.g., spatial and temporal scales considered, data sources used) that may have influence on the identification of driving forces?
- Which proximate drivers of landscape change were observed?
- What underlying drivers were considered?

2.2. Data analysis

We synthesized how the studies addressed proximate and underlying drivers of landscape change. For the classification of underlying drivers, we used the scheme established by Bürgi et al. (2004). As there is no standard classification for proximate drivers of landscape change, we started from the classification used in van Asselen et al. (2013) and adapted it to the European landscape context during our scoping. We then explored the relationship between the number of case studies that were performed in a country and the country's Gross Domestic Product (GDP, reference year: 2013, Source: World Bank), its per-capita GDP (reference year: 2013, Source: World Bank), its membership in the European Union (EU) and the European Free Trade Association (EFTA), and its ecological footprint (reference year: 2011, Source: Global Footprint Network) through Spearman correlation analyses and nonparametric Mann-Whitney *U* test. We used location data given in the studies (selecting a central point within each study area) to obtain parameter estimates for context variables (biogeographic regions, and land system archetypes) from the European Environment Agency (EEA, 2012) and from Levers et al. (2016). To identify knowledge gaps, we compared the observed percentage of studies performed in a particular biogeographical and land systems context to the percentage that these zones and systems cover in Europe as a whole. To identify proximate and underlying drivers, we carried out frequency analysis across all case studies. Finally, we assessed the most important interactions between proximate and underlying drivers through descriptive statistics. In addition, we performed hierarchical cluster analysis to identify typical clusters of studies identifying the presence or absence of similar proximate and underlying drivers. Monothetic divisive clustering method suggested for binary variables was applied for this purpose in R statistical package 3.2.2 (Everitt et al., 2011; Kaufman and Rousseeuw, 2008). Clustering used a single variable on which to base the split at a given stage. Hence, at each stage, clusters contained publications with a certain attribute (i.e., proximate or underlying driver) either all present or all absent. The split was based on the variable which had the maximal total association to the other variables, according to the observations in the cluster. Monothetic divisive clustering was chosen as it is effective in revealing the main structures in the data and reveals transparently which variables produce the separation of clusters. Four clusters were chosen as a meaningful interpretation to describe the data in this review.

3. Results

3.1. Study characteristics and analytical approaches

Our review resulted in 144 case studies, performed in 23 different countries (Fig. 1). Spain (17 studies), the Czech Republic (16 studies), Italy (16 studies), Germany (13 studies), and Greece (10 studies) were the most intensively studied countries. It was conspicuous that not a single study on landscape drivers was detected for many Eastern European countries (e.g., Belarus, Russia, Serbia, or Ukraine). Six studies were carried out across two countries.

The studies included in this review were published between 1990 and 2015, but only 2 studies were published before 1995. A first wave of publications followed the release of the Dobris Assessment of the European Environment Agency (Stanners and Bourdeau, 1995), which was the first continental-scale assessment of landscape trends in Europe (10 studies from 1995 to 1999). The bulk of the studies was published after the adoption of the European Landscape Convention (ELC, 2000) (15 studies from 2000 to 2004) and after the publication of an influential concept paper on driving forces of landscape changes (Bürgi et al., 2004) in 2004 (117 studies from 2005 to 2015).

Studies of landscape drivers were published in 55 different journals and books, covering research areas such as geography, environmental sciences, ecology, agriculture, forestry, urban studies, biodiversity and conservation, engineering, and remote

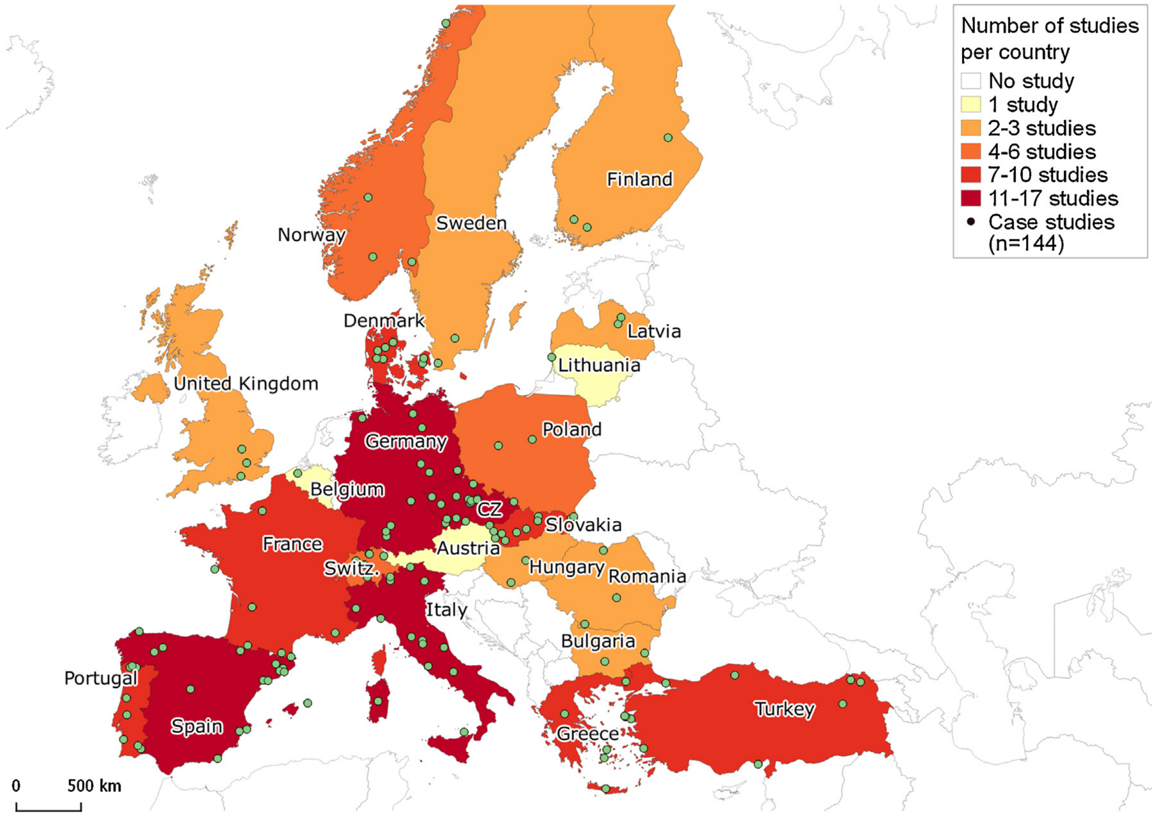

Fig. 1. Map of case study sites and number of case studies per country.

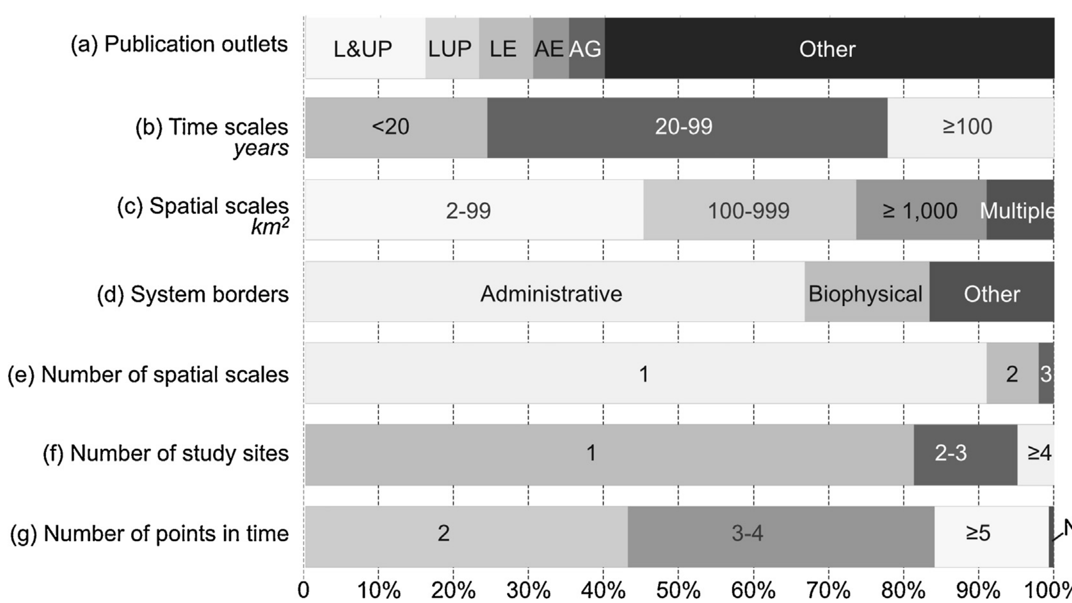

Fig. 2. Percentage of case studies following different analytical approaches: a) Publication outlets, b) Time scales, c) Spatial scales, d) System borders, e) Number of spatial scales considered, f) Number of study sites considered, g) Number of points in time considered. L&UP = Landscape and Urban Planning, LUP = Land Use Policy, LE = Landscape Ecology, AE = Agriculture, Ecosystems and Environment, AG = Applied Geography.

sensing. The most prominent outlets were Landscape and Urban Planning (16% of the papers), Land Use Policy (7%), Landscape Ecology (7%), Agriculture, Ecosystems and Environment (5%), and Applied Geography (5%), covering together 40% of all papers (Fig. 2a). A majority of studies (69%) used satellite and aerial imagery to determine proximate drivers of change. Other important data sources were maps (50% of studies), official statistics (22%), and biophysical field data (17%). Cadastral data (12%) and social surveys (10%) were less common. The bulk of studies relied exclusively on personal interpretation (55%), while literature and archival sources (28%), statistical modeling (23%), and expert interviews (9%) were less often used. Most studies (53%) assessed drivers of mid-term landscape changes (20–99 years), while short- and long-term studies were less frequent (Fig. 2b). Starting dates of the landscape change analyses ranged from 1670 to 2002. Study areas ranged from 2 km^2 to ca. 10,000 km^2, with a spatial scale of 2–99 km^2 being most frequent (51%, Fig. 2c). System borders were defined mainly by administrative units (67%) and less by biophysical units or other units, which were most often rectangular landscape sections (Fig. 2d). A very large portion of the studies considered only one spatial scale (91%, Fig. 2e) and only a single study landscape (81%, Fig. 2f). Landscape changes were assessed using between 2 and 14 points in time (Fig. 2g).

3.2. Coverage of socio-economic, biogeographical, and land systems attributes

Our spatial exploration of the location of study areas reveals several tendencies in research efforts on landscape change across the different parts of Europe (Fig. 1). Studies were significantly more frequent in EU/EFTA member countries (mean number of studies: 4.4 ± 0.9 S.E.), compared to non-member states (mean: 0.5 ± 0.5) ($U = 378.0$, $p < 0.001$, $n = 46$). There was a significantly positive correlation between the number of landscape change studies in a country and its Gross Domestic Product (Spearman's rho = 0.661, $p < 0.001$, $n = 46$) and between the number of studies and a country's per-capita GDP (Spearman's rho = 0.392, $p = 0.008$, $n = 46$). The correlation between the number of case studies and a country's ecological footprint was less strong (Spearman's rho = 0.319, $p = 0.045$, $n = 40$). In terms of biogeographical zones, a clear tendency toward Mediterranean (30.5% of studies, but covering only 10.8% of Europe according to EEA, 2012) and Continental (30.5%/23.4%) parts of Europe could be identified. In contrast, landscape change in the boreal (6.5% of studies, 25.7% European coverage), steppic (0.0%/11.8%), and arctic (0.0%/5.5%) zones were rarely or not at all investigated. A large number of studies investigated urban land systems (15.7% of studies, but covering only 1.8% of the EU surface according to Levers et al., 2016). In contrast, forest systems, in particular low-intensity forest systems (10.7% of studies, 19.3% EU coverage), received little consideration. (See supplementary material 2 for full documentation.)

3.3. Proximate drivers

Fig. 3 displays the proximate and underlying drivers of landscape change that were extracted in the review. The most important proximate drivers included land abandonment/extensification; agricultural expansion/intensification; expansion/intensification of forestry; and urban/infrastructure development categories, as documented in 65%, 62%, 56%, and 53% of the case studies respectively (Table 1). Extraction of nonrenewable resources and nature/heritage conservation activities were less frequently listed. In Northern and Western Europe, intensification/expansion of agriculture was the most frequently recorded proximate driver (Fig. 4). In Eastern Europe, the expansion/intensification of forestry was particularly important, together with agricultural intensification/expansion. In Southern Europe, land abandonment/extensification was by far the most frequent proximate driver, documented both in the Eastern and the Western Mediterranean countries (Table 1). Most studies (83% of cases) reported a combination of (typically two to three) proximate drivers of landscape change. For example, land abandonment/extensification was often related to expansion/intensification of forestry (35 cases). Agricultural expansion/intensification was frequently connected to urban/infrastructure development (25 cases). Concurrent land abandonment/extensification and agricultural expansion/intensification were reported in 21 cases, indicating that intensification and extensification of land uses occur in relatively close spatial proximity (Fig. 5).

3.4. Underlying drivers and interactions between proximate and underlying drivers

The dominant underlying drivers were political/institutional (75% of cases), natural/spatial (65%), and cultural (65%) factors (Table 2). The transition from socialist to post-socialist policy regimes in many Central and Eastern European countries was the most frequently mentioned specific underlying driver. Political/institutional factors dominated by far in Northern (81% of cases), Western (88%), and Eastern Europe (82%); in contrast, cultural factors were most prominent in Southern Europe (74%) and Turkey (88%) (Table 2).

Political and institutional underlying drivers were frequently cited for all proximate drivers of landscape change (Table 3). Cultural factors were likewise important, but appeared with the highest relative frequency among studies observing nature/heritage conservation activities. Economic factors were most typically related to agricultural expansion/intensification. Natural/spatial factors were cited most frequently among land abandonment/extensification studies. Technological factors were the category that was generally least identified as being an important underlying driver of landscape change. Only few proximate drivers of landscape change were related to one single key underlying driver (10 out of 77 cases for urban/infrastructure development; 10 out of 89 cases for agricultural expansion/intensification; 14 out of 81 cases for expansion/intensification of forestry; 1 out of 11 cases for extraction of nonrenewable resources; 10 out of 94 cases for land abandonment/extensification; 1 out of 33 cases for nature/heritage conservation activities). More typically, landscape change was identified as determined by a combination of underlying drivers.

The best splitting variable in the clustering of the studies was land abandonment/extensification which divides the data into 94 publications with presence of this proximate driver and 50 without (Fig. 6). Those 35% of publications not addressing land abandonment/extensification were in the second separation step divided into those without (group A, $n = 29$) and those with (group B, $n = 21$) technological factors identified as relevant underlying drivers. The majority of the publications (65%) dealing with land abandonment/extensification were then again divided based on the concomitant absence (group C, $n = 44$) or presence (group D, $n = 50$) of agricultural expansion/intensification. At this separation step there were four distinctive clusters, the largest one being D (35%) with the presence of land abandonment/extensification and agricultural expansion/intensification.

4. Discussion

Global and regional economic and environmental changes are increasingly influencing local landscapes, but the processes by which these act upon landscapes, in particular the interactions between multiple drivers and their geographic manifestations, remain poorly understood. Our study addresses recent calls for applying synthetis and meta-study techniques to generate global and regional knowledge from local case studies of land change (Magliocca et al., 2015; Turner et al., 2013) and presents the first comprehensive systematic review of proximate and underlying drivers of landscape change in Europe. Compared to previous review of land-use changes (e.g., Keys and McConnell, 2005; Robinson et al., 2014; Seto et al., 2011; van Vliet et al., 2015b; van Vliet et al., 2012), our study is much broader in scope, covering multiple aspects of landscape change, from agricultural intensi-

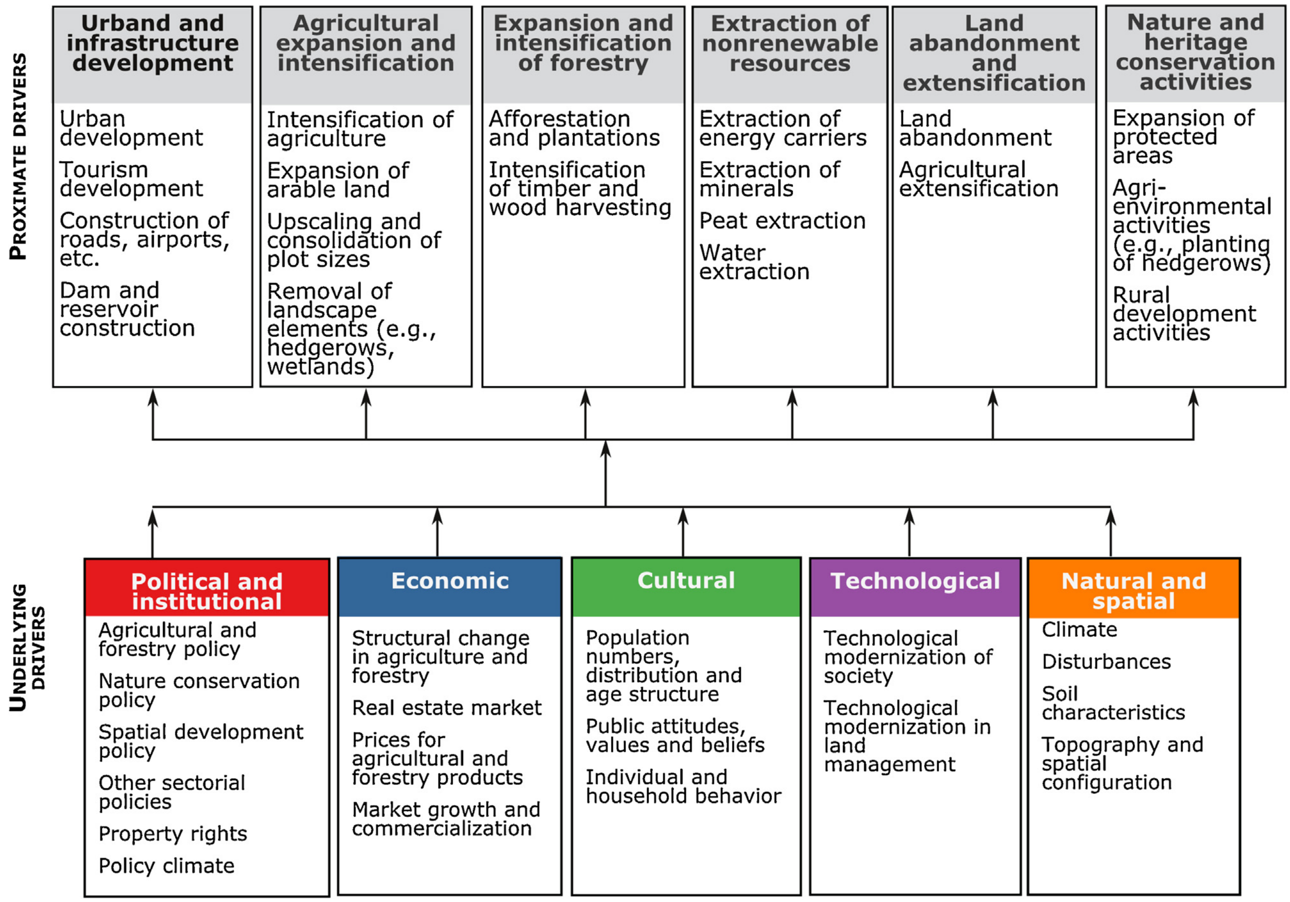

Fig. 3. Variables used to describe proximate and underlying drivers of landscape change.

Table 1
Frequency of proximate drivers of landscape change in Europe.

	All cases (n = 144)		Northern Europe (n = 21)		Western Europe (n = 26)		Eastern Europe (n = 39)		Southern Europe (n = 50)		Other (n = 8)	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
Urban/infrastructure development	77	53%	4	19%	17	65%	24	62%	25	50%	7	88%
Urban development	64	44%	3	14%	15	58%	19	49%	22	44%	5	63%
Tourism development	21	15%	2	10%	3	12%	4	10%	12	24%	0	0%
Construction of roads, airports, etc.	25	17%	3	14%	5	19%	6	15%	8	16%	3	38%
Dam/reservoir construction	10	7%	0	0%	0	0%	7	18%	1	2%	2	25%
Agricultural expansion/intensification	89	62%	17	81%	20	77%	28	72%	20	40%	4	50%
Intensification of agriculture	52	36%	5	24%	13	50%	16	41%	17	34%	1	13%
Expansion of arable land	37	26%	7	33%	6	23%	16	41%	5	10%	3	38%
Upscaling/consolidation of plot sizes	40	28%	11	52%	9	35%	12	31%	7	14%	1	13%
Removal of landscape elements	35	24%	12	57%	10	38%	12	31%	1	2%	0	0%
Expansion/intensification of forestry	81	56%	8	38%	9	35%	28	72%	28	56%	8	100%
Afforestation/plantations	74	51%	7	33%	8	31%	26	67%	27	54%	6	75%
Intensification of forestry	20	14%	2	10%	1	4%	10	26%	2	4%	5	63%
Extraction of nonrenewable resources	11	8%	1	5%	3	12%	5	13%	2	4%	0	0%
Extraction of energy carriers	5	3%	0	0%	2	8%	3	8%	0	0%	0	0%
Extraction of minerals	5	3%	1	5%	1	4%	2	5%	1	2%	0	0%
Peat extraction	2	1%	0	0%	1	4%	1	3%	0	0%	0	0%
Water extraction	1	1%	0	0%	0	0%	0	0%	1	2%	0	0%
Land abandonment/extensification	94	65%	6	29%	16	62%	26	67%	44	88%	2	25%
Land abandonment	90	63%	6	29%	13	50%	25	64%	44	88%	2	25%
Agricultural extensification	24	17%	3	14%	6	23%	8	21%	7	14%	0	0%
Nature/heritage conservation activities	33	23%	12	57%	7	27%	5	13%	8	16%	1	13%
Expansion of protected areas	8	6%	1	5%	1	4%	3	8%	3	6%	0	0%
Agri-environmental activities	24	17%	11	52%	6	23%	2	5%	4	8%	1	13%
Rural development activities	4	3%	0	0%	1	4%	2	5%	1	2%	0	0%

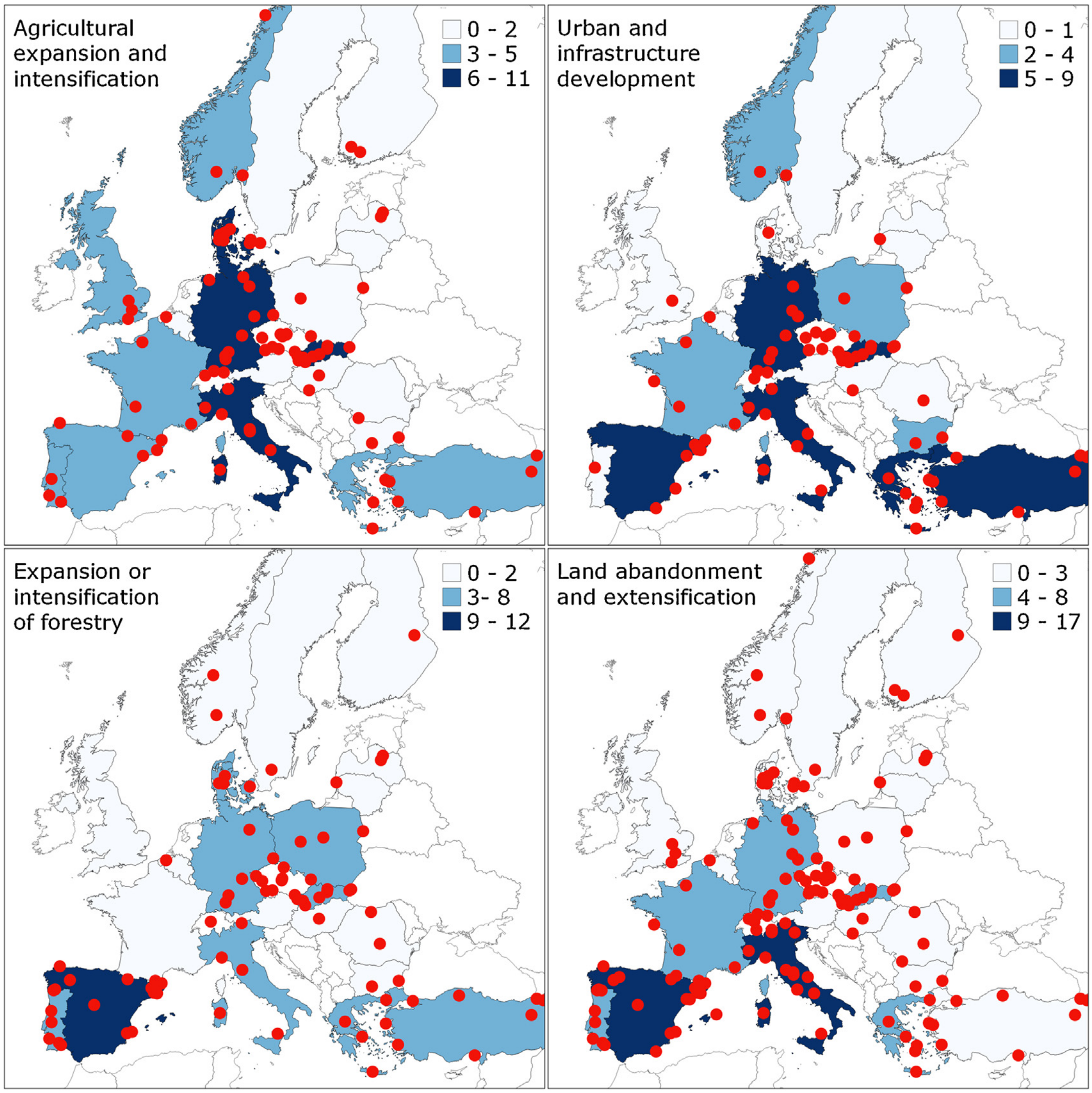

Fig. 4. Location of case studies that identified major proximate drivers of landscape change: a) agricultural expansion/intensification, b) urban/infrastructure development, c) expansion/intensification of forestry, and d) land abandonment/extensification.

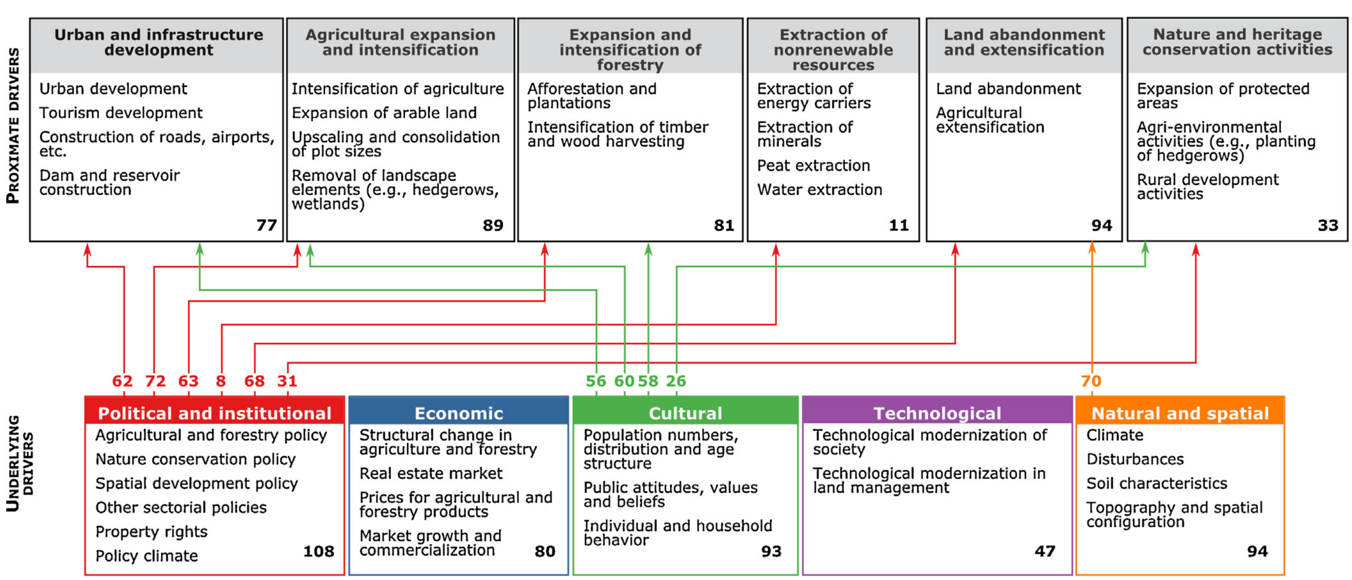

Fig. 5. Causal patterns of landscape change in Europe (n = 144). Numbers within a box indicate the number of times each proximate or underlying driver has appeared in the 144 cases. Colored numbers on arrows specify the number of times that (for the 1–2 most important underlying drivers) an underlying driver influences a proximate driver.

Table 2
Frequency of underlying drivers of landscape change in Europe.

	All cases (n = 144)		Northern Europe (n = 21)		Western Europe (n = 26)		Eastern Europe (n = 39)		Southern Europe (n = 50)		Other (n = 8)	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
Political/institutional	108	75%	17	81%	23	88%	32	82%	31	62%	5	63%
Agricultural and forestry policy	63	44%	15	71%	14	54%	11	28%	20	40%	3	38%
Nature conservation policy	34	24%	9	43%	7	27%	11	28%	4	8%	3	38%
Spatial development policy	18	13%	1	5%	5	19%	8	21%	4	8%	0	0%
Other sectorial policies	19	13%	0	0%	8	31%	8	21%	3	6%	0	0%
Property rights	32	22%	5	24%	8	31%	16	41%	2	4%	1	13%
Policy climate	26	18%	3	14%	3	12%	18	46%	2	4%	0	0%
Economic	80	56%	10	48%	16	62%	22	56%	30	60%	2	25%
Structural change in agriculture/forestry	49	34%	6	29%	8	31%	15	38%	19	38%	1	13%
Real estate market	3	2%	0	0%	1	4%	1	3%	1	2%	0	0%
Prices for agricultural/forestry products	23	16%	3	14%	4	15%	5	13%	11	22%	0	0%
Market growth and commercialization	30	21%	2	10%	10	38%	8	21%	9	18%	1	13%
Cultural	93	65%	9	43%	16	62%	24	62%	37	74%	7	88%
Population numbers/distribution/age structure	69	48%	1	5%	10	38%	21	54%	31	62%	6	75%
Public attitudes/values/beliefs	17	12%	7	33%	4	15%	1	3%	5	10%	0	0%
Individual and household behavior	37	26%	6	29%	10	38%	6	15%	10	20%	5	63%
Technological	47	33%	10	48%	14	54%	15	38%	7	14%	1	13%
Modernization of society	9	6%	0	0%	4	15%	3	8%	2	4%	0	0%
Modernization in land management	44	31%	10	48%	14	54%	13	33%	6	12%	1	13%
Natural/spatial	94	65%	13	62%	17	65%	25	64%	34	68%	5	63%
Climate	12	8%	0	0%	3	12%	2	5%	7	14%	0	0%
Disturbances	23	16%	2	10%	2	8%	4	10%	13	26%	2	25%
Soil characteristics	46	32%	8	38%	11	42%	13	33%	14	28%	0	0%
Topography and spatial configuration	74	51%	12	57%	12	46%	16	41%	31	62%	3	38%

Table 3
Frequency of underlying drivers as attributed to proximate drivers of landscape change in Europe.

	Political/institutional		Economic		Cultural		Technological		Natural/spatial	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
Urban/infrastructure development (n = 77)	62	81%	46	60%	56	73%	31	40%	50	65%
Agricultural expansion/intensification (n = 89)	72	81%	58	65%	60	67%	43	48%	58	54%
Expansion/intensification of forestry (n = 81)	63	78%	47	58%	58	72%	23	28%	54	67%
Extraction of nonrenewable resources (n = 11)	8	73%	6	55%	6	55%	4	36%	6	55%
Land abandonment/extensification (n = 94)	68	72%	63	67%	67	71%	26	28%	70	74%
Nature/heritage conservation activities (n = 33)	31	94%	23	70%	26	79%	16	52%	19	61%

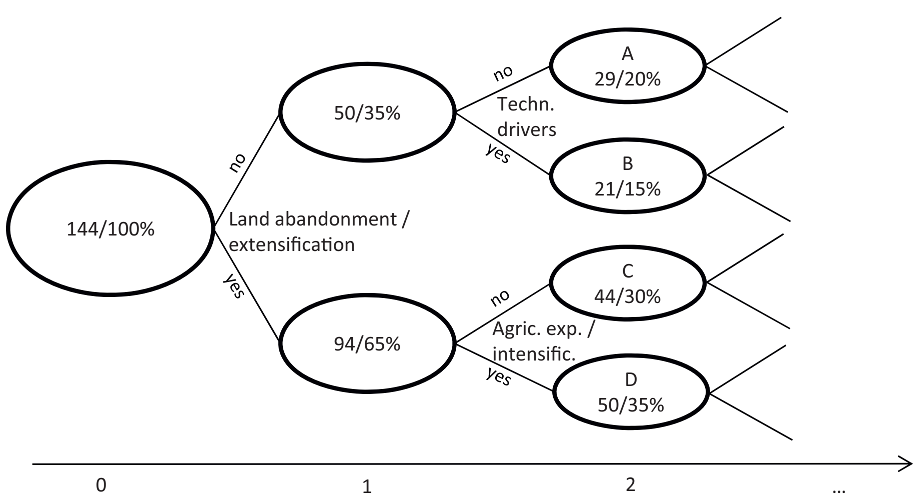

Fig. 6. Results of applying monothetic divisive clustering to characterize typical clusters of studies (n and % of studies) on the basis of presence absence of similar proximate and underlying drivers of landscape change.

fication to urbanization to the rise of nature conservation. Our study assumes a holistic and systemic understanding of landscapes, which is particularly focused on the linkages between the interwoven change processes within a given landscape (Plieninger et al., 2015). By this, it may be less useful for the identification of individual causal event chains (Walters and Vayda, 2009).

4.1. Research on landscape change drivers is diverse, covering multiple disciplines, methods, as well as spatial and temporal scales

Our review indicates that research on landscape change drivers has been carried out in all parts of Europe, using a broad range of disciplinary approaches, data sources, spatial and temporal scales, methods, and publication outlets. Most of the reviewed studies quantified the proximate drivers of landscape change with great rigor, often based on satellite and aerial imagery. In contrast, the underlying drivers of landscape change were in most studies simply identified through a personal interpretation by the authors. The role of actors and how they relate to driving forces is typically not considered in a systematic way. Most prominently, time scales between 20 and 99 years and spatial scales between 2 and 99 km^2 were studied, typically assessing one study area only, one spatial scale, and between two and four points in time. The latter indicates a move from bi-temporal detection of landscape change to the analysis of multitemporal trajectory analysis and rates of change, as advocated by Bürgi et al. (2004) and Gillanders et al. (2008). As most studies put more interest on political/institutional, economic, and cultural drivers than on natural/spatial underlying drivers and probably due to better data availability, administrative units were more prominently used as system borders than biophysical ones (e.g., watersheds). The diversity of approaches that we found is certainly a consequence of landscape being an ambiguous term that carries a plurality of meanings (Aronson, 2011). Although landscape studies are fragmented into many isolated communities (ESF, 2010), the conceptual openness makes landscape a useful boundary object with great potential to inform sustainability sciences, similar to the likewise ambiguous concept of ecosystem services (Abson et al., 2014).

4.2. Major research tendencies are revealed related to countries, biogeographic regions and land systems

Research on landscape change drivers has not been carried out with the same intensity for all areas of Europe, confirming the findings from a global review of the landscape literature (Conrad et al., 2011). Our analysis showed that less affluent countries that are not EU/EFTA members and that have a low GDP are underrepresented. We also found a neglect of remote and economically marginal areas, such as the arctic, boreal, and steppe regions of Europe. Much research focused on urban and peri-urban landscapes, indicating that research has followed the intentions of the European Landscape Convention to put more emphasis on those landscapes that people experience in their everyday life and that are directly relevant for individual and social well-being (Déjeant-Pons, 2006; Luginbühl, 2006). Few studies focused on landscapes that remained stable (but see recent studies of landscape stability, e.g. Pătru-Stupariu et al., 2016; Skalos and Kasparova, 2012).

4.3. Land abandonment is the most prominent among multiple proximate drivers of landscape change in Europe

Land abandonment/extensification was the most prominently identified proximate driver of landscape change, in particular in the Mediterranean (Sluiter and de Jong, 2007), but also in the Eastern part of Europe (Estel et al., 2015). Land abandonment is a global phenomenon (Cramer et al., 2008; Munroe et al., 2013), but has frequently been overlooked by science and policy in the face of the dominating trends of worldwide expansion of land management activities (Foley et al., 2005) and accelerating competition for land (Smith et al., 2010). In a recent Pan-European analysis, land abandonment and de-intensification were likewise identified as the dominant land change processes between 1990 and 2006 (Levers et al., 2016). Land abandonment can have both positive and negative effects on biodiversity, ecosystem services, and human well-being (Höchtl et al., 2005; Plieninger et al., 2014; Queiroz et al., 2014 Plieninger et al., 2014; Queiroz et al., 2014), requiring locally-adapted management strategies for example towards purposeful rewilding (Navarro and Pereira, 2012) or towards conservation and development of valuable cultural landscapes (Plieninger and Bieling, 2013).

Our review also revealed that opposing causes of landscape change often act within the same study area. Specifically, land abandonment/extensification causes and agricultural expansion/intensification causes were concurrently identified in 31% of the studies. On the one hand, co-occurrence of multiple causes of change is common in multifunctional landscapes that are dedicated to different (and often contrasting) land uses (Wiggering et al., 2006). On the other hand, overlapping causes of change provide evidence of a polarization of land-use that has been described as an overall change pattern in European landscapes (Antrop, 2004, 2006; Primdahl et al., 2013). Such polarization of land uses may occur within local, regional, national, and continental scales; on short-term and long-term temporal scales; and both within the same broad land-use category (e.g., pasture abandonment on some sites, grazing intensification on other sites) and between different land-use sectors (e.g., abandonment of crop cultivation, intensification of livestock husbandry). Conceptualizing polarizing land-uses and exploring its effects on landscapes was outside the scope of this study, but would be an interesting topic for further research.

4.4. Combinations of underlying drivers are determining landscape change, rather than single key drivers

Political/institutional, cultural, and natural/spatial factors were frequently identified as underlying drivers of landscape change. But similar to other recent work (Jepsen et al., 2015; van Vliet et al., 2015a), the studies included in our review typically related combinations of factors to landscape change, rather than singling out individual factors. Actually, the most common type of causation was a combination of all five categories of underlying drivers. Studies identified an average of 4.4 factors within the 19 categories in our driving forces framework, but there was distinct variation among the driving forces of different landscape change processes and geographical regions (Table 3). For example, natural/spatial drivers were described as being more influential on land abandonment than on other change processes. Our analysis showed that cases cluster in groups of a small number of shared characteristics, with land abandonment/extensification, agricultural expansion/intensification and technological drivers being most relevant for separating clusters. While the major clustering reflects the dominance of land abandonment/extensification, further subdivision of clusters indicates the importance of agricultural expansion/intensification and technological driving forces (Fig. 6).

4.5. Limitations

When interpreting the results of our systematic review, several caveats need to be taken into account. Although systematic review is acknowledged as a straightforward method that yields robust results (Pullin and Stewart, 2006), relevant information reported in the empirical studies used may be lost, and some relevant studies may have been missed in the selection process. Landscape as a concept has different meanings to different disciplines (Angelstam et al., 2013). We selected only papers that described themselves to study "landscape change" or "landscape dynamics" and that were written in English, French, or German. Other papers (for example, those that focused on more isolated land change processes or those that were published in other languages) remained unconsidered. Therefore, we think that our review includes a broad sample of internationally published landscape research, but may neglect studies of more regional relevance as well as studies that investigate individual change processes without a landscape perspective.

Our analysis also showed that certain countries, biogeographic regions, and land systems are underrepresented in landscape research, and we cannot assess how these are affected by the drivers that we identified from our sample. Stable landscapes were particularly underrepresented. We believe that this is not only due to our selection process but expression of a larger trend in landscape research to concentrate on processes of change rather than on stability of landscapes. Such focus on change is even formalized in names of research fields and programs such as "land change science" or "land use/land cover change". Stronger consideration of stable landscapes may be important for four reasons: First, many European landscapes are remarkably stable, compared to other areas of the world. For example, 41% of the EU-27 area did not experience any substantial changes between 1990 and 2006 (Levers et al., 2016). Second, the study of stable landscapes is as informative as that of changing landscapes, as stability is a consequence of particular drivers that counter the drivers of change, for example regulations, subsidies, or traditions (Bürgi et al., 2004). Third, the question of change versus maintained management practices is highly relevant in a wide array of landscape policies (e.g., habitat management and conservation policies), but this dimension has been generally overlooked in evaluation studies (Primdahl et al., 2003). Fourth, stable landscapes may act as repositories of social-ecological memory that store experiences of living pasts and provide sense of place to individuals and societies (Barthel et al., 2010; Skalos and Kasparova, 2012).

5. The way forward

Bürgi et al. (2004) defined a set of "new directions" to tackle the challenges of landscape change studies. Here, we build on these directions with a series of key lessons that we derive from our review and that should be of relevance for the advancement of landscape change research both in Europe and beyond (c.f. Plieninger et al., 2015). We propose that the way forward for the analysis of proximate and underlying drivers of landscape change needs to comprise:

- An expansion of the scope of studies to include underrepresented countries, biogeographic regions, and land-use systems and to also consider drivers of landscape stability;
- An improvement of conceptual clarity with regard to the role and identification of actors vs. driving forces of landscape change (c.f. Hersperger et al., 2010);
- The deployment of more robust tools and methods to quantitatively assess the causalities of landscape change, while maintaining the holistic character of landscape studies;
- Long-term studies that go beyond the use of satellite imagery, considering diverse types of data on landscape change (c.f. Fuchs et al., 2015);
- A strengthening of standardized cross-site and cross-country comparisons of landscape change drivers to foster generalizability of insights;
- The design of multi-scale studies that consider distal relations between actors, drivers, and patterns of landscape change (c.f. Eakin et al., 2014); and
- Stronger consideration of subtle and/or novel processes of landscape change.

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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.2016.04.040.

References

Abson, D.J., von Wehrden, H., Baumgärtner, S., Fischer, J., Hanspach, J., Härdtle, W., Heinrichs, H., Klein, A.M., Lang, D.J., Martens, P., Walmsley, D., 2014. Ecosystem services as a boundary object for sustainability. Ecol. Econ. 103, 29–37.
Angelstam, P., Grodzynskyi, M., Andersson, K., Axelsson, R., Elbakidze, M., Khoroshev, A., Kruhlov, I., Naumov, V., 2013. Measurement, collaborative learning and research for sustainable use of ecosystem services: landscape concepts and Europe as laboratory. AMBIO 42, 129–145.
Antrop, M., 2004. Landscape change and the urbanization process in Europe. Landsc. Urban Plann. 67, 9–26.
Antrop, M., 2006. Sustainable landscapes: contradiction, fiction or utopia? Landsc. Urban Plann. 75, 187–197.
Aronson, J., 2011. Sustainability science demands that we define our terms across diverse disciplines. Landsc. Ecol. 26, 457–460.
Bürgi, M., Hersperger, A.M., Schneeberger, N., 2004. Driving forces of landscape change—current and new directions. Landsc. Ecol. 19, 857–868.
Barthel, S., Folke, C., Colding, J., 2010. Social-ecological memory in urban gardens—retaining the capacity for management of ecosystem services. Global Environ. Change 20, 255–265.
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.
Brandt, J., Primdahl, J., Reenberg, A., 1999. Rural land-use and landscape dynamics—analysis of'driving forces' in space and time. In: Krönert, R., Baudry, J., Bowler, I.R., Reenberg, A. (Eds.), Land-Use Changes in Europe and Their Environmental Impact in Rural Areas in Europe. UNESCO, Paris, New York, pp. 81–102.
Centre for Evidence-Based Conservation, 2010. Guidelines for Systematic Review in Environmental Management. Version 4.0. Environmental Evidence, Available at: <http://www.environmentalevidence.org/information-for-authors>.
Cohen, J., 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Meas. 20, 37–46.
Conrad, E., Christie, M., Fazey, I., 2011. Is research keeping up with changes in landscape policy? A review of the literature. J. Environ. Manag. 92, 2097–2108.
Cramer, V.A., Hobbs, R.J., Standish, R.J., 2008. What's new about old fields? Land abandonment and ecosystem assembly. Trends Ecol. Evol. 23, 104–112.
Crumley, C.L., 2012. A heterarchy of knowledges: tools for the study of landscape histories and futures. In: Plieninger, T., Bieling, C. (Eds.), Resilience and the Cultural Landscape: Understanding and Managing Change in Human-Shaped Environments. Cambridge University Press, Cambridge, pp. 303–314.
Déjeant-Pons, M., 2006. The European landscape convention. Landsc. Res. 31, 363–384.
EEA, 2012. Biogeographic Regions in Europe. European Environment Agency, Available at: <http://www.eea.europa.eu/data-and-maps/figures/ds_resolveuid/e001d623865845e3ba8f6bd2f28a5ed3>.
ELC (2000) European Landscape Convention. Available at: <http://conventions.coe.int/Treaty/en/Treaties/html/176.htm>.
ESF, 2010. Landscape in a Changing World. Bridging Divides, Integrating Disciplines, Serving Society. Science Policy Briefing 41. European Science Foundation, Strasbourg.
Eakin, H., Defries, R., Kerr, S., Lambin, E.F., Liu, J., Marcotullio, P.J., Messerli, P., Reenberg, A., Rueda, X., Swaffield, S.R., 2014. Significance of telecoupling for exploration of land-use change. In: Seto, K.C., Reenberg, A. (Eds.), Rethinking Global Land Use in an Urban Era. MIT Press, Cambridge, MA, pp. 141–162.
Ellis, E.C., 2015. Ecology in an anthropogenic biosphere. Ecol. Monogr. 85, 287–331.
Estel, S., Kuemmerle, T., Alcántara, C., Levers, C., Prishchepov, A., Hostert, P., 2015. Mapping farmland abandonment and recultivation across Europe using MODIS NDVI time series. Remote Sens. Environ. 163, 312–325.
Everitt, B.S., Landau, S., Leese, M., Stahl, D., 2011. Hierarchical clustering, Cluster Analysis. John Wiley & Sons, Ltd, Chichester, pp. 71–110.

Farina, A., 2000. The cultural landscape as a model for the integration of ecology and economics. BioScience 50, 313–320.
Fischer, J., Hanspach, J., Hartel, T., 2011. Continental-scale ecology versus landscape-scale case studies. Front. Ecol. Environ. 9, 430.
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., Verburg, P.H., Clevers, J.G.P.W., Herold, M., 2015. The potential of old maps and encyclopaedias for reconstructing historic European land cover/use change. Appl. Geogr. 59, 43–55.
Geist, H.J., Lambin, E.F., 2001. What Drives Tropical Deforestation? A Meta-analysis of Proximate and Underlying Causes of Deforestation Based on Subnational Case Study Evidence? LUCC Report Series 4. LUCC International Project Office, Louvain-la-Neuve.
Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience 52, 143–150.
Gillanders, S.N., Coops, N.C., Wulder, M.A., Gergel, S.E., Nelson, T., 2008. Multitemporal remote sensing of landscape dynamics and pattern change: describing natural and anthropogenic trends. Prog. Phys. Geogr. 32, 503–528.
Hersperger, A.M., Bürgi, M., 2009. Going beyond landscape change description: quantifying the importance of driving forces of landscape change in a Central Europe case study. Land Use Policy 26, 640–648.
Hersperger, A.M., Gennaio, M., Verburg, P.H., Bürgi, M., 2010. Linking land change with driving forces and actors: four conceptual models. Ecol. Soc., 15, 4. art. 1.
Höchtl, F., Lehringer, S., Konold, W., 2005. "Wilderness": what it means when it becomes a reality"a case study from the southwestern Alps. Landsc Urban Plann. 70, 85–95.
Jepsen, M.R., Kuemmerle, T., Müller, D., Erb, K., Verburg, P.H., Haberl, H., Vesterager, J.P., Andrič, M., Antrop, M., Austrheim, G., Björn, I., Bondeau, A., Bürgi, M., Bryson, J., Caspar, G., Cassar, L.F., Conrad, E., Chromý, P., Daugirdas, V., Van Eetvelde, V., Elena-Rosselló, R., Gimmi, U., Izakovicova, Z., Jančák, V., Jansson, U., Kladnik, D., Kozak, J., Konkoly-Gyuró, E., Krausmann, F., Mander, Ü., McDonagh, J., Pärn, J., Niedertscheider, M., Nikodemus, O., Ostapowicz, K., Pérez-Soba, M., Pinto-Correia, T., Ribokas, G., Rounsevell, M., Schistou, D., Schmit, C., Terkenli, T.S., Tretvik, A.M., Trzepacz, P., Vadineanu, A., Walz, A., Zhllima, E., Reenberg, A., 2015. Transitions in European land-management regimes between 1800 and 2010. Land Use Policy 49, 53–64.
Jones, M., Howard, P., Olwig, K.R., Primdahl, J., Herlin, I.S., 2007. Multiple interfaces of the European landscape convention. Norwegian J. Geogr. 61, 207–215.
Kaufman, L., Rousseeuw, P.J., 2008. Monothetic analysis (program MONA). In: Kaufman, L., Rousseeuw, P.J. (Eds.), Finding Groups in Data. John Wiley & Sons, Inc., 280-311.
Keys, E., McConnell, W.J., 2005. Global change and the intensification of agriculture in the tropics. Global Environ. Change 15, 320–337.
Kinzig, A.P., 2012. Towards a deeper understanding of the social in resilience: the contributions of cultural landscapes. In: Plieninger, T., Bieling, C. (Eds.), Resilience and the Cultural Landscape. Understanding and Managing Change in Human-Shaped Environments. Cambridge University Press, Cambridge, pp. 315–327.
Klijn, J.A., 2004. Driving forces behind landscape transformation in Europe, from a conceptual approach to policy options. In: Jongman, R.H.G. (Ed.), The New Dimensions of the European Landscape. Springer, Dordrecht, pp. 201–218.
Levers, C., Müller, D., Erb, K., Haberl, H., Rudbeck Jepsen, M., Metzger, M.J., Meyfroidt, P., Plieninger, T., Plutzar, C., Stürck, J., Verburg, P.H., Verkerk, P.J., Kuemmerle, T., 2016. Archetypical patterns and trajectories of land systems in Europe. Reg. Environ. Change, http://dx.doi.org/10.1007/s10113-015-0907-x.
Luginbühl, Y., 2006. Landscape and Individual and Social Wellbeing Challenges of the European Landscape Convention. Council of Europe Publishing, Strasbourg.
MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Lazpita, J.G., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. J. Environ. Manag. 59, 47–69.
Magliocca, N., Rudel, T., Verburg, P., McConnell, W., Mertz, O., Gerstner, K., Heinimann, A., Ellis, E., 2015. Synthesis in land change science: methodological patterns, challenges, and guidelines. Reg. Environ. Change 15, 211–226.
Mottet, A., Ladet, S., Coque, N., Gibon, A., 2006. Agricultural land-use change and its drivers in mountain landscapes: a case study in the Pyrenees. Agric. Ecosyst. Environ. 114, 296–310.
Munroe, D.K., van Berkel, D.B., Verburg, P.H., Olson, J.L., 2013. Alternative trajectories of land abandonment: causes, consequences and research challenges. Curr. Opin. Environ. Sustain. 5, 471–476.
Navarro, L.M., Pereira, H.M., 2012. Rewilding abandoned landscapes in Europe. Ecosystems 15, 900–912.
OECD (1999) Environmental Indicators for Agriculture. Concepts and Frameworks. Volume 1, Paris.
Pătru-Stupariu, I., Tudor, C.A., Stupariu, M.S., Buttler, A., Peringer, A., 2016. Landscape persistence and stakeholder perspectives: the case of Romania's Carpathians. Appl. Geogr. 69, 87–98.
Pinto-Correia, T., Kristensen, L., 2013. Linking research to practice: the landscape as the basis for integrating social and ecological perspectives of the rural. Landsc. Urban Plann. 120, 248–256.
Plieninger, T., Bieling, C., 2012. Connecting cultural landscapes to resilience. In: Plieninger, T., Bieling, C. (Eds.), Resilience and the Cultural Landscape. Understanding and Managing Change in Human-Shaped Environments. Cambridge University Press, Cambridge, pp. 3–26.
Plieninger, T., Bieling, C., 2013. Resilience-based perspectives to guiding high nature value farmland through socio-economic change. Ecol. Soc. 18, 4, art. 20.
Plieninger, T., Hui, C., Gaertner, M., Huntsinger, L., 2014. The impact of land abandonment on species richness and abundance in the Mediterranean Basin: a meta-analysis. PLoS One 9, e98355.
Plieninger, T., Kizos, T., Bieling, C., Le Dû-Blayo, L., Budniok, M.-A., Bürgi, M., Crumley, C.L., Girod, G., Howard, P., Kolen, J., 2015. Exploring ecosystem-change and society through a landscape lens: recent progress in European landscape research. Ecol. Soc., 20, 2. art. 5.
Primdahl, J., Peco, B., Schramek, J., Andersen, E., Oñate, J.J., 2003. Environmental effects of agri-environmental schemes in Western Europe. J. Environ. Manag. 67, 129–138.
Primdahl, J., Andersen, E., Swaffield, S., Kristensen, L., 2013. Intersecting dynamics of agricultural structural change and urbanisation within European rural landscapes: change patterns and policy implications. Landsc. Res. 38, 799–817.
Pullin, A.S., Stewart, G.B., 2006. Guidelines for systematic review in conservation and environmental management. Conserv. Biol. 20, 1647–1656.
Queiroz, C., Beilin, R., Folke, C., Lindborg, R., 2014. Farmland abandonment: threat or opportunity for biodiversity conservation? A global review. Front. Ecol. Environ. 12, 288–296.
Rindfuss, R.R., Entwisle, B., Walsh, S.J., Mena, C.F., Erlien, C.M., Gray, C.L., 2007. Frontier land use change: synthesis, challenges, and next steps. Ann. Assoc. Am. Geogr. 97, 739–754.
Robinson, B.E., Holland, M.B., Naughton-Treves, L., 2014. Does secure land tenure save forests? A meta-analysis of the relationship between land tenure and tropical deforestation. Global Environ. Change 29, 281–293.
Rudel, T.K., 2008. Meta-analyses of case studies: a method for studying regional and global environmental change. Global Environ. Change 18, 18–25.
Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., van Oosten, C., Buck, L.E., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. U. S. A. 110, 8349–8356.
Selman, P.H., 2012. Sustainable Landscape Planning: The Reconnection Agenda. Routledge, Milton Park.
Serra, P., Pons, X., Sauri, D., 2008. Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. Appl. Geogr. 28, 189–209.
Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K., 2011. A meta-analysis of global urban land expansion. PLoS One 6, e23777.
Skalos, J., Kasparova, I., 2012. Landscape memory and landscape change in relation to mining. Ecol. Eng. 43, 60–69.
Sluiter, R., de Jong, S.M., 2007. Spatial patterns of Mediterranean land abandonment and related land cover transitions. Landsc. Ecol. 22, 559–576.
Smith, P., Gregory, P.J., van Vuuren, D., Obersteiner, M., Havlik, P., Rounsevell, M., Woods, J., Stehfest, E., Bellarby, J., 2010. Competition for land. Philos. Trans. R. Soc. B-Biol. Sci. 365, 2941–2957.
Stanners, D., Bourdeau, P., 1995. Europe's Environment: The Dobris Assessment. European Environmental Agency, Copenhagen.
Turner II, B.L., Janetos, A.C., Verburg, P.H., Murray, A.T., 2013. Land system architecture: using land systems to adapt and mitigate global environmental change. Global Environ. Change 23, 395–397.
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. Landsc. Ecol. 25, 217–232.
Walters, B.B., Vayda, A.P., 2009. Event ecology, causal historical analysis, and human–environment research. Ann. Assoc. Am. Geogr. 99, 534–553.
Wiggering, H., Dalchow, C., Glemnitz, M., Helming, K., Müller, K., Schultz, A., Stachow, U., Zander, P., 2006. Indicators for multifunctional land use—linking socio-economic requirements with landscape potentials. Ecol. Indic. 6, 238–249.
van Asselen, S., Verburg, P.H., Vermaat, J.E., Janse, J.H., 2013. Drivers of wetland conversion: a global meta-analysis. PLoS One 8, e81292.
van Vliet, N., Mertz, O., Heinimann, A., Langanke, T., Pascual, U., Schmook, B., Adams, C., Schmidt-Vogt, D., Messerli, P., Leisz, S., Castella, J.C., Jorgensen, L., Birch-Thomsen, T., Hett, C., Bruun, T.B., Ickowitz, A., Vu, K.C., Yasuyuki, K., Fox, J., Padoch, C., Dressler, W., Ziegler, A.D., 2012. Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: a global assessment. Global Environ. Change-Hum. Policy Dimens. 22, 418–429.
van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H., 2015a. Manifestations and underlying drivers of agricultural land use change in Europe. Landsc. Urban Plann. 133, 24–36.
van Vliet, J., Verburg, P.H., Magliocca, N., Ellis, E.C., Buchner, B., Cook, E., Rey Benayas, J., Heinimann, A., Keys, E., Lee, T., Liu, J., Mertz, O., Meyfroidt, P., Moritz, M., Robinson, B., Seppelt, R., 2015b. Meta-studies in land use science: current coverage and prospects. AMBIO 45, 15–28.
van der Sluis, T., Pedroli, B., Kristensen, S.B.P., Lavinia Cosor, G., Pavlis, E., 2015. Changing land use intensity in Europe–recent processes in selected case studies. Land Use Policy, http://dx.doi.org/10.1016/j.landusepol.2014.12.005.
Wu, J.G., 2013. Landscape sustainability science: ecosystem services and human well-being in changing landscapes. Landsc. Ecol. 28, 999–1023.