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Exploring the effects of drastic institutional and socio-economic changes on land system dynamics in Germany between 1883 and 2007

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ABSTRACT

Long-term studies of land system change can help providing insights into the relative importance of underlying drivers of change. Here, we analyze land system change in Germany for the period 1883–2007 to trace the effect of drastic socio-economic and institutional changes on land system dynamics. Germany is an especially interesting case study due to fundamentally changing economic and institutional conditions: the two World Wars, the separation into East and West Germany, the accession to the European Union, and Germany's reunification. We employed the Human Appropriation of Net Primary Production (HANPP) framework to comprehensively study long-term land system dynamics in the context of these events. HANPP quantifies biomass harvests and land-use-related changes in ecosystem productivity. By comparing these flows to the potential productivity of ecosystems, HANPP allows to consistently assess land cover changes as well as changes in land use intensity. Our results show that biomass harvest steadily increased while productivity losses declined from 1883 to 2007, leading to a decline in HANPP from around 75%–65% of the potential productivity. At the same time, decreasing agricultural areas allowed for forest regrowth. Overall, land system change in Germany was surprisingly gradual, indicating high resilience to the drastic socio-economic and institutional shifts that occurred during the last 125 years. We found strikingly similar land system trajectories in East and West Germany during the time of separation (1945–1989), despite the contrasting institutional settings and economic paradigms. Conversely, the German reunification sparked a fundamental and rapid shift in former East Germany's land system, leading to altered levels of production, land use intensity and land use efficiency. Gradual and continuous land use intensification, a result of industrialization and economic optimization of land use, was the dominant trend throughout the observed period, apparently overruling socio-economic framework conditions and land use policies.

1. Introduction

Land use has emerged as a major driver of global environmental change, with far-reaching effects on ecosystems, the services they provide, and biodiversity (Tilman, 1999; Bouwman et al., 2011; Matson et al., 1997). Transitioning to sustainable land systems that satisfy growing demands while avoiding the detrimental environmental and social outcomes of land use is one of the main challenges humankind faces in the coming decades (Foley et al., 2011). Meeting this challenge requires a better understanding of how and why land systems change.

A substantive body of literature suggests that land system change results from the collective impact of individuals' land use decisions. These decisions depend on a range of factors which operate and interact at different spatial and temporal scales (Lambin et al., 2001; McConnell and Keys, 2005; Geist et al., 2006; Lambin and Meyfroidt, 2011). The relative importance of these underlying drivers, however, is often unclear. A major reason for this is that drivers in complex systems are often intrinsically interlinked and tend to change in parallel, making attribution difficult (Lambin et al., 2001).

Much can be learned about land system dynamics from a historic perspective, particularly regarding the role of underlying drivers, which are often hard to quantify when focusing on short time periods (i.e., years to decades; Willis & Birks, 2006; Gaillard et al., 2010; Singh et al., 2013; Krausmann et al., 2013). Long-term studies are particularly powerful in assessing the relative

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importance of socio-economic, institutional and political drivers for land system change (Liu et al., 2007; Turner et al., 2007). Especially rapid socio-economic change, induced by technological innovations, institutional shifts, economic crisis, as well as by shock events such as wars, can prompt major reorganization of land systems (Lepers et al., 2005; Hecht & Saatchi, 2007; Kuemmerle et al., 2009; Hostert et al., 2011). Most studies assessing the impacts of such events, however, have focused on land conversions (e.g., deforestation) and short time periods (i.e., decades), mainly because reliable and more comprehensive long-term historic datasets of land system change and its underlying drivers are missing for most parts of the world (Singh et al., 2013). This results in an incomplete picture of land change, because land use intensification has played a key role in the past (Lambin and Meyfroidt, 2011; Ellis et al., 2011). Intensification of land use allowed for a decoupling between biomass production and agricultural expansion and thus contributed to reducing conversion of natural areas into croplands (FAO, 2013). Sustainable intensification is also expected to play an important role in the future (Foley et al., 2011). However, large knowledge gaps persist with regard to intensification pathways and their drivers, and long-term studies of land system dynamics that assess the drivers of both area changes in broad land uses and intensity changes within these categories remain scarce (Erb et al., 2013; Kuemmerle et al., 2013).

The 'Human Appropriation of Net Primary Production' (HANPP, Haberl et al., 2007; Martinez-Alier, 2004) is excellently suited for analyzing long term changes in land systems, and to explore the relative importance of land cover change versus land use intensification (Erb et al., 2013; Kuemmerle et al., 2013; Krausmann et al., 2013). HANPP quantifies the share of Net Primary Production (NPP) appropriated through the three main processes of human land use: (1) productivity changes associated with land conversions (e.g., conversion of forests to croplands), (2) productivity changes through changes in management intensity (e.g., fertilization and irrigation) or through land degradation, and (3) direct harvests through agriculture, forestry and livestock grazing. NPP refers to the annual amount of biomass produced by photosynthetic organisms and serves as a benchmark for ecosystem productivity (Roy et al., 2001). HANPP addresses both socio-economic as well as ecological aspects of land change, because it explicitly allows for quantifying societal biomass consumption patterns and management interventions, while measuring the amount of productivity remaining in ecosystems after land use. In comparing potential NPP to current NPP flows, HANPP controls for bioclimatic and environmental disparities when comparing land system change across heterogeneous areas, which renders it a suitable indictor for analyzing drivers of land system change (Erb et al., 2009). Finally, a central feature of HANPP is its usefulness as an integrated indicator of land use intensification, because HANPP combines information on output intensification (i.e., yields) with system-level outcomes of land use (e.g., changes in productivity, Erb et al., 2013; Kuemmerle et al., 2013).

Here, we apply the HANPP framework to analyze land system change in Germany over the past 125 years. Germany provides an interesting example of a country in which drastic political and institutional changes affected land systems. Germany experienced several episodes of rapid reorganization of its institutional and socio-economic setup, encompassing the transition from the German Empire to the Weimar Republic after World War I, the rise and fall of the German Reich, the separation into West Germany and East Germany after World War II, the establishment of the European Economic Community (EEC) in 1957 with West Germany as a founding member, the accession to the European Union, and finally the reunification in 1990. The political separation from 1949 to 1990 into socialist East Germany with a centralized planning economy and West Germany with a capitalistic, market-oriented economy is particularly interesting in this context. Because history, culture, and environmental conditions in both countries are relatively homogenous, the Germany separation can be interpreted as a unique natural experiment for studying the influence of two starkly contrasting political ideologies, economic paradigms, and institutional setups on land system change. Yet, to our knowledge, no study has so far comprehensively assessed long-term land system change in Germany to understand how rapid institutional and socio-economic changes, and specifically the separation and reunification of Germany, affected land system dynamics.

Our overarching goal was to analyze long-term land system dynamics, including both land use conversions and intensity changes, in Germany with the HANPP framework. We used our results to assess the impact of Germany's separation and reunification on land change and to explore the relative importance of institutional and socio-economic factors versus other factors of land system change. Specifically, we ask three main research questions:

1. How did land systems change in Germany during the last 125 years in terms of land cover, land use intensity and HANPP?
2. What was the impact of the drastic institutional and socio-economic changes on land system change since 1883?
3. How did the contrasting institutional and socio-economic setup during the separation into East and West Germany and the reunification affect land system dynamics?

2. Materials and methods

2.1. Data

We gathered statistical data on land cover and land use for the time period 1883–2007. Datasets were collected at sub-national level before World War II (e.g., in the German Empire) and between 1991 and 2007. In addition, we gathered data at national level between 1950 and 1989, allowing us to aggregate datasets to the current (2013) territorial boundaries and thus accounting for political border changes that occurred during our study period. Between 1950 and 1989 (German separation), we collected data separately for East and West Germany. All primary data were taken from the official German national statistics (Kaiserliches Statistisches Amt, 1884–1917; StRA, 1918–1948; Destatis 1950–2013; SZS, 1950–1989) and were collected in 5-year intervals. Some historical statistics were available from secondary literature, such as forestry harvest before 1938 (Hoffmann et al., 1965), cereal production, forestry harvest, land cover (Franzmann, 2012a, 2012b; Franzmann, 2013), as well as population and labor statistics between 1950 and 1989 (Fritz, 2001; Sensch, 2004a, 2004b). We did not consider the period 1936–1950 (World War II and aftermath) and 1990–1991 due to data deficiencies.

The four main datasets to derive consistent time series of land system change and biomass flows can be summarized as follows (Table 1; all primary data sources and definitions of individual sub-categories are reported in the text and Figs. S1–S3 of the Supporting Information).

1. Data on land use change for five land use categories (cropland, forestland, grassland, settlement areas, other land), expressed in km^2. The category "other land" includes inland water bodies, wetlands, permanent snow and ice, permanent rocks, and other unused land.
2. The amount of biomass harvest on all land use classes. Primary crop and forestry harvest was available in the national statistics,