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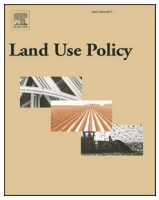

Linking food and land system research in Europe

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ABSTRACT

Food-system studies often assess dynamics in production, consumption or processing and logistics in a spatially abstract manner. Land-system studies traditionally analyze land-use/land cover change with its environmental and societal drivers as well as impacts and are typically spatially explicit. Primary production is a main node where food and land systems overlap. We used a systematic literature review to determine how existing studies in Europe address the interface of food and land systems. We identified three pathways of studies: economic, footprint and crop modeling studies (pathway 1), and scenario-based land-use/land-cover change and remote sensing studies (pathway 2), and (qualitative) policy studies (pathway 3). The reviewed studies only partially integrate land- and food-system research. Most of these studies are stronger on the land- than on the food-system side and miss processing as well as distribution and sales. In addition, major linkages between land and food systems are implemented deterministically in the reviewed studies (e.g., through static land requirements for diets). Here, the role of actors and dynamic models considering systemic feedbacks could improve the realisms of studies. Therefore, this study develops a framework to reveal the interplay between food- and land-system research. It focusses on urban-rural linkages as both research strands analyze major processes at this interface: the rural-urban exchange of food and urban sprawl. Future research should especially address and quantify governance, which is hardly quantified to date. Urban-rural linkages are weakly considered in the reviewed literature and if considered only from an urban perspective. Thereby, it would be interesting to study to which extent rural population and governance shape urban-rural-linkages, and how a change of focus from rural to urban areas could provide additional insights.

1. Introduction

Food systems are globally interdependent human-environment systems with different spatial and temporal dimensions (Ericksen, 2008; Ingram, 2011). Past research has focused on changes in production and technology or consumption habits (Lang and Barling, 2012, 2013) and was less linked to spatially explicit dynamics. Recently, the High-Level Panel of Experts on Food Security and Nutrition advanced the food system framework towards a dashboard to support policy making on food security. It contains the supply chain, food environments, individual factors such as economic, aspirational or cognitive factors, as well as consumer behavior and diets. Equally, major categories of drivers such as environment and climate change as well as urbanization are monitored at country level (Fanzo et al., 2020). While this perspective provides a comprehensive overview on major outcomes and interactions, the interaction with individual drivers (e.g., land consumption as a major process studied in land system science) for use at regional scale requires further details and quantification.

Land-system science has a more holistic perspective beyond farming systems and considers its interactions within a landscape (Verburg et al., 2013). Land-system science aims to understand in the frame of a human-environment system how land-use/land cover change is linked to environmental and societal drivers and impacts (Turner et al., 2007; Rounsevell et al., 2012). For that reason, food- and land-system studies likely complement each other (Verburg et al., 2013). An interesting perspective on food- and land-system studies are urban-rural linkages that might show a beneficial or detrimental interplay between both research strands. Typically, food-system research looks at exchange relationships such as food production in rural areas based on affordable land and food consumption in densely populated areas (Zasada et al., 2013). Land consumption such as urban sprawl into rural areas represents a common pattern studied in land-system science (Nilsson et al.,

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2014). Although these examples show potential links between both research strands, existing research in land-system science typically takes an overarching perspective (see Meyfroidt et al., 2013 or Plieninger et al., 2016 for major reviews). Food-system elements only have a subordinate role and limit their analysis to land-system dynamics (e.g., agricultural land-use/land-cover change (van Vliet et al., 2015)). Contrastingly, food-system studies often disregard land-system dynamics beyond actual land demand for different pathways (Schreiber et al., 2021) such as spatially explicit impacts of food-system transformation. Land-use/land-cover change as a central element helps to limit the focus to major processes in land system research while complementing food system research.

For the Global South, Meyfroidt (2018) identifies research needs such as better information on the impact of land-system dynamics on food security. However, a better overview on current research on the interplay between food and land system research is needed for the Global North. Major issues linking land and food systems in the Global North likely differ: availability in the context of food security might be less central, while utilization and stability such as human (especially healthy diets) as well as environmental health might be considered of higher importance (Moragues-Faus et al., 2017; Opitz et al., 2016). A clear focus on a global sub-region such as Europe might allow for better identification of major dynamics and research needs due to likely lower heterogeneity (e.g., fewer differences in spatial planning or agricultural governance) in studies in contrast to global studies such as Schreiber et al. (2021). A joint analysis of food- and land-system studies that considers urban-rural linkages might create synergies between different disciplines and research strands that are hardly explored so far.

Existing research on food systems on the one hand predominately focusses on primary production (Gaitán-Cremaschi et al., 2019) and often disregards other elements of the value chain beyond farmers and consumers (Meyer, 2020). On the other hand, food system studies (and frameworks) with a focus on public health and nutrition put primary production into a subordinate role (e.g., Gillespie and van den Bold, 2017). Spatially, trade within the globalized food system increases the distance between consumption and production and has implications on food systems' sustainability (Clapp, 2016). Only a smaller portion of worldwide food demand is locally sourced (Kriewald et al., 2019; Kinnunen et al., 2020). This development is linked to the productivist paradigm originating from the green revolution. Such regime resulted in negative environmental and social impacts outside the economic frame (Gaitán-Cremaschi et al., 2019). To capture these side effects of food systems, a more holistic assessment of food systems is required. (i) For example, European studies on food systems miss a holistic perspective and mostly focus on sectors as identified by Moragues-Faus et al. (2017). (ii) Only a small share of food-system studies is spatially explicit and assesses impacts of food systems and feedbacks from land on food systems (see, e.g., Schreiber et al., 2021 for a review on foodshed studies). (iii) Cross-scale dynamics are weakly dealt with in food-system-related research (Moragues-Faus and Marceau, 2019; Meyer, 2020). Land-based food-system studies nearly exclusively rely on the availability of fertile land and might use or modify approaches from land-system science. For cross-scale issues, food-system studies might borrow concepts and approaches from land-system science as shown through existing interfaces from telecoupling or indirect land-use change (Hull and Liu, 2018; Meyfroidt et al., 2018).

Transferring concepts from neighboring fields such as land-system science might address some deficiencies in food-system studies. Studies on land systems analyze patterns of land-use/land-cover change and link them to drivers (Meyfroidt et al., 2018). Dynamics in food systems could be relevant drivers as discussed by Meyfroidt (2018). Plieninger et al. (2016) identified major drivers for landscape change including agricultural land-use/land-cover change in a European review. Studies on agricultural land-use/land-cover change have been reviewed for the European context (van Vliet et al., 2015). Both studies identified major drivers of agricultural land-use/land-cover change. van Vliet et al. (2015) put the land managers (i.e., mainly the farmer) with their characteristics into focus and identified major demographic, economic, technological, and sociocultural drivers as well as locational factors that shape land-system dynamics. Food system characteristics were not specifically stated in their framework reflecting the focus of the reviewed studies. Equally, the dynamics of major systems shaping the drivers are often less elaborated. For example, actors' decision-making is underrepresented in land system studies (Turner et al., 2020). Recent synthesis studies hardly analyze the quality of interactions of food and land systems, especially for the link between food security and urbanization/urban sprawl (Abu Hatab et al., 2019b).

At the urban-rural interface, major processes happen that link food systems with land use/cover change: the rural-urban exchange of food and urban sprawl. Multiple conceptualizations, distances, and scales exist considering urban-rural linkages in the realm of food systems. For instance, Opitz et al. (2016) describe the concept of urban and peri-urban agriculture, Seto et al. (2012) telecouplings, or Schreiber et al. (2021) foodsheds. Schreiber et al. (2021) review foodshed studies and distinguish capacity, flow and hybrid studies. Capacity studies tackle the aspect of self-sufficiency of a spatial area. Flow studies map food flows between different spatial sourcing regions including urban and rural areas as well as international trade (i.e., the global hinterland (Seto et al., 2012)). Interactions between actors shaping food systems and the interaction of the food and land system were identified for the Global South as relevant field of analysis (Abu Hatab et al., 2019b; Abu Hatab et al., 2019a). For a European perspective, however, comparable studies identifying research needs linking land consumption (especially urbanization) and food-system dynamics are missing.

This study develops with experts (i) a framework to clarify the interplay between food- and land-system research along urban-rural linkages in Europe, (ii) a systematic literature review to determine how existing studies cover the idealized framework and categorize different sets of studies through a cluster analysis. (iii) It further identifies deficits of existing research and opportunities for future studies at this interplay of food- and land-system research. The core of the paper is to look at food systems that are affected by land-use change. In detail, we aim to look specifically at the interaction between land-use change as a major process in land-system research and the food system as we want to assess what happens if studies address land-use change as a major dynamic linked to the food system. As land consumption is often driven by (peri-)urban development in Europe (i.e., decline of agricultural land) and rural areas equally provide major land for food, we include the aspect of the exchange relationship between urban and rural areas.

2. Methods

2.1. Systematic literature search

We conducted a systematic literature review, using the approach *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) (Page et al., 2021), based on an ISI Web of Science (WoS) keyword search (TOPIC) (October 08, 2020) for journal articles. We used the following search terms (land AND use AND change AND food system AND agricultur* AND (urban OR city OR cities OR metropoli*)). It resulted in 338 publications. The search was limited to English, peer-reviewed journal articles with primary research. Regarding the search terms, we equally explored whether it is adequate to add the term rural as well, but this approach limited the number of relevant papers to 91. Therefore, we omitted the term rural and conducted the classification of the assessed regions in the studies considered in our review according to the EU urban-rural typology (Eurostat, 2021). We checked manually through study characteristics how urban-rural linkages were addressed.

We additionally tested our results adding the search term 'land system' and found that only a small extension of the literature body can be expected using the adapted search. Still, the results presented further on

are limited to the reviewed studies.

We screened the articles following the scheme in Fig. 1. We included only papers addressing food and land systems. Identified review and opinion papers have been used to frame the research of this study, but were not considered in the systematic review.

2.2. Categories and criteria for the review

We aimed to analyze food- and land-system studies with an emphasis on studies addressing urban-rural linkages. We coded, beyond general study characteristics, mainly parameters of food- and land-system studies, and urban-rural linkages as well as their interplay. General parameters of interest were *study characteristics* (e.g., country, study size), *data collection*, and *analysis methods*.

We analyzed *land-use/land-cover change*, *environmental impacts and benefits* as major characteristics of land systems. Equally, major influencing factors of the land system were analyzed following the drivers identified by van Vliet et al. (2015). We analyzed the studied food systems with respect to major value-chain elements (primary production, processing, distribution and sales, consumption, waste management) and actors (e.g., farmers, processors, governmental and non-governmental actors). We coded major influencing factors of the food systems such as population characteristics of food system governance, which can be equally found in earlier (Ericksen, 2008; Ingram, 2011) and more recent frameworks (Fanzo et al., 2020), and which have been checked for completeness in the development of the framework (see Section 2.3).

The interface between land- and food-system studies was the central element of analysis in this review. In that respect, we coded a*gricultural land management* as a further category of interest. Moreover, the *direction of analysis from the land to the food system* or vice versa were of main interest. For example, the quantity and quality of primary products produced affects the food system from a land system perspective. Vice versa, the food system may influence the land system through consumer trends.

As the urban-rural gradients were determined through study characteristics, we coded whether the studies had an urban towards rural perspective or vice versa, were purely urban or rural, or analyzed the relationships in both directions.

If applicable, we distinguished in the coding whether studies considered an effect, e.g., from land on food systems in qualitative or quantitative manner. For *land-use/land-cover change* and *environmental impacts and benefits*, we were also able to indicate whether the reviewed studies identified positive or negative effects.

To ensure consistent coding of studies, we aligned our coding in a first sample of publications that were coded and checked by all co-authors. Two co-authors each coded the remaining papers to increase the consistency in coding.

2.3. Framework

In parallel to developing the review categories, we drafted a

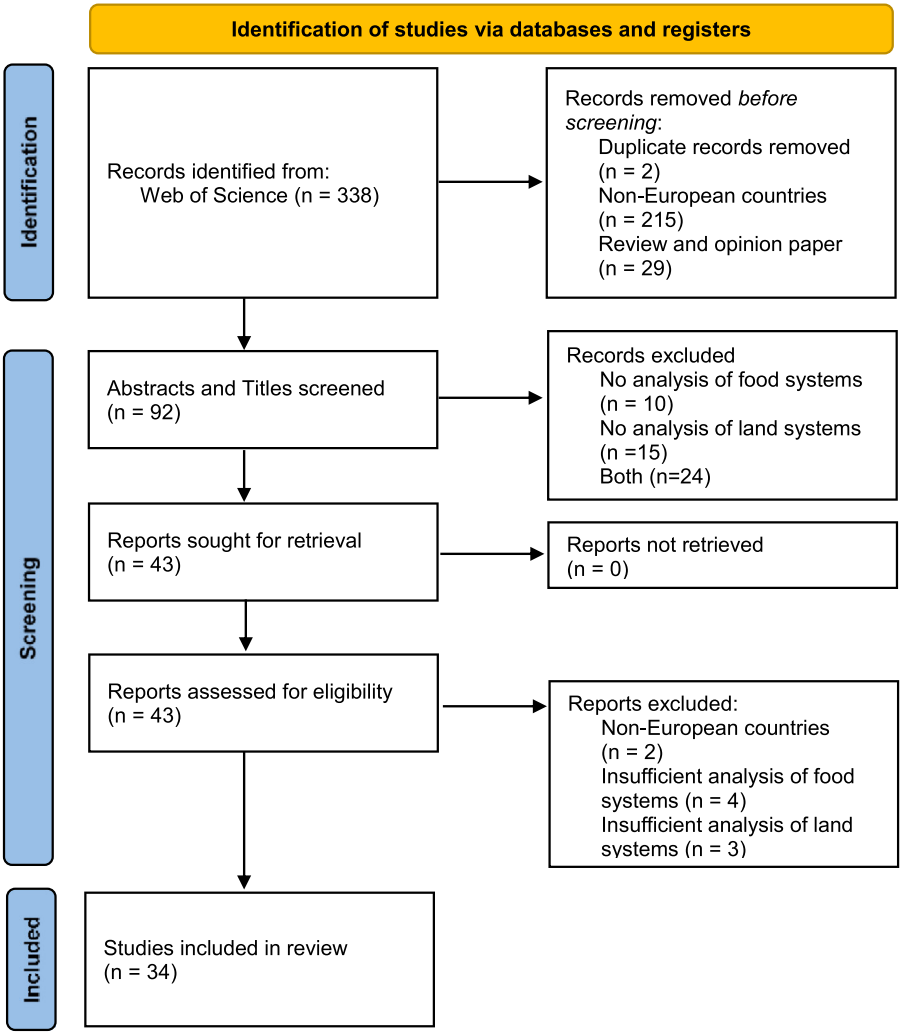

Fig. 1. Selection strategy to identify relevant papers; the template is taken from PRISMA (Page et al., 2021).

conceptual framework highlighting the links between the land and food systems. We developed a framework to visualize the relationships between land-system science and research on food systems (see Fig. 2). In addition, we added society including governance as it underpins and shapes major activities in land and food systems. It includes formal and informal governance, especially spatial governance such as regulations for spatial planning and agricultural and food system governance such as the Common Agricultural Policy. The main components of the land system were land cover classes and value chain steps in the food system (rectangles in Fig. 2). Major actors were farmers, companies, private households NGOs, and governmental institutions with associated individuals (diamonds in Fig. 2). Major system properties and in- as well as output parameters were visualized as rounded rectangles (Fig. 2) and interactions between main elements, actors and other elements were visualized as arrows.

The framework should show an idealized study on the interface between land and food systems. It should consider all value-chain elements as well as waste management and its interactions. Food systems should be linked to land-system dynamics such as land-use/land cover change and associated impacts on ecosystem services, biodiversity and overall environmental quality. Ideally, it also quantifies the impact of spatial governance mechanisms on the land system and of agricultural and food policies on the food system. We included major parameters that could be relevant to capture and to conceptualize major interactions between our system's components. We used the framework (Fig. 2) to test whether the reviewed studies in Europe cover major parts of food and land systems and its interrelationships.

We validated a draft version of the framework in an expert workshop at the Sustainable & Resilient Urban-Rural Partnerships conference in Leipzig, Germany, in 2020. Six participants actively contributed to the revision (professional occupation indicated in brackets): one economist and one environmental scientist (consultancy on agriculture and rural development), one agricultural and one environmental scientist (urban development) (university), one landscape planner (NGO on food systems), and one environmental scientist (environment agency). Based on the discussion, we revised the framework and updated the categories. We then revisited all papers in the review to complete the new categories. This updated database was the basis for our cluster analysis.

2.4. Data analysis

To identify major groups of studies, we followed Meyer (2020) and conducted a multiple factor analysis to reduce dimensionality in the data with the package *FactorMineR* in R (R Core Team, 2020). We defined for the different analysis criteria and categories the following groups: *study size*, *data collection*, and *analysis methods*, *environmental impacts and benefits, food system, food-system drivers, land system, land-system drivers, agricultural land management, land-to food system perspective, food-to-land system perspective, actors, environmental drivers and spatial governance.* Based on the factor analysis, we conducted a hierarchical cluster analysis. We identified the optimal number of clusters by cutting the tree where the branches were visually longest and the relative gain of within cluster inertia change highest (Lê et al., 2008). To interpret the clusters, we plotted the frequencies of the coding options per category for each cluster. We used the case studies in the reviewed papers for the cluster analysis.

3. Results

3.1. Overview of studies: pathways linking land and food systems

We clustered the sets of studies considered in our review in three main clusters: economic, footprint and crop modelling studies (11 case studies), scenario-based land-use/land-cover change and remote sensing studies (27 case studies), and (qualitative) policy studies (9 case studies) (see Fig. 3). Spatially, the studies mostly cover the Mediterranean area, especially Spain. The reviewed studies hardly cover Eastern Europe apart from two case studies: one in Romania and one in Slovenia. Fig. 4.

The most frequent methods are scenario-based land-use/land-cover change and remote sensing studies, followed by economic, footprint and crop modelling studies, and surveys (see Fig. 5). The majority of the reviewed studies is spatially explicit and most studies use secondary data, whereas less than 50 % use primary data (see supporting information 1,Fig. S 1).

The reviewed studies address urban-rural linkages more frequently from an urban-to-rural perspective and less frequently in the opposite direction or in a bilateral manner. Interestingly, the reviewed studies focus most frequently on cities, followed by rural areas as well as towns and suburbs in descending order (see supporting information 1,Fig. S 2).

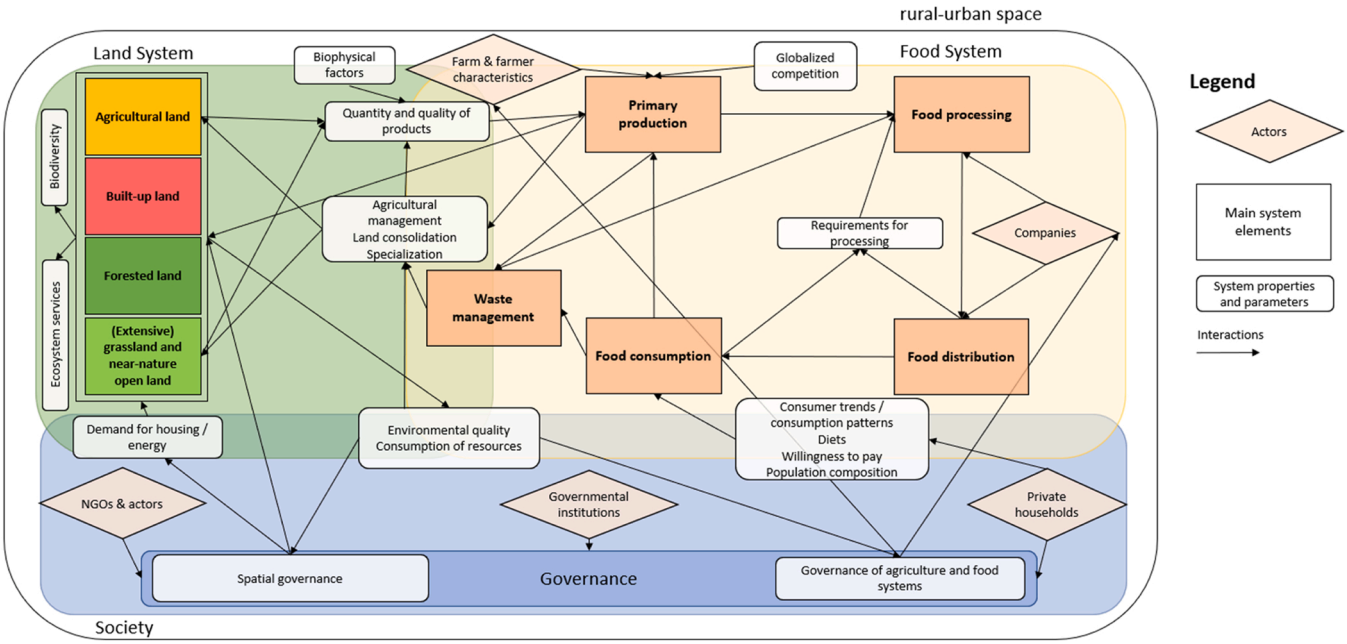

Fig. 2. General framework linking food and land system research.

Economic, footprint and crop modelling studies (pathway 1)	Cardoso et al. (2017), Lombardi et al. (2019), Monaco et al. (2017; 5 case studies), Sali et al. (2016), Wascher & Jeurissen (2017; 3 case studies)
Scenario-based land-use/land-cover change and remote sensing studies (pathway 2)	Bariamis et al. (2018), Benis & Ferrao (2017), Caputo et al. (2020), Edmondson et al. (2020), Gomes et al. (2019), Irabien & Darton (2016), Le Guern et al. (2018), Loures et al. (2020, 3 case studies), Lupia et al. (2017), Malek et al. (2018), Marull et al. (2020), Moran Alonso et al. (2017, 2 case studies), Palomo et al. (2014), Poelling & Mergenthaler (2017), Recasens et al. (2016), Ricca & Guagliardi (2015), Rogge & Theesfeld (2018), Sanye-Mengual et al. (2013), Sanz et al. (2018), Smiraglia et al. (2016, 2 case studies), Terribile et al. (2015), Theodorou et al. (2017), Wästfelt & Qian (2018)
(Qualitative) policy studies (pathway 3)	Bacon et al. (2012, 2 case studies), Gomes et al. (2020), Gradinaru et al. (2018), Leger-Bosch et al. (2020), Olsson et al. (2016, 3 case studies), Vinge (2018)

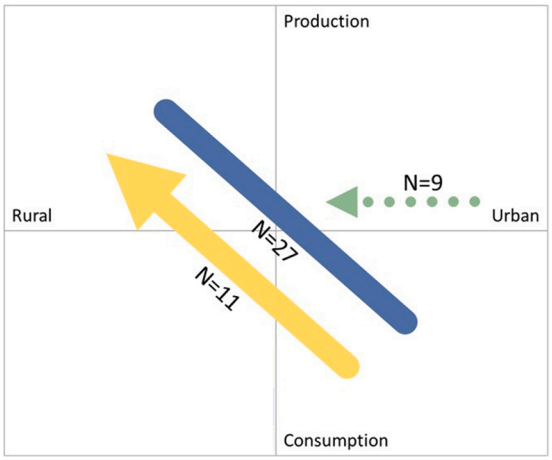

Fig. 3. Overview of pathways (clusters) along the value chain (production to consumption) and the degree of urbanity/rurality; continuous arrows indicate quantitative and dotted arrows qualitative research; the arrow head indicates the direction/perspective of the analysis.

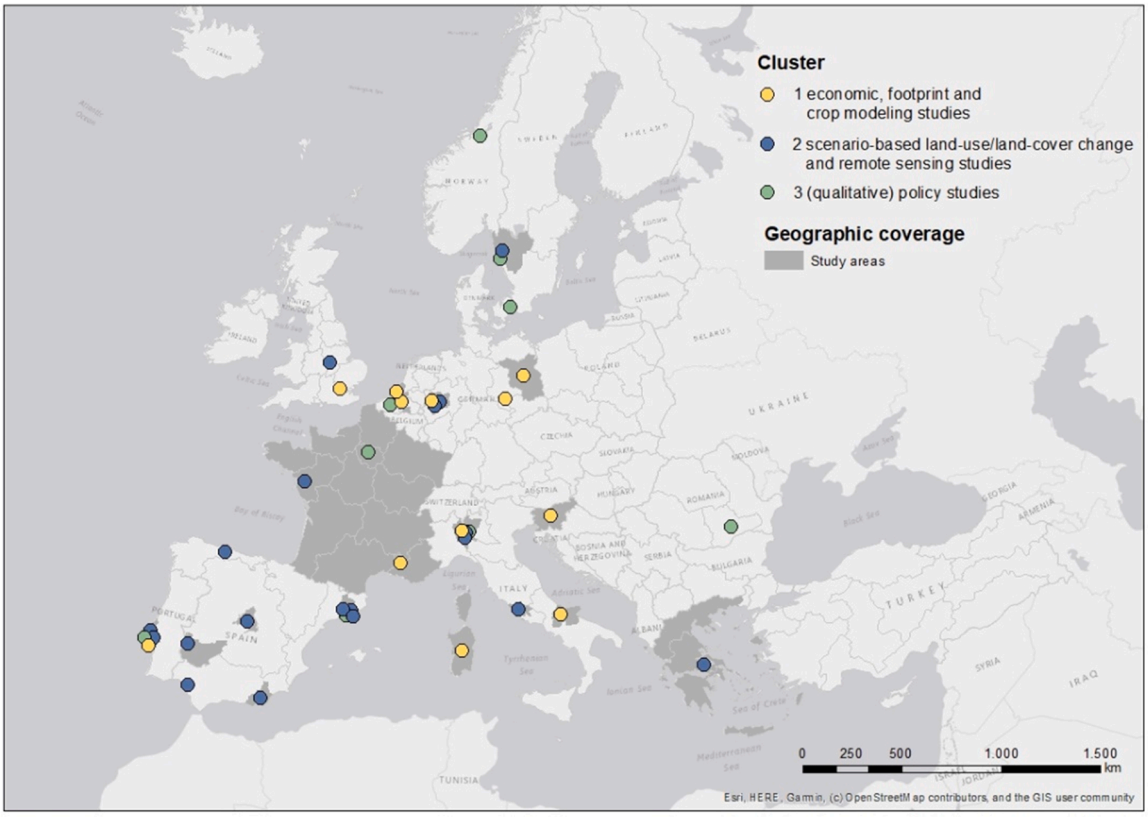

Fig. 4. Map of case studies; colors indicate different clusters and gray shades indicate the extent of the study area if indicated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Land-use/land-cover change dynamics (see Fig. 6) result often in a decline of agricultural land and in an increase of built-up land. Equally important is the increase of extensive grassland which some studies also quantified. Environmental impacts are less frequently analyzed than land-use/land-cover change (see supporting information 1,Fig. S 3).

Analyzed drivers of land-use/land-cover change are mostly demand for housing (mostly qualitatively assessed) and parameters inherent to the farming system (agricultural management, farm and farmer characteristics and increased (global) competition in food-related markets) (see Fig. 7).

Environmental quality and landscape diversity are predominately quantitatively analyzed and mostly negatively affected. Ecosystem services and biodiversity are primarily qualitatively analyzed and positively affected (see supporting information 1,Fig. S 3).

Nearly all studies considered in our review analyze primary (food) production as a driver of the food system (see supporting information 1,

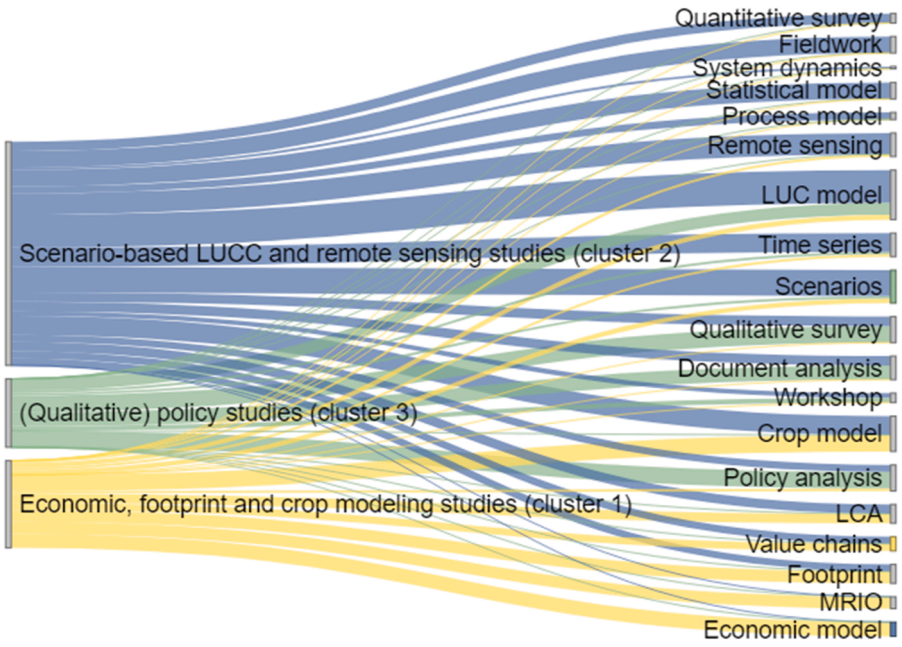

Fig. 5. Methods used by pathway (cluster) 1: economic, footprint and crop modeling studies (yellow), pathway (cluster) 2: scenario-based land-use/land-cover change and remote sensing studies (blue), and pathway (cluster) 3: (qualitative) policy studies (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

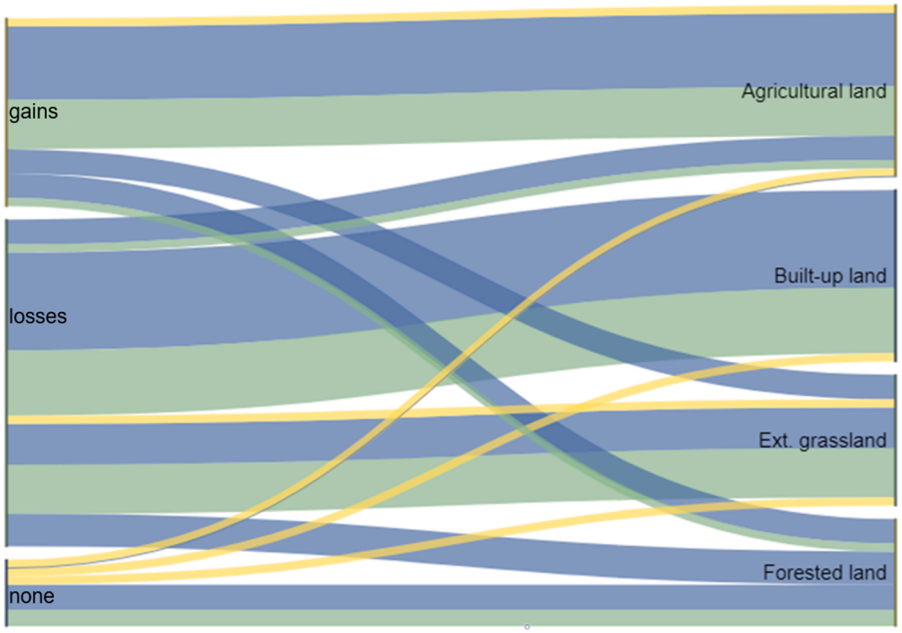

Fig. 6. Land-use/land-cover change differentiated by direction of change and pathway (cluster) 1: economic, footprint and crop modeling studies (yellow), pathway (cluster) 2: scenario-based land-use/land-cover change and remote sensing studies (blue), and pathway (cluster) 3: (qualitative) policy studies (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. S 4). The majority of studies analyzes primary production in a quantitative manner. Food consumption is the second-most frequent studied driver, but less than 50 % of the reviewed studies address this element of the food system. Few studies address other elements of the food system and very few studies consider waste management. Most common drivers of food-system changes are population composition and agricultural policies (see Fig. 8). Most of the reviewed studies quantify population composition, but analyze impacts of agricultural governance in a qualitative manner. The impact of consumer trends and consumption patterns (diets) is quantitively considered in cluster 1 and qualitatively in cluster 3 (see Figs. 9–11).

The majority of the studies in our review identifies an effect of land-system dynamics on food systems. The studies quantify the effect mostly through product quantity and quality. They test for the opposite effect from food on land systems less frequently. Specific parameters to link both systems are food consumption and the question of locally supplied demand (e.g., regional foodsheds) (see supporting information 1, Fig. S 5 and Fig. S 6).

Most of the reviewed studies consider stakeholders shaping the dynamics in food and land systems only in a qualitative manner. Major

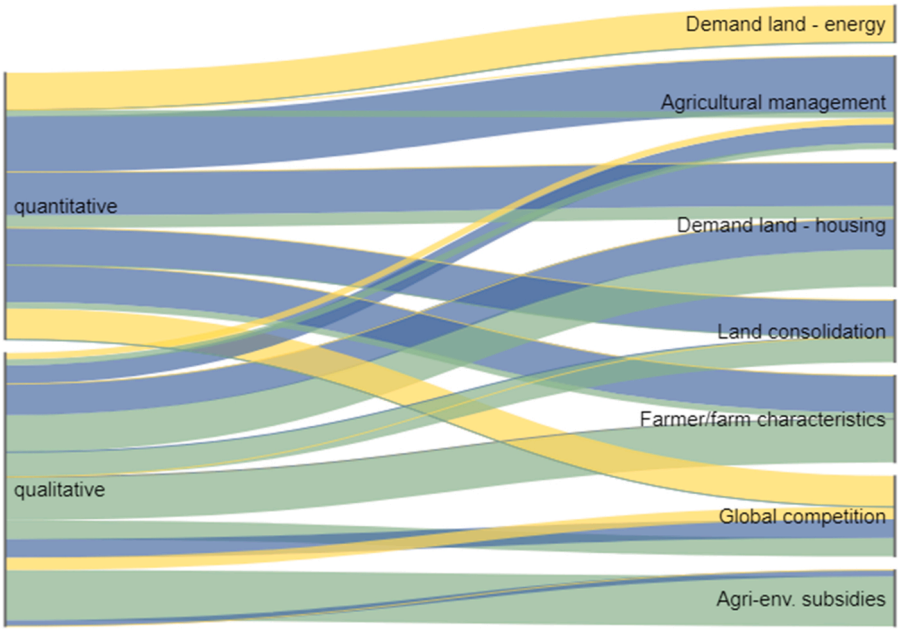

Fig. 7. Drivers of land-use/land-cover change differentiated by pathway (cluster) 1: economic, footprint and crop modeling studies (yellow), pathway (cluster) 2: scenario-based land-use/land-cover change and remote sensing studies (blue), and pathway (cluster) 3: (qualitative) policy studies (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

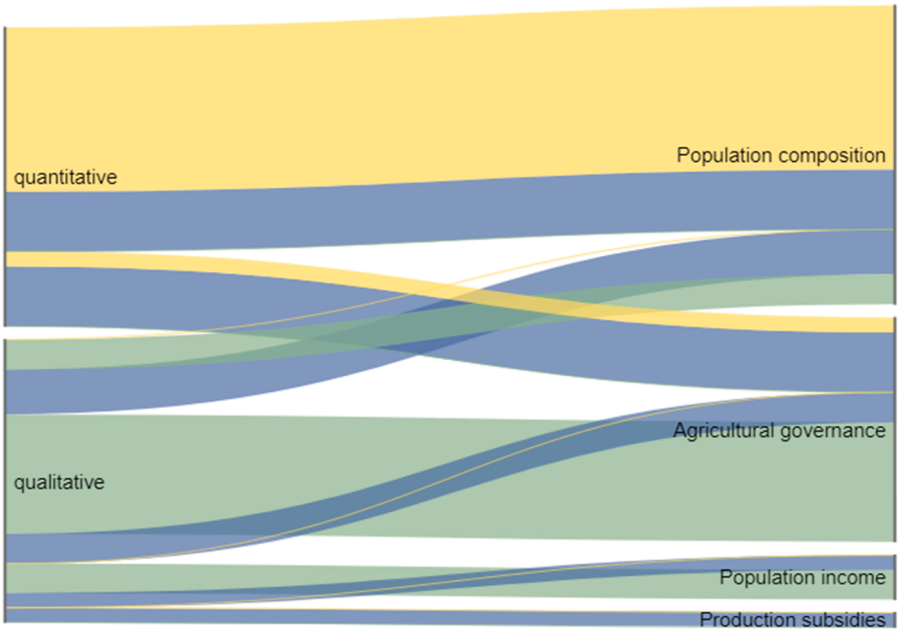

Fig. 8. Drivers of the food system differentiated by pathway (cluster) 1: economic, footprint and crop modeling studies (yellow), pathway (cluster) 2: scenario-based land-use/land-cover change and remote sensing studies (blue), and pathway (cluster) 3: (qualitative) policy studies (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

stakeholders are farmers followed by governmental and non-governmental institutions (see supporting information 1, Fig. S 7). The role of companies is marginal. Few of those studies quantify the impact of environmental drivers and spatial governance on land and food systems. They consider the role of spatial governance mostly in a qualitative manner (see supporting information 1,Fig. S 8).

Spatial and temporal study characteristics are not complete for the reviewed papers. Therefore, we only give an overview, but do not analyze these parameters in further detail. Spatially, the reviewed case studies range from less than 1 square kilometer to more than 2 million square kilometers. The population of the study areas varies from unpopulated areas to about 420 million inhabitants. The study period varies from one-time studies (one point in time) to more than 100 years (see supporting information 1, data table).

3.1.1. Economic, footprint and crop-modeling footprint studies (pathway 1)

Crop-based modeling studies with economic modeling, footprint and life-cycle assessment components represent a smaller set of the reviewed studies illustrated in Fig. 9. They exclusively use secondary data and less than 50 % are spatially explicit. The reviewed studies cover cities, towns

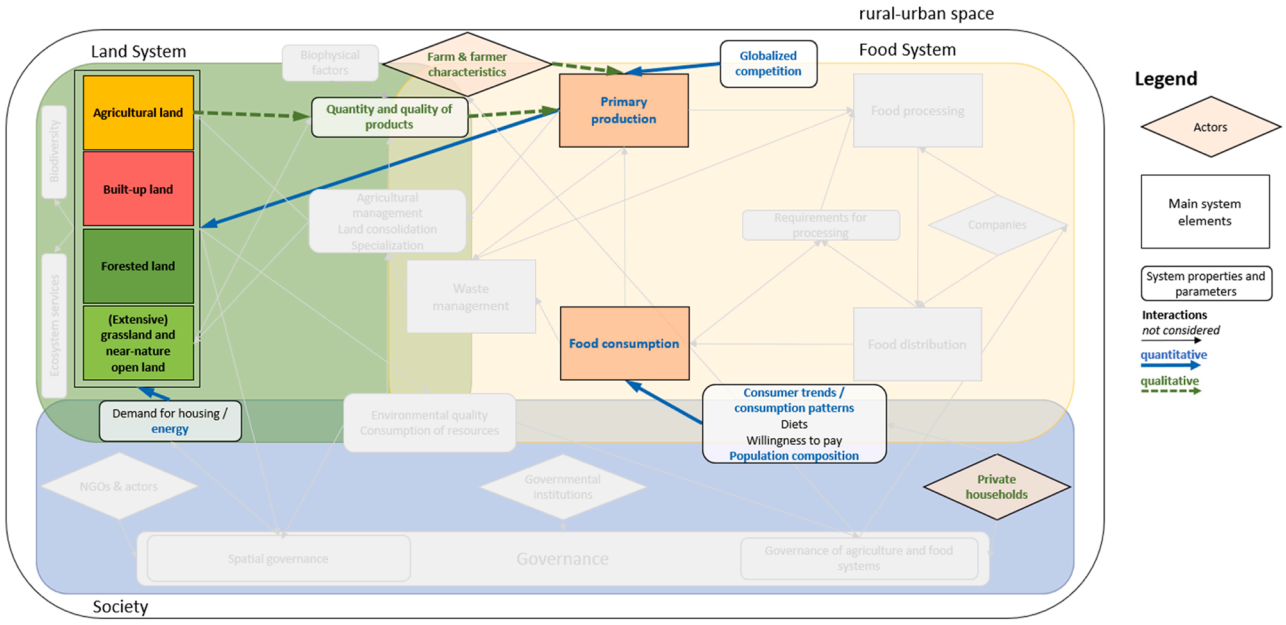

Fig. 9. Economic crop-modeling and footprint studies (pathway 1).

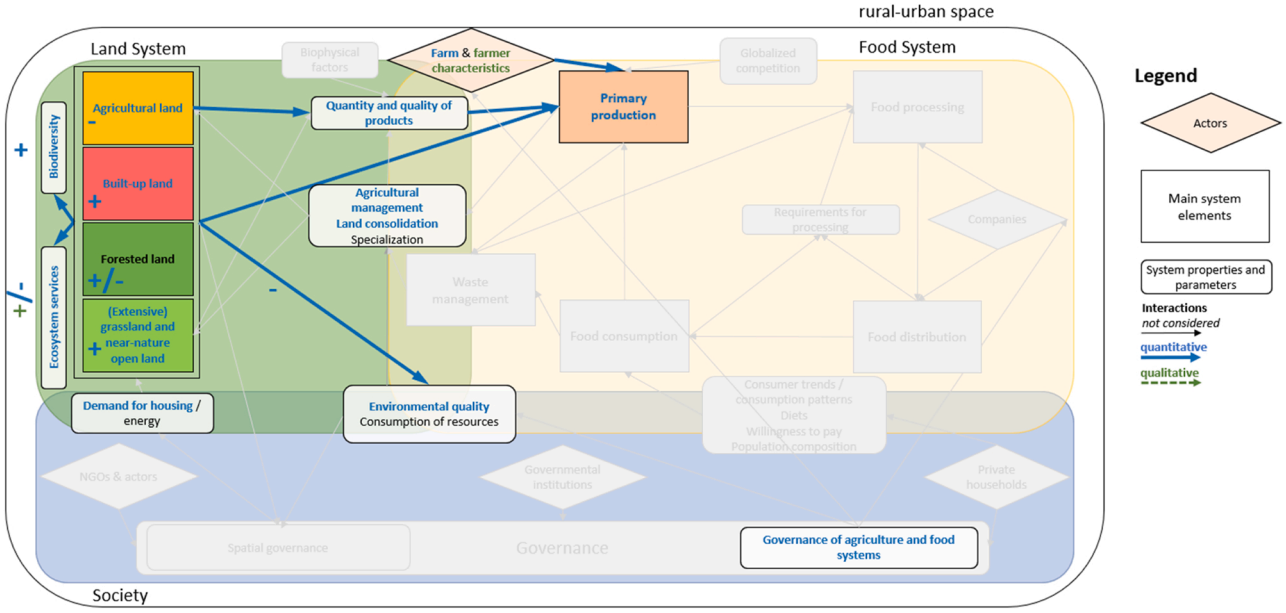

Fig. 10. Scenario-based land-use/land-cover change and remote sensing studies (pathway 2).

and suburbs, as well as rural areas. The studies analyze food- and land-system dynamics from an urban to rural perspective (e.g., quantifying urban diets) (see Fig. 3). Thematically, these studies hardly analyze land-use/land cover change and environmental impacts or links from the land to the food system. They cover both ends of the food system: primary production and food consumption. Furthermore, links from the food to the land system are very prominent through quantified consumer demand patterns. The only drivers considered for land-use/land-cover change in these studies are the global demand for energy and the global competition on food-related markets. Identified drivers of food-system dynamics are primarily population size and population composition. Stakeholders are only qualitatively considered, mostly private households and farmers. Environmental drivers and spatial governance are not considered in the reviewed studies in pathway 1.

Wascher and Jeurissen (2017) provide an illustrative case for this kind of study (Table 1). The authors use the Metropolitan Foodscape Planner to assess the supply-demand balance of the agricultural area required for food production based on consumption patterns of the population of three metropolitan regions.

3.1.2. Scenario-based land-use/land-cover change and remote sensing studies (pathway 2)

Scenario-based land-use/land-cover change and remote sensing studies (Fig. 10) are the majority of studies illustrated in our review. They are mostly spatially explicit and include primary and secondary data in most cases. These studies do not analyze food and land systems considering material or immaterial flows from rural or rural to urban areas (Fig. 3). These studies often focus either on cities, towns and suburbs, or on rural areas. If analyzed, land-use/land-cover change is quantified, and an increase of built-up land and a decline of agricultural

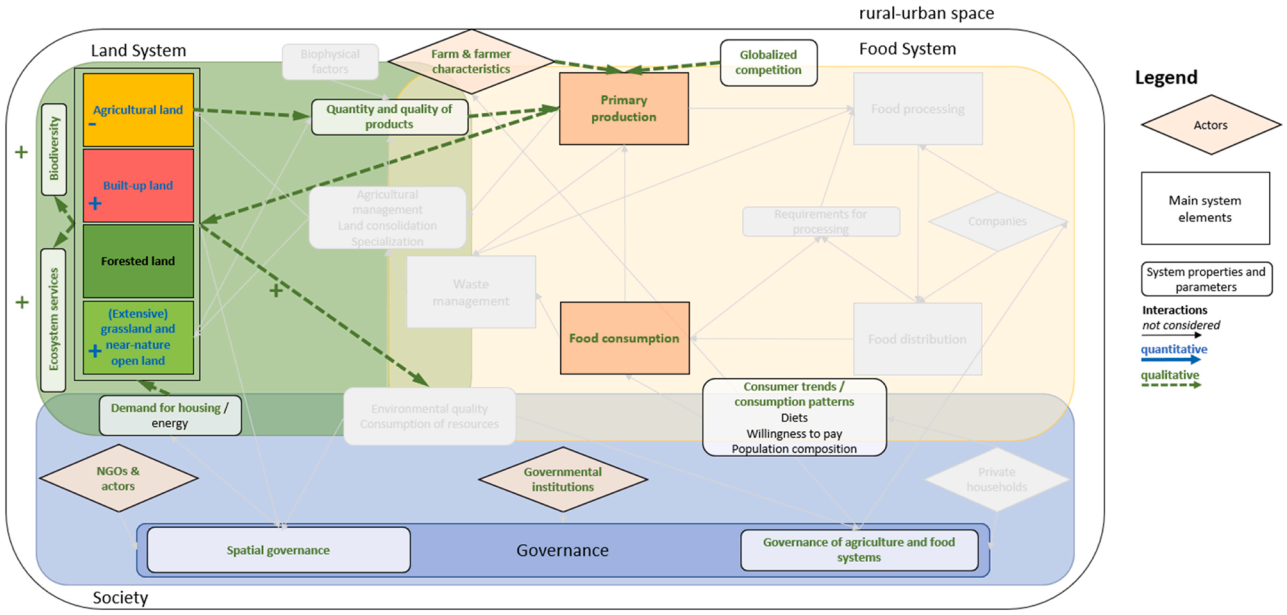

Fig. 11. (Qualitative) policy studies (pathway 3).

land is revealed. For forested land, no clear trend can be identified. Extensive grassland, if analyzed, rather increases. The reviewed studies quantify mostly negative impacts on the environment and on landscape diversity. The impacts on ecosystem services, if quantified, are primarily negative, but qualitative assessments show positive impacts. Impacts on biodiversity are mostly positive, but often only qualitatively assessed. These studies cover primarily food production, more often quantitatively than qualitatively. These studies hardly quantify other food-system elements. The reviewed studies have frequent quantitative links from the land to the food system, which often manifest in specifications of product quantity and quality. Vice versa, links from the food to the land system are hardly addressed. These studies quantify the impact of different drivers of land-use/land-cover change: agricultural management and farm characteristics, land consolidation, and demand for housing. Drivers of food-system change are population composition and agricultural governance, but less frequently considered. Few studies considered in our review identify the impact of environmental drivers and spatial governance. They consider stakeholders, mainly farmers, mostly qualitatively.

The representative study by Gomes et al. (2019), for instance, investigates the degree of agricultural land fragmentation, the underlying driving forces and simulated land fragmentation for 2025 in a business-as-usual scenario (Table 2). The authors of this representative study provide knowledge on the degree of land-use/land-cover change (e.g., conversion of 891 ha of agricultural land into artificial surfaces between 1995 and 2010) and identify significant driving forces of these changes. Qualitative recommendations for land policies to control and mitigate land-use/land-cover change complement the study through pointing out the relevance of the case study area as the major national supplier of selected food products.

3.1.3. (Qualitative) policy studies (pathway 3)

Qualitative surveys, policy and document analysis (Fig. 11) are joined with land-use/land-cover change analyses in this pathway. The studies we reviewed are hardly spatially explicit and include secondary data and – to a lesser extent – primary data. Pathway 3 focuses on cities and considers towns and suburbs as well as rural areas to a lesser extent, with few case studies analyzing urban-rural exchange relationships (Fig. 3). Most of the reviewed studies quantify land-use/land-cover change with an increase of built-up land, a decline of agricultural land, and an increase of extensive grassland. They determine positive qualitative impacts on the environment, on ecosystem services, and on biodiversity. These studies cover primarily food production and consumption in a qualitative manner. All other food system elements are understudied. These studies have qualitative links from the land to the food system. Vice versa, these studies qualitatively address links from the food to the land system through consumption patterns and demand. They qualitatively assess the impact of multiple drivers of land-use/land-cover change. Drivers of food-system change are qualitatively relevant, mostly agricultural governance, and discussed in the studies we reviewed. Spatial governance is an important driver and qualitatively considered. Apart from private households and companies, these studies identify all other stakeholders as relevant (qualitative consideration).

The study by Léger-Bosch et al. (2020) as representative example, for instance, provides an illustrative case for qualitative policy studies (Table 3). The authors characterize institutional land tenure change in France. This qualitative study identifies all relevant actors (e.g., collaborating groups, civil society, farmers, territorial government), organizational frameworks (e.g., working and financing methods), and social innovations in two underlying case studies.

4. Challenges and future research needs

4.1. Linking land and food systems

This systematic review revealed a partial integration of land- and food-system research. The reviewed land-system studies predominately consider primary production if addressing food systems as also highlighted by Verburg et al. (2015). One reason might be that land use is the nexus between land and food systems as stated by Meyfroidt et al. (2019). Although all pathways consider land use as interface between land and food systems, the implementation differs between the two more quantitative pathways on economic, footprint and crop modeling studies (pathway 1) and scenario-based land-use/land-cover change and remote sensing studies (pathway 2) as well as the (qualitative) policy studies (pathway 3). The reviewed European studies focus on land-use/land-cover dynamics and use scenario as well as remote sensing techniques (pathway 2). Their emphasis on the land system leads to a weak or strongly simplified consideration of food-system dynamics. Equally, these studies mainly consider the impact of land-system dynamics on the food system (push perspective), but disregard major

Table 1
Representative example of pathway 1: Economic crop-modeling and footprint studies.

Study	Wascher and Jeurissen (2017) Urban food security at the crossroads between metropolitan food planning and global trade: the case of the Antwerp – Rotterdam – Düsseldorf region
Study region (s)	Metropolitan region Flemish diamond (Ghent, Leuven, Antwerp), Belgium Metropolitan region Rotterdam-The Hague, Netherlands Metropolitan region Düsseldorf, Germany
Goals	• Understand the sustainability impacts along the full agro-food chain in metropolitan foodsheds • Analysis of the spatial extent of the agricultural area required for food production • Analysis of the distribution of the land-use types, which are required for food production • Assessing food demand and food supply of the Metropolitan Food Ring (MFR) and the Transition Zone (TZ)
Methods used	• Footprint analysis with the Metropolitan Foodscape Planning tool (MFP): • Calculation of food demand based on consumption patterns of people and the population number. • Metropolitan Food Ring (Foodshed size): Estimation of the supply of land eligible for farming in ha based on calculated food demand and regional productivity (yields). • Assessment of the supply-demand balance of crops.
Data	• Food consumption statistics: European Food Safety Authority • Land cover information: CORINE Land Cover 2016 • European network of protected sites: Natura 2000 • Crop area data: Homogenous Soil Mapping Units
Key findings	Metropolitan region Flemish diamond (Ghent, Leuven, Antwerp), Belgium: • Deficit of grassland supply compared to demand • Undersupply of fruit production • Oversupply of land dedicated to livestock feed (fodder) • Oversupply of vegetables and the crop rotation of potatoes - sugar beet – wheat; Metropolitan region Rotterdam-The Hague, Netherlands • Agricultural land requirement is twice as large as the total surface area of Metropolitan region • Balance of supply and demand of grassland (grazing land) • Tomato, paprika and cucumber production in greenhouses exceeds the demand of the Dutch population and is exported to other European and global locations • Oversupply for "rotation crops" • Fruit supply is smaller than demand Metropolitan region Düsseldorf, Germany • Almost match of supply and demand of grassland • Oversupply for "rotation crops" and "other cereals" • Almost match of supply and demand for vegetables • Deficit of fruit production Overall finding: • Self-sufficiency of analyzed metropolitan areas is in principle possible and dependencies upon food imports vary considerably between regions. • Regional food supply is dependent on agricultural land use, however also on designated areas for nature conservation and recreation, urban development, flood protection, and other land use requirements.

Table 2
Representative example of pathway 2: scenario-based land-use/land-cover change studies.

Study	Gomes et al. (2019) Agricultural land fragmentation analysis in a peri-urban context: From the past into the future
Study region (s)	Torres Vedras municipality, Portugal
Goals	• Assess agricultural land fragmentation for 1995 and 2010 based on landscape metrics • Recognize and analyze underlying driving forces • Identify the effect of scale • Predict agricultural land fragmentation for 2025 in a business-as-usual scenario
Methods used	• Land-use change analysis for 1995 and 2010 • Assessment of land fragmentation based on landscape metrics (patch size, edge, shape, connectivity, and isolation/proximity) • Statistical modeling (Multicollinearity analysis, cluster analysis; multi-regression analysis, artificial neural networks)
Data	• Land use data based on General Directorate of the Territory (DGT) • Socio-economic, agricultural variables based on Statistics Portugal • Environmental and political variables based on planning documents
Key findings	• Analysis on 5 km grid is most efficient to identify influential driving forces of land-use change • Between 1995 and 2010, 891 ha of agricultural land was converted into artificial surfaces • Influential driving forces of agricultural land fragmentation are related to socio-economic development and human activity • Agricultural land fragmentation will increase in the future (2025)

Table 3
Representative example of pathway 3: (qualitative) policy studies.

Study	Léger-Bosch et al. (2020) Changes in property-use relationships on French farmland: A social innovation perspective
Study region (s)	France
Goals	• Analyze current agricultural land changes through the lens of the property-use relationship • Understand drivers of change of property-use relationships
Methods used	• Review of literature and policy analysis • Qualitative survey based on semi-structured interviews with actors involved in local farmland management in two contrasting case studies of different property-use relationships
Data	• Interviews with farmers and other involved actors about land-use relationships and document analysis
Key findings	• In recent years, farmland management has changed due to institutional changes and new actors: environmental management has been included in specific land lease contracts, and new actors have become involved in the land market by purchasing land by means of crowdfunding • Land change is based on interaction between different levels of organization, on strong links between the local networks of actors, and on social capital existing at the local level. • The bottom-up movement Terre de Liens (TdL) (English: land of ties) aims at implementing sustainable farming through the collective acquisition of farmland, to provide fair access to land for new farmers, and to raise awareness for farmland concerns. • Rural land leases subject to environmental clauses (BREs) is rather a more institutionalized process and leads to a top-down process towards local assimilation • The two case studies result in different property use relationships in terms of the organization of decision-making between owners and users: a kind of partnership-based relationship in the case of TdL, and a more hierarchical or at least distant relation in the case of BREs.

consumer trends (pull perspective). The footprint studies we reviewed consider consumption as additional value-chain echelon, but largely miss most other value-chain echelons such as processing or retail (pathway 1). Few studies translate the influence of consumer trends into land-system dynamics (e.g., demand for organic or regional food) or consider global competition on food and land markets (c.f. Meyfroidt et al., 2019 for comparable findings). These footprint studies miss the spatial impact of food-system dynamics and do not completely consider the food system and its value chains. Qualitative policy studies (pathway 3) in our systematic review seemingly quantify land-use/land-cover change to justify their analysis of food- and land-system dynamics. Unsurprisingly, their qualitative nature allows more easily describing the role of drivers and actors both in the land and the food system.

Future studies should extend the perspective in both food- and land-system studies. For example, the interaction between food and land systems should be bidirectional and not only focus on one direction (pathway 1: from the food to the land system, pathway 2: from the land to the food system). Furthermore, a relevant consideration of

governance in future studies could help to explain current interaction between land and food systems. The role of private and public governance is understudied, especially in quantitative studies (pathways 1 and 2). Schreiber et al. (2021) equally identify governance as research area for foodshed studies.

4.2. Opening the black box: food system value chains

Comparing our general framework (Fig. 2) with the pathways (Fig. 9, Fig. 10, and Fig. 11), we identified several gaps. First, most of the reviewed studies only consider primary production (pathways 1, 2, and 3) and to some extent consumption (pathways 2 and 3). However, the consideration of food processing, distribution and retail, as well as waste management is limited. An existing framework analyzing land- and food-system overlaps such as Meyfroidt et al. (2019) equally has a limited perspective on the food system. Second, current studies in Europe on food- and land-system dynamics reviewed in our study consider the food value chain as a black box; derived parameters are mostly based on assumptions if quantified at all (footprint studies in pathway 1 and scenario studies in pathway 2). Especially footprint studies, which also include life-cycle assessments, should better address individual value-chain echelons and especially waste management as state-of-the art for life-cycle assessments (c.f. Notarnicola et al., 2017).

Future studies should deepen the food-system perspective in all types of studies (pathways 1, 2, and 3) since understudied value-chain actors (retail and distribution as well as processing) and their behavior could create deviating food supply and demand patterns. Including these missing value-chain actors could help to better explain and predict land-system dynamics as identified for the Global South (Meyer, 2020). It could be interesting to analyze, to which extent food system value chains evolve depending on different urban-rural relationships (e.g., highly urbanized areas with high purchasing power in Southern Germany compared with thinly populated areas in Northeastern Germany with a rather low purchasing power). Given such contrasting study areas, one could identify thresholds (e.g., with respect to population density, economic prosperity) that decide whether (local) food value chains persist or evolve or whether other land-system dynamics persist (e.g., land consumption, agricultural land abandonment (Meyer and Früh-Müller, 2020; Meyer et al., 2021)).

4.3. Urban-rural linkages from a rural perspective?

We analyzed the reviewed studies for urban-rural linkages. Most study areas in pathways 1 and 2 comprise urban, intermediate, and rural areas (see urban-rural-typology of the European Union (Eurostat, 2021)). However, the perspective is primarily from urban to rural areas in pathway 1, which is in line with urban-rural disparities (stronger urban areas vs. weaker rural areas) as discussed for the US by Shellabarger et al. (2019). Pathways 2 and 3 hardly focus on a clear direction, from urban to rural or vice versa. Equally, a balanced approach with emphasis neither on urban nor on rural areas is equally missing. Although the spatial extent of the reviewed studies in pathways 1 and 2 would allow for analyzing urban-rural linkages, this focus is rather weak. This underlines the unaddressed need to consider the effect of increasing urbanization on food production (Lerner and Eakin, 2011). Interestingly, the reviewed qualitative policy studies in pathway 3 have a clear focus on urban areas in their spatial extent. This may have the following reasons: First, qualitative policy studies can less easily cover larger areas, stakeholders are difficult to address and to integrate stakeholders representing urban and rural interests alike is challenging. Secondly, the analyzed case studies often represent administrative units such as cities or planning regions, which often have cities at their center. Thirdly, we ensured through our keyword search that an urban "component" has to be included. This could also explains mostly missing purely rural studies, as we did not include this component as mandatory to avoid narrowing down the number of eligible studies.

Future studies should extend their perspective emphasizing more strongly on urban-rural linkages to consider material and immaterial exchange relationships as done in foodshed studies (Schreiber et al., 2021). However, this should not only consider material flows of goods and services but also the role of urban and rural actors shaping these exchange relationships. Interesting insights could equally arise if future studies addressed urban and rural areas in a more balanced manner or even took a rural-to-urban perspective while analyzing food- and land-system dynamics. Typically, rural development aims to create beneficial impacts of food systems mostly independent from existing linkages to urban areas although these are increasingly mentioned and considered important (Knickel et al., 2018). However, it would be interesting to analyze whether and how changes such as strengthened structures in food systems (e.g., increased processing and sales in rural areas) (Poelling and Mergenthaler, 2017) and more restrictive spatial planning would affect changes in urban behavior. Potential changes could be increased grocery shopping of urban residents in rural areas (Knickel et al., 2018) and a slowdown of urban sprawl (e.g., less residents moving to periurban areas for housing due to more frequent opportunities for remote working in remoter rural areas spurred by COVID-19 (Meyer et al., 2021)). Interesting questions are to which extent rural patterns are shaped by urban residents and urban governance (e.g., urban development policies), and to which extent these patterns are and could be shaped by rural population and governance.

4.4. Strengthening the quantification of major processes

Most of the reviewed studies in pathways 1 and 2 deterministically capture how different consumption patterns affect the land system or how changes in the land system affect production. Qualitative policy studies (pathway 3) explain the interaction between land and food systems but miss to quantify major processing and distributution in the food system. While considering governance, the reviewed qualitative studies often miss to quantify interaction between governance and the land as well as the food system.

Future research should therefore i) quantify and analyze processes linking the land (e.g., land-use/land-cover change) and the food system (e.g., consumption). The aim should be tangible figures including the role and behavior of individual actors and relevant environmental conditions. Future research at this interface should not only quantify assumptions as in previous studies (pathways 1 and 2) but also quantify or simulate how actors decide to modify the food and the land system. This could be achieved via simulations of food value-chain actors such as van Voorn et al. (2020). ii) Moving from deterministically captured impacts to considering drivers and dynamics in the food system for major impacts could allow addressing deficiencies with respect to land consumption or value-chain organization. For example, a better understanding of different actors' roles and power in shaping value-chains such as the consolidation of value chains or driving land consumption could support more targeted governance. Regulatory or informative governance instruments targeting major actors in social networks driving land consumption or critical agricultural subsidies could more effectively counteract the likely vulnerability of food systems under threats such as climate change or changing consumer preferences.

4.5. Quantifying Governance

Overall, few studies in our review consider governance at the interface between land- and food-system studies. Agricultural governance is partially a qualitative (pathway 3) or a quantitative driver (pathway 2). Only qualitative policy studies (pathway 3) consider spatial governance. Institutional and non-governmental actors play a role in these qualitative studies. These actors are hardly considered in the reviewed quantitative studies (pathways 1 and 2) although considered as relevant in the reviewed policy studies (pathway 3) and in existing research (Candel, 2014). Interaction between governance

(spatial and agricultural) and the land and food systems is understudied (see also van Bers et al., 2019).

Future research should consider further actors shaping public and private governance to understand and to predict impacts of decision making of linked land and food systems. Other reviews such as Meyfroidt et al. (2019) only highlight the role of corporate governance such as the financialization of agriculture and the entire food sector as crucial research themes. However, consistent quantification of governance mechanisms at this interface is largely missing and should integrate both food- and land-system dynamics. For example, Teeuwen et al. (2022) identified in a review on modelling food security governance two main issues of quantifying governance: social and spatial targeting of governance measures. Social targeting (i.e., quantifying the impact on individuals vs. groups or at-large) is met by different models. Agent-based models are better able to address the impact on and the contribution of the individual, whereas system-dynamics and computable general equilibrium models focus on at-large effects. Spatial targeting of governance measures and the assessment of spatially explicit impacts is even less frequently done than social disaggregation. If done, agent-based models, cellular automata or system-dynamics approaches have been more frequent. Future studies should also elaborate on quantifying spatial and agricultural governance impacts on food and land systems in a joint manner to answer research questions on their interactive impact on the environment and on society. Here, heterogeneous decision-making (van Zanten et al., 2014) between stakeholders could explain past and predict future patterns in land and food systems. The marginal impact of both policy domains on land systems has been comprehensively studied in the European Union (e.g., Früh-Müller et al., 2019). However, research domains addressing spatial planning or agricultural policies less frequently interact likely due to separate professional or scientific communities. In that respect, it would be interesting to test how the integration of policies that are not sufficiently spatially explicit implemented such as agri-environmental measures of the Common agricultural policy (CAP) of the EU would affect the interface of land and food systems. This research arena could help to show deficits both of the CAP and of spatial planning. For example, a higher efficiency of agri-environmental measures through spatial targeting could be achieved (Pe'er et al., 2020). Secondly, further food-system elements such as infrastructure for processing or transportation could equally be relevant for spatial planning.

4.6. *Local self-sufficiency still depending on locational factors?*

The reviewed studies hardly see a decisive role of biophysical factors driving land- or food-system dynamics. The scope of these studies on impacts on environmental quality including biodiversity and ecosystem services (quantitative (pathway 2) and qualitative (pathway 3) might explain the missing analysis of biophysical factors as drivers (output perspective on food and land systems). However, biophysical factors might be less important or are overruled in analyses of land-system dynamics in Europe given a highly specialized agricultural system that is primarily shaped by institutional or economic factors and developments (e.g., urbanization, off-farm employment, land consolidation). Locational, mainly biophysical factors still play a decisive role for the agricultural extensification in Europe (van Vliet et al., 2015). Recent studies have confirmed Plieninger et al. (2016) and van Vliet et al. (2015) that land abandonment is considerably affected by biophysical factors (shown for southern Germany for marginal locations (Meyer and Früh-Müller, 2020; Meyer et al., 2021)).

Although biophysical factors might not be as decisive in driving land- and food-system dynamics under the narrative of increased food production, it might be still interesting to analyze how differences between marginal and favorable locational factors affect landscapes and its services as well as biodiversity. This should extend previous research analyzing the impact of landscape elements such as Schulze et al. (2016). Biophysically unfavorable conditions might even affect the local food self-sufficiency as identified for > 60 countries by Clapp (2017).

Systematic reviews are limited by the selection of search terms. To examine the extent of the limitations, we carried out a literature search in the Web of Science with the additional search term "system" (land AND system AND food system AND agriculture* AND urban) to check if different search results can be obtained using 'land system'. This search resulted in 987 publications. Of this large number of studies, 319 hits could be excluded as duplicates of the original search. Of the remaining 668 records, a random sample of 5 % (33 records) was drawn, which were pre-screened according to the previously described procedure. Only one hit would be eligible for further analysis. Therefore, we are positive that our literature review includes the main studies relevant for the assessed topics. Still, the results presented in this paper will be limited to the reviewed literature. We equally explored whether it is adequate to add the term rural as well, but this approach limited the number of relevant papers to 91. Therefore, we omitted the term rural and checked manually whether an urban-rural gradient was assessed.

5. Conclusions

Food-system research and land-system science will likely benefit from further integration in future studies as land and food systems are considerably linked. Although a variety of methods has been used in previous studies, further quantification of actual processes that link land and food system beyond land-use/land-cover change is largely missing. We found that the current studies we reviewed quantify primarily impacts of food- and land-system dynamics (e.g., spatial land demand for diets), but hardly quantify dynamics in food systems.

The role of governance has been acknowledged in the reviewed qualitative policy studies, but was quantified neither in economic, footprint and crop modeling studies nor in most scenario-based land-user/land- cover and remote sensing studies we reviewed. Both food- and land-system studies are subject to a broad variety of governance mechanisms (e.g., spatial planning, agricultural and food policies). It might be of major interest to quantify jointly spatially targeted policies (e.g., land-use planning) with overarching policies such the CAP in the EU or even market interventions in the food sector with its local impacts and dynamics such as processing requirements. A joint analysis might provide new insights, how these different policies interact in a beneficial or detrimental manner. Furthermore, future studies should dive deeper into decision-making processes of major actors, which can provide further insights how the current relationships of food and land systems evolve and how they might change in future. For example, considering the market power and behavior in processing and retail instead of assuming static food demand and diets or production systems might provide a better understanding and allow for more targeted governance.

Urban-rural linkages have been mostly analyzed from an urban perspective although spatially major land for food production is in rural areas. Equally, land-system dynamics are stronger in rural areas. Therefore, future research should also take a rural perspective considering governance and major actors and quantify how urban areas shape rural land systems or vice versa. Secondly, it is worth analyzing how these urban-rural linkages could be better governed if considering a rural-to urban perspective.

CRediT authorship contribution statement

Markus A. Meyer: Funding acquisition, Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Andrea Früh-Müller:** Conceptualization, Formal analysis, Data curation, Writing – review & editing. **Isabella Lehmann:** Conceptualization, Formal analysis, Data curation, Writing – review & editing. **Nina Schwarz:** Conceptualization, Formal analysis, Data curation, Writing – review & editing.

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Data availability

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2023.106692.

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