Journal of Environmental Management 351 (2024) 119769

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Farmland expansion and intensification do not foster local food self-sufficiency. Insights from the Mediterranean area

Esther Sanz Sanz [a,*], Claude Napoléone [a], Marta Debolini [b,c], Davide Martinetti [d], Olga Moreno Pérez [e], Cristina de Benito [a], Michel Mouléry [a], Teresa Pinto Correia [f], Rosalia Filippini [g], Lamia Arfa [h,j], Carolina Yacamán-Ochoa [i]

[a] INRAE (French National Institute for Research on Agriculture, Food and Environment), ACT department, Ecodéveloppement unit, 228 route de l'aérodrome, 84914, Avignon, France
[b] INRAE, AgroEcoSystem department, EMMAH unit (Environnement Méditerranéen et Modélisation des AgroHydrosystèmes), Avignon, France
[c] CMCC Foundation – Euro-Mediterranean Centre on Climate Change, IAFES Division, Viale Italia 39, 07100, Sassari, Italy
[d] INRAE, MathNum department, BIOSP unit (Biostatistique et Processus Spatiaux), Avignon, France
[e] UPV (Universitat Politècnica de València), Group of International Economics and Development, Department of Economics and Social Sciences, Valencia, Spain
[f] MED (Mediterranean Institute for Agriculture, Environment and Development) & CHANGE (Global Change and Sustainability Institute), Departamento de Paisagem, Ambiente e Ordenamento, Escola de Ciências e Tecnologia, Universidade de Évora, Pólo da Mitra, Ap. 94, 7006-554 ,Évora, Portugal
[g] University of Parma, Department of Economics and Management, Parma, Italy
[h] University of Carthage, National Agronomic Institute of Tunisia, Department of Agricultural and Agri-food Economics and Management. 3, Avenue Charles Nicolle 1082, Tunis, Tunisia
[i] UAM (Universidad Autónoma de Madrid), Department of Geography, Madrid, Spain
[j] National Agronomic Research Institute of Tunisia, Agricultural Economics Department, Rue Hedi karray, 2049, Tunis, Tunisia

ARTICLE INFO

Handling editor: Raf Dewil

Keywords:
Local food systems
Land system changes
Regionalisation of food self-sufficiency
Context-based policies
Multi-level modelling
Mixed methods

ABSTRACT

Bridging the gap between the micro and the macro scale in modelling food security to inform context-specific regionalised policies remains a major scientific challenge. A better understanding of the relations between global and local drivers impacting local food self-sufficiency (LFSS) is essential. We applied to the whole Mediterranean environmental area (Southern and Northern) a modelling framework for structural estimates (PLS-PM) using qualitative and quantitative methods to combine local-level information from field surveys and participatory workshops with global-level data. Our findings show that farmland expansion and intensification spatially disconnected from urban consumption areas do not appear to foster LFSS. On the other hand, public policies appear key to enhancing LFSS in the Mediterranean area if appropriate to the particular regional context. We outline how this multi-level modelling methodology can contribute to a place-based approach by informing context-specific regionalised policies aimed at food security.

1. Introduction

In a context marked by food price hikes, dwindling natural resources, land grabbing activities, social unrest and the effects of climate change, food insecurity is the focus of growing attention (Sonnino, 2016). The Food and Agriculture Organisation of the United Nations describes food sufficiency as a country's ability to satisfy its food needs from its own domestic production, while the food self-sufficiency ratio is defined as the share of domestic production in total domestic use, excluding stock changes (FAO, 1998). Particularly for food commodities such as cereals and meat, the self-sufficiency ratio has often been considered a strategic target variable heavily influencing food and agricultural policies (FAO, 2018). However, some national policies aiming at reducing the poverty rate by means of increasing the agricultural gross domestic product have a negative impact on the level of food self-sufficiency (Bezner-Kerr, 2012; Saidi and Diouri, 2017). Countries like Turkey are net food exporters, but it is anticipated that geographically varying domestic food insecurity will rise in the coming decades (Iba Gürsoy, 2020). There is an urgent need to identify the enabling and constraining factors in local food self-sufficiency (LFSS) to support the design and implementation of policies and public, civil society and private interventions at local and regional levels (Béné et al., 2019).

* Corresponding author.
E-mail address: esther.sanz-sanz@inrae.fr (E. Sanz Sanz).

https://doi.org/10.1016/j.jenvman.2023.119769
Received 21 August 2023; Received in revised form 5 November 2023; Accepted 3 December 2023
Available online 25 December 2023

Most of the drivers of LFSS identified in the literature, such as urbanisation and the associated change in life style, technological innovations or the intensification and homogenisation of the agricultural sector, are linked to the forces causing food system change at a global level (Bissoffi, 2019; Denning and Fanzo, 2016; The Government Office for Science, 2011). Cropland expansion and intensification are generally considered the two main strategies to increase food production (Hu et al., 2020), but the actual relationship between these global trajectories and LFSS has not been explored. Brink et al. (2023) identify a lack of coherent and consistent data about the relationship between local food supply and demand and the mapping of LFSS. Similarly, Kaufmann et al. (2022) find widespread disconnectedness in Europe between agricultural land use and consumption, particularly regarding livestock systems. Moreover, Wu et al. (2014) analysed possible future global strategies to increase food production, i.e. cropland expansion, crop allocation and agricultural intensification. They concluded that crops need to be properly allocated in both space and time so as to take into account factors like food production, climate change, dietary preferences and various socio-economic influences without impacting environmental components. However, rather than universally supporting agricultural intensification, more consideration needs to be given to the specific local food system, especially local foods that could potentially be lost under intensification strategies (Ickowitz et al., 2019). In fact, agricultural intensification and expansion can increase pressure on water (Eckert et al., 2017), GHG emissions (Olén et al., 2021; Van Loon et al., 2019) and biodiversity (Shaver et al., 2015; Zabel et al., 2019).

Interactions amongst multiple drivers have led to the transitional changes currently taking place, such as the rapid increase in demand for processed food or the anticipated decreases in productivity for several major crops (Béné et al., 2019). Analysis of the multi-level drivers of food systems and the related processes, including trade-offs in land-use competition, is handled in research via analytical quantitative approaches that enable multiple plausible futures to be examined (Jin et al., 2019). Notably, mathematical and statistical models aimed at land use and food security links across multiple scales often either employ local-level proxies when analysing large-scale processes or use global drivers when analysing local processes (Baldos and Hertel, 2014; Müller et al., 2020). What is needed is a more “nested” analytical approach to food systems’ interlinked activities and outcomes at multiple levels, as called for by other scholars (Gill et al., 2018; Poggi et al., 2021; Ruben et al., 2018). From a methodological point of view, the modelling of global determinants of LFSS based on existing databases should be combined with information on local realities obtained through field surveys or interviews (Delattre et al., 2015). Thus, the challenge is to understand the relations between global and local drivers impacting LFSS in order to be able to adopt a territorial approach to food security policy (OECD/FAO/UNCDF, 2016).

To address this gap, we applied to the Mediterranean environmental area proposed by Metzger et al. (2005) a modelling framework from the field of structural estimates (PLS-PM). Qualitative and quantitative methods are used to combine local-level data from field surveys with global-level data. The Mediterranean area provides an excellent opportunity to identify a large set of connections between global dynamics and local food systems, with the related multi-scale processes, particularly urban sprawl, farmland development and farmland abandonment (Debolini et al., 2018; Soulard et al., 2017). For instance, urban pressure has historically been less regulated in the Northern Mediterranean area than elsewhere in the EU (EEA, 2006). The abandonment of annual crop cultivation is noticeable in peri-urban areas throughout the Mediterranean environmental area, largely in anticipation of urbanisation and leading in turn to the development of market-oriented agriculture farther away from the cities (Debolini et al., 2015; Geniaux et al., 2011). On the other hand, farmland development results from the expansion of farming areas and the intensification of agricultural activities (Temme and Verburg, 2011). Moreover, Mediterranean food systems are historically linked to traditional agricultural land use and management systems (García-Martín et al., 2020), generally with a stronger urban-rural linkage than in other western areas (like North America) (Cerrada-Serra et al., 2018; Lamine et al., 2019). However, the Mediterranean area is facing massive global change, including increasing water shortages, demographic pressure and the growing dependence on food imports, all of which threaten LFSS (Verger et al., 2018a).

2. Methodological framework

Through a multi-level methodological approach, we transferred the hypotheses on LFSS drivers that were derived from field surveys to a broader set of assumptions (Fig. 1). Qualitative empirical research was performed at local scale on nine case studies in seven countries to explore the drivers of LFSS in the Mediterranean basin (we term “local” the scale of direct links between city and agriculture; depending on practices, this scale ranges from the municipality to a group of neighbouring cities). Quantitative spatial analysis at global scale was used to detect the main land use and management trajectories, namely urban expansion, farmland development and farmland abandonment. Finally, a structural statistical model (Partial Least Squares Path Modelling, PLS-PM) was developed for small regions (equivalent to the NUTS 3 nomenclature of territorial units for statistics by Eurostat; number of small regions = 416). Its aim was to identify the strength and direction of the relationships among global and local drivers impacting LFSS, including land use and management dynamics. Using the PLS-PM approach, we explored complex multivariate relationships among theoretical non-measurable concepts, namely latent variables (for instance, social innovation) and manifest variables measured or computable from data freely available (see complete list in Table 1). Our results highlight how modelling approaches hold great promise for integrating geographical analysis of land use change with socio-economic analysis of local and regional food systems, offering a valuable tool for food policy-making tailored to specific regional contexts.

3. Methods

3.1. Global database spatial and statistical analysis

A comprehensive database at Mediterranean level was built from geographical information regarding land use, topography, crop composition, livestock, population and bioclimate, for 2005 and 2015. According to Metzger et al. (2005), the Mediterranean area is the ecological limit of the Mediterranean biotope. We added the Mediterranean mountain areas, for a fuller picture of landscape heterogeneity. Sources and references are detailed in Supplementary Table 1 and the whole database is fully described in (Fusco et al., 2018). The whole database was reported at a spatial resolution of 2 km. Through a hierarchical classification, we obtained 20 classes for the two years 2005 and 2015, representing the full range of land uses and management systems in the Mediterranean. A detailed description of the land system classes is given in Supplementary Table 2 and presented in (Fusco et al., 2019). For the purpose of this paper, we aggregated agricultural classes for the two years 2005 and 2015 (Fig. 2). Moreover, agricultural land use and management systems’ changes were evaluated by comparing maps from the two years and locating spatial differences in the transition matrix. Notably, we detected and mapped the clusters of high increase in farming intensification, concentration and/or specialisation of food production in 2015 (Fusco, 2019), including land system changes from dry areas with sparse vegetation to productive rainfed arable lands (Fig. 3a). Moreover, following the Global Human Settlement Layer, we made a spatial statistical and analysis of the urban clusters and urban centres in 2015 (Fig. 3b).

3.2. Local case studies: data collection and analysis

In order to identify the drivers that are both enhancing and limiting

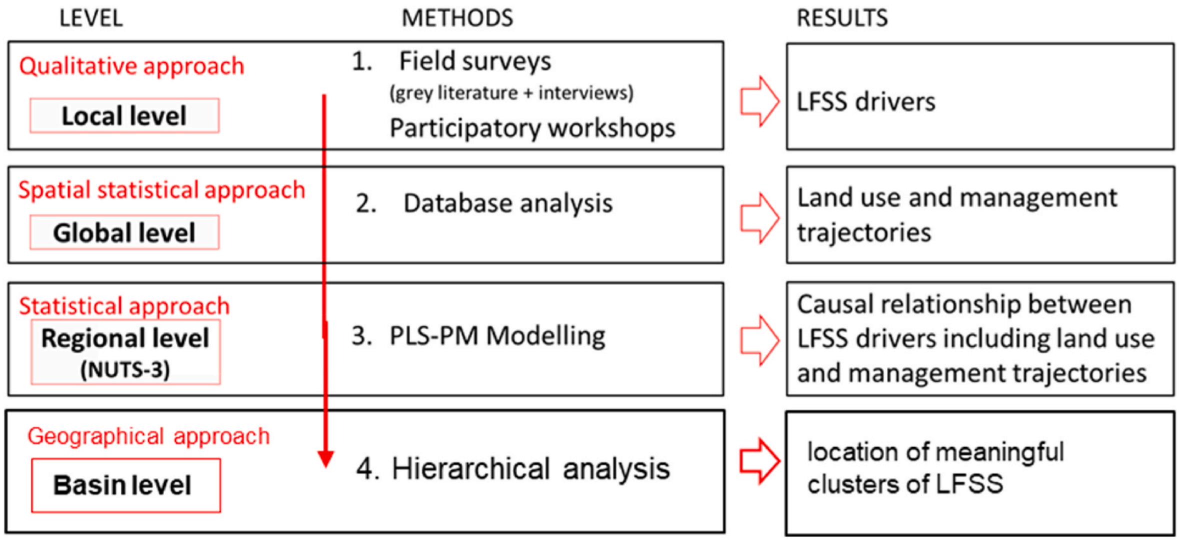

Fig. 1. Multi-level methodology used to understand the relations between global and local drivers impacting local food self-sufficiency (LFSS), showing steps and results expected from each level of analysis.

local food self-sufficiency, we analysed nine Mediterranean local cases located in Italy, France, Malta, Portugal, Spain, Tunisia and Algeria (Supplementary Fig. 1). The group of case studies needed to meet three criteria: a/cover both Northern and Southern Mediterranean countries, b/cover both rural and peri-urban contexts and c/be representative of the four main trajectories of change. Each case study therefore represents a major agri-food context: the Comtat Venaissin and the Haouaria area are huge producers of fruit and vegetables, mainly for the global market – Comtat Venaissin for the north and Haouaria for the south of the basin; the Pisa region is a historical farming area very highly disturbed by urban sprawl; the Madrid region is representative of the changes in space brought about by a large city; the Alentejo region illustrates the current trends in agro-ecological systems, particularly the Montado; Malta shows the agricultural production stakes for islands and the Algerian case study based on three municipalities highlights the new global south response to farming – namely high-tech gardening in dry areas (Biska region) aimed at supplying densely-populated cities in the north of the country.

Our first step was to conduct a grey literature analysis including statistical data analysis to characterise the agri-food context in each case study. This was complemented by 107 interviews with key informants in the field study area (local experts, public officials from local and regional government and farmers' representatives - 18 in Portugal, 11 in Italy, 9 in France, 11 in Malta, 13 in Spain, 27 in Tunisia and 18 in Algeria) to identify the factors perceived by stakeholders as impacting the local food systems, including local food self-sufficiency (see details in Sup. Info.2 and questionnaire in Sup. Info. 1). In the second step, 6 participatory workshops[1] were held with stakeholders involved in the local food supply chain of two outstanding locally-grown food products (Ferchichi et al., 2020). It was not possible to organise a stakeholders' workshop in Malta, but expert knowledge and interviews covering most of the study area provided the necessary information. The participants included consumers, farmers, private economic actors and public officials (see Methods of Investigation in Sup. Info. 2). We chose to meet stakeholders in participatory workshops to avoid focusing on individual issues and to exploit shared knowledge. The aim was to share knowledge on the proportion of local self-sufficiency for each product (i.e. the proportion of these local products locally consumed) and discuss the factors impacting it. The products chosen needed to fulfil at least one of these requirements: a) a high volume of local production, b) commonly grown and consumed in the area of interest, c) embody identity values for the local population. The food products analysed were either fresh horticulture or orchard products (cherries in France, asparagus in Spain and tomatoes in Tunisia and Algeria), arable crops (potatoes in Malta, Tunisia and Algeria) or food products requiring transformation (olive oil in France, Spain, Italy, Malta and Portugal; meat in Italy and Portugal). All the information gathered was compiled in structured regional reports, and the main results are included in Esgalhado et al., 2021, Moreno Pérez et al., 2019; De Benito et al., 2019, where the authors cross-compared the case studies to inductively identify and categorise the drivers most strongly influencing local food self-sufficiency. In this work, the previous insights were used to quantitatively estimate the underlying drivers.

We identified seven categories of drivers at local level (see Sup. Info. 4 for details): 1) Urban sprawl (i.e. urban expansion and/or peri-urbanisation); 2) Farmland abandonment (i.e. decreased farmland or fragmentation) and, conversely, 3) Farmland development (i.e. farmland expansion and intensification, concentration and/or specialisation of food production); 4) Rootedness (i.e. the preservation of the traditional local production and consumption of a specific food product); 5) Propensity to consume locally-grown food; 6) Social innovation aimed at local food sufficiency; and 7) Public policies on land use and food.

3.3. PLS-PM statistical modelling

3.3.1. Description of the PLS-PM statistical modelling

The change of scale from the results of local field surveys to the Mediterranean basin (i.e. global level) is, by definition, unmanageable using solely interviews (due to population size) or direct data analysis (due to lack of a database at plot or individual levels covering the whole area). However, there are models that allow the hypotheses derived from the local field surveys to be upscaled to a broader set of assumptions. For instance, PSL-PM, developed by Wold (1985, 1982) and further refined by Lohmöller (1989, 1988) and more recently by Tenenhaus et al. (2005) and Esposito Vinzi et al. (Esposito Vinzi et al., 2010). Partial Least Squares Path Modelling (PLS-PM) is a statistical method for studying complex multivariate relationships among manifest variables (MV) and latent variables (LV). Latent variables typically represent theoretical concepts that correspond to non-measurable or non-observable quantities. The inner model of a PSL-PM represents the causal relationship among LV and is defined by the modeller such that it

[1] Only 6 out of 10 countries; the situation in Algeria prevented us from organising the event properly.

Table 1
Drivers of local food self-sufficiency and description of the variables used in the model.

Drivers of local food self-sufficiency (from analysis of local case studies)	Latent Variables (LV)	Manifest Variables (MV)	Measurement Level
Land system fragmentation	Urban sprawl (**US**)	Shannon Diversity Index of the Global Human Settlement Layer -GHSL- in 2015 (SHDI_2015) Pesaresi, 2019	NUTS-3
Decrease in farmland	Farmland abandonment (**FLA**)	Patch Density of the aggregated agricultural land systems class in 2015 from Divercrop analysis (PD_AGRI_2015)	NUTS-3
Farmland fragmentation		Edge Density of the GHSL "urban centres" class (high density clusters) in 2015 (ED_URB_2015)	NUTS-3
Problems of access to farmland		Edge Density of the GHSL "urban clusters" class (low density clusters) in 2015 (ED_PERI_2015)	NUTS-3
Intensification of production	Farmland development (**FLD**)	Difference in surface areas of the aggregated agricultural land system classes between 2015 and 2005 from Divercrop analysis (DIF_AGRI_2015_05)	NUTS-3
Concentration of production		Largest Patch Index of the aggregated agricultural land system class in 2015 from Divercrop analysis (LPI_2015)	NUTS-3
Specialisation of production and decrease in agricultural diversity		Surface area of clusters of farming intensification in 2015 from Divercrop dynamic classification in hectares (SURF_INTENS)	NUTS-3
Access to facilities (ex. storage, transformation equipment, etc.)	Rootedness (**R**)	Population density in 2015 estimated from the GHS-POP dataset, in hab/Km2 (DENS_POP_2015) Schiavina et al., 2019	NUTS-3
Locally rooted food sector (identity)		Capacity for self-sufficiency: ratio between wheat domestic supply and wheat production quantity (1000 t) in 1980 from FaoStat (SELF_1980)	country
		Opening rate: ratio between wheat imports and exports (1000 t) in 1980 from FaoStat (OPEN_1980)	country
Access to irrigation facilities		Wheat complete crop production (Mt) in 2005 from MAPSpam (p_ta_wheat)	NUTS-3
		Wheat irrigated portion of crop (Mt) in 2005 from MAPSpam (p_ti_wheat)	NUTS-3
		Wheat rainfed subsistence portion of crop (Mt) in 2005 from MAPSpam (p_ts_wheat)	NUTS-3
Conditions for food growth		Surface areas of agricultural land systems in 2015 from Divercrop classification (AGRI_HA_2015)	NUTS-3
Tourism demand	Propensity to consume locally grown food (**PL**)	International inbound tourists 2016 (thousands) from UNDP, weighted for coastal regions according to PNUE expertise 2005 (TOURIST)	NUTS-3
International market competition		Closure rate: ratio between wheat export and import quantity (1000 t) in 2013 from FaoStat (CLOSE_2013)	country
Consumer willingness to consume local products		Degree of reliance: ratio between wheat production quantity and domestic supply (1000 t) in 2013 from FaoStat (RELIANT_2013)	country
Consumer awareness of impact of diet on health and environment		Skilled labour (% of labour force), in 2010–2017 from UNDP (SKILLED_LA)	country
Population income		Gross Domestic Product per capita, PPP (current international $), in 2018 or most recent value from World Bank (GDP)	country
Existence of food strategies and social organisations for food sovereignty	Social innovation (**SI**)	Number of cities committed to the Milan Urban Food Policy Pact in 2019 (MILAN_PACT)	NUTS-3
Willingness of farmers and distributors to participate in midscale food supply chains		Number of Agri-Food clusters in 2014 from Euromed Invest (CLUSTERS)	NUTS-3
Cooperation among farmers and between consumers and farmers		Number of associations integrating the Family Farming Knowledge Platform in 2019 from FAO (FFKP)	NUTS-3
Existence of public subsidies for local farmers	Policies (**P**)	Member State of European Union under the Common Agricultural Policy -CAP- in 2019 (EU)	country
Land-use policy limiting urban sprawl		Number of national laws concerning "Land and soil" in 2019, from FAOLEX (LAW_LAND)	country
Public food procurement initiatives		Number of national laws concerning "Food and nutrition", from FAOLEX (LAW_FOOD)	country

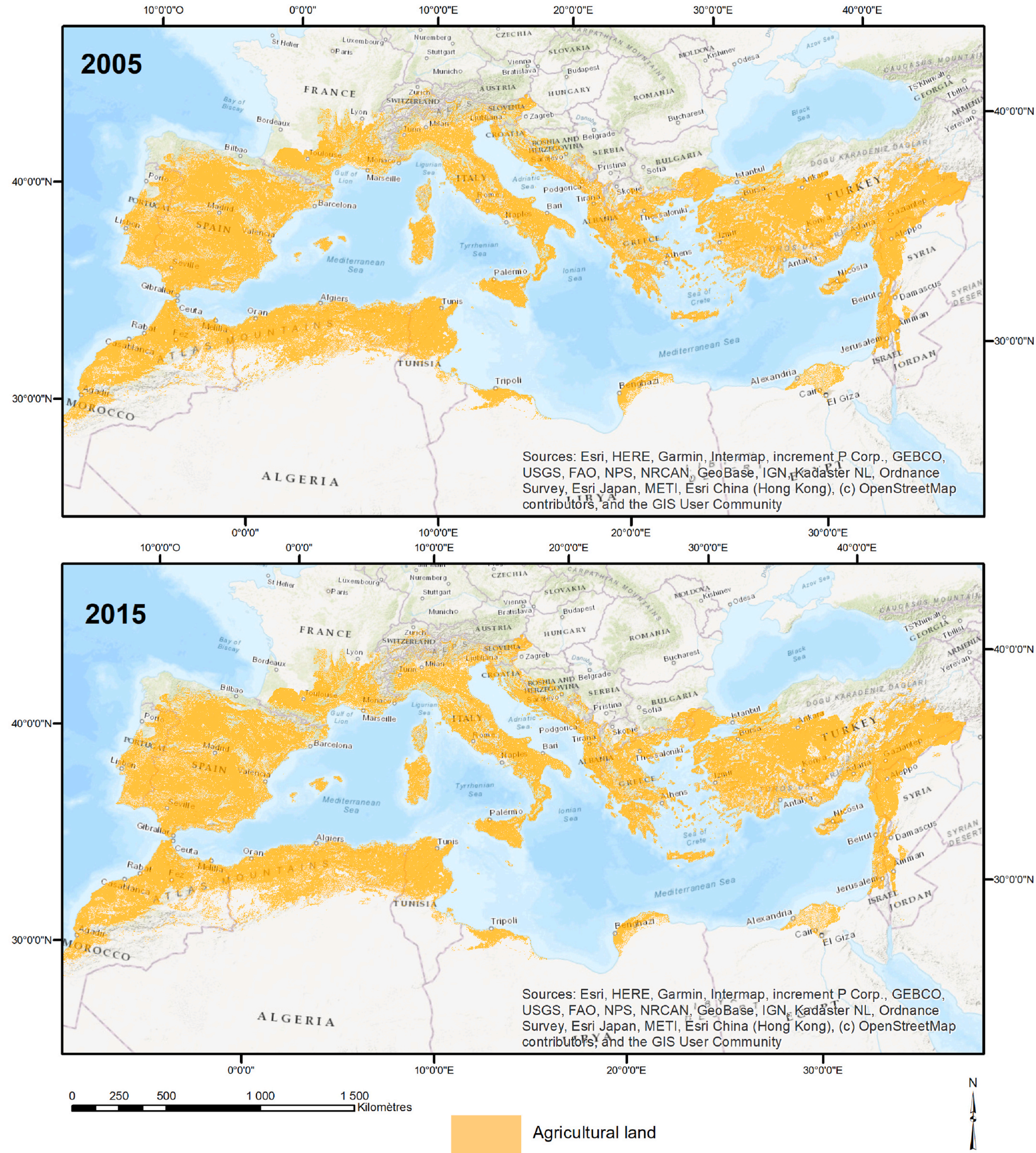

Fig. 2. Agricultural land in 2005 and 2015.

can describe a set of hypotheses verifiable in reality. Manifest variables are observable quantities that are supposed to provide an indirect way of measuring latent variables. Multiple manifest variables contribute to the definition of a single latent variable, and their relationship is referred to as the outer model. The outer model also accounts for the type of relationship between MV and LV, either reflective or formative: in the former case, MV are considered to be caused by LV, while in the latter, LV are considered to be formed by MV. In this work, we consider the MV as formative of their corresponding LV.

The algorithm of PSL-PM computes an estimate of LV as a linear combination of their associated MV such that the obtained LV takes into account the relationships of the inner and the outer models in order to maximise the explained variance of the dependent variables (both LV and MV). The core of the PLS algorithm is the iterative computation of

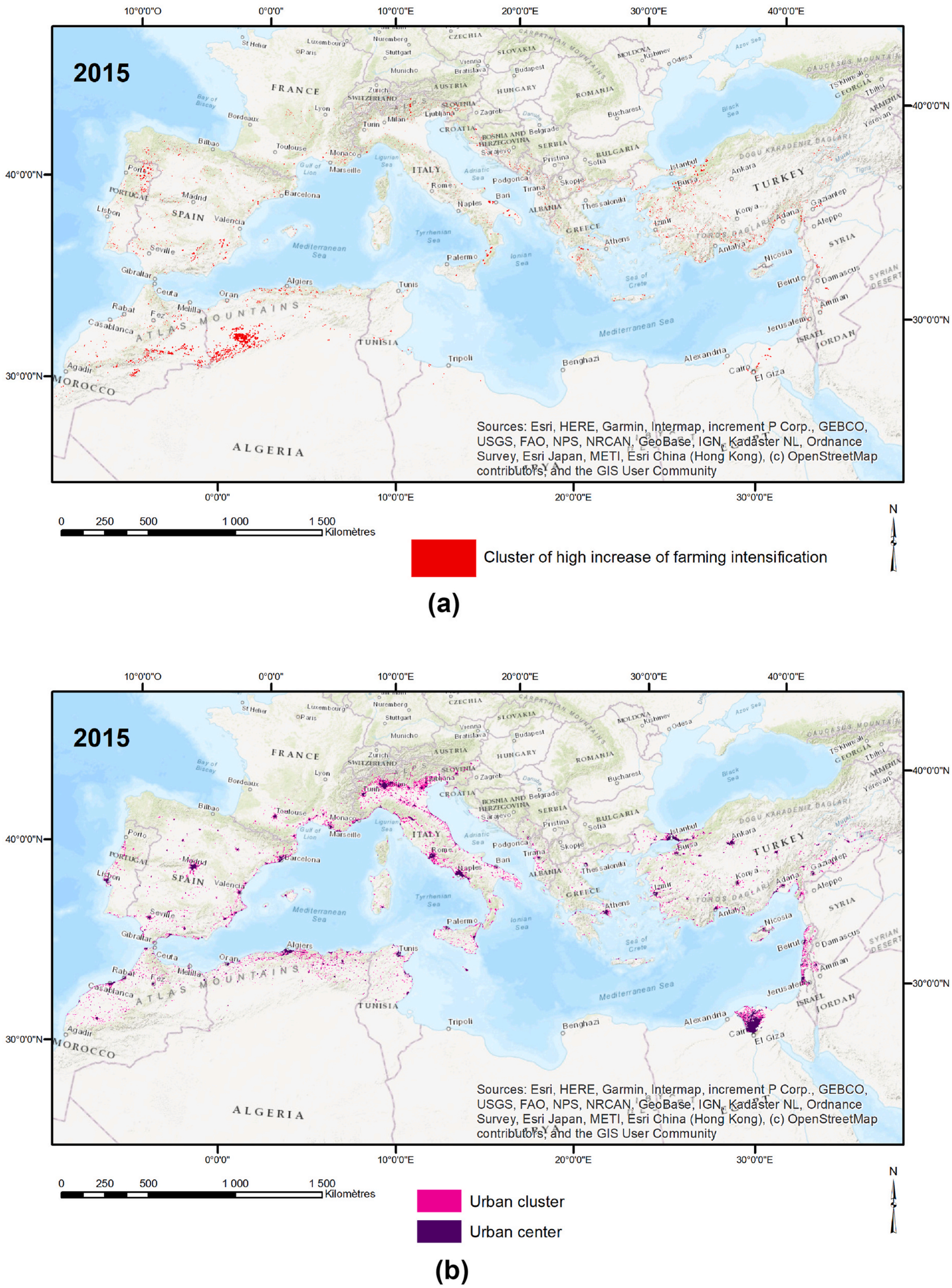

Fig. 3. a Clusters of high increase in farming intensification, concentration and/or specialisation of food production in 2015. Fig. 3b. Urban clusters and urban centres in 2015. Source: Global Human Settlement Layer.

the weights of the linear combination required to estimate the LV. These weights are obtained by means of an iterative procedure based on how the inner and the outer model are specified, where two kinds of approximation for the LV are alternated until convergence of the weights is achieved (Tenenhaus et al., 2005). For the work presented here, we used the functions of the *plspm* package of R (Sanchez et al., 2017).

The first step consists in determining the structure of relationships among latent variables (LV) so as to grasp and describe the complex factors driving the relationships between the factors driving local food self-sufficiency. We took the seven categories of drivers of local food self-sufficiency inferred from the qualitative analysis as latent variables (LV): urban sprawl (US), farmland abandonment (FLA), farmland development (FLD), rootedness (R), propensity to consume locally grown food (PL), social innovation (SI) and policies (P). Then, we defined the causal relationships among them based on a set of hypotheses founded on a literature review. The structure of the PLS model is depicted in Fig. 4. Public action aimed at developing local food systems, captured here by the LV *Policies*, is hypothesised to drive the LV *Propensity to consume locally grown food* (Bellows and Hamm, 2001; Forster et al., 2015; Lehtinen, 2012; Smith et al., 2016) and the LV *Urban Sprawl* (which is explained here by two opposing trends in land-use change, captured by the LV *Farmland abandonment* and *Farmland development* (Aranzabal et al., 2008; Debolini et al., 2018; Nainggolan et al., 2011; Poggi et al., 2021; Romero-Calcerrada and Perry, 2004; van Vliet et al., 2015). Hence all the arrows of the LV *Policies* are outgoing. Concomitantly, the LV *Urban Sprawl* is hypothesised to drive *Propensity to consume locally grown food* (Brinkley, 2017a; Rivera et al., 2020) and *Rootedness* (Grebitus et al., 2020; Hinojosa et al., 2016; Ngo and Brklacich, 2014). Furthermore, we assume that the LV *Social innovation* is not a new LV built from scratch but a construct reacting to social, economic or political changes – formally, the LV *Rootedness* and the LV *Propensity to consume locally grown food* (Berti and Mulligan, 2016; Brinkley et al., 2017; FAO/INRA, 2016; Marchetti et al., 2020).

The second step was analysing the set of available data to assess the LV effect, through the measurement of their internal characteristics (manifest variables; MV). The manifest variables (MV) used in the PLS model to form LV and the measurement level are shown in Table 1. Most MV were measured at NUTS-3 level, while others were only available at national level. All data were freely available or computable from freely available data, making our study replicable (sources are cited in Table 1). It should be noted that choosing indicators for the LV *Rootedness* (R) and the LV *Propensity to consume locally grown food* (PL) was challenging due to the heterogeneity of Mediterranean agricultural land-use dynamics in different farming systems (ex. breeding, gardening, etc.), which is further complicated by their uneven distribution (Malek and Verburg, 2017). As an indicator representing a common trend throughout the study area, we chose "wheat" because it is a food crop that can be produced and consumed everywhere and is subject to the same global constraints – namely, the global grains market (Puma, 2015).

Assessing formative measurement models involves first of all examining the validity of formative indicators using theoretical rationale and expert opinion (Henseler et al., 2009). We therefore checked that the formative indexes behave as expected within a set of hypotheses. A second assessment of the validity of formative constructs consisted of statistical analyses at the indicator level to check whether each MV indeed contributes to the formative index by carrying the intended meaning. An MV can be irrelevant for the construction of the formative index, either because it is correlated to another MV, which could make the indicator's information redundant, or because it does not have a significant formative impact on the LV. To check for the first case, we tested correlations among the five sets of MV (Supplementary Fig. 2). The model results were assessed in two stages. First, the outer model (i.e. measurement model) was used to assess correlations and weights between latent and manifest variables. Then, the inner model (i.e. structural model) was estimated to determine the path coefficients and factor loadings.

3.3.2. Analysis of the PLS-PM outer model

There are seven blocks of MV. The correlation between the variables or their indicators was found to be below the recommended value of 0.8, thus indicating no problem of collinearity (Kennedy, 2008). We therefore checked the standardised factor loading, which reflects the explanatory power of MV with regard to their corresponding LV, calculated on the basis of the MV datasets as represented in Fig. 4. The loading of each MV with its associated LV and its cross loadings on other LV are shown in Table 2.

Urban Sprawl (US) is formed by the Shannon Diversity Index explaining the richness and the evenness of the urban centres and clusters (SHDI) so as to control the effects of urbanisation on the other land use systems. *Farmland abandonment* (FLA) is particularly formed by the edge density of low-density urban clusters (ED_PERI_2015), whereas it is negatively affected by patch density of aggregated agricultural land

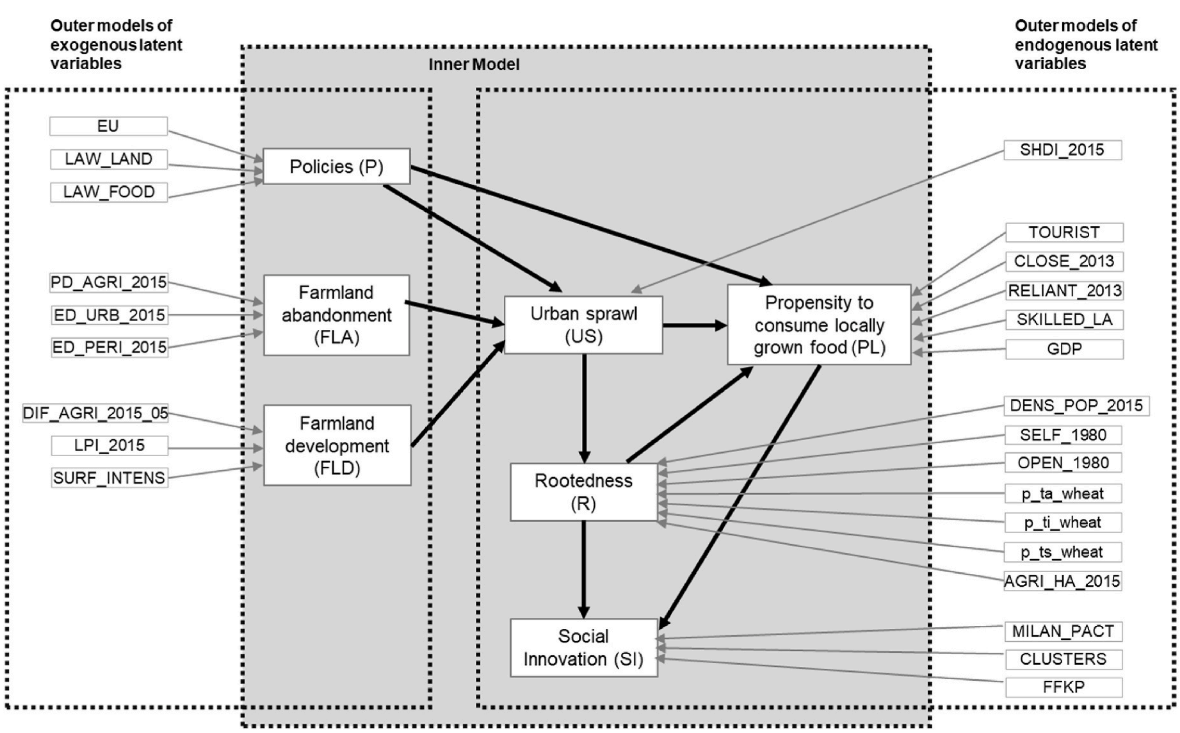

Fig. 4. The proposed path model showing the causal relations among the latent variables.

Table 2
Latent variable loadings and cross-loadings.

Manifest Variables (MV)	block	Urban sprawl (US)	Farmland abandon. (FLA)	Farmland development (FLD)	Rootedness (R)	Propensity to consume local (PL)	Social innovation (SI)	Policies (P)
SHDI_2015	LSD	1000	0.336	0.199	0.323	−0.31	0.162	−0.38
PD_AGRI_2015	FLA	−0.122	−0.365	−0.133	−0.087	0.051	−0.112	0.098
ED_URB_2015	FLA	0.118	0.351	−0.094	0.231	0.007	0.186	−0.035
ED_PERI_2015	FLA	0.291	**0.868**	−0.144	0.082	0.002	0.147	−0.04
DIF_AGRI_2015_05	FLD	0.093	−0.104	**0.468**	0.308	−0.256	−0.045	−0.233
LPI_2015	FLD	−0.013	−0.046	−0.066	−0.034	0.009	−0.016	0.023
SURF_INTENS	FLD	0.196	−0.047	**0.987**	**0.434**	−0.322	−0.057	−0.315
DENS_POP_2015	R	0.049	0.308	−0.075	0.345	−0.031	0.237	−0.068
SELF_1980	R	0.128	0.287	0.049	**0.494**	−0.33	−0.004	−0.231
OPEN_1980	R	0.164	0.158	0.251	0.344	−0.228	−0.076	−0.382
p_ta_wheat	R	0.157	−0.106	0.169	**0.441**	−0.298	−0.05	−0.284
p_ti_wheat	R	0.08	−0.006	0.076	0.316	−0.268	−0.058	−0.261
p_ts_wheat	R	0.228	−0.083	0.303	**0.594**	−0.419	−0.102	**−0.489**
AGRI_HA_2015	R	0.217	−0.325	**0.514**	**0.584**	−0.337	−0.017	−0.253
TOURIST	PL	0.021	−0.118	−0.196	−0.191	0.357	0.136	0.367
CLOSE_2013	PL	−0.07	−0.078	−0.081	−0.152	0.166	0.001	0.09
RELIANT_2013	PL	0.02	−0.248	−0.049	−0.092	−0.014	−0.055	−0.044
SKILLED_LA	PL	−0.327	−0.138	−0.258	**−0.554**	**0.847**	0.082	**0.634**
GDP	PL	−0.203	−0.039	−0.338	**−0.447**	**0.834**	0.173	**0.749**
MILAN_PACT	SI	0.152	0.148	−0.065	0.013	0.196	**0.981**	0.121
CLUSTERS	SI	0.114	0.08	0.031	0.103	−0.05	0.253	0.009
FFKP	SI	0.067	0.144	−0.042	0.074	0.05	**0.584**	0.067
EU	P	−0.363	−0.104	−0.344	−0.55	0.831	0.116	**0.98**
LAW_LAND	P	0.238	0.018	0.136	0.083	−0.125	0.043	−0.297
LAW_FOOD	P	−0.205	−0.144	−0.28	−0.438	0.583	0.078	**0.647**

use and management systems (PD_AGRI_2015). The surface areas of intensification clusters (SURF_INTENS) strongly contribute to *Farmland development* (FLD), and two other MV - the surface area of agricultural land use and management systems in 2015 (AGRI_HA_2015) and the difference in surface area between 2005 and 2015 (DIF_AGRI_2015_05) - also have a positive impact. *Rootedness* (R) is strongly and positively impacted by the portion of subsistence rainfed wheat (p_ts_wheat), the surface area of agricultural land use and management systems (AGRI_HA_2015), capacity for self-sufficiency in 1980 (SELF_1980), total wheat production (p_ta_wheat) and the surface areas of the clusters of farming intensification (SURF_INTENS). On the other hand, *Rootedness* is negatively impacted by the proportion of skilled labour (SKILLED_LA) and gross domestic product per capita (GDP), which in turn have a strong positive impact on *Propensity to consume locally grown products* (SKILLED_LA: 0.847, GDP: 0.834). It should be noted that the self-consumption of food or the market bartering without monetary exchange commonly practiced in poor countries are not captured by the model. SKILLED_LA and GDP also have a strong positive impact on *Policies*, which is positively impacted in addition by the proportion of subsistence rainfed wheat (p_ts_wheat), the number of national laws concerning food and nutrition (LAW_FOOD) and particularly by the country's commitment to the Common Agricultural Policy of the European Union (EU). Surprisingly, the number of national laws concerning land and soil (LAW_LAND) has a negative impact on *Policies* but a positive impact on *Urban sprawl,* which is in turn negatively impacted by the country's EU membership (EU); we will discuss this result in the following section. Finally, *Social Innovation* (SI) is formed by cities' commitment to the Milan Urban Food Policy Pact (MILAN_PACT). Associations integrating the Family Farming Knowledge Platform (FFKP) also have a positive impact on *Social innovation*.

Two MV do not have a significant impact on their associated LV, nor on other LV: The Largest Patch Index of the aggregated agricultural land use and management systems (LPI_2015) and closure rate (CLOSE_2013). Generally, an MV's loading on its associated LV is greater than its cross-loading on other LV in the model. That is true for all MV in the model except degree of reliance (RELIANT_2013), which is more associated with *Farmland abandonment* than with *Propensity to consume locally grown products* (PL).

4. Results

4.1. Analysis of the PLS-PL inner model

Reliable and valid outer model estimations allow the inner model path estimates to be evaluated. Since the goal of PLS modelling is to maximise the variance of the dependent constructs, the first criterion for model evaluation is assessing the coefficient of determination (R^2) of the endogenous variables. Models with significant bootstrap parameter estimates may still be considered invalid in a predictive sense. The R^2 values associated with the endogenous LV *Social innovation*, *Rootedness*, *Urban Sprawl* and *Propensity to consume locally grown food* are respectively 0.057, 0.14, 0.249 and 0.721. Thus, following Ringle et al. (2010) and Chin (1998), we consider that *Social Innovation* and *Rootedness* have weak explanatory power, that *Urban sprawl* has moderate explanatory power and that the explanatory power of *Propensity to consume locally grown food* is substantial. We therefore carefully evaluated the path coefficients using the original datasets of 416 NUTS 3 regions. As explained by Henseler et al. (Henseler et al., 2016, p. 12) "the path coefficients are essentially standardized regression coefficients, which can be assessed with regard to their sign and their absolute size. They should be interpreted as the change in the dependent variable if the independent variable is increased by one and all other independent variables remain constant". We particularly explored their significance through bootstrapping (Henseler et al., 2009) (Fig. 5). We ran 200 resamples, with results summarised in Supplementary Table 3. The path coefficient results indicate that the original path coefficient values are closely matched with the path coefficient values obtained from bootstrap results, with the exception of R- > SI and PL- > SI, which have confidence intervals that contain 0 and should be taken with caution. The other paths drawn in the model have consistent relationships and are significant.

Fig. 5 represents the loadings of the MVs to corresponding LVs. It gives the general structure of the model and the sign of the effects (positive or negative) of one LV on another. LV scores are calculated as weighted sums of their MV. Line width of arrows reflects the magnitude of the path coefficients (i.e. the "strength and direction" of the relationships) and not a causal relationship. From Supplementary Table 5 and it can be inferred that latent exogenous variable (LEXV) *Policies* (P)

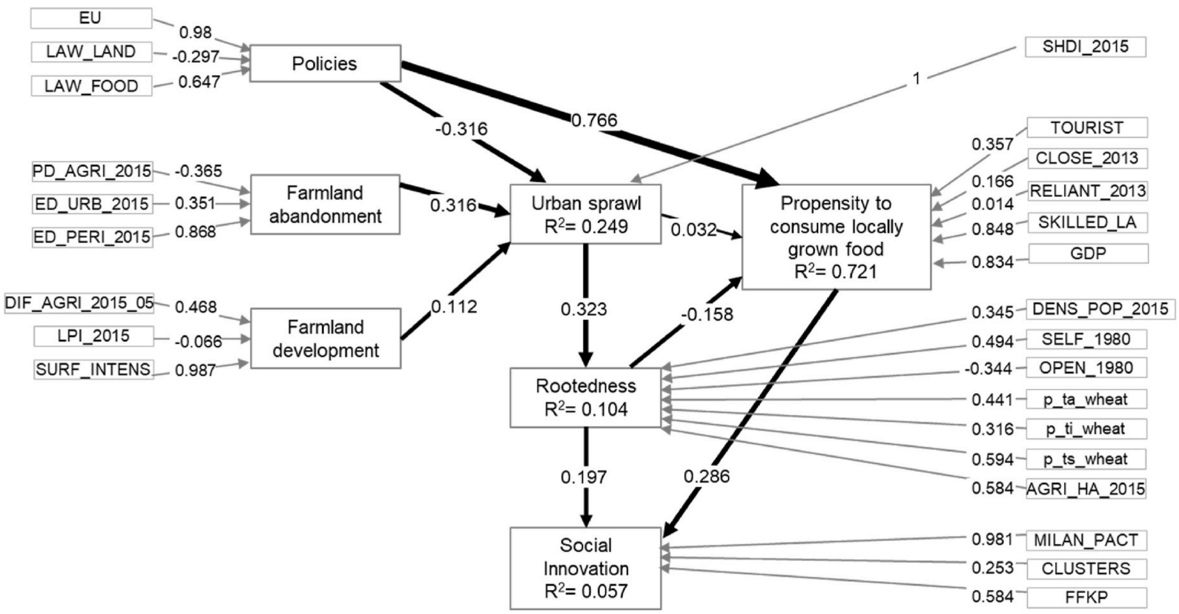

Fig. 5. Estimated loadings and path coefficients of the PLS-PM model.

has the highest positive impact (0.771) on the latent endogenous variable (LENV) *Propensity to consume locally grown food* (PL). Similarly, *Policies* (P) has a significant negative impact (−0.316) on the LENV *Urban sprawl* (US), which in turn is positively impacted (0.316) by the LEXV *Farmland abandonment* (FLA). It is also clear that the LENV *Urban Sprawl* (US) has a positive impact (0.323) on the LENV *Rootedness* (R). Likewise, LENV *Propensity to consume locally grown food* (PL) has a positive impact on the LENV *Social innovation* (SI).

Another important evaluation relates to LV indirect effects on other LV as assessed by subtracting direct effects from total effects. Mathematically, indirect effects are calculated as the multiplication of the path coefficient of indirect paths. Direct effects, indirect effects and total effects of various paths of the structural model are summarised in Table 3. It is worthy of note that the LV *Policies* (P) has a positive indirect effect (0.20) on the LV *Social innovation* (SI) as well as a negative indirect effect (−0.102) on the LV *Rootedness* (R) via *Urban sprawl* (US). Similarly, the LV *Farmland abandonment* (FLA) has a positive indirect effect (0.102) on the LV *Rootedness* (R) via *Urban Sprawl* (US). In other words, policies have a substantial positive impact on the propensity to consume locally grown food and a moderate impact on social innovation. At the same time, policies have a negative impact on farmland abandonment and rootedness.

Table 3
Direct, indirect and total LV effects.

Relationships	Direct effects	Indirect effects	Total effects
P - > FLA	0.000	0.000	0.000
P - > FLD	0.000	0.000	0.000
P - > US	−0.316	0.000	−0.316
P - > R	0.000	−0.102	−0.102
P - > PL	0.766	0.006	0.772
P - > SI	0.000	0.201	0.201
FLA - > FLD	0.000	0.000	0.000
FLA - > LSD	0.316	0.000	0.316
FLA - > R	0.000	0.102	0.102
FLA - > PL	0.000	−0.006	−0.006
FLA - > SI	0.000	0.018	0.018
FLD - > US	0.112	0.000	0.112
FLD - > R	0.000	0.036	0.036
FLD - > PL	0.000	−0.002	−0.002
FLD - > SI	0.000	0.007	0.007
US - > R	0.323	0.000	0.322
US - > PL	0.032	−0.051	−0.019
US - > SI	0.000	0.058	0.058
R - > PL	−0.158	0.000	−0.158
R - > SI	0.197	−0.045	0.152
PL - > SI	0.286	0.000	0.286

4.2. Hierarchical analysis at regional level

A hierarchical analysis was used to group similar NUTS-3 regions in meaningful clusters concerning LFSS. We obtain seven classes that show the descriptive statistics of the Manifest Variables (MV) and the median values in each class resulting from the hierarchical analysis (Table 4).

The following seven classes are based on the seven clusters resulting from analysis:

- Class 1 are regions with low *Policies* concerning food and nutrition (LAW_FOOD) but a great number of policies concerning land and soil (LAW_LAND). This class shows *Farmland development* explained by the positive difference in area of agricultural land systems (expansion) between 2005 and 2015 (DIF_AGRI_2015_05).
- Class 2 are regions characterised by *Propensity to consume locally grown food* (PL) explained by the highest reliance (RELIANT_2013), which negatively impacts PL, combined with the lowest proportion of skilled labour force (SKILLED_LA) and the lowest gross domestic product per capita (GDP). This class also shows *Farmland development* explained by the greatest increase in area of agricultural land systems. *Rootedness* is high and *Policies* and *Urban sprawl* are low.
- Class 3 features *Farmland development,* mainly explained by farming intensification (SURF_INTENS) and no concomitant trend to *Farmland abandonment.* Class 3 regions are characterised by *Rootedness.* However, *Propensity to consume locally grown food* and *Policies* are low.
- Class 4 features *Farmland abandonment* with zero clusters of farming intensification. In contrast, these regions are characterised by *Propensity to consume locally grown food* explained by a high gross domestic product per capita (GDP) and closure to the global market (CLOSE_2013). Class 4 stands out in terms of *Policies* on food and nutrition (EU, LAW_FOOD).
- Class 5 regions are characterised by high *Urban sprawl* (SHDI_2015). The most noticeable feature is *Social innovation* explained by the commitment of cities to the Milan Urban Food Policy Pact (MILAN_PACT). In parallel, low *Farmland development* is explained by

Table 4
Descriptive statistics of the Manifest Variables (MV) and median values in the seven classes resulting from the hierarchical analysis.

LV	MV name	Min	Median	Mean	Max	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
US	SHDI_2015	0	0.45	0.35	0.69	0.4919	0.0565	0.5363	0.5355	0.5964	0	0.554
FLA	PD_AGRI_2015	0.007	0.212	0.197	0.449	0.202	0.199	0.160	0.177	0.208	0.225	0.223
	ED_URB_2015	0	56	366	11,278	87	85	39	599	234	0	94
	ED_PERI_2015	0	585	985	6335	719	497	257	2492	1338	305	674
FLD	DIF_AGRI_2015_05	−518000	−3200	4554	1,574,800	61,600	63,600	18,000	−4800	−6400	−2400	−4800
	LPI_2015	0	0.074	0.273	39	0.089	0.034	0.05	0.097	0.058	0.101	0.075
	SURF_INTENS	0	800	6716	156,400	400	9200	108,400	0	400	400	1600
R	DENS_POP_2015	10	117	388	11,329	149	132	72	396	274	58	124
	SELF_1980	0	1.20	1.52	19.1	1.05	1.91	1.91	1.20	1.20	0.80	0.80
	OPEN_1980	0	2.14	263,481	2,916,000	217	49	563	2	2.1	1.3	1.3
	p_ta_wheat	0	41,667	91,560	1,202,429	21,228	109,208	95,113	3616	61,840	20,901	70,685
	p_ti_wheat	0	1732	19,678	863,459	2326	16,697	22,266	141	1760	826	2582
	p_ts_wheat	0	0	9671	269,031	5185	31,924	17,536	0	0	0	0
	AGRI_HA_2015	800	244,600	371,292	3,124,000	198,800	590,400	828,400	73,600	265,200	210,200	265,600
PL	TOURIST	26	426	517	3187	196	196	33	426	508	508	588
	CLOSE_2013	0	0.37	0.98	10.46	0.1	0.09	0.07	0.58	0.58	0.46	0.58
	RELIANT_2013	0.02	0.66	0.74	1.9	0.45	0.74	0.38	0.66	0.66	0.66	0.72
	SKILLED_LA	0	67.5	62.4	90.6	56	44	58	68	68	72	68
	GDP	8611	31,503	31,284	45,342	15,481	15,481	15,481	41,830	41,830	39,715	39,715
SI	MILAN_PACT	0	0	0.13	6	0	0	0	0	1	0	0
	CLUSTERS	0	0	0.09	3	0	0	0	0	0	0	0
	FFKP	0	0	0.07	5	0	0	0	0	0	0	0
P	EU	0	1	–	1	0	0	0	1	1	1	1
	LAW_LAND	4	71	77	138	129	80	129	71	71	61	71
	LAW_FOOD	19	397	325	627	124	127	124	458	458	419	458

the extensive reduction in area of agricultural land systems (DIF_AGRI_2015_05). Similar to class 4, these areas are characterised by *Propensity to consume locally grown food* and stand out in *Policies.*

- Class 6 shows low *Farmland abandonment*, low *Farm development* and low *Rootedness.* However, *Propensity to consume locally grown food* is high, mostly due to the very high proportion of skilled labour force (SKILLED_LA). It is noticeable that despite the high level of *Policies*,

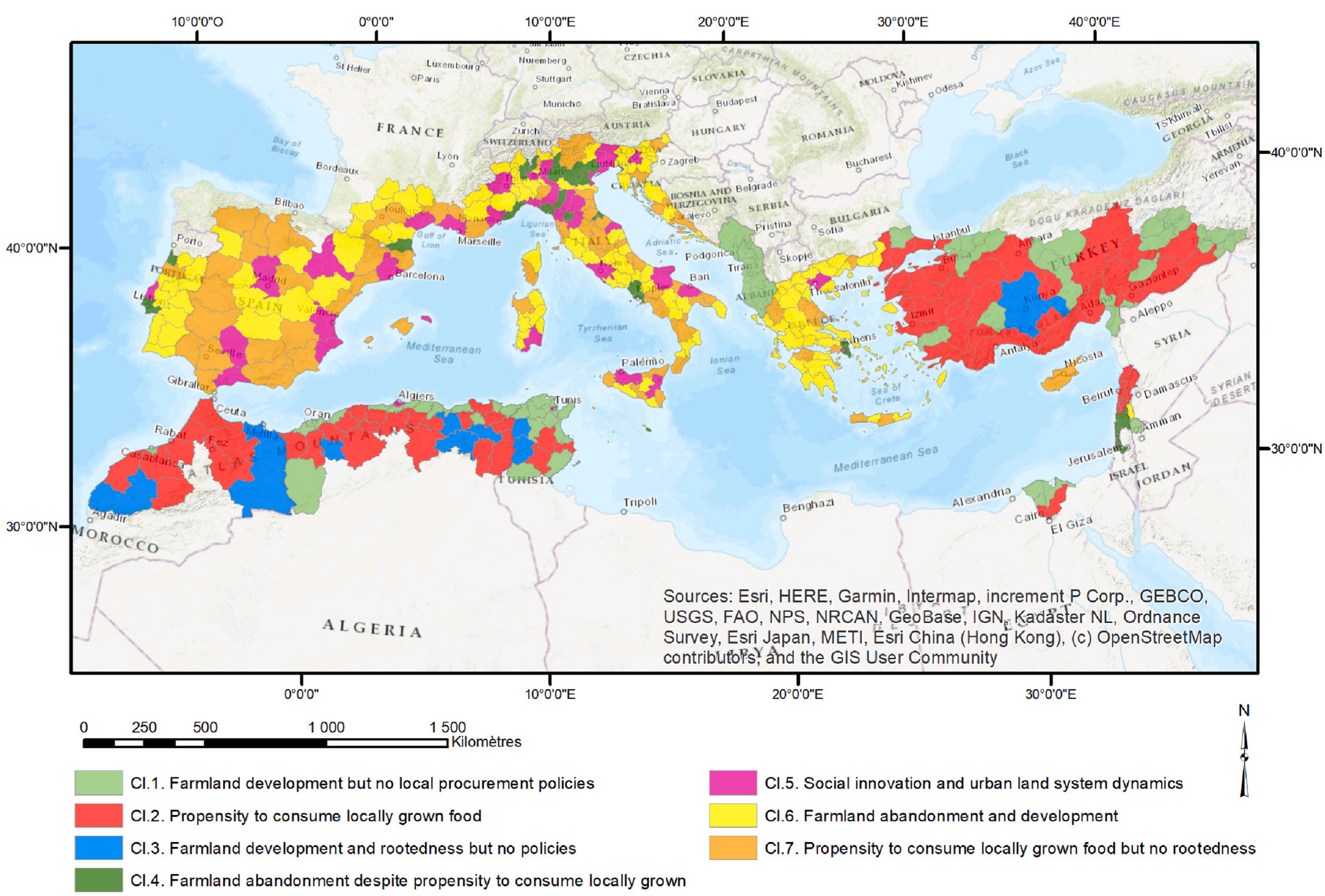

Fig. 6. Seven types of NUTS-3 regions concerning LFSS resulting from the hierarchical analysis.

class 6 group regions belonging to the European Union present the lowest number of laws concerning land and soil (LAW_LAND).

- Class 7 stands out in *Propensity to consume locally grown food,* registering the highest values for the number of international inbound tourists (TOURIST) and closure to the global market (CLOSE_2013). However, *Rootedness* is low, despite the numerous *Policies* concerning food and nutrition (EU, LAW_FOOD).

Then, these seven classes were mapped in order to reveal the geographical organisation of the model, at global scale (here, the Mediterranean basin – Fig. 6). Some interesting differences appear, for instance differences between the north and south of the basin in food locally consumed. Differences also appear at the regional scale, for instance the opposition between regions showing social innovation and those characterised by farmland abandonment. This does not mean that regions differ totally in nature, but rather highlights the factor which, all else being equal, has the greatest influence on the current regional trend.

4.3. Advantages of a four-step approach

The challenge of modelling how land system dynamics impact LFSS at the scale of the Mediterranean basin is successfully addressed here via a four-step approach that reveals the multi-scale links and effects between land system dynamics and local food self-sufficiency (Table 5). We found no impact of mainstream farming development on local food self-sufficiency, nor any clear relationship between mainstream farm development and the propensity to consume locally (Fig. 5 and Table 2). We call mainstream farming development, the improvement of agricultural gross domestic product through agricultural intensification focused on increasing yields of a very limited number of crops or on the spatial extension of monospecific productions. This is unsurprising, as farming intensification and production upscaling are more commonly linked to global markets (Erb et al., 2017). More unexpectedly, public policies appear to be the keystone of LFSS enhancement in the Mediterranean region. This is especially pertinent to the current global political economy debate, as it supports scholars who have recently shown how public policies play a much more significant role in innovation and changes in paradigm than commonly acknowledged (Mazzucato, 2018). Suitable public policies have a high positive impact on the propensity to consume locally-grown food, as well as on social innovation capacity (van Gameren et al., 2015). Indeed, the propensity to consume locally-grown food has substantial explanatory power regarding LFSS. In the remainder of this article, we will address each of these key findings in turn and discuss their implications for the design and implementation of context-specific regionalised policies aiming at food security through improving LFSS. In addition, through a structural model, we show how such methodology can be used to upscale findings/knowledge from local field studies to a geographical scale relevant for public regulation (a region, a country).

4.4. Farm development does not foster LFSS

Farmland expansion and intensification spatially and functionally disconnected from urban consumption areas do not appear to enhance LFSS. The latent variables “farm development” and “farm abandonment” do not impact (respectively −0.002 and −0.006) the latent variable “propensity to consume locally grown food” (see Table 3). In return, increasing local food demand appears as one of the key drivers of farming system change, including farming intensification dynamics and modified farmland surface areas (mainly near urban areas; Schneider et al., 2011; Wortman and Lovell, 2013). However, this is not enough to enhance local food supply chains and thus LFSS (Moustier, 2017), and we need to consider the links between land use and management dynamics, and local food systems (Debolini et al., 2018). Indeed, land use changes reflect competing high pressures that may dominate other local dynamics, both within the agricultural sector and between farming and other land uses, e.g. urban sprawl (Salvati et al., 2012). Moreover, urbanisation can affect food systems through channels like the physical expansion of urban areas impacting food supply chains (Seto and Ramankutty, 2016), shifting diets leading to nutrition transition and changing consumer behaviour (Popkin, 1999), or social pressure for sustainable farming and food practices impacting the food environment

Table 5
Main results and enabling and constraining factors of LFSS.

Variables	Result	Factors enabling LFSS	Factors constraining LFSS
Urban sprawl	The structure and dynamics of agricultural areas are linked to the spatial dynamics of cities where food demand is mainly situated.	Development of urban productive green infrastructures enabling the development of urban agriculture (e.g. community gardens, green roofs, urban orchards).	Urban sprawl and fragmented spatial morphology of the urban fringe favours farmland abandonment because agricultural activity is no longer possible.
Farmland abandonment	Farmland abandonment does not impact the propensity to consume locally grown food.	Farmland on the urban fringe is strategically placed to improve connectivity to local markets that can be enhanced by public policies supporting local farmers.	High land prices on the urban fringe may prevent the development of agricultural activity.
Farmland development	Farmland expansion and intensification spatially disconnected from urban consumption areas do not appear to enhance local food systems or to foster local food self-sufficiency	Increasing food demand appears as one of the key drivers of farming system change through, among others, intensification dynamics. Providing adequate support to smallholder farmers to meet sustainable standards.	Intensified farming practices associated with export and a lack of laws protecting land do not enhance local food systems.
Rootedness	High production capacity does not necessarily imply strong propensity to consume locally grown food.	Involvement of local policy-makers and institutions (such as producers’ organisations) in promoting the local value chain among consumers and in local markets.	High production associated with a high opening rate (i.e. ratio between imports and exports).
Propensity to consume locally grown food	Propensity to consume locally grown food has substantial explanatory power.	Alternative food supply chains and direct selling can renew ties between producers and favour co-operation leading to innovation (producer markets, box schemes, community-supported agriculture).	Due to the sometimes high prices of organic and local produce and to specific distribution channels, these are accessible mainly to upper middle- and upper-class consumers.
Social innovation	Social Innovation is positively impacted by the propensity to consume locally grown food.	Social innovation can counterbalance production-oriented policies at regional level. Social innovation is a way to tailor cross-sector and multi-level policies to a specific place.	Lack of public policy investments hinders innovation.
Policies	Policies have a positive impact on the propensity to consume locally grown food and on social innovation.	Policies fitting the particular regional context and developing inclusive food governance processes and bodies (food councils, policy labs)	Policies encouraging production such as EU Common Agricultural Policies have increased quantities produced where they apply, but through a competitive effect have decreased production in places where they do not apply.

and the landscape (Cohen and Ilieva, 2015). Thus, linking the dynamics of agricultural areas to the spatial dynamics of cities where food demand is situated, allows for a frame within which farmers can develop their activities. For instance, the development of urban productive green infrastructures enables the development of urban agriculture (Lin et al., 2017). Furthermore, residual agricultural spaces near urban areas are a by-product of land-use competition; at the same time, they are strategically placed to improve connectivity to local markets (Brinkley, 2017b; Opitz et al., 2016). In this sense, our analysis showed that manifest variables related to the spatial morphology of the urban centres and urban clusters have a substantial impact on farmland abandonment (respectively 0.351 and 0.868; see Table 2), as well as a moderate positive impact on social innovation (respectively 0.186 and 0.147). Few studies have explored the relationships between spatial organisation and abandonment, most addressing the relationship between land fragmentation and abandonment (Janus and Bozek, 2018; Morell-Monzó et al., 2020), including Wang and Qiu (2017), who found a relationship between road density and agricultural abandonment, and Ruiz Martinez et al. (2020), who explored how different urban region trajectories can lead to different forms of agriculture and land use dynamics.

4.5. Public policies are the keystone of LFSS enhancement

Polices have a positive impact on the propensity to consume locally-grown food (0.771; see Fig. 5), a key factor in LFSS (R2: 0.721) and, through a domino effect, the propensity to consume local food generates social innovation (0.286), in a politically contained urban sprawl context (−0.316; see Table 3). Public policies are thus strong drivers of LFSS, particularly by promoting the local value chain and supporting local farmers (thereby preventing farmland abandonment) (Filippini et al., 2020). However, our findings show that the policy needs to fit the particular regional context: in some regions, policy implementation has had a positive effect on the propensity to consume locally-grown food (class 4, 5, 7), whereas in other regions, the same policy has had no significant impact (class 1, 6). There are also regions doing little on policy, where local food systems are not being promoted (class 2, 3). Furthermore, our modelling approach considered policies mainly arising from a country's commitment to the Common Agricultural Policy of the European Union (0.98; see Table 2) and the number of national laws concerning food and nutrition (0.647). The policies have a significant negative impact (−0.316; see Table 3) on urban sprawl, positively impacted by farmland abandonment (0.316); it is as if the policies reflected an awareness of the loss of agricultural land, generating mainly constraints on new urban development. Surprisingly, however, the number of national laws concerning land and soil has a negative impact on policies (−0.297; see Table 2) and on the propensity to consume locally grown food (−0.125). It may be that laws oriented towards food and nutrition (food demand-oriented) would more effectively promote LFSS than land-use laws focused on tradable commodities supply (food supply-oriented). Actually, the existing national laws are not directed towards the four policy aspects considered here: public subsidies for local farmers, the curbing of urban sprawl, short supply chains and public food procurement. The negative relationship found here between national laws and supra-national policies underlines the lack of explicit public engagement at national level on these aspects.

On the other hand, propensity to consume locally-grown food has a positive impact on social innovation (0.286; see Fig. 5) as already seen by Filippini et al. (2020). Some scholars have demonstrated that short food supply chains can renew ties between producers and foster cooperation leading to innovation (Chiffoleau, 2009). It is worthy of note that policies have a positive indirect effect on social innovation (0.20; see Table 3). This finding is consistent with other work showing that private innovations benefit from public policy investments (Mazzucato, 2018). Indeed, innovation and empowerment of communities are among the four priority areas of the EU Food 2030 policy framework (together with nutrition, climate and circularity) to achieve sustainable, resilient, responsible, competitive, diverse and inclusive food systems (Gill et al., 2019).

5. Discussion

5.1. The regionalisation of food self-sufficiency means addressing food policy in relative terms

The traditional approach to food self-sufficiency is one of competing options. Competition with international trade in food or even between industrial agro-systems, local food production and short supply chains is commonly recommended to reduce the vulnerability of rural-urban regions (Blay-Palmer et al., 2018) and to increase sustainability in the food chain by drastically reducing its footprint (Rothwell et al., 2016), although some scholars argue that local food chains have a bigger footprint than global ones (Coley et al., 2009). In addition, given the disruptions to food supply chains during the Covid-19 pandemic increased by the political crisis on eastern Europe, there have been calls for territorialisation of food production and consumption (Altieri and Nicholls, 2020; Thilmany et al., 2021), and for a stronger role for urban (O'Hara and Toussaint, 2021) and peri-urban agriculture (Filippini et al., 2018; Yacamán-Ochoa et al., 2020). Efforts to refine the sustainable food self-sufficiency agenda should therefore take a place-based approach bringing together civil society, private stakeholders and local governments around more effective and socially just food production-consumption (Sonnino et al., 2016).

Far from a straightforward binary choice between relying solely on locally grown food and a fully open food trade policy (Clapp, 2017; Hinrichs, 2013), the regionalisation of food self-sufficiency means addressing food policy in relative terms. Our results show clearly that public policies do have a key role to play in fostering an enhanced position for locally grown food in regional food systems. To this end, policy-makers need to consider place-based interactions between local and global food systems, going beyond the usual distinction between urban, rural, adjacent and remote rural regions (OECD/FAO/UNCDF, 2016). Different territorial settings demand different complementary action across sectors and areas of intervention. Notably, current land system dynamics have been linked to food systems through factors like agricultural carrying capacity (Filippini et al., 2014; Peters et al., 2007) or competition between agricultural and other urbanisation-related land uses, especially in coastal or urban areas (Salvati et al., 2012). Most of these changes arise through a feedback chain: disturbance of traditional agriculture surrounding urban areas due to city expansion leads to the development of market-oriented agriculture farther from the cities, while new forms of agriculture linked to the city are created (Monaco et al., 2017; Verburg et al., 2013). However, the extent to which land use dynamics impact food self-sufficiency at local level remains largely unknown. Recent studies show that it is possible to distinguish peri-urban farmland oriented towards local markets (i.e. local food system) from that dedicated to global foodstuff supply, based on a GIS analysis combined with an analysis of the regulations and socio-economic context (Boussougou et al., 2021; Sanz et al., 2018). To date, such research has been largely qualitative, as few data are currently available and tend to be incomplete. For instance, in a recent study on a sample of 33 cities which are members of EUROCITIES network and formally committed to the Milan Urban Food Policy Pact, 80% stated that they do not know where their food comes from and that they would not be able to quantify the percentage of food they import and export (De Cunto et al., 2017; Morrison et al., 2011a). Lack of comprehensive datasets prevents a holistic understanding of the dynamics and complexity of food systems in terms of food self-sufficiency at local level (Mouléry et al., 2022; Vicente-Vicente et al., 2021). In this context, our multi-level modelling approach can inform place-based food policies at regional level by providing an integrated and systemic approach to food supply that goes beyond the two ends of the food system, production and consumption.

5.2. Cross-scalar context-specific policies and interventions are required

"Understanding the current state of local agriculture is a first step towards aligning agricultural and nutritional goals" (Morrison et al., 2011b, p. 498). Applying food regionalism as opposed to "one-size--fits-all" will require place-based approaches and context-specific policies and interventions putting emphasis on bottom-up actions and their alignment with top-down priorities (Sonnino et al., 2019). Yet, as we stated in the introduction, the multi-level aspect of food systems remains a remarkable scientific challenge in analysing the relocation of food supply, and thus for the development of tailor-made food security policies at regional level. No standard method of systematically linking different levels of analysis exists, although such linkage is needed to integrate local stakeholder vision with global statistical data. This paper seeks to fill this gap by proposing an original way to understand the relations between global and local drivers impacting LFSS. Thus, our methodology provides a way to generalise regional assessments to the Mediterranean area. It would be interesting to explore the extrapolability of this method to other regions of the world involving different features. It uses freely available data to inform policy makers regarding the drivers of food system change and how they are interconnected, highlighting the enabling and constraining factors of LFSS.

6. Conclusion: Designing and implementing place-based public policies appropriate for the conditions of change

Identifying the drivers of local food systems affecting modes of food provisioning, and acting as enabling and constraining factors in LFSS, is a necessary step towards designing and implementing food policies at regional level that will foster sustainable food systems in specific contexts. This calls for a "fork-to-farm" multi-scale approach (Verger et al., 2018b) starting by improving food and nutrition security in a specific place to deal with cross-scale dynamics and capture the diversity of LFSS situations. In this perspective, our contribution lies in proposing a methodology that combines local-level data from field surveys with global-level data from statistical approaches. This yields a useable framework to scale up public interventions - i.e. to calibrate food self-sufficiency actions according to specific geographical contexts while simultaneously taking into account global constraints and dynamics. This article has shown how to locate and map areas where public interventions (e.g. incentives, regulations) could be more efficient. We have also highlighted seven basin-level dynamics that can structure global policy at the Mediterranean biome level.

Food import dependence is not simply the result of natural resource constraints. The loss of cropland due to urban expansion is likely to be more a regional problem than a global one (Seto and Ramankutty, 2016), and the level of LFSS may not depend on agricultural capacity alone, but on the social and political context in which farmers make their decisions (Schreiber et al., 2021; Vicente-Vicente et al., 2021). This means that local stakeholders and institutions are key to designing appropriate ameliorative food security policies, especially under current rapid urbanisation and global change (Moragues-Faus et al., 2017). Further research is needed to highlight which land use and management systems should be considered when enhancing local food systems, especially in urban contexts. In that respect, a major challenge in the Mediterranean area is understanding the effects of urban sprawl on resource use and on diet, in terms of nutrition and health (Perignon et al., 2019). How does the spatial morphology of urban land use affect food demand? How do complex mosaics mixing urban and agricultural land uses, like peri-urban areas, affect populations' access to locally grown food, as well as food choices?

Code availability

The computer code that supports the findings of this study is available in the Sup. Info. 5.

Funding sources

This research has been developed in the framework of DIVERCROP project (2017-20, financed by Arimnet2 European programme ANR-16-ARM2-0003-01): "Land system dynamics in the Mediterranean basin across scales as relevant indicator for species diversity and local food systems" (see https://divercropblog.wordpress.com/for more details).

CRediT authorship contribution statement

Esther Sanz Sanz: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Visualization, Writing - original draft, Writing - review & editing. **Claude Napoléone:** Conceptualization, Methodology, Project administration, Funding acquisition, Writing - review & editing. **Marta Debolini:** Conceptualization, Project administration, Funding acquisition, Writing - review & editing. **Davide Martinetti:** Methodology, Writing - review & editing. **Olga Moreno Pérez:** Investigation, Formal analysis, Writing - review & editing. **Cristina de Benito:** Investigation, Writing - review & editing. **Michel Mouléry:** Data curation. **Teresa Pinto Correia:** Conceptualization, Writing - review & editing. **Rosalia Filippini:** Writing - review & editing. **Lamia Arfa:** Writing - review & editing. **Carolina Yacamán-Ochoa:** Writing - review & editing.

Declaration of competing interest

The authors declare no competing interests.

Data availability

We have shared our code and data in the Supplmentary materials

Acknowledgements

We thank the following people in charge of the local case studies: Carla Scorsino (INRAE, France), Cataria Esgalhado and M[a] Helena Guimaraes (Universidade de Évora - ICAAM, Portugal), Mario Balzan, Laura Scalvenzi and Dawn Grech (The Malta College of Arts, Science & Technology), Sabine Gennai-Schott and Tiziana Sabbatini (Sant'Anna School of Advanced Studies, Italy), Marian Simón Rojo and Andrés Couceiro Arroyo (Universidad Politécnica de Madrid, Spain) and Salah Bouchemal (Université Larbi Ben M'hidi, Algeria).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.119769.

References

Altieri, M.A., Nicholls, C.I., 2020. Agroecology and the emergence of a post COVID-19 agriculture. Agric. Hum. Val. 37, 525–526. https://doi.org/10.1007/s10460-020-10043-7.

Aranzabal, I.D., Schmitz, M.F., Aguilera, P., Pineda, F.D., 2008. Modelling of landscape changes derived from the dynamics of socio-ecological systems A case of study in a semiarid Mediterranean landscape. Ecol. Indicat. 14.

Baldos, U.L.C., Hertel, T.W., 2014. Global food security in 2050: the role of agricultural productivity and climate change. Aust. J. Agric. Resour. Econ. 58, 554–570. https://doi.org/10.1111/1467-8489.12048.

Bellows, A.C., Hamm, M.W., 2001. Local autonomy and sustainable development: testing import substitution in localizing food systems. Agric. Hum. Val. 18, 271–284.

Béné, C., Prager, S.D., Achicanoy, H.A.E., Toro, P.A., Lamotte, L., Cedrez, C.B., Mapes, B. R., 2019. Understanding food systems drivers: a critical review of the literature. Global Food Secur. 23, 149–159. https://doi.org/10.1016/j.gfs.2019.04.009.

Berti, G., Mulligan, C., 2016. Competitiveness of small farms and innovative food supply chains: the role of food Hubs in creating sustainable regional and local food systems. Sustainability 8, 616. https://doi.org/10.3390/su8070616.

Bezner-Kerr, R., 2012. Lessons from the old Green Revolution for the new: social, environmental and nutritional issues for agricultural change in Africa. Prog. Dev. Stud. 12, 213–229. https://doi.org/10.1177/146499341101200308.

Bissoffi, S., 2019. A meta-analysis of recent foresight documents in support of the 5th SCAR Foresight exercise. Study carried out under the project "Support Action to a common agricultural and wider bioeconomy research agenda" (CASA contract: Study "Meta-Analysis of Recent Foresight and Horizon Scanning Documents". PO 42195489 of 17.08.2018), 124p.
Blay-Palmer, A., Santini, G., Dubbeling, M., Renting, H., Taguchi, M., Giordano, T., 2018. Validating the city region food system approach: enacting inclusive, transformational city region food systems. Sustainability 10, 1680. https://doi.org/10.3390/su10051680.
Boussougou Boussougou, G., Sanz Sanz, E., Napoléone, C., Martinetti, D., 2021. Identifying agricultural areas with potential for city connections: a regional-scale methodology for urban planning. Land Use Pol. 103, 105321 https://doi.org/10.1016/j.landusepol.2021.105321.
Brink, B.T., Giesen, P., Knoope, P., 2023. Future responses to environment-related food self-insufficiency, from local to global. Reg. Environ. Change 23, 87. https://doi.org/10.1007/s10113-023-02069-4.
Brinkley, C., 2017a. Visualizing the social and geographical embeddedness of local food systems. J. Rural Stud. 54, 314–325. https://doi.org/10.1016/j.jrurstud.2017.06.023.
Brinkley, C., 2017b. Visualizing the social and geographical embeddedness of local food systems. J. Rural Stud. 54, 314–325. https://doi.org/10.1016/j.jrurstud.2017.06.023.
Brinkley, C., Raj, S., Horst, M., 2017. Culturing food deserts: recognizing the power of community-based solutions. Built. Environ. 43, 328–342. https://doi.org/10.2148/benv.43.3.328.
Cerrada-Serra, P., Colombo, L., Ortiz-Miranda, D., Grando, S., 2018. Access to agricultural land in peri-urban spaces: social mobilisation and institutional frameworks in Rome and Valencia. Food Secur. 10, 1325–1336. https://doi.org/10.1007/s12571-018-0854-8.
Chiffoleau, Y., 2009. From politics to Co-operation: the dynamics of embeddedness in alternative food supply chains. Sociol. Rural. 49, 218–235. https://doi.org/10.1111/j.1467-9523.2009.00491.x.
Chin, W.W., 1998. The partial least squares approach to structural equation modeling. In: Marcoulides, G.A. (Ed.), Modern Methods for Business Research. Lawrence Erlbaum Associates Publisher, Mahwah (New Jersey), London, pp. 295–336.
Clapp, J., 2017. Food self-sufficiency: making sense of it, and when it makes sense. Food Pol. 66, 88–96. https://doi.org/10.1016/j.foodpol.2016.12.001.
Cohen, N., Ilieva, R.T., 2015. Transitioning the food system: a strategic practice management approach for cities. Environ. Innov. Soc. Transit. 17, 199–217. https://doi.org/10.1016/j.eist.2015.01.003.
Coley, D., Howard, M., Winter, M., 2009. Local food, food miles and carbon emissions: a comparison of farm shop and mass distribution approaches. Food Pol. 34, 150–155. https://doi.org/10.1016/j.foodpol.2008.11.001.
De Cunto, A., Tegoni, C.L.S., Sonnino, R., Michel, C., Lajili-Djalaï, F., 2017. Food in Cities: Study on Innovation for a Sustainable and Healthy Production, Delivery, and Consumption of Food in Cities (No. Framework Contract 30-CE-0833121/0049). European Commission, Brussels, p. 128p.
Debolini, M., Marraccini, E., Dubeuf, J.P., Geijzendorffer, I.R., Guerra, C., Simon, M., Targetti, S., Napoléone, C., 2018. Land and farming system dynamics and their drivers in the Mediterranean Basin. Land Use Policy 702–710. https://doi.org/10.1016/j.landusepol.2017.07.010.
Debolini, M., Valette, E., François, M., Chéry, J.-P., 2015. Mapping land use competition in the rural–urban fringe and future perspectives on land policies: a case study of Meknès (Morocco). Land Use Pol. 47, 373–381. https://doi.org/10.1016/j.landusepol.2015.01.035.
De Benito, C., Sanz Sanz, E., Moreno Pérez, O.M., Simon Rojo, M., Yacamán-Ochoa, C., 2019. Enabling and constraining drivers of local food systems: a comparative study in Mediterranean countries. In: Proceedings of the 14th European IFSA Symposium. Presented at the Farming Systems Facing Climate Change and Resource Challenges Evora (Portugal).
Delattre, L., Chanel, O., Livenais, C., Napoléone, C., 2015. Combining discourse analyses to enrich theory: the case of local land-use policies in South Eastern France. Ecol. Econ. 113, 60–75. https://doi.org/10.1016/j.ecolecon.2015.02.025.
Denning, G., Fanzo, J., 2016. Ten forces shaping 19 the global food system. In: Eggersdorfer, M., Kraemer, K., Cordaro, J.B., Fanzo, J., Gibney, M., Kennedy, E., Labrique, A., Steffen, J. (Eds.), Good Nutrition: Perspectives for the 21st Century, pp. 19–30.
Eckert, S., Kiteme, B., Njuguna, E., Zaehringer, J., 2017. Agricultural expansion and intensification in the Foothills of mount Kenya: a landscape perspective. Rem. Sens. 9, 784. https://doi.org/10.3390/rs9080784.
EEA, 2006. Urban Sprawl in Europe: the Ignored Challenge. European Environment Agency ; Office for Official Publications of the European Communities [distributor], p. 60p. Copenhagen, Denmark; Luxembourg. ISSN 1725-9177.
Erb, K.-H., Luyssaert, S., Meyfroidt, P., Pongratz, J., Don, A., Kloster, S., Kuemmerle, T., Fetzel, T., Fuchs, R., Herold, M., Haberl, H., Jones, C.D., Marín-Spiotta, E., McCallum, I., Robertson, E., Seufert, V., Fritz, S., Valade, A., Wiltshire, A., Dolman, A.J., 2017. Land management: data availability and process understanding for global change studies. Global Change Biol. 23, 512–533. https://doi.org/10.1111/gcb.13443.
Esgalhado, C., Guimarães, M.H., Lardon, S., Debolini, M., Balzan, M.V., Gennai-Schott, S. C., Simón Rojo, M., Mekki, I., Bouchemal, S., 2021. Mediterranean land system dynamics and their underlying drivers: stakeholder perception from multiple case studies. Landsc. Urban Plann. 213, 104134. https://doi.org/10.1016/j.landurbplan.2021.104134.
Esposito Vinzi, V., Chin, W.W., Henseler, J., Wang, H. (Eds.), 2010. Handbook of Partial Least Squares: Concepts, Methods and Applications. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-32827-8.
FAO, 2018. The Future of Food and Agriculture - Alternative Pathways to 2050. Food and Agriculture Organisation of the United Nations, Rome. ISBN 978-92-5-130158-6. 224 pp. Licence: CC BY-NC-SA 3.0 IGO.
FAO, 1998. Implications of Economic Policy for Food Security : a Training Manual. Prepared by Thomson A. and Metz M. for the Agricultural Policy Support Service & Policy Assistance Division of the Food and Agriculture Organization of the United Nations and the Deutsche Gesellschaft Fur Technische Zusammenarbeit (GTZ). Training materials for agricultural planning 40. https://www.fao.org/3/x3936e/x3936e03.htm.
FAO/INRA, 2016. Innovative markets for sustainable agriculture. How innovations in market institutions encourage sustainable agriculture in developing countries. Edited by. In: Loconto, A., Poisot, A.S., Santacoloma, P. (Eds.), Food And Agriculture Organization of the United Nations (FAO) and Institut National de la Recherche Agronomique (INRA), p. 390p.. Rome (Italy). ISBN 978-92-5-109327-6.
Ferchichi, I., Mekki, I., Elloumi, M., Arfa, L., Lardon, S., 2020. Actors, scales and spaces dynamics linked to groundwater resources use for agriculture production in Haouaria plain, Tunisia. A territory game approach. Land 9, 74. https://doi.org/10.3390/land9030074.
Filippini, R., Gennai-Schott, S., Sabbatini, T., Lardon, S., Marraccini, E., 2020. Quality Labels as drivers of peri-urban livestock systems resilience. Land 9, 211. https://doi.org/10.3390/land9070211.
Filippini, R., Lardon, S., Bonari, E., Marraccini, E., 2018. Unraveling the Contribution of Periurban Farming Systems to Urban Food Security in Developed Countries, vol. 38. Agronomy for Sustainable Development. https://doi.org/10.1007/s13593-018-0499-1.
Filippini, R., Marraccini, E., Lardon, S., Bonari, E., 2014. Assessing food production capacity of farms in periurban areas. Ital. J. Agron. 9, 63. https://doi.org/10.4081/ija.2014.569.
Forster, T., Egal, Getz Escudero, A., Dubbeling, M., Renting, H. (Eds.), 2015. Milan Urban Food Policy Pact. Selected Good Practices from Cities, Utopie/29. Fondazione Giangiacomo Feltrinelli, Milano (Italy), p. 125p. SBN 978-88-6835-221-9.
Fusco, J., 2019. Land systems on the move: a new spatiotemporal data-driven approach on land system modelling applied to the Mediterranean basin. In: Presentation of the Results from the Spatial Analysis of the Global Database. 3rd Divercrop Project Meeting. 28/02/2019. The Malta College of Arts, Science & Technology, Malta.
Fusco, J., Marraccini, E., Debolini, M., 2019. Intensification, periurbanization and specialization of agriculture as significant short-term land system dynamics in the Mediterranean basin. In: Bimonte, S., Lardin, S. (Eds.), Proceedings of the 2019 SAGEO Conference – Spatial Analysis and Geomatics. Clermont-Ferrand. https://doi.org/10.5281/ZENODO.3564776, 13-15 November 2019.
Fusco, J., Villani, R., Mouléry, M., Sabbatini, T., Hinojosa, L., Napoléone, C., Bondeau, A., 2018. DIVERCROP Project - Deliverable 1.1: Report on the Comprehensive Database Building.
García-Martín, M., Torralba, M., Quintas-Soriano, C., Kahl, J., Plieninger, T., 2020. Linking food systems and landscape sustainability in the Mediterranean region. Landsc. Ecol. https://doi.org/10.1007/s10980-020-01168-5.
Geniaux, G., Ay, J.-S., Napoléone, C., 2011. A spatial hedonic approach on land use change anticipations. J. Reg. Sci. 51, 967–986. https://doi.org/10.1111/j.1467-9787.2011.00721.x.
Gill, M., den Boer, A.C.L., Kok, K.P.W., Breda, J., Cahill, J., Callenius, C., Caron, P., Damianova, Z., Gurinovic, M.A., Lähteenmäki, L., Lang, T., Laperrière, A., Mango, C., Ryder, J., Sonnino, R., Verburg, G., Westhoek, H., Regeer, B.J., Broerse, J. E.W., 2018. A systems approach to research and innovation for food system transformation. Published by FIT4FOOD2030. https://fit4food2030.eu/eu-think-tank-policy-brief/.
Gill, M., den Boer, A.C.L., Kok, K.P.W., Lapperrière, A., Lähteenmäki, L., Damianova, Z., Breda, J., Cahill, J., Callenius, C., Caron, P., Gurinovic, M.A., Lang, T., Mango, C., Ryder, J., Sonnino, R., Verburg, G., Westhoek, H., Cesuroglu, T., Regeer, B.J., Broerse, J.E.W., 2019. Key research and innovation questions on engaging consumers in the delivery of FOOD 2030. Published by FIT4FOOD2030. https://fit4food2030.eu/eu-think-tank-policybrief/.
Grebitus, C., Chenarides, L., Muenich, R., Mahalov, A., 2020. Consumers' perception of urban farming—an exploratory study. Front. Sustain. Food Syst. 4, 79. https://doi.org/10.3389/fsufs.2020.00079.
Henseler, J., Hubona, G., Ray, P.A., 2016. Using PLS path modeling in new technology research: updated guidelines. Ind. Manag. Data Syst. 116, 2–20. https://doi.org/10.1108/IMDS-09-2015-0382.
Henseler, J., Ringle, C.M., Sinkovics, R.R., 2009. The use of partial least squares path modeling in international marketing. In: Sinkovics, R.R., Ghauri, P.N. (Eds.), Advances in International Marketing. Emerald Group Publishing Limited, pp. 277–319. https://doi.org/10.1108/S1474-7979(2009)0000020014.
Hinojosa, L., Lambin, E.F., Mzoughi, N., Napoléone, C., 2016. Place attachment as a factor of mountain farming permanence: a survey in the French Southern Alps. Ecol. Econ. 130, 308–315. https://doi.org/10.1016/j.ecolecon.2016.08.004.
Hinrichs, C.C., 2013. Regionalizing food security? Imperatives, intersections and contestations in a post-9/11 world. J. Rural Stud. 29, 7–18. https://doi.org/10.1016/j.jrurstud.2012.09.003.
Hu, Q., Xiang, M., Chen, D., Zhou, J., Wu, W., Song, Q., 2020. Global cropland intensification surpassed expansion between 2000 and 2010: a spatio-temporal analysis based on GlobeLand30. Sci. Total Environ. 746, 141035 https://doi.org/10.1016/j.scitotenv.2020.141035.
Iba Gürsoy, S.İ., 2020. Addressing the challenge of food security in Turkey. In: Savaşan, Z., Sümer, V. (Eds.), Environmental Law and Policies in Turkey, the

Anthropocene: Politik—Economics—Society—Science. Springer International Publishing, Cham, pp. 127–140. https://doi.org/10.1007/978-3-030-36483-0_8.
Ickowitz, A., Powell, B., Rowland, D., Jones, A., Sunderland, T., 2019. Agricultural intensification, dietary diversity, and markets in the global food security narrative. Global Food Secur. 20, 9–16. https://doi.org/10.1016/j.gfs.2018.11.002.
Janus, J., Bozek, P., 2018. Using ALS data to estimate afforestation and secondary forest succession on agricultural areas: an approach to improve the understanding of land abandonment causes. Appl. Geogr. 97, 128–141. https://doi.org/10.1016/j.apgeog.2018.06.002.
Jin, G., Chen, K., Wang, P., Guo, B., Dong, Y., Yang, J., 2019. Trade-offs in land-use competition and sustainable land development in the North China Plain. Technol. Forecast. Soc. Change 141, 36–46. https://doi.org/10.1016/j.techfore.2019.01.004.
Kaufmann, L., Mayer, A., Matej, S., Kalt, G., Lauk, C., Theurl, M.C., Erb, K.-H., 2022. Regional self-sufficiency: a multi-dimensional analysis relating agricultural production and consumption in the European Union. Sustain. Prod. Consum. 34, 12–25. https://doi.org/10.1016/j.spc.2022.08.014.
Kennedy, P., 2008. A Guide to Econometrics, sixth ed. Blackwell Pub, Malden, MA, p. 585p. ISBN: 978-1-4051-8258-4.
Lamine, C., Garçon, L., Brunori, G., 2019. Territorial agrifood systems: a Franco-Italian contribution to the debates over alternative food networks in rural areas. J. Rural Stud. 68, 159–170. https://doi.org/10.1016/j.jrurstud.2018.11.007.
Lehtinen, U., 2012. Sustainability and local food procurement: a case study of Finnish public catering. Br. Food J. 114, 1053–1071. https://doi.org/10.1108/00070701211252048.
Lin, B.B., Philpott, S.M., Jha, S., Liere, H., 2017. Urban agriculture as a productive green infrastructure for environmental and social well-being. In: Tan, P.Y., Jim, C.Y. (Eds.), Greening Cities, Advances in 21st Century Human Settlements. Springer Singapore, Singapore, pp. 155–179. https://doi.org/10.1007/978-981-10-4113-6_8.
Lohmöller, J.-B., 1989. Latent Variable Path Modeling with Partial Least Squares. Physica-Verlag Heidelberg, Heidelberg. https://doi.org/10.1007/978-3-642-52512-4.
Lohmöller, J.-B., 1988. The PLS program system: latent variables path analysis with partial least squares estimation. Multivariate Behav. Res. 23, 125–127. https://doi.org/10.1207/s15327906mbr2301_7.
Malek, Ž., Verburg, P., 2017. Mediterranean land systems: representing diversity and intensity of complex land systems in a dynamic region. Landsc. Urban Plann. 165, 102–116. https://doi.org/10.1016/j.landurbplan.2017.05.012.
Marchetti, L., Cattivelli, V., Cocozza, C., Salbitano, F., Marchetti, M., 2020. Beyond Sustainability in Food Systems: Perspectives from Agroecology and Social Innovation, vol. 24.
Mazzucato, M., 2018. The Entrepreneurial State: Debunking Public vs. Private Sector Myths. Penguin Books, UK, p. 260p. ISBN: 978-0-14-198610-4.
Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mücher, C.A., Watkins, J.W., 2005. A climatic stratification of the environment of Europe: a climatic stratification of the European environment. Global Ecol. Biogeogr. 14, 549–563. https://doi.org/10.1111/j.1466-822X.2005.00190.x.
Monaco, F., Zasada, I., Wascher, D., Glavan, M., Pintar, M., Schmutz, U., Mazzocchi, C., Corsi, S., Sali, G., 2017. Food production and consumption: city regions between localism, agricultural land displacement, and economic competitiveness. Sustainability 9, 96. https://doi.org/10.3390/su9010096.
Moreno Pérez, O., de Benito, C., Sanz Sanz, E., Simón Rojo, M., Yacamán-Ochoa, C., 2019. DIVERCROP Project - Deliverable 5.2: Possibilities to Reconnect Urban Consumption to Peri-Urban Agriculture.
Moragues-Faus, A., Sonnino, R., Marsden, T., 2017. Exploring European food system vulnerabilities: towards integrated food security governance. Environ. Sci. Pol. 75, 184–215. https://doi.org/10.1016/j.envsci.2017.05.015.
Morell-Monzó, S., Estornell, J., Sebastiá-Frasquet, M.-T., 2020. Comparison of sentinel-2 and high-resolution Imagery for mapping land abandonment in fragmented areas. Rem. Sens. 12, 2062. https://doi.org/10.3390/rs12122062.
Morrison, K.T., Nelson, T.A., Ostry, A.S., 2011a. Methods for mapping local food production capacity from agricultural statistics. Agric. Syst. 104, 491–499. https://doi.org/10.1016/j.agsy.2011.03.006.
Morrison, K.T., Nelson, T.A., Ostry, A.S., 2011b. Mapping spatial variation in food consumption. Appl. Geogr. 31, 1262–1267. https://doi.org/10.1016/j.apgeog.2010.11.020.
Mouléry, M., Sanz Sanz, E., Debolini, M., Napoléone, C., Josselin, D., Mabire, L., Vicente-Vicente, J.L., 2022. Self-Sufficiency Assessment: Defining the Foodshed Spatial Signature of Supply Chains for Beef in Avignon, France. https://doi.org/10.3390/agriculture12030419. Agriculture 419.
Moustier, P., 2017. Short urban food chains in developing countries: signs of the past or of the future? Nat. Sci. Soc. 25, 7–20. https://doi.org/10.1051/nss/2017018.
Müller, B., Hoffmann, F., Heckelei, T., Müller, C., Hertel, T.W., Polhill, J.G., van Wijk, M., Achterbosch, T., Alexander, P., Brown, C., Kreuer, D., Ewert, F., Ge, J., Millington, J. D.A., Seppelt, R., Verburg, P.H., Webber, H., 2020. Modelling food security: Bridging the gap between the micro and the macro scale. Global Environ. Change 63, 102085. https://doi.org/10.1016/j.gloenvcha.2020.102085.
Nainggolan, D., Termansen, M., Reed, M.S., Cebollero, E.D., Hubacek, K., 2011. Farmer typology, future scenarios and the implications for ecosystem service provision: a case study from south-eastern Spain. Reg. Environ. Change 601–614. https://doi.org/10.1007/s10113-011-0261-6.
Ngo, M., Brklacich, M., 2014. New farmers' efforts to create a sense of place in rural communities: insights from southern Ontario, Canada. Agric. Hum. Val. 53–67. https://doi.org/10.1007/s10460-013-9447-5.
OECD/FAO/UNCDF, 2016. Adopting a territorial approach to food security and nutrition policy. In: OECD Rural Studies. OECD Publishing, Paris, p. 158. https://doi.org/10.1787/9789264257108-en. ISBN: ISBN 978-92-64-25710-8.
O'Hara, S., Toussaint, E.C., 2021. Food access in crisis: food security and COVID-19. Ecol. Econ. 180, 106859 https://doi.org/10.1016/j.ecolecon.2020.106859.
Olén, N.B., Roger, F., Brady, M.V., Larsson, C., Andersson, G.K.S., Ekroos, J., Caplat, P., Smith, H.G., Dänhardt, J., Clough, Y., 2021. Effects of farm type on food production, landscape openness, grassland biodiversity, and greenhouse gas emissions in mixed agricultural-forestry regions. Agric. Syst. 189, 103071 https://doi.org/10.1016/j.agsy.2021.103071.
Opitz, I., Berges, R., Piorr, A., Krikser, T., 2016. Contributing to food security in urban areas: differences between urban agriculture and peri-urban agriculture in the Global North. Agric. Hum. Val. 33, 341–358. https://doi.org/10.1007/s10460-015-9610-2.
Perignon, Marlène, Sinfort, Carole, El, Ati, Jalila, Traissac, Pierre, Drogué, Sophie, Darmon, Nicole, Amiot, M.-J., Amiot, M.J., Achir, N., Alouane, L., El Ati, J., Bellagha, S., Bosc, P.M., Broin, M., Darmon, N., Dhuique-Meyer, C., Dop, M.C., Drogué, S., Dury, S., Ferchoui, A., Gaillard, C., Ghrabi, Z., Jacquet, F., Kameli, Y., Kefi, F., Khamassi, F., Kesse-Guyot, E., Lairon, D., Martin-Prevel, Y., Méjean, C., Mouquet, C., Njoumi, S., Padilla, M., Perignon, M., Sinfort, C., Traissac, P., Verger, E. O., 2019. How to meet nutritional recommendations and reduce diet environmental impact in the Mediterranean region? An optimization study to identify more sustainable diets in Tunisia. Global Food Secur. 23, 227–235. https://doi.org/10.1016/j.gfs.2019.07.006.
Pesaresi, Martino, Florczyk, Aneta, Schiavina, Marcello, Melchiorri, Michele, Maffenini, Luca, 2019. GHS-SMOD R2019A - GHS settlement layers, updated and refined REGIO model 2014 in application to GHS-BUILT R2018A and GHS-POP R2019A, multitemporal (1975-1990-2000-2015). European Commission, Joint Research Centre (JRC) [Dataset]. https://doi.org/10.2905/42E8BE89-54FF-464E-BE7B-BF9E64DA5218. http://data.europa.eu/89h/42e8be89-54ff-464e-be7b-bf9e64da5218.
Peters, C.J., Wilkins, J.L., Fick, G.W., 2007. Testing a complete-diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: the New York State example. Renew. Agric. Food Syst. 22, 145–153. https://doi.org/10.1017/S1742170507001767.
Poggi, S., Vinatier, F., Hannachi, M., Sanz Sanz, E., Rudi, G., Zamberletti, P., Tixier, P., Papaïx, J., 2021. How can models foster the transition towards future agricultural landscapes? Advances in Ecological Research S0065250420300453. https://doi.org/10.1016/bs.aecr.2020.11.004.
Popkin, B.M., 1999. Urbanization, Lifestyle changes and the nutrition transition. World Dev. 27, 1905–1916. https://doi.org/10.1016/S0305-750X(99)00094-7.
Puma, M.J., 2015. Assessing the evolving fragility of the global food system. Environ. Res. Lett. 15.
Ringle, C.M., Wende, S., Will, A., 2010. Finite Mixture partial least quares analysis: methodology and Numerical examples. In: Esposito Vinzi, V., Chin, W.W., Henseler, J., Wang, H. (Eds.), Handbook of Partial Least Squares, Springer Handbooks of Computational Statistics. Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg, pp. 195–219. https://doi.org/10.1007/978-3-540-32827-8_3.
Rivera, M., Guarín, A., Pinto-Correia, T., Almaas, H., Mur, L.A., Burns, V., Czekaj, M., Ellis, R., Galli, F., Grivins, M., Hernández, P., Karanikolas, P., Prosperi, P., Sánchez Zamora, P., 2020. Assessing the role of small farms in regional food systems in Europe: evidence from a comparative study. Global Food Secur. 26, 100417 https://doi.org/10.1016/j.gfs.2020.100417.
Romero-Calcerrada, R., Perry, G.L.W., 2004. The role of land abandonment in landscape dynamics in the SPA 'Encinares del río Alberche y Cofio, Central Spain, 1984–1999. Landsc. Urban Plann. 66, 217–232. https://doi.org/10.1016/S0169-2046(03)00112-9.
Rothwell, A., Ridoutt, B., Page, G., Bellotti, W., 2016. Environmental performance of local food: trade-offs and implications for climate resilience in a developed city. J. Clean. Prod. 114, 420–430. https://doi.org/10.1016/j.jclepro.2015.04.096.
Ruben, R., Verhagen, J., Plaisier, C., 2018. The challenge of food systems research: what difference does it make? Sustainability 11, 171. https://doi.org/10.3390/su11010171.
Ruiz-Martinez, I., Debolini, M., Sabbatini, T., Bonari, E., Lardon, S., Marraccini, E., 2020. Agri-urban patterns in Mediterranean urban regions: the case study of Pisa. J. Land Use Sci. 1–19. https://doi.org/10.1080/1747423X.2020.1836054.
Saidi, A., Diouri, M., 2017. Food self-sufficiency under the green-Morocco plan. JEBAS 5, 33–40. https://doi.org/10.18006/2017.5(Spl-1-SAFSAW).S33.S40.
Salvati, L., Munafo, M., Morelli, V.G., Sabbi, A., 2012. Low-density settlements and land use changes in a Mediterranean urban region. Landsc. Urban Plann. 105, 43–52. https://doi.org/10.1016/j.landurbplan.2011.11.020.
Sanchez, G., Trinchera, L., Russolillo, G., 2017. Plspm: tools for partial least squares path modeling (PLS-PM). R package version 0.4.9. https://CRAN.R-project.org/package=plspm.
Sanz Sanz, E., Martinetti, D., Napoléone, C., 2018. Operational modelling of peri-urban farmland for public action in Mediterranean context. Land Use Pol. 75, 757–771. https://doi.org/10.1016/j.landusepol.2018.04.003.
Schneider, U.A., Havlík, P., Schmid, E., Valin, H., Mosnier, A., Obersteiner, M., Böttcher, H., Skalský, R., Balkovič, J., Sauer, T., Fritz, S., 2011. Impacts of population growth, economic development, and technical change on global food production and consumption. Agric. Syst. 104, 204–215. https://doi.org/10.1016/j.agsy.2010.11.003.
Schreiber, K., Hickey, G.M., Metson, G.S., Robinson, B.E., MacDonald, G.K., 2021. Quantifying the foodshed: a systematic review of urban food flow and local food self-sufficiency research. Environ. Res. Lett. 16, 023003 https://doi.org/10.1088/1748-9326/abad59.
Seto, K.C., Ramankutty, N., 2016. Hidden linkages between urbanization and food systems. Science 352, 943–945. https://doi.org/10.1126/science.aaf7439.

Shaver, I., Chain-Guadarrama, A., Cleary, K.A., Sanfiorenzo, A., Santiago-García, R.J., Finegan, B., Hormel, L., Sibelet, N., Vierling, L.A., Bosque-Pérez, N.A., DeClerck, F., Fagan, M.E., Waits, L.P., 2015. Coupled social and ecological outcomes of agricultural intensification in Costa Rica and the future of biodiversity conservation in tropical agricultural regions. Global Environ. Change 32, 74–86. https://doi.org/10.1016/j.gloenvcha.2015.02.006.

Smith, J., Lang, T., Vorley, B., Barling, D., 2016. Addressing policy challenges for more sustainable local–global food chains: policy frameworks and possible food "futures.". Sustainability 8, 299. https://doi.org/10.3390/su8040299.

Sonnino, R., 2016. The new geography of food security: exploring the potential of urban food strategies. Geogr. J. 182, 190–200. https://doi.org/10.1111/geoj.12129.

Sonnino, R., Marsden, T., Moragues-Faus, A., 2016. Relationalities and convergences in food security narratives: towards a place-based approach. Trans. Inst. Br. Geogr. 41, 477–489. https://doi.org/10.1111/tran.12137.

Sonnino, R., Tegoni, C.L.S., De Cunto, A., 2019. The challenge of systemic food change: insights from cities. Cities 85, 110–116. https://doi.org/10.1016/j.cities.2018.08.008.

Soulard, C.-T., Valette, E., Perrin, C., Abrantes, P.C., Anthopoulou, T., Benjaballah, O., Bouchemal, S., Dugué, P., Amrani, M.E., Lardon, S., Marraccini, E., Mousselin, G., Napoleone, C., Paoli, J.-C., 2017. Peri-urban agro-ecosystems in the Mediterranean: diversity, dynamics, and drivers. Reg. Environ. Change. https://doi.org/10.1007/s10113-017-1102-z.

Temme, A.J.A.M., Verburg, P.H., 2011. Mapping and modelling of changes in agricultural intensity in Europe. Agric. Ecosyst. Environ. 140, 46–56. https://doi.org/10.1016/j.agee.2010.11.010.

Tenenhaus, M., Vinzi, V.E., Chatelin, Y.-M., Lauro, C., 2005. PLS path modeling. Comput. Stat. Data Anal. 48, 159–205. https://doi.org/10.1016/j.csda.2004.03.005.

Thilmany, D., Canales, E., Low, S.A., Boys, K., 2021. Local food supply chain dynamics and resilience during COVID -19. Appl. Econ. Perspect. Pol. 43, 86–104. https://doi.org/10.1002/aepp.13121.

van Gameren, V., Ruwet, C., Bauler, T., 2015. Towards a governance of sustainable consumption transitions: how institutional factors influence emerging local food systems in Belgium. Local Environ. 20, 874–891. https://doi.org/10.1080/13549839.2013.872090.

Van Loon, M.P., Hijbeek, R., Ten Berge, H.F.M., De Sy, V., Ten Broeke, G.A., Solomon, D., Van Ittersum, M.K., 2019. Impacts of intensifying or expanding cereal cropping in sub-Saharan Africa on greenhouse gas emissions and food security. Global Change Biol. 25, 3720–3730. https://doi.org/10.1111/gcb.14783.

van Vliet, J., de Groot, H.L.F., Rietveld, P., Verburg, P.H., 2015. Manifestations and underlying drivers of agricultural land use change in Europe. Landsc. Urban Plann. 24–36.

Verburg, P.H., Mertz, O., Erb, K.-H., Haberl, H., Wu, W., 2013. Land system change and food security: towards multi-scale land system solutions. Curr. Opin. Environ. Sustain. 5, 494–502. https://doi.org/10.1016/j.cosust.2013.07.003.

Verger, E.O., Perignon, M., El Ati, J., Darmon, N., Dop, M.-C., Drogué, S., Dury, S., Gaillard, C., Sinfort, C., Amiot, M.-J., 2018a. A "fork-to-farm" multi-scale approach to promote sustainable food systems for nutrition and health: a perspective for the Mediterranean region. Front. Nutr. 5, 30. https://doi.org/10.3389/fnut.2018.00030.

Verger, E.O., Perignon, M., El Ati, J., Darmon, N., Dop, M.-C., Drogué, S., Dury, S., Gaillard, C., Sinfort, C., Amiot, M.-J., 2018b. A "fork-to-farm" multi-scale approach to promote sustainable food systems for nutrition and health: a perspective for the Mediterranean region. Front. Nutr. 5, 30. https://doi.org/10.3389/fnut.2018.00030.

Vicente-Vicente, J.L., Sanz Sanz, E., Napoléone, C., Moulery, M., Piorr, A., 2021. Foodshed, agricultural diversification and self-sufficiency assessment: beyond the Isotropic circle foodshed—a case study from Avignon (France). Agriculture 11, 143. https://doi.org/10.3390/agriculture11020143.

Wang, H., Qiu, F., 2017. Investigation of the dynamics of agricultural land at the urban fringe: a comparison of two peri-urban areas in Canada. Can. Geogr./Le Géographe canadien 61, 457–470. https://doi.org/10.1111/cag.12389.

Wold, H., 1985. Systems analysis by partial least squares. In: Nijkamp, P., Leitner, H., Wrigley, N. (Eds.), Measuring the Unmeasurable. Martinus Nijhoff Publishers, pp. 221–251.

Wold, H., 1982. Soft modeling the basic design and some extensions. In: Jöreskog, K.G., Wold, H. (Eds.), Systems under Indirect Observation: Causality, Structure, Prediction Part II. North-Holland, Amsterdam, pp. 1–54.

Wortman, S.E., Lovell, S.T., 2013. Environmental challenges threatening the growth of urban agriculture in the United States. J. Environ. Qual. 42, 1283–1294. https://doi.org/10.2134/jeq2013.01.0031.

Wu, W., Yu, Q., Peter, V.H., You, L., Yang, P., Tang, H., 2014. How could agricultural land systems contribute to raise food production under global change? J. Integr. Agric. 13, 1432–1442. https://doi.org/10.1016/S2095-3119(14)60819-4.

Yacamán-Ochoa, C., Matarán Ruiz, A., Mata Olmo, R., Macías Figueroa, Á., Torres Rodríguez, A., 2020. Peri-urban organic agriculture and short food supply chains as drivers for strengthening city/region food systems—two case studies in Andalucía, Spain. Land 9, 177. https://doi.org/10.3390/land9060177.

Zabel, F., Delzeit, R., Schneider, J.M., Seppelt, R., Mauser, W., Václavík, T., 2019. Global impacts of future cropland expansion and intensification on agricultural markets and biodiversity. Nat. Commun. 10, 2844. https://doi.org/10.1038/s41467-019-10775-z.