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Assessing the Impacts of Climate Change on Agricultural Land Markets: A Comprehensive Review of Economic Models

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Assessing the Impacts of Climate Change on Agricultural Land Markets: A Comprehensive Review of Economic Models

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Les impacts du changement climatique sur les marchés fonciers ruraux : une revue des modèles en économie agricole

Résumé

Le changement climatique affecte les mécanismes d'allocation des terres agricoles. Or, à notre connaissance, aucune étude ne propose d'appréhender de manière systémique ses effets sur les marchés fonciers. Ce travail présente un cadre d'analyse qui formalise les liens entre changement climatique et marchés fonciers, et identifie les questions méthodologiques et thématiques qui en résultent. Ce cadre est étoffé par une revue de modèles en économie agricole. Au-delà de la diversité des approches mobilisées pour appréhender les dimensions spatiale et temporelle, les dynamiques et les incertitudes, les résultats montrent que ces modèles représentent les impacts du changement climatique sur les marchés fonciers à différentes échelles : des ajustements globaux entre usages des terres aux adaptations microéconomiques des exploitations agricoles. La modélisation des impacts du changement climatique porte principalement sur l'état et l'usage des terres tandis que les marchés fonciers sont abordés de manière segmentée : certains modèles se concentrent sur la demande foncière, d'autres sur la valeur des terres ou les mécanismes de transaction. Ainsi, ce travail met en lumière comment les effets du changement climatique sur les marchés fonciers sont abordés en économie et dégage des perspectives de recherche.

Mots-Clés : marché foncier, prix foncier, utilisation du sol, modélisation économique, revue de littérature

Classification JEL : Q18, Q15, Q54

Assessing the Impacts of Climate Change on Agricultural Land Markets: A Comprehensive Review of Economic Models

Abstract

Climate change challenges the allocation mechanisms of agricultural land, yet there is currently no systemic framework for assessing its impact on land markets. We conceptualise the climate change–land market nexus and identify its methodological and thematic issues. To support our original framework, we selectively review how agricultural economic approaches address it. We highlight that the impact of climate change on land markets has been studied at various scales, from global land use adjustments to micro-level farm adaptations, and each of these scales relates with a specific approach. The modelling of climate change effects mainly refers to land conditions, *e.g.* land state, use or cover change. The land market is usually addressed in rather segmented views: Models focus either on land demand, land value, or transaction mechanisms. Results also show different methods to address micro and macro levels, spatial and temporal dimensions, dynamics, and uncertainties. This paper provides a comprehensive review of agricultural economics, outlining gaps and research perspectives. It paves the way for further work on how to design better policies for effective land markets in the climate change context.

Keywords: land market, land price, land use, economic modelling, literature review

JEL classification: Q18, Q15, Q54

1. Introduction

Ensuring efficient land allocation is becoming an increasingly important issue as climate change disrupts the established regional balance of agricultural land demand and supply.

According to FAO projections, by 2050, an increase of up to 5% in arable land compared to 2020 will be necessary to meet the needs of the growing global population (FAO 2017, 2021). At the same time, by 2100, 8% of the area currently suitable for major crops and livestock is projected to become climatically unsuitable under the SSP1-2.6 scenario (IPCC 2022). Rising temperatures, changes in precipitation patterns, increases in frequency and intensity of hazards and land degradation processes will affect the availability of land both quantitatively and qualitatively (IPCC 2019). Meanwhile, market adjustments to these impacts will change local demand for agricultural land. Adaptation mechanisms may involve reallocating agricultural production across regions through changes in technologies and practices, as well as crop substitution (IPCC 2019; Arora *et al.* 2020; Sloat *et al.* 2020). Concurrently, new land uses are emerging from mitigation strategies, such as large-scale afforestation and bioenergy production (Haberl *et al.* 2014; Harvey and Pilgrim, 2011). This simultaneous shift in land supply (resulting from uneven changes in the quality and quantity of land worldwide) and demand (due to the development of new uses and the reallocation of existing uses) is worsening land scarcity. This may put pressure on existing land allocation mechanisms, which are recognised as essential for ensuring food security and human resilience in the face of climate change (Murken and Gornott 2022; FAO 2021; Arial *et al.* 2011; Quan and Dyer 2008; Mitchell and McEvoy 2019). In Western contexts, where freehold tenure regimes dominate (EC-JRC, 2021; Swinnen *et al.*, 2016), this raises the question of whether land markets will continue to provide effective signals for efficient allocation in a changing climate (Anderson *et al.* 2019).

Studying the potential effects of climate change on land markets reveals a complex set of questions, as it involves various dimensions related to both climate change (Farmer *et al.*, 2015; McCarl and Hertel, 2018) and land markets (Hurrelmann, 2022; Odening and Hüttel, 2020; Swinnen *et al.*, 2016). The literature on agricultural adaptation to climate change, land-use change and climate-induced land needs and losses, suggests that resource allocation mechanisms may be affected by these mitigation and adaptation strategies (Arora *et al.* 2020; Sloat *et al.* 2020). However, the economic implications of such climate-induced changes in land conditions and land use on the functioning and dynamics of agricultural land markets remain only partially explored. Then, a body of literature questions the opportunity of securing or establishing a land market as a way to enhance land tenure security in the context of climate change (Murken and Gornott 2022). These studies demonstrate the various ways in which land markets, rooted in their environmental and societal contexts, are impacted by climate change. While mostly case studies with diverse methodologies, they highlight the importance of the issue and point to the need for a generalized conceptual framework. Finally, the economic literature related to climate change effects on land markets is mainly covered by the Ricardian approach (Ortiz-Bobea 2021). Building on the seminal work of Mendelsohn *et al.* (1994), this method enables the investigation of climate change impacts on land values, but offers limited insights into changes in land market equilibrium or trade dynamics. Overall, while the interplay between climate change and land markets is frequently discussed in research, there is, to the best of our knowledge, no comprehensive framework that offers both a systemic and theoretical understanding of the interactions between climate change and well-established agricultural land markets.

This paper aims to explicitly frame the climate change – land markets system and identify the critical issues it presents for agricultural economic research. We first develop a conceptual framework, grounded in extensive literature, to define the diverse and complex economic mechanisms linking climate change and land markets. This framework draws on the concept of nexus (Albrecht *et al.* 2018; Hoff 2011) and the triple dimensions of land conditions: land state, use, and cover (IPCC 2019). We then outline the methodological and thematic requirements for economic modelling and assess how major economic approaches address these challenges. Through a selective review of econometric, equilibrium and optimization, and agent-based literature, we provide an overview of the methodologies used and the insights gained from previous agricultural economic research. Finally, we identify new research perspectives on the climate change – land markets nexus.

This work emphasises the complexity of the issue and provides a thorough understanding of its methodological and thematic dimensions. We demonstrate that the impacts of climate change on land markets have been studied in the agricultural economic literature at various scales, from global land use adjustments to micro-level farm adaptations, but in a segmented manner. We identify several potential effects of climate change on land markets, each mainly (but not only) studied by one modelling approach. First, we examine the direct and indirect effects of climate change on the condition of land, and highlight the importance of the spatial dimensions when modelling them. Direct effects on land amenities and land suitability may affect land prices (hedonic approach). Additionally, future land-use changes, driven by agricultural adaptation and mitigation strategies, and urban dynamics, could alter land markets dynamics (equilibrium approach). Second, as climate change may affect agents' behaviour and heterogeneity—through their responses to or anticipation of its impacts – we also highlight how these changes might influence land market dynamics (agent-based models). Although this review remains selective and may suggest the need for further exploration, it provides a broad overview of the literature, allowing to identify three key perspectives for future research: i) the need to explore the heterogeneous impacts of changing land conditions – due to climate change – on supply-demand balances in land markets within a spatialized context; ii) the importance of accounting for the heterogeneity of land market stakeholders and their interactions; iii) the necessity of considering land markets within their institutional and legal environment.

This paper contributes to a deeper understanding of the impacts of climate change on land markets by offering an original formalisation of the climate change–land market nexus (CC-LM nexus). Additionally, it provides a comprehensive review of agricultural economics models, outlining critical gaps and new research perspectives. By doing so, it does not only shed light on the complex interactions between climate change and land markets but also paves the way for further work that can better inform policies for effective land allocation in the context of climate change.

The next section formalises the CC-LM nexus by defining and framing the system. Section 3 presents the methodology of the economic literature survey. Section 4 explains how the main economic approaches deal with the interactions between climate change and farmland markets. Section 5 discusses the results and outlines research perspectives before briefly concluding.

2. The climate change – land market nexus

The concept of a nexus permits the development of a comprehensive approach to a complex system. The current section presents the CC–LM nexus by first defining its components and then identifying the interactions that connect them.

2.1. The impact of climate change on land conditions

Climate change here refers to the change in the climate state observed over a long period (a decade or more) mainly due to an anthropogenic increase of greenhouse gas emissions. The main indicators of such changes are temperature, precipitation rate and soil moisture, and extreme climatic events (IPCC, 2021). Four scenarios based on different radiative forcing scenarios, the Representative Concentration Pathways (RCP), describe the potential evolution of the climate by 2100. Each of them foresees multiple and heterogeneous short- and long-term consequences for territories (IPCC, 2021, 2019, 2018). In addition, spatial variations and distributional effects, cross-scale effects and feedbacks characterize the expected climatic evolutions (Farmer *et al.*, 2015). Moreover, climate change is particularly subject to a high degree of uncertainty because of the random nature of weather events, and because we do not know how the climate will transform the future with regards to the uncertain reactions of natural and human systems (Schimmelpfennig, 1996). Even if global warming does not exceed 2°C, the IPCC (2022) states that climate change will lead to unavoidable consequences on socio-ecosystems in the short- and long-run; climate change effects will happen, even with mitigation efforts and reduced consequences.

Climate change affects socio-ecosystems through three channels: direct impacts on the bio-physical Earth system, adaptation mechanisms, and mitigation strategies (Hertel, 2011). The latter two could be considered as indirect impacts of climate change. Among other impacts, climate change affects land conditions, both directly and indirectly (IPCC, 2019). Indeed, if land is simply described as an area of Earth's surface, it is characterized by two main dimensions: biophysical and anthropic (Briassoulis, 2020; Parker *et al.*, 2008). Land conditions incorporate these two dimensions and can be described by three levels of analysis:

- *Land state* refers to soil characteristics, *i.e.* physico-chemical, biological, hydrological and geomorphological conditions (FAO, 1988). Put more simply, it refers to soil moisture, salinity, snow cover, soil slope, soil and surface mean temperature, erosion rate, organic carbon concentration, *etc.*
- *Land cover* refers to the biophysical features of the land surface. It could be described in terms of the degree of vegetal or urban cover (Briassoulis, 2020). Broadly speaking, main land cover types can relate to agricultural, forestry, natural or urban.
- *Land use* refers to the "human employment of land", that is, how and for what purpose land is used (Meyer and Turner, 1992: 39). Focusing on agronomic practices, it relates to crop choices, irrigation and crop management.

Land use and land cover are often confused in the literature (Briassoulis, 2020). In the following, to avoid this and simplify the analysis, we will consider land use as only referring to the different types of agricultural use, and land cover as referring to one of the main categories just identified above; namely agriculture, forest, natural area or urban area. In this sense, land cover could be defined as a supra category of land use, in which agricultural use stands in its aggregate form. Accordingly, land state and land use both affect land cover.

Based on these definitions, it is now possible to characterize the direct and indirect impacts of climate change on land conditions:

- Climate change directly affects *the state of land* by modifying its various properties. On the one hand, it contributes to land degradation (through erosion, aridification, salinization or reduced water availability). On the other hand, rising temperatures are providing new agronomic opportunities (IPCC, 2019). Several papers have evaluated the impact of climate change on land availability. Fitton *et al.* (2019) find that around 11% to 10% of current crop- and grassland could lose their productive capacity because of reduced water availability. Dasgupta *et al.* (2009) estimate that around 70,671 sq.km of agricultural land would be affected by a one-meter elevation of the sea level. Working on the regional evolution of land availability, Zhang and Cai (2011) conclude that regions located in relatively high latitudes (such as Russia, China or the United States) may expect an increase in total arable land of 4% to 67%, depending on the scenario considered.
- The change in the agronomic properties of soils implies a change in potential agricultural yields, and hence induces adaptive behaviours from farmers. Crop choices, the planting calendar or irrigation practices are evolving (Adams *et al.*, 1998; Döll, 2002; Olesen *et al.*, 2011). These spatio-temporal and technical adaptive strategies at the farm-level could result in a spatial redistribution of agricultural production at the regional and global scales. The scientific literature refers to such land use reallocations as “land switching” (Leclère *et al.*, 2014; Schimmelpfennig *et al.*, 1996). Furthermore, land abandonment may occur when land becomes unproductive due to aridification and desertification, erosion or salinization processes (Schimmelpfennig *et al.*, 1996). New mitigation efforts also lead to agricultural land-use changes through the emergence of new demands for land, such as the production of bio-energy or soil carbon storage. Thus, adaptation and mitigation, as indirect climate change impacts, also lead to agricultural land-use changes.

Finally, climate change also affects *land cover*: urbanization evolves in response to new climate risks for populations (flooding, desertification) and resulting migrations (Anderson *et* *al.*, 2019; McLeman and Smit, 2006). This could generate increasing urban pressure at the local scale. Mitigation strategies, such as afforestation programmes and area protection; could also affect the land cover. For instance, Lambin and Meyfroidt (2011) evaluate an additional 44 to 118 million hectares (Mha) will be needed for the production of biofuel crops in 2030 with respect to 2000, and another 26 to 80 Mha due to the expansion of protected areas.

2.2. The land market

The land market facilitates the balancing of land supply and demand, through land use and land property rights transactions. It results in the allocation of the land resource across its different uses, which may pertain to agricultural, urban, forestry or natural uses. These uses are mostly mutually exclusive and some of them are non-reversible. For instance, urban use leads to soil sealing through the artificialization process (Béchet *et al.*, 2017). Land that becomes urban will remain so and will, therefore, be exchanged on the urban sub-market. Urban and agricultural uses, two potential land uses, must not be confused with urban and farmland markets. The latter are two sub-markets for land, differing in their features. In this paper, we focus on the farmland market, where urban use is one of the potential uses of farmland. Therefore, we assume the existence of a friction zone between the agricultural and urban land markets, when the conversion of farmland to urban land occurs. When considering farmland, the market equilibrium depends closely on the characteristics of land itself. Land is a finite, immobile and heterogeneous natural resource. Its supply is therefore local by nature, non-extensible, and characterized by both quantitative (finite supply) and qualitative (heterogeneous supply) scarcity (Ay, 2011; Odening and Hüttel, 2020). In contrast, the demand for land is potentially infinite and mobile. Thus, market equilibrium depends closely on the economic scarcity of land (in terms of quantity and quality with regard to use preferences), itself varying with the spatial scale considered (Ay, 2011). As in any other market, the land market is a "*price making mechanism*" (Hurrelmann, 2002: 2). Farmland price is then often modelled within the net present value framework, which defines the current price of a plot as the sum of its current rent, its differential rent (which is the anticipation of actual rent evolution) and the option value. The latter corresponds to the floor price beyond which the agricultural use of land is no longer profitable (with regard to its fertility and environmental signals) and an alternative use is put in place (Cavailhès *et al.*, 1996). Owing to land immobility and heterogeneity, the farmland market is assumed to be thin (Kionka *et al.*, 2021). The number of agents is limited, weakening the atomicity condition of a perfectly competitive market (Ay, 2011) and opening the way to market powers (Balmann *et al.*, 2021; Cotteleer *et* *al.*, 2008). The land market is then characterized by high transaction costs that pertain to information, negotiation and the enforcement of rights (Ciaian and Swinnen, 2006; Hurrelmann, 2022; Seifert *et al.*, 2021). In order to limit transaction costs and ensure an efficient allocation of the resource, some countries or regions have put in place a set of institutions to regulate the land. When implemented, they aim to define allocation objectives, secure land rights, and distribute them in a fair, efficient and effective way with regard to social welfare (Haberl *et al.*, 2014). Whether formal (*e.g.* regulations) or informal (*e.g.* customs), land tenure institutions are characteristic of a culture and a social group, and are thus generally specific to a country or even a sub-national region (Colin, 2002).

2.3. The land market – climate change nexus

The description of the impacts of climate change on the conditions of land and the main land market characteristics enables the interactions between them to be sketched out. By affecting land conditions, climate change induces a variation in the local supply of land, upward or downward, both in quantity and quality, therefore changing the market equilibrium. This may result in changes in the intrinsic value of land and evolutions of the market structure and functioning. Indeed, the uncertain context of land availability is changing at different scales, and may affect how farmland market stakeholders operate. In this respect, several publications evidence or question the emergence of new actors on the land market, who anticipate an increase in resource scarcity or react to economic and political incentives to develop crops for energy or forests as carbon sinks (Byerlee and Deininger, 2013; Kay, 2016). Such new players usually differ from local farmers with respect to their objective functions. This diversification of stakeholders is reshaping economic interactions on the land market, with repercussions for the distribution of both use and ownership land rights and, eventually, for the structure of farms. In the end, this challenges the roles of land tenure institutions in sustaining fair and efficient agricultural land allocation in the context of climate change.

3. Analytical framework

Studying the CC-LM nexus is challenging since it requires combining natural (*e.g.* land state change) and human mechanisms (*e.g.* adaptation and mitigation strategies, market process). Additionnaly, it involves micro-dynamics (*e.g.* farmer adaptation, agent economic behaviour) with macro-dynamics (*e.g.* land-use change, economic adjustments, institutional framework), which vary over space and time. Short- and long-term mechanisms affect the CC-LM nexus differently. Within the CC-LM nexus framework, we identify critical aspects that economic models addressing this issue should consider. Table 1 classifies these aspects into several general modelling requirements, highlighting the key features of each.

Thematic requirements:

- *Climate change features:* climate change is characterized by spatial and temporal heterogeneous mechanisms that directly and indirectly affect socio-ecosystems. Adaptation and mitigation strategies are part of the evolution of socio-ecosystems. It is essential to uncover how models capture changes in land states, land use, and land cover in response to climate change.
- *Land market features*: land markets encompass a range of critical research issues. The land market allocates land rights (use, property); the coupling of the renting and sales market is meaningful. Moreover, land markets are usually distinguished according to land-use (urban or farmland market), the porosity of both sub-markets also being a research issue. Land markets could therefore be characterized from several perspectives: market equilibrium, land value, market structure, transaction mechanisms, and institutional framework. Finally, land markets are distinguished by their intrinsic properties, mainly land immobility and illiquidity, transaction costs and associated regulations. The way models accommodate these characteristics is key to evaluating their potential to inform the CC-LM nexus analysis.

Methodological requirements:

- *Agent heterogeneity and microeconomic considerations:* numerous and diverse agents operate on land markets. They may differ in their economic behaviour in response to environmental signals, since their objective function, risk preferences and adaptation mechanisms may be separately or jointly distinct. It is therefore important to assess the level of microeconomic detail adopted in the available models to represent the agent's behaviour.
- *Macroeconomic considerations:* climate impacts on land markets operate in a complex socio-ecosystem shaped by macroeconomic variables such as input and output prices, land-based products' demand and supply, the political framework, demographic dynamics, *etc.* Whether the integration of such elements is endogenous or exogenous needs to be made explicit.
- *Spatial dimension*: climate change impacts are spatially heterogeneous, while the land market is inherently local. Therefore, spatial heterogeneity is an essential component

of the CC-LM nexus. Spatial explicitness and scale combining are key components of the models that need to be identified precisely.

- *Time dimension:* climate change is a phenomenon that happens over a long period and calls for forward-looking approaches. It will therefore manifest itself differently depending on whether the short- or the long-term are considered in the modelling structure.
- *System dynamics*: socio-ecosystems set complex mechanisms between their components. For example, considering the CC-LM nexus, the macroeconomic readjustments and adaptation processes of economic agents are many, from global prices adjustment to inter-country land-use reallocation through individual decisions to adapt. Indirect impacts of climate change could be considered as endogenous or exogenous, as land use results from land state change that occurs because of weather shocks, for example. Therefore, models could start exploring paths of feedback mechanisms and emergent properties and, more broadly, be part of a forward-looking approach, depending on how they capture these dynamic and feedback interrelations.
- *Uncertainty:* as a long-term and complex phenomenon, climate change involves many uncertainties in terms of mechanisms and evolution. Since results will depend on how agents respond to such uncertainties based on their risk preferences, it is important to understand how models address the multiple sources of uncertainty.

In order to support and enrich this analytical framework, we investigate how agricultural economics research addresses the CC-LM nexus so far. We consider three broad categories of modelling approaches: equilibrium and optimization models; econometric models; and single- and multi-agent models. Given the scope of the subject, we conducted a selective literature analysis. Based on a set of keywords (see Appendix A), we identified relevant literature reviews, seminal articles serving as key references in the field, and a selection of publications that address the issue appropriately. Hence, each cited paper should be viewed as a tool to illustrate and bolster the overall analysis, rather than as a perfect representation of the entire modelling literature. This approach facilitates a thorough understanding and structuring of an analysis on how economic research addresses the impacts of climate change on farmland markets.

Table 1: Critical requirements related to the climate change – land market nexus for economic modelling

General modelling requirements		Key modelling issues
THEMATIC REQUIREMENTS	1. Climate change features	Climate change indicator (*i.e.* temperature, rain, etc) Direct and indirect impacts on land conditions (land state/land use/land cover) Reaction mechanisms (adaptation/mitigation) Climate dynamics (exogenous/endogenous)
	2. Land market features	Land markets dimensions (market equilibrium /land value / market structure / transactions mechanisms / institutional framework) Land markets characteristics (land immobility and illiquidity / transaction cost / institution framework) Interaction of sales and rental land markets Interaction of rural and urban market
METHODOLOGICAL REQUIREMENTS	3. Microeconomics	Agent heterogeneity Microeconomic behaviour
	4. Macroeconomics	Demographic dynamics Political frameworks Price and economic drivers Other macroeconomic features
	5. Spatial dimension	Spatial explicitness Spatial heterogeneity, aggregation degree Combination of spatial scales
	6. Time dimension	Short-run mechanisms Long-run mechanisms Combination of time scales
	7. System dynamics	Interaction and feedback mechanisms Emergent properties Time horizon and prospective approach
	8. Uncertainty	Consideration of uncertainty

Source : Author's elaboration

4. Economic approaches on the climate change – land market nexus

The following section details the results of the papers' analysis carried out in the light of the framework described above. These are listed in Appendix B. For each category, we start by defining and introducing the type of model considered, and then review how each feature identified in Table 1 is generally addressed.

4.1. Econometric models

Econometric models aim to estimate the relationship between one or more dependent variables and a set of independent (also called explanatory) variables from empirical data, minimising the error term(s) of the equation(s) that model this relationship. Regarding the CC-LM nexus, we identify two main types of econometric models: the econometric land-use model, and hedonic and other regression models. From our analysis scope, the first one mainly investigates the direct and indirect effects of climate change on land use, while the second type analyse the extent to which climate change determines land prices.

Climate change. Ricardian analysis is a well-known hedonic method used to capture the effects of climate change on land conditions. It involves a cross-sectional analysis examining the long-term impacts of climate variables, such as temperature and rainfall, on agricultural rent per hectare. Initially introduced by Mendelsohn *et al.* (1994), subsequent developments have been made (Deaton and Lawley, 2022; Mendelsohn and Massetti, 2017; Ortiz-Bobea, 2021). They mainly differ in the areas of application or propose methodological extensions to address biases or broaden the methodology. Certain papers focus on adaptation processes, explicitly modelling farmers' crop choices (Seo and Mendelsohn, 2008), endogenously modelling land-use change (Timmins, 2006), or accounting for irrigation (Schlenker *et al.*, 2005). Additionally, alternative hedonic approaches examine various climate-related determinants of land prices. For instance, Deschênes and Greenstone (2007) employ a cross-sectional panel analysis to assess the impact of temperature and rainfall variations on agricultural profits, with per-acre production and land value as dependent variables. Slaboch and Čechura (2020) explore how climate-induced erosion affects farmland value in the Czech Republic. Dachary-Bernard *et al.* (2014) develop a hedonic pricing model to explain land price variations based on the vulnerability to flooding in French estuary areas.

Econometric land-use analysis primarily focuses on understanding how the adaptation mechanisms employed by the agricultural sector may lead to a shift in land use allocation, taking crop share as the dependant variable. For instance, the interplay between crop variability and climate trends in the USA, through historical data, has been explored (Reilly *et al.*, 2003; Sloat *et al.*, 2020). Other work assesses the impact of present and future climate conditions on crop composition across various regions in the USA, by modelling farmers' responses to shocks in temperatures and rainfall (Cho and McCarl, 2017), or models how the evolution of growing degree days may generate changes in both the location and composition of crop production (Nainggolan *et al.*, 2023). The indirect impacts of climate change are also considered by examining land-based mitigation strategies. For instance, Lungarska and Chakir (2018) integrate an econometric land-use share model with two bio-economic models — one for forests and another for the agricultural sector — to simulate the effects of climate and mitigation strategies on land use decisions, accounting for shocks in both agricultural and forest yields.

Land market features. While hedonic and regression models focus on land price formation assuming it reflects the present value of future incomes under perfect land market conditions, econometric land-use models focus on the supply and demand balance for agricultural products, addressing the impact of climate change on the derived demand for land. In this context, land price is evaluated as an endogenous shadow price (Lungarska and Chakir, 2018).

Microeconomics. Both types of econometric models, may explore the microeconomic dimension. In the context of climate change, some Ricardian studies specifically focus on understanding farmers' decision-making. Timmins (2006) proposes a model that acknowledges the endogeneity of these decisions by considering the connection between farmers' land use choices and climate change. Arshad *et al.* (2017) modify the conventional Ricardian regression to incorporate a farmer's perception of climate change and adaptive behaviors. Severen *et al.* (2018) propose a "forward-looking approach" to capture the capitalized expectations concerning future climates, recognizing that the existing and widespread information about climate change is already influencing the farmland market. In the model by Lungarska and Chakir (2018), landowners' adaptation mechanisms are accounted for by changes in land use shares and input use levels.

Macroeconomics. In econometric models, macroeconomic dimensions are mostly considered to be exogenous. Demographic parameters or government policies are included in land-use econometric models either as independant variables (Cho and McCarl, 2017) or as shocks (Lungarska and Chakir, 2018).

Spatial dimension. Spatial heterogeneity is addressed in various ways. In land use models, intrinsic land characteristics are incorporated. For instance, Lungarska and Chakir (2018) consider four land use classes, while Cho and McCarl (2017) focus on the concept of land capability. In Ricardian-type analyses, spatial heterogeneity is a key issue that takes shape through the level of data detail. Additionally, spatial explicitness is explored. For instance, Lippert *et al.* (2009) incorporate spatial autocorrelation in the error term. Vanschoenwinkel *et al.* (2016) consider adaptive response heterogeneity by comparing Eastern and Western Europe, allowing climate variable coefficients to vary by region.

Time dimension. Hedonic and regression models inherently operate under the assumption of long-term equilibrium, suggesting that system adjustments, including land-use changes, have already been capitalized in land value. This perspective grounds them in a long-term time dimension. In contrast, land-use change models appear to be more flexible. For instance, studies such as Mu *et al.* (2018) seek to explore both short- and long-term climate changes, examining shifts in land use shares in the USA in response to both inter-annual climate variability and longer-term climate change.

System dynamic. As *ex post* approaches, econometric approaches mainly use past data to explain present and future observations. Hence, they implicitly engage with system dynamics without explicit study them. For instance, the Ricardian analysis remains a "black box" regarding land-use change mechanisms.

Uncertainty. Climate uncertainty can be addressed through the consideration of various climatic scenarios, as demonstrated by studies such as those conducted by Lippert *et al.* (2009) and Mu *et al.* (2018). Additionally, a microeconomic-level risk assessment can be incorporated into the analysis, as illustrated in the work of Dachary-Bernard *et al.* (2014).

Finally, considering the CC-LM nexus, econometric approaches have been largely implemented. On the one hand, land-use econometric models address the evolution of land demand and supply under changing climate conditions, but they do not explicitly model the land market itself. On the other hand, the relevance of hedonic approaches, and particularly the Ricardian approach, is well recognised to assess the impacts of climate change on farmland values, through climate changing conditions, but also through induced economic behaviours. However, these methods suffer from several drawbacks. Omitted variables like local specificities (*e.g.*, farmers' skills, soil quality, fertilization effect of sequestrated carbon) require further exploration. Additionally, these models overlook the endogeneity of driving forces (Michetti and Zampieri, 2014) and fail to capture feedback mechanisms. Price bias is not fairly taken into account: There is a dynamic evolution of relative prices even though changes in agricultural products' prices due to climate change are expected (Ochou and Quirion, 2022). Furthermore, these models typically assume perfect market conditions (such as land homogeneity, perfect information, and transaction fluidity) before progressively relaxing these assumptions through refined data analysis and by studying biases. Yet, factors such as agent heterogeneity, transaction costs, and the institutional framework continue to challenge their theoretical foundations. Finally, these empirical approaches, relying on past data, hardly capture sudden changes, such as the impact of unexpected extreme weather events on crop yields (Lippert *et al.*, 2009), making them less suitable for simulating scenarios involving disruptive changes (Crooks and Heppenstall, 2012).

4.2. Equilibrium and optimization models

Equilibrium models, categorized as partial equilibrium (PE) or general equilibrium (GE) models, are based on the computable balance principle, assuming economic systems tend towards the equilibrium. GE models encompass the entire economy, representing all sectors, factor markets, and consumers at national and international levels. In contrast, PE models focus on specific sectors for selected products, assuming the rest of the economy is exogenous. Notably, GE models aim for a comprehensive representation of interconnected sectors, while PE models provide detailed analyses of supply and demand dynamics for specific products.

Climate change. Numerous models address the climate change effects on agricultural production, as highlighted in meta-analyses and multi-model comparisons (Nelson *et al.*, 2014; von Lampe *et al.*, 2014; Zimmermann *et al.*, 2018). These models mainly focus on examining market adjustments for agricultural commodities, including crop production and animal breeding, in response to exogenous shocks. Climate change is commonly represented as a shock affecting land productivity, thereby influencing commodity supply and prices. Several models enrich the agricultural supply component with an explicit crop model, introducing shocks based on meteorological variations (*i.e.* Gouel and Laborde, 2021; Nelson *et al.*, 2014). They, therefore, explore resulting adjustments on management intensity, land-use change, and trade dynamics. Indirect impacts of climate change are also integrated, often on the demand or supply of land-based products, as outlined in reviews on adaptation (Wei and Aaheim, 2023) and mitigation strategy (Babatunde *et al.*, 2017). As an illustration, Hertel *et al.* (2013) employ a PE model that accounts for macroeconomic demand and price adjustments for agricultural products to assess the impact of biofuel growth on land use depending on several climate and climatic scenarios.

Land markets. In these models, land is considered as an input for agricultural production, assumed to be perfectly mobile (Gohin *et al.*, 2015), its reallocation among different uses being an endogenous adjustment mechanism. Land markets are, therefore, predominantly implicitly assumed to be perfect. Gouel and Laborde (2021), for example, implicitly assume ideal land market conditions by applying the Ricardian principle to model land use choice: Farmers always plant the crop that yields the maximum land rent. Conversely, Lotze-Campen *et al.* (2008) simulate future land-use patterns considering increasing food demand and climate-induced changes in potential yields, accounting for technological change, land and water constraints, and land conversion costs. Few models explicitly focus on farmland market equilibrium. In this respect, Ciaian and Swinnen's paper (2006) develops a PE model of the farmland market that considers the effects of transaction costs and market imperfections on the annuity market. To our knowledge, no such model specifically addresses climate change issues.

Microeconomics. As inherently aggregated models, partial equilibrium (PE) and general equilibrium (GE) models often are not designed to intricately capture the microeconomic decisions of individual agents. Some models incorporate optimization functions for farmers, coupled with crop models that offer some refinements (Gouel and Laborde, 2021; Nelson *et al.*, 2014).

Macroeconomics. GE and PE models are designed primarily to analyse macroeconomic dynamics and policy effects, exploring trade adjustments, consumption demand or prices responses (Frank *et al.*, 2014; Gouel and Laborde, 2021; Nelson *et al.*, 2014). Nevertheless, most macroeconomic indicators are exogenously determined, including policy effects (Ciaian and Swinnen, 2006) or population dynamics (Frank *et al.*, 2014).

Spatial dimension. These models, being rather aggregated in nature, mainly cover regional, national, or global scales (Frank *et al.*, 2014; Palatnik *et al.*, 2011). Still, they allow for a broad range of finesse. For instance, GLOBIOM models application may provide great spatial detail (Janssens *et al.*, 2020). Land heterogeneity is therefore represented in various ways. Some focus on land specificities that could be represented as agronomic characteristics calibrated for each ecological zone (Palatnik *et al.*, 2011) or more broadly as comparative advantage between regions (Gouel and Laborde, 2021). Others focus on variations in terms of the agricultural system. For example, Lotze-Campen *et al.* (2008) represent several production activities, while Frank *et al.* (2014) focus on land management features.

Time dimension. These models are inherently designed for long-run equilibrium. In this sense, they are primarily implemented on a long-term scale (2050). In a prospective approach, they are well-suited for capturing long-run mechanisms, either through static comparisons of equilibrium situations or by considering the economy's evolution as a succession of equilibrium situations. Simultaneously, exploring short-term shocks and their immediate reactions, with potential changes of the system itself, appears to be more complex.

System dynamic. In this sense, PE and GE perform a comparative static analysis by comparing the results of several scenarios. They assess the endogenous adjustments resulting from an exogenous shock, such as climate change. Key parameters likely to adjust include trade patterns, area reallocation, and farming intensity (*e.g.* Gouel and Laborde, 2021; Nelson *et al.*, 2014).

Uncertainty. Climate uncertainty could be assessed using several climate and emission scenarios, as stressed by Zimmermann *et al.* (2018). For example, Nelson *et al.* (2014) simulate more than sixty combinations of climate, crop and economic model scenarios in order to investigate variation and uncertainty in modelling the future, while Frank *et al.* (2014) develop a comparison of two different models using the same set of scenarios (RCPs and SSPs) to catch potential variations.

Finally, while models focusing on land-based product markets offer valuable insights into land-use evolutions under climate change, they often lack the ability to balance the land market itself. Consequently, they provide limited exploration of land market mechanisms, such as land price evolution, transaction costs, urban land conversion, and heterogeneous agents' behaviour. Conversely, to the best of our knowledge, no paper has incorporated the dynamics of the land-based product market induced by climate change into a land market equilibrium model. Additionally, the level of aggregation in these models hardly provides a precise identification of land areas under pressure, which is crucial when addressing the functioning of the land market. Capturing the heterogeneity of land remain a challenge for accurately estimating the impacts of climate change on land use, as highlighted by Zhao *et al.* (2020).

4.3. Single and multi agent-based models

Agent-based models (ABMs) are modelling approaches that aim to capture the dynamics of a system, combining agents' interactions with each other and with their environment (Ferber, 1997). Single-agent models work as a centralised model, where one agent, based on his/her own goals and action choices, interacts with his/her environment. There is no interaction among agents. In contrast, multi-agent models set up mechanisms for agents' decisions and interactions with one another and with their environment, and observe the emerging patterns. Considering the CC-LM nexus, we only review multi-agent models, which capture interactions.

Climate change features. Regarding climate change issues, Berger and Troost (2014: 338) identify three ABM application perspectives: "*land use and supply response*, *stress-testing of adaptation strategies*, [and] *ex-ante policy analysis*". From a practical point of view, to date, ABMs have operated in several ways to tackle climate issues. Some works simulate the direct effects of climate as exogenous shocks on variables that characterize the environment, such as income loss (Alam *et al.*, 2014) or yield shocks (Mansoori *et al.*, 2021), sometime linked to a crop simulation model (García *et al.*, 2019). Other works explore adaptation mechanisms (Berger and Troost, 2014; Coronese *et al.*, 2023). Additionally, some studies focus on risk assessment related to extreme climate events, like drought (Hailegiorgis *et al.*, 2018), flood risk (Filatova and Bin, 2014) or agricultural production risk (Bert *et al.*, 2015; Freeman *et al.*, 2009).

Land market features. Over the past two decades, there has been a progressive expansion in the agent-based approach to modelling farmland markets, as emphasized in the reviews by Huber *et al.* (2018), Kellermann *et al.* (2008), and Kremmydas *et al.* (2018). Going into more detail, models differ primarily in the way they address land market mechanisms by focusing on the rental or the sale market. Some models depict the rental land market in order to analyse the agricultural structural change regarding innovation diffusion or policy implementation (Balmann, 1997; Berger, 2001; Bert *et al.*, 2015; Kellermann *et al.*, 2008), while others focus on land property rights transactions between heterogeneous agents, examining the evolution of farm size from a land-use change perspective (Alam *et al.*, 2014; Polhill *et al.*, 2001). Additionally, certain studies combine both urban and farmland markets, but primarily from an urban perspective rather than an agricultural one. For example, Magliocca *et al.* (2011) integrate both housing and farmland markets in their model, simulating the conversion of farmland to urban use, while Filatova *et al.* (2007) focus on the exchange of spatial goods (*i.e.* land plots or houses) in an urban area. Finally, ABMs explore various land market dimensions, such as land allocation mechanisms (Berger, 2001; Freeman *et al.*, 2009; Happe *et al.*, 2006; Polhill *et al.*, 2001), market structure and imperfect competition (Magliocca *et al.*, 2011), land price valuation process (Alam *et al.*, 2014; Filatova and Bin, 2014), and/or land tenure (Bert *et al.*, 2015).

Microeconomics. ABMs differ according to the designed types of agents and level of detail in the description of microeconomic behaviours. First, agent heterogeneity varies. For example, in the context of the farmland market, only a few studies introduce non-farmer agents. In this respect, Magliocca *et al.* (2011) consider not only farmer agents, but also consumer and developer agents, whereas Su (2017) includes an institutional investor in farm succession and land valuation mechanisms. Second, behavioural patterns bring heterogeneity among farm agents. Optimizing behaviour is often the core mechanism (Berger, 2001; Happe *et al.*, 2006; Magliocca *et al.*, 2011), enriched with behavioural specifications, such as risk aversion in farm production (Bert *et al.*, 2015; Freeman *et al.*, 2009), or risk perception related to coastal floods (Filatova *et al.*, 2011). Third, interactions between agents are a key concept of ABMs. They take shape through market transactions but also behavioural patterns. For example, Mansoori *et al.* (2021) model farmers' decision rules as a learning behaviour based on their neighbours' experiences of economic and climate changes.

Macroeconomics. ABMs capture various macroeconomic dimensions, which can be modelled either exogenously or endogenously to observe interactions among agents and their environment. For instance, demographic parameters are commonly implemented as exogenous factors (*i.e.* Alam *et al.*, 2014; Berger and Troost, 2014; Hailegiorgis *et al.*, 2018), while policy instruments may be introduced as shocks to the system (*i.e.* Freeman *et al.*, 2009; Happe *et al.*, 2006). Economic dimensions, such as market input and output prices, as well as technological frameworks, are also considered (Alam *et al.*, 2014; Mansoori *et al.*, 2021; Troost and Berger, 2015).

Spatial dimension. Implemented at the regional or country scale, these models enhance spatial heterogeneity at various levels, including soil characteristics, land use, climate features, and distance to cities (*e.g.* Berger, 2001; Filatova *et al.*, 2007; Hailegiorgis *et al.*, 2018). These models also open up multiple possibilities for coupling with other tools, such as Geographic Information Systems (GIS)-based models, to strengthen their spatial dimension.

Time dimension. In general, ABMs do not aim to identify the state of the system at a horizon T, but rather to observe its path up to horizon T. In this sense, represented in a continuous or discrete way, time remains a structural dimension of the model.

System dynamic. ABMs aim to investigate the interactions between agents and their environment, making micro-macro dynamics a crucial dimension. Modelling learning behaviour (Hailegiorgis *et al.*, 2018), considering path dependencies (Happe *et al.*, 2006;

Magliocca *et al.*, 2011), or incorporating openness to non-linear feedback, trade-offs, and interdependencies are some of the approaches used to capture these dynamics.

Uncertainty. Focusing on climate change issues, uncertainties are modelled in various ways, including the exploration of multiple climate scenarios (Troost and Berger, 2015), stylized climate shock distribution (Coronese *et al.*, 2023), the use of probability of natural hazard (Filatova and Bin, 2014), or the incorporation of risk assessment behavior (Filatova *et al.*, 2011). More generally, uncertainty is an intrinsic element of multi-agent models, and therefore a significant modelling challenge. A stochastic approach may be employed to account for it (Magliocca *et al.*, 2011), while other efforts aim to mitigate intrinsic uncertainties through meticulous calibration and documentation work (Troost and Berger, 2015).

Finally, to the best of our knowledge, no ABM has explicitly simulated the impacts of climate change on farmland markets, accounting for changes in agricultural uses and production structures. Additionally, urban dynamics have not been explicitly considered in modelling farmland markets, and the rental and sales markets are not distinguished and integrated. Moreover, a methodological challenge would consist in enhancing the extension of the agent set to all land market stakeholders, as cautiously atempted by some works (Su *et al.* 2023). Indeed, taking into account non-agricultural agents would improve the modelling of the effects of agent competition on land use, particularly in a context of increasing land resource scarcity. Broadly speaking, ABMs offer a wide range of modelling possibilities, as a systemic tool that permits to combine micro- and macro-economic parameters, time and spatial dimensions, and individual and collective dynamics. However, they are data intensive and face calibration and validation difficulties (Zimmermann *et al.*, 2009). Choosing the right level of detail to adequately represent the system while maintaining the right level of abstraction remains challenging (Crooks and Heppenstall, 2012).

5. Discussion

5.1. Drawbacks and contributions of a systemic approach

Limits and contributions often stem from the same causes. Exploring how climate change impacts the agricultural land market with a wide methodological scope leads to limitations in terms of specifications, exhaustiveness, and potential for superficial analysis. Simultaneously, it offers a comprehensive understanding of a complex issue grounded in a thorough examination of multiple economic modelling approaches. Therefore, the primary intention of this work was not to produce a systematic analysis of the literature in agricultural economics concerning the effects of climate change on land markets. The scope of the study intentionally remains broad, making it difficult to precisely define the boundaries of a systematic review. Moreover, attempting to cover various types of economic models does not allow for a detailed examination of each of them. Lastly, the decision to focus on three types of approaches, while representative of a vast research field, does not encompass all combined, transdisciplinary, or emerging approaches, such as integrated assessment models (van Beek *et al.*, 2020), which offer equally diverse possibilities and perspectives.

This work primarily contributes to frame a complex issue, relying on extensive bibliographic research. It provides a structured analytical framework, drawing on the concept of a nexus (Albrecht *et al.*, 2018; Zhang *et al.*, 2018), and integrating the triple dimension of land conditions (*i.e.* state, use, cover) (IPCC, 2019) to better identify connections and interactions within the climate change – farmland market system. This stresses the complexity of the issue and brings a comprehensive view of these thematic and methodological dimensions. Subsequently, the literature analysis enables the testing and validation of this framework while enhancing the understanding of its economic issues. Drawing on this broad but in-depth reading of selected scientific articles, this work provides an overview on how agricultural economics currently engages with these topics. It highlights the differences and complementarities of economic approaches and sketches their respective limitations and contributions. In turn, each modelling approach, by focusing in its own way, emphasizes research areas and perspectives that call to be deepened. Faced with the complexity of the subject, this work tends to mark the academic horizon and allows positioning within it.

5.2. An overview of modelling the climate change – land market nexus

To summarize, economic approaches differ in their understanding of the CC-LM nexus, through the climate or land market characteristics they address, and the way they assume interactions between the two. The results of the analysis are summarised in Table 2. The understanding of climate change impacts varies across models, but always refers to land conditions, even if not explicitly. The direct impacts on land state are mainly modelled as weather fluctuations or natural hazard environment drivers (*e.g.* econometric models), or as correlated agricultural yields shocks (*e.g.* equilibrium and agent-based models). Indirect impacts of climate change, such as land use and land cover change due to adaptation and mitigation strategies, are considered in different ways. Models either simulate them as exogenous shocks (*e.g.*, the implementation of a carbon storage policy) or as endogenous adjustment mechanisms (*e.g.*, crop reallocation). The land market is addressed through its different dimensions in rather segmented views. Models focusing on land-use change (equilibrium and econometric land use models) mostly project future land demand as a derived demand function of land-based products, but do not explicitly balance the land market equilibrium itself. Other econometric models deepen climate effects on land value, often assuming perfect land market conditions. Some agent-based models address the allocation of land rights and transactional mechanisms. Finally, few models provide a comprehensive approach that encompasses all the descriptive dimensions of the land market structure and processes. The specificities of land markets, including land heterogeneity and immobility, imperfect competition, transaction costs and institutional system have received limited or segmented attention. Sub-land market analyses, such as farmland versus urban market dynamics remains usually separated, with designated stakeholder types (*e.g.* farmer agent for farmland market for example). Additionally, the relationship between institutional land regimes and land market mechanisms remains scarcely explored.

In terms of methodological requirements, models do not all relate to microeconomic foundations. Agent-based models and, to a lesser extent, Ricardian-type analysis, explore adaptation mechanisms at the agent (*e.g.* farmer) or the firm/farm (*e.g.* agricultural structure) level. Similarly, macroeconomic drivers, such as prices, demographic rate or policy instruments, fit into the models in varying ways, in terms of precision and dynamics. One analytical level (micro or macro) usually shapes the models, even though the combination of micro- and macroeconomic mechanisms is essential, given the complexity of the CC-LM nexus. Papers address the spatial heterogeneity of the CC-LM system with variable levels of finesse. Equilibrium models are mostly implemented at the global scale, with a high level of data aggregation, even though spatial heterogeneity is essential when considering climate impacts and the state and uses of the land. Conversely, regressive analysis concentrates on evaluating local specificities impacts on land value as accurately as possible, but does not open up its analysis to market balances between neighbouring lands. Finally, temporal dimensions, strongly linked to the uncertain nature of the system, shape the models. While regression analysis first provides explicative contributions, as a deterministic top-down approach, equilibrium, mathematical and agent-based models, as bottom-up approaches, are part of prospective works. The use of scenarios, randomized data or probability attempts to master the field of uncertainties. Prediction of short- and long-term climate change variability and adjustment reactions of the system, which is itself characterized by random processes, remains an ambitious objective.

5.3. Some research perspectives

These resulting considerations draw some research perspectives. First, we demonstrate that the impacts of climate change, both direct and indirect, have been thoroughly examined in the literature across various scales, from global land use adjustments to micro-level farm adaptations. Consequently, it restates the core issue of this nexus approach: if climate change's impacts affect the use of land resources, how do they consequently alter the modalities of allocation, particularly in our case, within land markets? Multiple ways enable to address this question such as enhancing the endogenization of land prices in equilibrium models, to relaxing the perfect competition assumptions in Ricardian-type approaches. Additionally, considering future climate-induced changes in land use into buying/selling decisions and evaluating the present value in multi-agent models offers alternative avenues for exploration. In summary, there remains a need to further integrate the effects of land comparative evolution as a driver of land market dynamics changes, affecting both the supply and demand sides. This highlights the significance of the spatial dimension within land markets. The level of heterogeneity, considering both the heterogeneous nature of land and the diverse effects of climate along with spatial scale, remain an ongoing methodological issue. Lastly, the effects of climate change ultimately call into question the definition of spatial boundaries of land markets.

Second, this study underscores the human aspect inherent in land markets. As demonstrated in this work, while the perspective of farmers is pivotal, they are not a homogeneous group. Various economic agents may also play roles in the land market. Furthermore, the use of the CC-LM nexus framework shows that beyond decisions related to agricultural production, climate change also influences the decision to participate in the land market and the way agents may value land. As land is both a production and investment factor, how agents incorporate future climatic conditions into its pricing becomes a central concern, considering their risk behaviour and information about future uncertain climate. Consequently, as land market result from agent's interactions, considering agent heterogeneity is essential. In this sense, multi-agent models may open up vast perspectives.

Ultimately, as the analytical framework has revealed agricultural land markets to be part of a broader land tenure system, it is crucial to re-examine and explore the assumed link between the land market (an economic mechanism for the exchange of land rights) and land institutions as a whole. The societal dimension of interactions between climate change and land markets, and the role of public policy are significant in this regard, and interdisciplinary and participatory approaches may provide valuable insights.

6. Conclusion

While climate change is challenging the allocation mechanisms of agricultural land, there is currently no clear systemic and rigorous framework for analysing its impact on the land market. Therefore, this paper aims to propose a structured scheme for analysing the impacts of climate change on land markets in order to better understand this complex issue. Drawing on the concept of nexus and the triple dimension of land conditions, we present an original formalization of the climate change-land market nexus as a research object in its own right. A comprehensive literature review further solidifies this framework while examining how economic models tackle it. Since each approach differently and partially grasps the issue, we identify their contributions and limitations in understanding the CC-LM nexus. This helps delineate the academic landscape and allows to position themselves within it. Ultimately, although the analysis of the existing literature suggests the need for further exploration of the economic literature, this study draws various points for reflection and research perspectives.

We therefore identify three key perspectives for future research: first, the need to explore the heterogeneous impacts of changing land conditions – due to climate change – on supply-demand balances in land markets within a spatialised context; second, the importance of accounting for the heterogeneity of land market stakeholders and their interactions; and third, the necessity of considering land markets within their institutional frameworks.

Indeed, if the allocation of land between its uses is an age-old societal issue that has always been discussed, climate change is once again challenging the societies' ability to share the land resource in order to sustain common well-being. In this respect, the climate change – land market nexus calls for a renewed research agenda.

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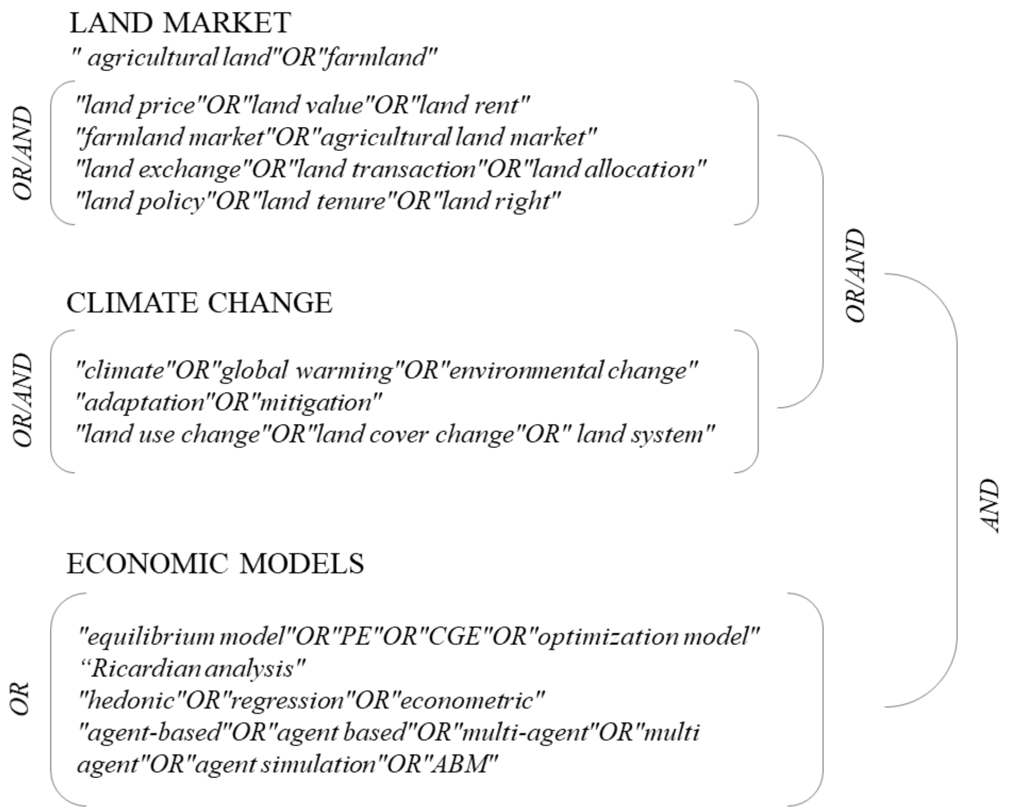
Appendix A. Indicative diagram of the literature search procedures



Appendix B. Analysed literature

ECONOMIC MODELS			**REVIEW & MULTI-MODELS COMPARISON**	**PAPER ANALYSED**
Optimization and equilibrium models	**Land-based product market model**		von Lampe *et al.* (2014), Zimmermann *et al.* (2018), Nelson *et al.* (2014), Wei and Aaheim (2023) Babatunde *et al.* (2017)	Nelson *et al.* (2014), Palatnik *et al.* (2011), Frank *et al.* (2014), (Gouel and Laborde (2021), Hertel *et al.* (2013), Lotze-Campen *et al.* (2008), Janssens *et al.* (2020)
	Land market models			Ciaian and Swinnen (2006)
Econometrical models	**Econometric land-use model**			Mu *et al.* (2018), Cho and McCarl (2017), Lungarska and Chakir (2018), Reilly *et al.* (2003), Sloat *et al.* (2020), Nainggolan *et al.* (2023)
	Regression model	**Ricardian-type analysis**	Mendelsohn and Massetti (2017), Ortiz-Bobea (2021), Deaton and Lawley (2022)	Mendelsohn *et al.* (1994), Lippert *et al.* (2009), Van Passel *et al.* (2017), Moretti *et al.* (2021), Vanschoenwinkel *et al.* (2016), Timmins (2006), Arshad *et al.* (2017), Severen *et al.* (2018), Seo and Mendelsohn (2008), Schlenker *et al.* (2005)
		Other hedonic models		Deschênes and Greenstone (2007), Slaboch and Čechura (2020), Dachary-Bernard *et al.* (2014)
Single and multi-agent based models	**Multi-agent models**		Huber *et al.* (2018), Kellermann *et al.* (2008), Kremmydas *et al.* (2018)	Magliocca *et al.*, (2011), Mansoori *et al.* (2021), Hailegiorgis *et al.* (2018), Alam *et al.* (2014), Berger (2001), Filatova and Bin (2014), Troost and Berger (2015), Bakker *et al.* (2015), Happe *et al.* (2006), Bert *et al.* (2015), Polhill *et al.* (2001), Freeman *et al.* (2009), Coronoese *et al.* (2023), Magliocca *et al.* (2011), Filatova *et al.* (2011), Polhill *et al.* (2001), Balmann (1997), Kellermann *et al.* (2008), García *et al.* (2019)

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