AAPG2022	ACCLIMATE		JCJC
Coordinated by:	François BAREILLE	36 months	170 936 €
D.7 - Sociétés et territoires en transition			

Adaptation au Changement CLImatique avec des MArchés de la Terre inEfficaces

Summary table of persons involved in the project:

Partner	Name	First name	Current position	Role & responsibilities in the project (4 lines max)	Involvement
UMR PSAE INRAE	*BAREILLE*	*François*	*Chargé de recherche*	***Principal investigator*** *Leader of tasks 0, 2, 3 and 4 Participant in tasks 1, 5 and 6*	*27 p.month*
UMR PSAE AgroParisTech	*WOLFERSBERGER*	*Julien*	*Maître de conférences*	***Co-investigator*** *Leader of tasks 1 and 5 Participant in tasks 2 and 6*	*8 p.month*
UMR PSAE INRAE	*CHAKIR*	*Raja*	*Directrice de recherche*	***Co-investigator*** *Leader of task 6, Participant in tasks 2 and 3*	*3 p.month*
UMR CESAER INRAE	*AY*	*Jean-Sauveur*	*Chargé de recherche*	***Co-investigator*** *Participant in tasks 2, 4 and 6*	*3 p.month*
UMR SMART AgroParisTech	*FROMAGE*	*Mathilde*	*Ingénieure des ponts, des eaux et des forêts (detached, PhD student)*	***Co-investigator*** *Participant in tasks 1, 2, 5 and 6*	*3 p.month*

Any changes that have been made in the full proposal compared to the pre-proposal

- We restrain the project to the primary land market, and leave the secondary land market (rental market) for complementary analyses outside ACCLIMATE.
- We detail the methodology and data sources. We justify the choice of France as a case study.
- We detail the team and how tasks are shared between the different members.

I. Proposal's context, positioning and objective(s)

a. Objectives and research hypothesis

Land-use activities (agriculture, forest and urban uses) are likely to be considerably affected by climate change, threatening the future provision of numerous market and non-market goods and services on which society relies (e.g. food, biodiversity, water and air quality – Lawler et al., 2014). Indeed, because agricultural and forestry activities depend on biological processes affected by weather (e.g. photosynthesis), it is suspected that climate change will differentially affect their profitability and, ultimately, will incentivize landowners to adapt and switch towards the most profitable activities under new climatic conditions. Such induced land-use changes are already occurring (IPCC, 2022). For example, Aragón et al. (2021) show that the Peruvian agricultural acreage has increased in areas where extreme heat exposure has grown, at the expense of other land-use activities.

The ACCLIMATE project will **theoretically** and **empirically** examine the role of the land market's specific features in shaping landowners' adaptation to climate change. Indeed, land markets present several specific features compared to other markets. In the first place, land is available in *fixed quantity*. This leads to a specific kind of competition among landowners for access to land, where an additional hectare put to one use decreases the aggregate area available for all the other uses by one hectare. This property differs from most markets, in particular from human-made asset markets, where supply is not constrained in the long term. Second, because land supports the provision of numerous market and non-market goods and services and because it is both immovable and perennial, institutions consider land to be a 'patrimonial' asset. These two properties lead institutions to implement *land regulations* aiming to achieve 'desirable' land allocation (Chari et al., 2021), thus favouring the provision of some goods and services over others (e.g. favouring food production over carbon sequestration). Institutions implement a wide range of land regulations. For example, institutions often define differentiated property tax rates for different land-use activities.[1] Local institutions can also implement command-and-control policies. For example, local land-use planning measures define parcels

[1] For example, the French reform of 2002 introduced a 10- to 50-year property tax exemption for new forests. In general, French institutions still authorize municipalities to set their own property tax rates for different uses.

that can be urbanized and those that must remain in agricultural or forest uses. Similarly, institutions can designate protected areas to protect valuable land from undesirable land-use changes. Institutions can expropriate landowners or pre-empt land transactions.[2] Even the secondary land market is strongly regulated (Chari et al., 2021). While these regulations have been implemented to correct some existing market inefficiencies (e.g. the internalization of non-market goods and services), they are likely to be(come) inappropriate under future climate conditions.[3] In particular, such inherited land regulations may prevent landowners' from fully adapting to climate change, ultimately preventing suitable land use changes among agricultural, forestry and urban uses.

By developing an integrated framework for **modelling** and **estimating** the impacts of climate change on the land-use sector (agriculture, forestry, urban and other uses; sometimes referred to as AFOLU), ACCLIMATE will provide better **understanding** of the source of the costs of climate change on agriculture and other land-use activities, and particularly the role of institutions in amplifying/attenuating those costs. The econometric models estimated in ACCLIMATE will rely on a combination of (i) commonly used models that will be estimated not only for agriculture but also, for the first time, for forestry and urban uses (using similar land price data) and (ii) newly proposed models that will be estimated using similar data. The theoretical and empirical results will be used to **simulate** a set of potential land reforms to assess whether institutions can facilitate landowners' adaptation to climate change, and how land use might be affected as a consequence. The combination of theoretical and empirical results on the impacts of ex-post and ex-ante policy analyses could **guide** policymakers in designing future land reforms to reduce the costs of climate change for the land-use sector.

Research hypothesis. The main hypothesis of ACCLIMATE is that most existing worldwide land market regulations constrain landowners' adaptation to climate change. In particular, we assume that these regulations tend to maintain agriculture in place in numerous areas (today as well as under future climate conditions) where other land-use activities could be(come) more profitable.[4] This mechanism would have three main consequences. First, if climate change negatively impacts agricultural profitability relatively more than other land-use activities, existing land regulations would lead to inefficient land-use allocations under future climate conditions. Second, existing land regulations would incur additional costs to the land-use sector on top of the initial costs of climate change. In particular, they probably transfer some of the costs of climate change that should have been borne by the agricultural sector towards the forestry and urban sectors (that compete with agricultural use and thus cannot freely adapt). Third, the existing assessment of the costs of climate change for the land-use sector would be biased, preventing policymakers from correctly anticipating the consequences of climate change and correctly investing to limit its negative effects (or even to mitigate it).

In the light of our research hypothesis, the objectives of ACCLIMATE are fourfold.

Objective 1. ACCLIMATE aims **to theoretically investigate the role of the land market's specific features** (existence of land regulations and specific competition for land) **in the assessment of the impacts of climate change on the land-use sector** (task **T1**). In particular, ACCLIMATE aims **to highlight the implications of ignoring the land market's specific features in commonly used approaches in the literature**. We will pay particular attention to the implications of these assumptions for the Ricardian analysis (a hedonic analysis of farmland prices) proposed by Mendelsohn et al. in 1994, and still widely used in the literature (Mendelsohn and Massetti, 2017). ACCLIMATE will propose testable propositions on usual Ricardian estimates suggesting that they suffer from non-inclusion of the land market's specific features. In addition, we will propose econometric extensions to correctly assess the costs of climate change for the land-use sector when accounting for land market functioning and land regulations. As a specific extension, we will propose a new structural Ricardian model that will jointly exploit

[2] In France, the Sociétés d'Aménagement Foncier et d'Etablissement Rural (SAFER) and the Commission Départementale d'Orientation Agricole (CDOA) pre-empt thousands of land transactions every year to acquire and resell the parcels concerned in order to encourage the installation of young or organic farmers (Piet et al., 2012, 2021).

[3] Hereafter, we use 'land regulations' to mean the set of taxes, planning measures, reforms and pre-emptions targeting primary land markets.

[4] There may be several reasons why institutions prefer agricultural use over others, e.g. the preference for the public goods and services that are provided jointly with agricultural use (food security, biodiversity and landscape conservation, etc.) or, simply, the great political power of the agricultural and food-manufacturing industrial representatives. ACCLIMATE's aim is not to determine the reasons behind the introduction of existing land regulations but rather to investigate their impacts on landowners' adaptation to climate change.

information on observed land prices and land-use shares (among agricultural, forestry and urban uses) to econometrically estimate the climate impacts on land value while accounting for the land market's specific features (land regulations and competition for access to land). Because the diversity of land regulations (land taxes, planning measures, reforms and pre-emptions) makes it very difficult to construct an exhaustive database with consistent information on all such regulations, a challenge will be to propose an econometric model that is structural, yet flexible enough to capture the effects of land regulations even *if these regulations are not observed*. Although we will try to compile and integrate such information on land regulations (**T2**), the developed structural Ricardian model needs to be easily adaptable to be estimated even with partial information about the different types of land regulations.

Objective 2. Based on the developed theoretical analyses, ACCLIMATE aims **to empirically test whether existing land regulations prevent landowners from fully adapting to climate change** (**T2, T3**). For this purpose, we will test our theoretical propositions by estimating and comparing the estimates from (i) commonly used reduced-form Ricardian models, that will be separately estimated for agricultural, forestry and urban uses, (ii) commonly developed land use share models explaining land allocation to the three uses and (iii) the newly proposed structural Ricardian model, whose original feature will be to combine the two previous types of model to estimate the value of climate for the three uses (controlling for land market's specific features). The objective with the estimation of these alternative models is to provide complementary evidence highlighting how constraints due to existing land market regulations shape landowners' adaption to climate change. The interest of these three types of model is that we do not need to actually observe land regulations to provide results that would suggest that existing land regulations affect landowners' adaptation to climate change. The observation of land prices, climate conditions and the area allocated to the three main land uses – together with insights from our theoretical analysis – would be sufficient to conclude that land regulations impose constraints. If possible, we will consider the heterogeneity of uses within the agricultural sector, distinguishing arable land from pastureland and land used for permanent crop production, ultimately investigating land-use changes among five categories (three agricultural uses, forestry and urban). As an illustrative example, we propose to estimate these models using data from France.

Objective 3. ACCLIMATE aims **to econometrically assess the impacts of specific land regulations on landowners' adaptation to climate change** (**T2, T4**). Indeed, while it is hardly possible to build a database with exhaustive and compatible information for all existing land regulations, we propose to run complementary econometric analyses in order to examine the role of *specific* land regulations on landowners' adaptation to climate change. In particular, we propose to include information on existing land regulations (e.g. land taxes, land planning measures, protected areas, etc.) in the structural Ricardian model to distinguish the effects of the different types of land regulations on landowners' adaptation to climate change. We will propose an identification strategy to deal with the potential endogenous bias linked to the implementation of these land regulations. Complementary econometric analyses will examine the impacts of specific land regulations on landowners' adaptation to climate change but using more *detailed*, municipal-level data and reduced-form models. Finally, we will, if possible, look at the impact of climate conditions on the decision by SAFER agencies to pre-empt farmland transactions. This last analysis would provide complementary evidence of the fact that institutional interventions on land market functioning depend on climate conditions. Though informative, this last step would require access to private SAFER data.

Objective 4. ACCLIMATE aims **to assess the costs of land regulations in constraining landowners' adaptation to climate change** (**T5**)**.** The final objective of the ACCLIMATE project is to provide refined assessment of the costs of climate change for the land-use sector in general – and for the three main uses in detail – when considering the land market's specific features (competition for access to land and land regulations). In particular, we aim to distinguish the costs due to the climate shock on land productivity (Auffhammer, 2018), from the costs due to land market imperfections induced by land regulations. For this purpose, we will perform highly-desegregated spatially-explicit simulations of French land market outcomes (in terms of land-use areas and land values for agricultural, forestry and urban uses at the pixel level) under future climate conditions and under the influence of various land

regulations. The simulations will rely on an adaptation of Costinot et al. (2016)'s model to the whole land-use sector in France, where the spatially-explicit shocks will be the heterogeneous climate changes across the country. We will use the theoretical and econometric insights derived from ACCLIMATE to properly calibrate the simulations. The simulations will pay particular attention to the differences between efficient and inefficient land-use allocation over space and time. The final outcome will be to simulate how different policy reforms could reduce the costs of climate change.

Case study region. The econometric and simulation analyses undertaken in ACCLIMATE will rely on **French data** (**T2**). Indeed, while agriculture and forestry together only represented 1.6% of French gross domestic product in 2019 (3.4% if we include food and wood processing), France presents several advantages compared to other countries (in particular compared to developing countries, whose economies depend more on agriculture and forestry). First, the quality and availability of French data related to land market regulations and land prices for agricultural, forestry and urban uses make them particularly appealing for the purposes of ACCLIMATE (compared to other countries where such data are not available). The quality of land-use and daily weather data, both in terms of temporal depth and spatial resolution, provides an additional advantage favouring the use of French data. Second, France presents wide geographical climate heterogeneity (Continental, Oceanic, Mediterranean and Mountain climates) and has already experienced significant and heterogeneous climate changes.[5] Third, ACCLIMATE's team members have already acquired great expertise in French land markets as well as detailed knowledge of French data on climate, land use and land markets (Ay et al., 2014; Bareille and Chakir, 2022; Léger-Bosch and Fromage, 2021; Lungarska and Chakir, 2018).

b. Position of the project as it relates to the state of the art

The questions addressed by ACCLIMATE are new and bring deeper insights into landowners' adaptation to climate change, paying special attention to the role of the land market's specific features, both in terms of (i) competition over access to land for different uses *induced by the fixed quantity of land available* and (ii) market inefficiencies *induced by land regulations*. ACCLIMATE proposes to theoretically and empirically investigate such specific features to identify the 'true' costs of climate change for agriculture and other land uses (forestry and urban).

The unbiased estimation of the costs of climate change constitutes a major challenge for the economic literature (Auffhammer, 2018). It is thus crucial to make the estimations using appropriate, consistent assumptions that capture the main mechanisms at stake (Timmins, 2006). However, the literature assessing the costs of climate change to land-use activities has so far largely ignored the role of the land market's specific features in shaping landowners' adaptation to climate change. In fact, the common assumption in the literature is that land markets *are* efficient (Mendelsohn et al., 1994). Under this convenient assumption, one can assume that current (resp. future) land use reflects the most valuable activity under current (resp. future) climate conditions. Relying on this hypothesis, the literature has proposed several methods for estimating the costs of climate change to *agriculture* (Mendelsohn et al., 1994; Deschênes and Greenestone, 2007; Seo and Mendelsohn, 2008; Fezzi et al., 2015; Burke and Emerick, 2016; Costinot et al., 2016). However, to our knowledge, this assumption of an efficient land market has been used so far to explain land-use changes *within the agricultural sector* only. In other words, they only consider crop reallocation within the limits of the existing agricultural area, without any impact of climate change on forestry and urban areas (i.e. ignoring land-use changes among major uses). Ignoring such competition for access to land among different types of landowners, the econometric literature assessing the costs of climate change to agriculture has thus implicitly assumed that farmland markets are efficient, but not integrated with forest and urban land markets.[6] They thus fail to account for the land market's specific features.

[5] We show in Bareille and Chakir (2022) that all French municipalities experienced increases in spring and summer temperatures between 1996 and 2019 ranging from +0.1°C to +2.4°C, with an average of +1.0°C. At the same time, they experienced an average increase of +0.4°C in autumn and winter temperatures, some experiencing a decrease of up to -1.1°C, while others experienced an increase of up to +1.6°C.

[6] An exception concerns the literature *simulating* land-use changes induced by climate change using partial- or general-equilibrium models representing the main land-use sectors at the general scale (e.g. Janssens et al., 2020) or local scale (Ay et al., 2014; Lungarska and Chakir, 2018). While this literature does examine the competition for access to land between the three uses induced by climate change, it still assumes that land markets are efficient. It also departs from the remainder of the literature by relying on simulations.

The ACCLIMATE project will pay attention to the implications of the land market's specific features for the above-mentioned methodologies. In particular, ACCLIMATE will investigate the implications of these specific features for the *Ricardian analysis*. Proposed by Mendelsohn et al. (1994), this methodology has become a cornerstone of the literature on the valuation of climate change for *agriculture*, with hundreds of published applications since (Mendelsohn and Massetti, 2017). Empirically, Ricardian analysis exploits cross-sectional differences in farmland prices (expressed per unit of land)[7] and climate conditions across space to infer the value of climate to agriculture. Because Ricardian analysis is in fact a hedonic analysis, Ricardian estimates can only retrieve the (true) value of climate under the two assumptions of fixed supply and pure and perfect competition (Rosen, 1974). While these two assumptions are necessary to apply hedonic analyses (Rosen, 1974), they are contradicted by the land market's specific features. Indeed, farmland supply is not fixed (forestry and urban uses compete for access to land) and land markets are not competitive (but regulated). The usual interpretation of the Ricardian estimates may thus be invalid. To our knowledge, despite several extensions to account for (i) omitted variable biases (Deschênes and Greenstone, 2007; Burke and Emerick, 2016; Bareille and Chakir, 2022), (ii) aggregation bias (Timmins, 2006; Fezzi and Bateman, 2015), (iii) adjustment costs (Kelly et al., 2005), (iv) landowners' anticipation of climate change (Severen et al., 2018) and (v) the influence of non-agricultural activities (Ortiz-Bobea, 2020), the implications of these two assumptions have never been discussed in either the Ricardian literature or, more generally, in the literature assessing the costs of climate change using alternative methods.

ACCLIMATE's first contribution will be **to refine the understanding of these two assumptions for climate change cost assessment**. For this purpose, we will develop a theoretical model emphasizing the role of two crucial and inter-related mechanisms determining the total value of climate for the different land uses: the effects of climate at the *intensive* and *extensive margins*. We illustrate these two mechanisms in Figure 1. Specifically, Figure 1 theoretically illustrates the impacts of climate change (noted as a change from C^0 to C^1) on forest and farmland values V_F and V_A, when the climate shock affects *only* the productivity of forest land.[8] In other words, climate change increases forest land value at the *intensive margin* in this hypothetical case. By assuming constant land-use shares, the existing literature (and in particular the Ricardian literature) would assess the value of climate change for forest land by measuring this change at the intensive margin (corresponding to a change from $V_F(C^0)$ to $V''_F(C^1)$ – the y-axis intersection of points A and A' – in Figure 1). However, this increase at the intensive margin would incite a rational representative landowner to *convert farmland to forest land*. In other words, on top of the initial positive impacts at the intensive margin, a rational landowner would increase the value of the land-use sector by *adapting at the extensive margin*.

The climate impacts at the extensive margins are not usually considered in the literature.[9] They are however likely to bias the Ricardian estimates because they change the apparent land value of the different uses (i.e. they change the – marginal and average – land values as expressed per unit of land). Indeed, looking at forest land in Figure 1, the difference between the two apparent values of forest land after induced land-use change (extensive margin) is less than the true impact at the intensive margin $V''_F(C^1) - V_F(C^0)$, because the *converted land is of intrinsically lower value for forestry than the initial forest area*. The opposite pattern holds for farmland. Indeed, in our example, the least valuable land for agriculture under C^0 is turned into forest land under C^1, which *increases the apparent value of farmland*. However, if the apparent farmland value does increase, this is due to the impacts at the extensive margin (induced by an increase in forest land value at the intensive margin) but, in any case, to an increase in farmland value at the intensive margin (which is null in our hypothetical case). In other words, the Ricardian analysis would conclude with an increase in the value of agriculture under

[7] Because farmland prices are not easily observable, alternative indicators of land rents are sometimes used (e.g. agricultural profits).

[8] We do not detail climate change here; one could think, e.g., of a change in temperature and precipitation distribution across the year.

[9] An exception is Timmins (2006), who does account for climate impacts on landowners' land use decisions and explores how it could bias Ricardian estimates. This article differs, however, from our proposition because Timmins does not observe the land value of each use, but only the aggregate value covering all uses. His work is motivated by the correction of aggregation biases in the Ricardian analysis when data on land values for the different uses are not available. In addition, Timmins (2006) relies on the assumption that land markets are efficient, which, as we explain above, is likely to be false. Failure to include land regulations in his framework is likely to bias his proposed correction.

C^1 while, actually, the profitability of agriculture would remain unaffected by climate change. Accordingly, the Ricardian estimates would be biased in this case. As explained in the following paragraph, the size of the bias depends on whether or not land markets are efficient.

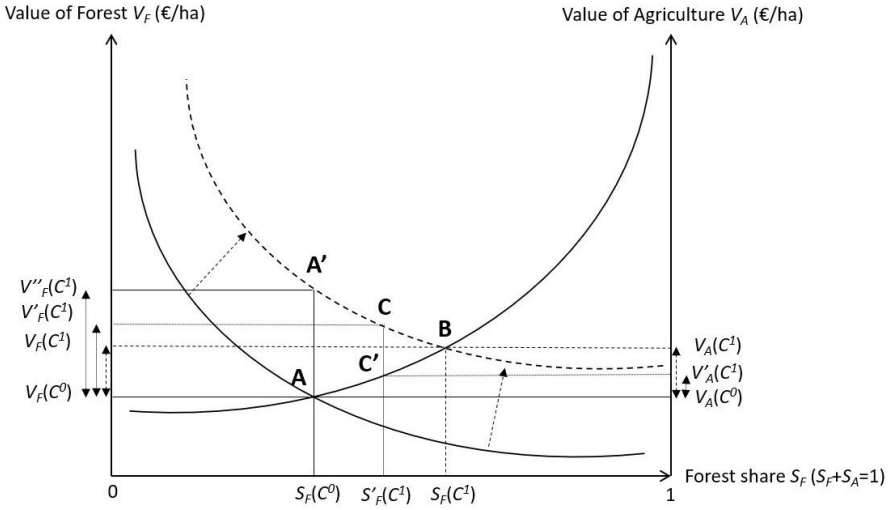


Figure 1: Land values under climate change with (in)efficient land markets. *Solid curves indicate the value of forest land and farmland under initial climate* C^0 *as a function of the proportions of land area allocated to the two uses. In this illustrative example, the climate change shock is illustrated as a positive shift of forest productivity, which is materialized as a positive impact on forest land value (dashed curves). Point* **A** *indicates the land market equilibrium under initial climate* C^0*. Point* **A'** *indicates the value of forest land considering land uses as fixed (i.e. without a land market). Point* **B** *indicates the land market equilibrium under new climate* C^1 *when land markets are efficient. Points* **C** *and* **C'** *indicate the land market equilibriums when a hypothetical regulation partly protects farmlands.*

Indeed, in the case of efficient land markets, Figure 1 shows that the land-use changes induced by climate change would correspond to the conversion of farmland to forest land *until the marginal values for the two uses are equal*, i.e. they would correspond to a change from the x-axis intersection of point A (corresponding to a forest share $S_F(C^0)$) to the x-axis intersection of point B ($S_F(C^1)$). In this case, the apparent impact of climate change for forest land as measured by the Ricardian literature (i.e. as differences in forest land values across climates) is $V_F(C^1) - V_F(C^0)$, which is *exactly* equal to the change in farmland value $V_A(C^1) - V_A(C^0)$. However, in the case of regulated land markets (here illustrated with a hypothetical protection of farmlands), Figure 1 illustrates that the apparent change in values for the two uses are different (with $V'_F(C^1) - V_F(C^0) > V'_A(C^1) - V_A(C^0)$). Figure 1 thus illustrates two distinct cases, but both contradict the usual interpretations of the Ricardian results. In the case of efficient land markets, a Ricardian analysis of farmland would provide information about the costs (or benefits) of climate change for the *whole land use sector* (and, in any case, not the agricultural sector only). In the case of regulated land markets, the Ricardian results do not even approximate the costs of climate change for the land-use sector. In the two cases, the problem of the usual analyses is that they do not account for land-use adjustments (whose effects depend on the existence of land regulations) and thus miss the implications of the land market's specific features in shaping landowners' adaptation to climate change. As a response, we propose to contribute to the literature by developing the type of theoretical analysis presented in Figure 1 with (i) integration of dynamic aspects to account for potential adjustment and conversion costs, (ii) extensions to the three uses (agricultural, forestry and urban) and (iii) representation of several types of regulations. This first (theoretical) contribution will allow us to define corrections and extensions to commonly used methods in the literature, and to make progress in the assessment of the costs of climate change for the land-use sector (in general) and the three land uses (in particular).

ACCLIMATE's second contribution will be **to econometrically measure the costs of climate change for the three main uses (agricultural, forestry and urban) at the same time.** Indeed, while the literature has paid considerable attention to measuring the impacts of climate change on the value of agriculture (e.g. Burke and Emerick, 2016) and to a lesser extent of forest (Mihiar and Lewis, 2021) and urban lands (Sinha et al., 2018), no study has ever econometrically measured the consequences of

climate change for all uses *at the same time* in a united framework.[10] To our knowledge, ACCLIMATE will develop the first econometric assessment of the impacts of climate change on *the value of the three uses* using *similar* and *consistent* indicators of land rents (*land prices* here). In addition, we will use these estimates to calibrate a general equilibrium model with spatially-explicit climate shocks (*à la* Costinot et al., 2016) introducing, for the first time, forest and urban land into the model (in addition to agriculture). The simulation outcomes will be an evaluation of the costs of climate change for the whole land-use sector (in general) and the three uses (in particular) in France under different climate change scenarios. The developed model will in addition indicate likely land-use patterns among agricultural, forestry and urban uses in France under future climates (under a range of land regulations).

In line with the first two contributions, ACCLIMATE's third contribution will be to **estimate a new structural Ricardian model that will account for the climate impacts on land use at both the *intensive* and *extensive margins*.** The proposed model will use aggregated observations of land prices, climate conditions and land-use shares to simultaneously estimate the impacts of climate on land values for the three uses (as in the usual reduced-form Ricardian model proposed by Mendelsohn et al. in 1994) and the induced land-use changes using a multinomial logit structure. Multinomial logit models are commonly used in the literature for estimating aggregated land-use changes (expressed as shares; Miller and Plantinga, 1999; Ay et al., 2014; Lungarska and Chakir, 2018). They usually rely on the assumption of efficient land markets, where the shares of the different land-use categories represent the optimal land-use allocation in the existing context. The Ricardian literature itself has exploited this property of multinomial logit models to run 'structural Ricardian models' (Seo and Mendelsohn, 2008), where observed land-use shares are explained by climate conditions (and controls). Such structural Ricardian models have notably been used in developing countries to infer the value of climate for agriculture when farmland prices (or even agricultural profits) are unobserved. ACCLIMATE will thus propose and estimate a new structural model that (i) jointly integrates the insights of usual reduced-form Ricardian models (intensive margin) and land-use share models (extensive margin) to (ii) build a unique system where the parameters related to the impacts at the intensive margin are shared among the different system equations, and (iii) can be estimated by making simultaneous use of information about land prices, climate conditions and land use shares. Compared to usual land-use share models, the interest of using additional observations on land prices will be that one could verify whether the impacts of climate on land use categories at the intensive margin are fully translated into changes at the extensive margin, i.e. if landowners can optimally adapt land use in response to climate change. In other words, it will allow us to verify whether land markets are efficient (as usually assumed) or not.

Our last contribution will be to **examine the land institutions' role in shaping agents' adaptation to climate change**. The role of institutions in providing incentives for landowners to invest and improve land productivity has become an active field of research in development economics (Adamopoulos and Restuccia, 2020; Chari et al., 2021).[11] However, to our knowledge, only Bezabih et al. (2021) have studied the role of these incentives in the context of climate change. Using Ethiopian data, they showed that strengthening land rights via a land certification programme can reduce the costs of climate change. While this study provides the first evidence that institutions can incentivize landowners to undertake adaptation-related investments, their results are valid within the context of Ethiopia. We will thus extend this emerging research question to the case of France. Indeed, although France and other developed countries have provided individual land rights to landowners for a long time, their institutions still rely on a diversity of land-related legislation and land regulations that affect land market equilibria (e.g. Fienup and Plantinga, 2021). More generally, our econometric analyses of the impacts of specific land regulations (e.g. French land consolidation programmes) on the land-use sector (in terms of land-use changes and land prices) will contribute to the economic literature on the role of institutions in affecting economic outcomes.

[10] One exception is Ay et al. (2014) that estimates non-parametric Ricardian models for the three uses in France (department scale), but the authors used heterogeneous rent indicators for the three uses (respectively farmland prices, forest land revenues and population density). Moreover, they do not account for climate impacts at the extensive margin in their estimations, but only *simulate* them ex-post. Figure 1 however illustrates that these impacts matter for the unbiased estimation of Ricardian models.

[11] Research in agricultural economics has also studied the impacts of land regulations on agriculture in developed countries (Piet et al., 2012).

c. Methodology and risk management

ACCLIMATE will develop new theoretical and empirical analyses for assessing the future impacts of climate change on the land-use sector (in terms of land-use and land-value changes), across a set of land regulations. This will be done at various scales, based on empirical assessment of past (econometric analyses) and future (simulation analyses) climate impacts in France. As described in Figure 2, ACCLIMATE builds on seven tasks. Specifically, the theoretical and data management tasks (**T1** and **T2**) will feed into the econometric analyses (**T3** and **T4**) and the simulation analyses (**T5**). The simulation analyses will also use the estimates from **T3** and **T4** to parametrize the model. The five tasks thus provide complementary (theoretical, econometric and simulation) analyses to provide answers to the four ACCLIMATE objectives. The dissemination task (**T6**) uses the different analyses to communicate ACCLIMATE's results to academic, professional and policymaker audiences. The coordination task (**T0**) ensures that the project runs effectively and smoothly over the three years. The details of the different tasks are described below.

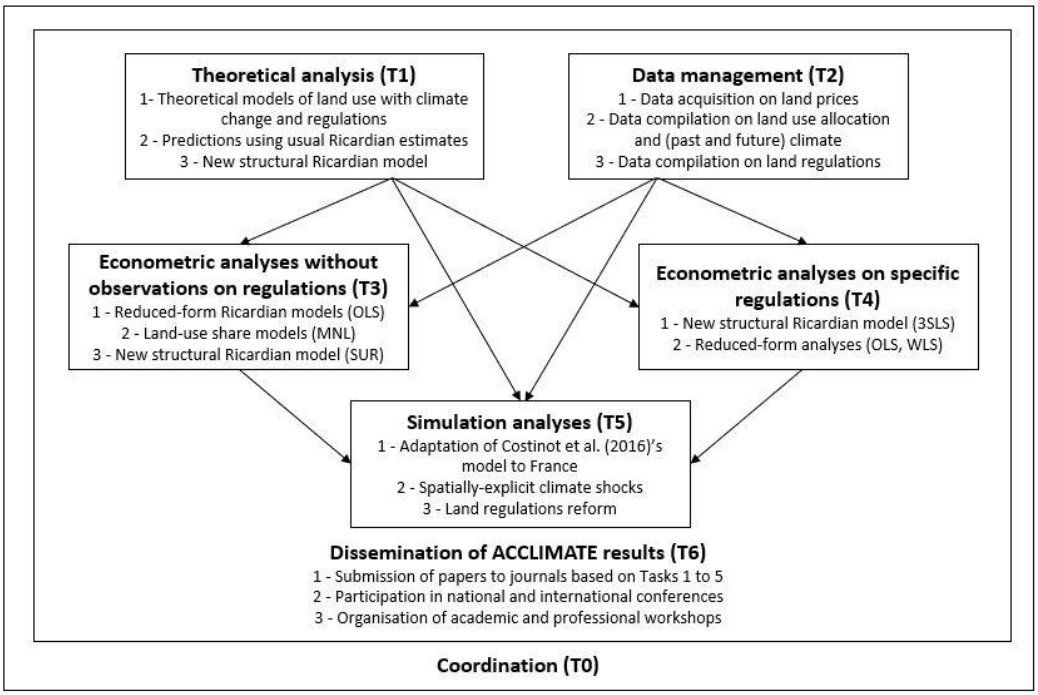


Figure 2: ACCLIMATE structure and task description.

Task 1. Analysis: theoretical investigation of climate impacts on land use
Leader: *Julien Wolfersberger.* ***Participants:*** *François Bareille, Mathilde Fromage.* ***Period:*** *Q1-Q3.*

The objectives of task **T1** are to (i) theoretically understand the implications of the land market's specific features (competition for land and existence of land regulations) in shaping landowners' adaptation to climate change, (ii) develop testable propositions suggesting biases in common reduced-form Ricardian estimates and, (iii) develop new Ricardian models that will account for the developed theoretical insights and improve the assessment of the costs of climate change for the land-use sector.

The theoretical modelling will be jointly developed by François Bareille and Julien Wolfersberger. It will build upon the mechanisms developed in Figure 1, emphasizing the impacts of climate change at both the intensive and extensive margins, under different land regulations. Specifically, we will introduce climate as a land productivity shifter in a common land-use model,[12] and analyse how different land regulations affect land market equilibria (in terms of prices and land-uses) through changes in incentives for landowners to adapt to climate change at the extensive margin. The comparative statics

[12] While the climate impacts at the intensive margin are easily justifiable for agriculture and forestry activities, they are less obvious for urban uses. We will develop two versions of the model: one without any impact of climate on urban uses at the intensive margin (only at the extensive margin), the other with climate impacts at the intensive margin induced by exogenous residential preferences (Sinha et al., 2018). These preferences could represent preferences for leisure activities under different climates but, also, climate impacts on labour productivity.

of the model will then provide insights into how land regulations affect landowners' adaptation to climate change and, ultimately, social welfare. In addition to land regulations, we will include adjustment and conversion costs (e.g. costs due to forest clearance) as specific constraints to land-use changes in the model. Because these costs are inherently dynamic, we will develop a dynamic version of the model on top of the static version (Wolfersberger et al., 2021). The three land-use categories (agriculture, forestry, urban) will be explicitly modelled. A modelling challenge will be to correctly model the competition between urban and other uses, as land-use changes towards urban use are irreversible and localized in specific places who depend on several exogeneous and endogenous factors (e.g. Coisnon et al., 2014). To this end, we will perform a specific analysis including insights from urban and regional economics in modelling urbanization fronts. Another modelling challenge will be to appropriately represent how the diversity of instruments used (land taxation schemes, land-use planning measures, protected areas, land consolidation programmes, pre-emptions, etc.) differ one from another in the modelling, and how they differentially affect landowners' utilities and social welfare. Mathilde Fromage will bring her knowledge of French land institutions to help in this respect. The insights of this theoretical analysis will provide information about the costs of climate change for the three land-use categories (and for the whole land-use sector) under different land regulations, and whether land regulations transfer some costs of climate change from one use to another. This analysis will provide elements to help answer ACCLIMATE **objectives 1 and 4**.

A particular outcome of the theoretical analysis will be to develop testable propositions that, if empirically verified, would suggest biased estimates in common reduced-form Ricardian models. Indeed, common Ricardian analyses claim to only account for the impacts at the intensive margin for agriculture. However, we show in Figure 1 that, because landowners adapt at the extensive margin, such claims may be false. We will propose a specific test as to whether land markets are efficient. Indeed, in this case, the apparent value of climate should be exactly equal at the margin among the three uses. If verified, this would imply that the estimated costs in Mendelsohn et al. (1994) and more recent Ricardian studies cannot be attributed to the agricultural sector only, but actually to the whole land-use sector. François Bareille will propose additional tests based on observed land-use shares. This particular part will provide elements to help answer ACCLIMATE **objective 1**.

The last objective of this task is to provide econometric extensions for the assessment of the costs of climate change in the Ricardian analysis (**objective 1**). François Bareille will propose new Ricardian models that explain the total land values for each of the three uses (i.e. multiplying average land prices by their total area in each observation unit) in order to account for the impacts of climate change at the extensive margin (in addition to the impact at the intensive margin). He will also develop a new structural Ricardian model that will be able to simultaneously measure the impacts of climate change at both the intensive and extensive margins while including the impacts of a diversity of land regulations. The development of the structural Ricardian model will be inspired by (i) common reduced-form Ricardian models (climate impacts at the intensive margin), (ii) common land-use share models (climate impacts at the extensive margin) and (iii) the econometric literature on the identification of hedonic models (e.g. Ekeland et al., 2004). In particular, we will base the new structural model on Carpentier and Letort (2014)'s multicrop production model, where a multinomial logit of crop shares (price impacts at the extensive margin) is simultaneously estimated with input demand and yield equations (price impacts at the intensive margin) for three crops. A modelling challenge will be to adapt this existing microeconometric model, developed to explain crop allocation within agriculture, to the more general case of aggregated data for major land uses (agriculture, forest, urban). The model will incorporate the insights of the theoretical model to correctly incorporate the different land regulations. Together with **T3** and **T4**, it will provide elements to help answer ACCLIMATE **objectives 2 and 3**.

Task 2. Data management

Leader: *François Bareille.* ***Participants:*** *Jean-Sauveur Ay, Raja Chakir, Mathilde Fromage, Postdoc, Julien Wolfersberger.* ***Period:*** *Q2-Q6.*

The objective of task **T2** is to compile consistent French data to conduct econometric (**T3**, **T4**) and simulation (**T5**) analyses. The ACCLIMATE team members will compile such information using a mix of

publicly available and purchased private data. Because tasks **T3**, **T4** and **T5** do not use data at the same spatial scale, special attention will be devoted to providing consistent data on land prices, land areas, land regulations and climate conditions in France at appropriate spatial resolutions.

For land-use areas, we will use the publicly-available Corine Land Cover satellite data, which provide land cover and changes using a 44-item nomenclature at a 1/100,000 scale (i.e. pixels covering 25 ha). Finer scale resolution exists but the interest of Corine Land Cover is that the data are available from 1990 (i.e. for 1990, 2000, 2006, 2012 and 2018). Although the interpretation techniques evolve with each cross-section, the IGN reinterprets the new data with the previous techniques to provide comparable results. We will aggregate the 44 land-uses into forestry, urban and agricultural uses (identifying grasslands, arable and permanent crops within the agricultural use where necessary). We will use the Corine Land Cover grid at the pixel level to undertake the spatially-explicit simulations in **T5**.

We will compute climate conditions using Météo-France's daily weather data. This database has provided a set of average meteorological measurements (temperature, precipitation, etc.) on the SAFRAN 8km x 8km grid since 1960. These data are already available at INRAE thanks to an agreement established between Météo-France and INRAE. In addition to computing seasonal long-term averages (30 years) as is commonly done in the Ricardian literature, we will compute the frequency of extreme events (e.g. heatwaves). Data on future climate conditions for **T5** will use ALADIN model projections from the Météo-France research centre. The ALADIN output has the advantage of providing simulated daily weather conditions until 2100 under all IPCC's RPC scenarios using similar 8km x 8km grids to the historical weather database. We will downscale historical and future weather data from the SAFRAN grid level to lower levels (municipality or CLC grid) using GIS cross-referencing methods.

For land prices, we will acquire aggregated information from the PERVAL database. Usually used for fiscal purposes, this database compiles information about the majority of real-estate asset transactions that have occurred in France since 1996 (including all houses, flats, forests, farmland, etc.).[13] The French agency representing notaries, ADNOV, which owns PERVAL, has already said that they could sell us aggregated data for land prices (specifically, average, median, minimum and maximum prices, number of transactions) for the three land uses in France at the departmental scale for 2000, 2006, 2012 and 2018.[14] Based on ADNOV's estimate, we have budgeted €1,500 to buy these data. We would ideally like access to data with a finer spatial resolution (e.g. municipalities) but ADNOV cannot provides us this information since it does not guarantee statistical secrecy (more than three transactions) for forest land. We will therefore ask the relevant SAFER agency to provide us with individual transaction data for farmland and forest land.[15] These data are not public and can only be provided with the consent of the relevant SAFER agency. The involvement of ACCLIMATE members who have already accessed these data in the past or who are in touch with the SAFER will be useful in this respect.

A major challenge of this task will be to compile data on existing land regulations into as exhaustive a database as possible. For this purpose, we will first review and compile existing public databases that present exhaustive information about land regulations in France. We have already identified several such databases, including exhaustive data on land consolidation programmes at the municipal scale since 1945 (Philippe and Polombo, 2009), exhaustive data with GIS location and implementation dates for French protected areas (with details on their stringency) and exhaustive data on municipal property taxes on built and non-built properties since 2016. We will use these data directly at the municipal level but also aggregate them at the departmental level. An objective of this task will be to make these data as complete as possible, either by identifying additional public databases on land regulations or by contacting institutions in charge of these land regulations to ask them to share their data. We will in particular ask the SAFER agency for data on pre-emptions. Jean-Sauveur Ay, Raja Chakir and Mathilde Fromage's contacts with French land institutions will be useful in this respect.

[13] Since law n° 2011-331 dated 2011, came into effect French notaries have been legally bound to exhaustively fill in the PERVAL database.
[14] Data for urban uses will include transactions for building and prepared plots, but exclude transactions for houses, flats and unviable plots.
[15] SAFER data are particularly interesting inasmuch as they discriminate between the agricultural uses (between arable land, pasture and land with permanent crops). This information about the heterogeneity of land uses within agriculture will enable us to correct for potential aggregation effects. Indeed, climate does not necessarily benefit pasture and arable and permanent crops similarly. If we cannot access these data, we will anyhow correct for this aggregation issue using the method proposed by Timmins (2006).

In summary, we have already accessed (or identified) coherent data to build a panel of information on climate conditions and land use, prices and regulations at the departmental level for 2000, 2006, 2012 and 2018. The data will be used in **T3** to **T5** to run econometric and simulation analyses. For the purpose of **T4**, we will seek finer scale data on land prices. In both cases, we will combine our variables of interest with controls from publicly available databases (e.g. municipal socioeconomic data from INSEE, agricultural prices from AGRESTE, etc.) or already compiled information such as soil conditions at the municipality level (data from the JRC and GTOPO model that we have already used in Bareille and Chakir, 2022) at compatible scales. A particular control in the analyses will relate to the introduction of information on the proportion of females among landowners at the department/municipality scale (e.g. agricultural census data from AGRESTE). François Bareille will be in charge of this task. The task will involve all ACCLIMATE team members.

Task 3. Analysis: econometric estimations without observations on land regulations
Leader: *François Bareille.* ***Participant:*** *Raja Chakir, Postdoc.* ***Period:*** *Q3-Q9.*

The main objective of this task is to estimate complementary econometric models to test whether landowners can freely adapt to climate change or not (**objective 2**), *without observing land regulations* (which constitutes the main difference from **T4**). For this purpose, we will use the data compiled in **T2** at the departmental scale for 2000, 2006, 2012 and 2018 and run three types of analysis. First, François Bareille will run reduced-form Ricardian models *à la* Mendelsohn et al. (1994) but for both agricultural, forestry and urban uses. In the light of the testable propositions developed in **T1**, the comparison of the estimates for the three uses will suggest whether French land markets are efficient or not, and whether common reduced-from Ricardian estimates could be biased.

Second, François Bareille, Raja Chakir and the hired postdoc will estimate common land-use share models with climate conditions as explanatory variables (e.g. Chakir and Le Gallo, 2013). We will estimate two forms of this model: one with land prices as additional explanatory variables, the other without. The comparison of the two sets of estimates using the test proposed by Acharya et al. (2016) will provide information about the 'controlled direct effect' of climate on land use. In our context, this will allow us to test whether the impacts of climate change on land use are fully translated into changes in land prices (**objective 2**). A negative outcome would notably suggest that some land regulations are implemented in areas where climate change modifies the competition for access to land between the three uses, i.e. that land regulations are not implemented orthogonally with respect to climate conditions, and thus may be considered as endogenous (**T4**).

Finally, François Bareille and Raja Chakir will estimate the new structural Ricardian model developed in **T1** on similar data. The structural model will consist of three equations explaining apparent land values (expressed per unit of land) for the three uses (as in usual Ricardian analyses) and two equations related to land-use shares (we will exploit the property that the three uses sum to one to omit one equation) and where the parameters related to the impact of climate change at the intensive margin will be shared within the different equations. We will use these estimates to provide answers to ACCLIMATE **objectives 1 and 2**. Regarding **objective 1**, the set of estimates related to the intensive margin impacts will be compared to the reduced-form Ricardian estimates to compute the size of the biases in the approach proposed by Mendelsohn et al. (1994). Indeed, the additional structure and the consideration of the climate impacts at the extensive margin are likely to modify the Ricardian estimates. Regarding **objective 2**, the set of estimates related to the extensive margin impacts will provide information about the constraints preventing landowners to convert from one use to another. These estimates will be particularly informative about land-use changes induced by climate change (induced by changes in land values). The remaining estimates will provide information about the constraints that face landowners when adapting to climate change due to existing land market regulations.

As explained, the estimates of three models will inform us about whether land regulations affect landowners' adaptation to climate change *without observing land regulations*. Indeed, the analyses of the estimates in the light of the insights from our theoretical analysis should be sufficient to conclude that constraints imposed by land regulations do exist (or not). From an econometric point of view, we

will respectively estimate the three models using ordinary (or weighted) least squares, maximum likelihood and seemingly unrelated regressions. The estimations will exploit the spatial and temporal heterogeneities in our variables across France. They will include specific controls for the different uses (e.g. population density, trends) and will rely on a mix of cross-sectional estimations, as in usual Ricardian analyses (Mendelsohn et al., 1994), and panel econometrics to limit omitted variable biases (e.g. using long differences; Burke and Emerick, 2016). The spatial autocorrelation in the (land use and climate) data will be corrected using spatial econometrics or Conley (1999)'s clustering correction.

Task 4. Analysis: econometric estimations with specific land regulations
Leader: *François Bareille.* ***Participants:*** *Jean-Sauveur Ay, Raja Chakir, Postdoc.* ***Period:*** *Q4-Q10.*
The objective of this task is to econometrically examine the impacts of specific land regulations that apply in France on landowners' adaptation to climate change. It will thus provide answers to ACCLIMATE **objective 3**. The task is divided into three steps. First, François Bareille and Raja Chakir aim to use aggregated information on some land regulations at the departmental level to improve the estimation of the structural Ricardian model proposed in **T1** and estimated in a simplified version in **T3**. The new estimates will provide information about the amplitudes of the constraints for specific land regulations (in particular land taxes and protected areas, for which such departmental data are available). Because these land regulations may have been implemented as a response to the increasing pressure on access to land induced by climate change, we propose to estimate the structural Ricardian models using the Three-stage Least Squares method, instrumenting the land regulations by inherited land regulations (that were introduced before climate change was even discussed in policy spheres) and agricultural and forestry commodity prices (which are generally determined in global markets and are thus not correlated to local climate change).

Second, François Bareille and Jean-Sauveur Ay will measure the long-term impacts of these inherited land regulations on landowners' adaptation to climate change. As a specific analysis, we will in particular investigate the impacts of French land consolidation programmes. Land consolidation programmes are collective measures for exchange of land between landowners in the same municipality, organized by French municipalities after the First World War. These data indicate that land consolidation programmes have been established in about 55% of all French municipalities and that, because more than 90% of land consolidation programmes were implemented before 1990, they can be considered as orthogonal with respect to recent climate changes. The estimation of the long-term impacts of land consolidation programmes on farmers' adaptation to climate change should thus not suffer from any endogenous bias (contrary to more recent land regulations). Methodologically, we will perform usual reduced-form Ricardian estimations on farmland values (measured at the municipal scale) but including interactions between climate conditions and the occurrence of land programmes (dichotomous variable) in the municipality before 1990 (or another threshold year). We will estimate the model using ordinary or weighted least squares.

Finally, we propose to test whether the implementation of specific land regulations could be explained by climate change. As a specific application, we propose to focus on the occurrence of pre-emption events decided by departmental SAFER and CDOA agencies. The econometric analysis will exploit temporal and spatial variations in climate and occurrence of pre-emption events in order to conclude. The postdoc would be involved in this last step together with François Bareille.

Task 5. Analysis: simulations of climate change impacts on land use with policy reforms
Leader: *Julien Wolfersberger.* ***Participants:*** *François Bareille, Mathilde Fromage, Postdoc.* ***Period:*** *Q6-Q11.*
In line with ACCLIMATE **objective 4**, the main objective of this task is to conduct spatially-explicit simulations of land market outcomes (land prices and areas allocated to the three uses) under future climate conditions to (i) highlight the role of existing land regulations in shaping landowners' adaptation to climate change and (ii) assess the costs of climate change under existing land regulations. For this purpose, we will adapt Costinot et al. (2016)'s general equilibrium model to our specific analysis. Such a general equilibrium model has the advantage of breaking down, in a theoretically consistent manner,

the market impacts induced by a shock into a large amount of spatially-explicit micro-data (at the pixel level) where land-use cover can be modelled as a discrete choice. It is thus particularly appropriate to model the impacts of climate change on land use for France. The simulations will use the developed theoretical analysis (**T1**) and the estimated coefficients (**T3**, **T4**) to simulate such outcomes under spatially-explicit future climate conditions in France at the 5ha x 5ha scale using the Corine Land Cover grid (**T2**).[16] We will pay particular attention to the differences between efficient and inefficient land-use allocation over space and time, at different geographical resolutions. The different simulations will use the usual IPCC's RCP scenarios 2.6 to 8.5 (available for the 8km x 8km SAFRAN grid) for 2050 or 2100. The final outcomes will be to simulate how different policy reforms (e.g. end of differentiated property tax rates for different land-uses) could reduce the costs of climate change and impact land market equilibria. The simulations will in particular provide information about the optimal timing of the land regulations (i.e. when to remove or implement certain land reforms in order to limit the costs of climate change). Julien Wolfersberger will be in charge of this task. The postdoc will help him to code the model and be responsible for model calibration. François Bareille and Mathilde Fromage will participate in the definition of the simulated land reforms and in analysing the results.

Task 6. Dissemination

Leader: *Raja Chakir.* ***Participants:*** *Jean-Sauveur Ay, François Bareille, Mathilde Fromage, Postdoc, Julien Wolfersberger.* ***Period:*** *Q1-Q12.*

The objective of this task is to disseminate the ACCLIMATE results from tasks **T1** to **T5** to interested audiences. We plan five activities. First, we plan to present ACCLIMATE's scientific output to international academic conferences. We estimate a total of six conferences (one per year for François Bareille and the postdoc).

Second, after presentations to conferences, we plan to write three to five academic papers and submit them in top peer-reviewed scientific journals. In detail, we plan two or three papers that we will submit to economic journals (e.g. American Journal of Agricultural Economics, Journal of Environmental Economics and Management) and one or two papers for generalist journals (e.g. Environmental Research Letters, Nature Climate Change). The papers will combine results from tasks **T1** to **T5**, on topics related to (i) refinements of the Ricardian method for the assessment of the costs of climate change, (ii) evidence of constraints on landowners' adaptation to climate change (linked or not to land regulations) and (iii) impact of climate change on land-use changes.

Third, given rising public concerns about the impacts of climate change on land use, dissemination of ACCLIMATE results to a general audience could be very valuable. Blog posts, such as on https://theconversation.com/fr can have large impacts outside the academic community and reach policymakers. We will make a particular effort to disseminate to policymakers our results on the impacts of potential land policy reforms on reducing the costs of climate change. We therefore plan to produce policy briefs or short digests of our results.

Fourth, we plan to organize a two-days scientific workshop to the highest international standards. Speakers working on the impacts of climate change on the land-use sector will be invited, with a thematic focus on the role of the land market's specific features. This workshop might create opportunities to launch joint projects on the topic. This workshop will take place by the end of 2025 in Palaiseau and will be hosted by Paris-Saclay Applied Economics. François Bareille and Raja Chakir will coordinate the organization of the workshop and draw up a coherent program.

Finally, we want to promote the co-organization of a professional workshop on the future impacts of climate change on land use and the role of land regulations in this context. Speakers will include French researchers working on land use and climate (including ACCLIMATE team members), land institution representatives (including SAFER, CDOA, Agriculture and Environment ministry representatives) and local policymakers involved in the design of land regulations. Raja Chakir will coordinate the organization of the conference for ACCLIMATE together with François Bareille and Mathilde Fromage.

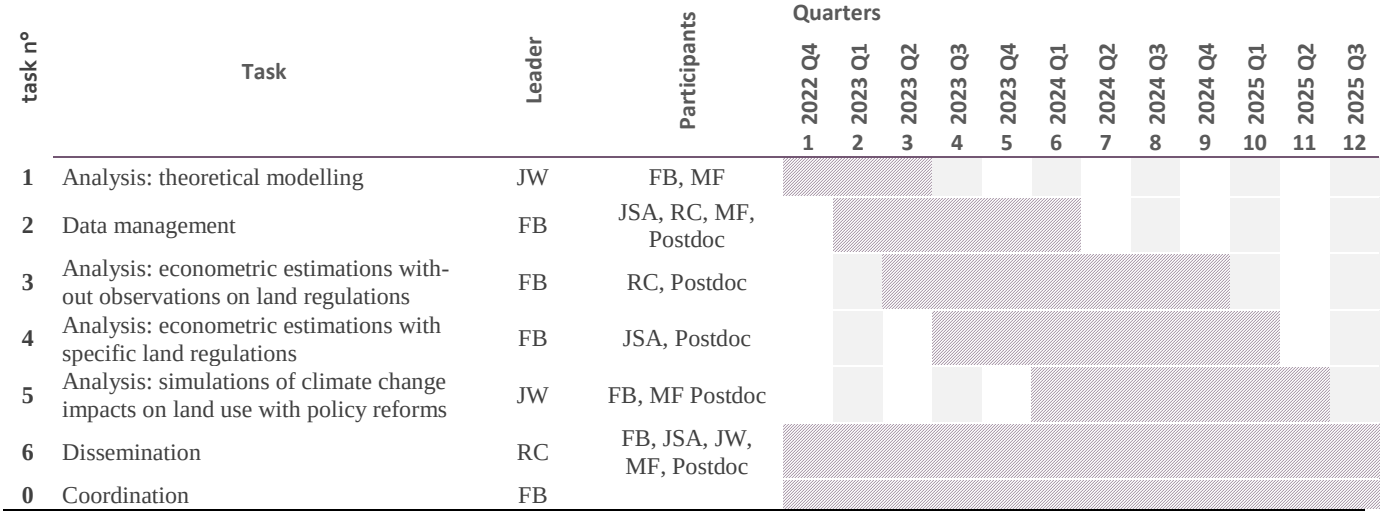
[16] The observed land uses provided by Corine Land Cover will be used to calibrate the model, in particular to capture the set of parameters related to pixels' land productivity (Costinot et al. 2016).

AAPG2022	ACCLIMATE		JCJC
Coordinated by:	François BAREILLE	36 months	170 936 €
D.7 - Sociétés et territoires en transition			

Task 0. Coordination

Leader: *François Bareille.* ***Period:*** *Q1-Q12.*

Given the number of tasks and analyses to be performed, coordination is imperative to ensure joint knowledge development among the ACCLIMATE team members. Special care will be taken to ensure that data are collected in due time. The coordinator will recruit the 24-month postdoc for a position starting at the beginning of 2023 (Q2). The coordinator will anticipate the needs of each party in order to achieve smooth interactions between team members once knowledge production starts.



François Bareille (FB), Jean-Sauveur Ay (JSA), Julien Wolferberger (JW), Mathilde Fromage (MF), Raja Chakir (RC)

Figure 3: ACCLIMATE Gantt chart.

Risk management and uncertainties. The main risk of ACCLIMATE relates to the compilation of land regulation data in task **T2**. Data on land regulations are compiled by a large set of stakeholders (mainly institutional) to whom access is not necessarily public. In addition, the existing publicly available data on land regulations are not necessarily spatially and temporally exhaustive, but rather made available for a diversity of areas and years. This represents a major difference to the other data that we will use. Thus, although we have already identified coherent data to build a panel of information on climate conditions, land uses and land prices for all mainland French departments for 2000, 2006, 2012 and 2018, the compilation of exhaustive data on land regulations for similar years and departments will represent a major challenge. This risk explains why we have split the econometric analysis into two complementary tasks (**T3** and **T4**). In task **T3**, we will estimate several complementary models using data on climate, land use and land prices, but *without observing land regulations*. Indeed, the analysis of the estimates in the light of our testable propositions from **T1** will be enough to conclude as to whether landowners are constrained in their adaptation to climate change. As such, task **T3** does not present a major risk for the success of ACCLIMATE.[17] In task **T4**, however, our econometric analyses require the inclusion of land regulations. As explained, building exhaustive, consistent data for all land regulations (e.g. land taxes, land planning measures, land consolidation programmes, protected areas, pre-emptions, etc.) will be difficult. This explains why we have devoted a large part of this task to analyses of *specific* land regulations for which we know that data are available. The estimation of the structural Ricardian model (the other part of **T4**) would however benefit from the widest possible information about land regulations (compiled at departmental level). A challenge of ACCLIMATE will thus be to obtain additional data on land regulations.[18] Jean-Sauveur Ay, Raja Chakir and Mathilde Fromage's contacts in French land-related institutions (SAFER in particular) will be useful in this respect. The theoretical and simulation tasks do not present major risks, except those of missing estimates to

[17] In order to refine the spatial resolution of the analysis, we will however ask the relevant SAFER agency to provide access to transaction (individual) data for a similar period. Such data exist for agriculture and forests and have already been used by ACCLIMATE team members. If our request is unsuccessful, we could still refine the analysis by using decennial agricultural census data on gross production (in euros) at the municipality level, which, even if only available for agriculture and are declarative, have the advantage of public availability.

[18] For example, we will request access to pre-emption event data from the relevant SAFER agency in **T2**.

calibrate the model for the simulations (**T5**). In this event, we will calibrate the model using qualitative information from Mathilde Fromage's on-going PhD work.

II. Organisation and implementation of the project

a. Scientific coordinator and its consortium / its team

François Bareille, scientific coordinator

François Bareille is the ACCLIMATE project's scientific coordinator. He has been researcher ("Chargé de recherche") at INRAE since January 2020 and a member of Paris-Saclay Applied Economics team (UMR PSAE). He defended his PhD thesis in economics in 2018. François Bareille works at the cross-roads between agricultural and environmental economics, on topics related to biodiversity conservation and climate change. He has published ten papers in leading international peer-reviewed journals in agricultural and environmental economics, including one for which he received the 2018 prize for the outstanding European Review of Agricultural Economics paper. Methodologically, François Bareille mainly uses applied econometric analyses but also commands theoretical and simulation analyses.

The fact that François Bareille works in PSAE, a unit accustomed to conducting research into the links between climate and land use (De Cara and Jayet, 2000; Ay et al., 2014; Lungarska and Chakir, 2018), will be an asset for the ACCLIMATE project's development. His participation in the convergence institute CLAND, involving 12 Paris-Saclay University research teams working on climate and land use in several disciplines (including climatology, agronomy and economics) allows him to rely on a strong research community working on the topics dealt with by ACCLIMATE (including lead authors of previous IPCC reports). The scientific coordinator will also rely on administrative staff from INRAE who are used to managing large research projects, including ANR, ERC and H2020 grants.

As part of ACCLIMATE, François Bareille aims to develop new, ambitious research axis, grounded on a solid knowledge base. In on-going works (Bareille and Chakir, 2021, 2022), he has already proposed several innovations related to the econometric assessment of the costs of climate change for agriculture, using novel databases (e.g. accounting agency data with detailed input uses, repeat-sales data for farmland) and original econometric approaches (e.g. structural econometrics, long-differences). This initial work has contributed to two ANR projects (CLAND and FAST) on farmers' adaptation to climate change. In this context, he has been jointly supervising (with Raja Chakir) a postdoc since December 2021 (one-year contract) and will supervise another starting in June 2022 (one-year contract, renewable once). Though focused on agricultural use, the work undertaken together with the two postdocs will be complementary to that developed in ACCLIMATE.[19] The research planned within ACCLIMATE will thus allow François Bareille to consider landowners' adaptation beyond the agricultural sector. While the topic has gained popularity in the public debate (e.g. induced deforestation due to climate change), economic work on the topic is still scarce and, in any case, is not related to the potential role of institutions. For these reasons, ACCLIMATE will be an opportunity for François Bareille to establish himself in the economic and interdisciplinary research communities working on climate and land use by putting forward these new ideas. It will also allow him to strengthen his recent efforts to contribute to the literature on the role of institutions in promoting environmental policy instruments (Bareille et al., 2021). Finally, the postdoc supervision will allow him to gain management experience in view of his future application for the "Habilitation à Diriger des Recherches" qualification.

In addition to the official ACCLIMATE team, François Bareille will occasionally work with David Lewis (Oregon State University, USA), Daniel Bigelow (Montana State University, USA) and Carlo Fezzi (Trento University, Italy) on specific issues related to ACCLIMATE topics. In particular, these international partners will provide their expertise on land markets and land regulations (Daniel Bigelow; e.g. Bigelow et al., 2022), climate impacts on the forest and urban sectors (David Lewis; e.g. Mihiar and Lewis, 2021) and structurally-consistent estimations of the impacts of climate change on different land uses (Carlo Fezzi; e.g. Fezzi et al., 2015). François Bareille already communicates with these academics

[19] In particular, the work undertaken with the second postdoc will assess the impacts of land ownership on European farmers' adaptation to climate change. Contrary to ACCLIMATE, the work will focus on differences of farmers' adaptation between landowners and tenants.

for his ongoing works on farmers' adaptation to climate change. The ACCLIMATE project would allow him to strengthen these links, in particular by helping to finance scientific visits to their departments.

Implication of the scientific coordinator in on-going project(s)

Name of the researcher	Person.month	Call, funding agency, grant allocated	Project title	Name of the scientific coordinator	Start - End
François Bareille	4	ANR-20-PCPA-0005; €2,986,894	FAST	Julie Subervie	2021-2027
François Bareille	4	ANR-6-CONV-0003; €9,696,780	CLAND	Philippe Ciais	2017-2027

Julien Wolfersberger, co-investigator

Julien Wolfersberger is "Maître de conférences" in economics at AgroParisTech and a member of PSAE. His research focuses on the impacts of structural changes on deforestation in developing countries. Julien Wolfersberger specialises in the theoretical development of static and dynamic land-use models and compatible simulations (e.g. Wolfersberger et al., 2021). In collaboration with Douglas Gollin (Oxford University), he is developing a model similar to Costinot et al. (2016) for Brazil, where he explicitly introduces forests as a new land-use category and simulates the impact of exogeneous shocks (modelled as changes in transportation costs) on deforestation (Wolfersberger and Gollin, 2021). His main contribution to ACCLIMATE will be to lead (i) the theoretical analysis (**T1**) of the role of the land market's specific features in the assessment of the costs of climate change as well as (ii) the spatially-explicit simulations of climate impacts on land use in France (**T5**). Julien Wolfersberger will adapt the model he is currently developing for Brazil to the specific case of ACCLIMATE, adding urban uses as an additional land-use category. He will participate in **T2** and **T6**.

Raja Chakir, co-investigator

Raja Chakir is researcher ("Directrice de recherche") in economics at INRAE, affiliated to UMR PSAE. She has published some of the most internationally-prominent applied econometrics papers on the impacts of climate change on land-use changes (e.g. Ay et al. 2014; Lungarska and Chakir, 2018), although this work assumes efficient land markets only. Her expertise in applied econometric models used to explain spatial allocation of land use and drivers of land-use changes (e.g. Chakir and Le Gallo, 2013) and in French data will be critical to the success of **T2** and **T3**. Raja Chakir is also well integrated into the national and international communities working on land use and climate change. For example, she is work package leader for the ANR convergence institute CLAND (2017-2027) and for the new European Horizon project LAMASUS (2022-2026) on the econometric assessment of the impacts of policy on land-use changes at the EU level. This integration will be a major asset for the pursuit of ACCLIMATE objectives as it will allow the team to receive feedback on specific issues related to land-use modelling and to the management of land-use data. Finally, Raja Chakir has taken part in the organization of six scientific conferences and workshops (five since 2019). Her experience in the organization of scientific workshops and her large academic network on topics related to land use and climate change will be critical to the success of **T6**, for which she is responsible.

Jean-Sauveur Ay, co-investigator

Jean-Sauveur Ay is researcher ("Chargé de recherche") in economics at UMR CESAER (INRAE). His research focuses on the role of land-use choices and land price patterns in relation to agricultural, environmental and urban outcomes, with a special focus on the impacts of public policies on land use and land prices. Jean-Sauveur Ay has published several papers on the impacts of exogeneous changes (including climate change) on land use and land prices in France (Ay et al., 2014, 2018). His expertise in French databases and advanced econometric methods will be an asset for the ACCLIMATE project. In particular, Jean-Sauveur Ay's command of econometric methods correcting for endogeneity issues related to land market functioning will be a major advantage for ACCLIMATE. His contacts at SAFER will also be an asset for ACCLIMATE, in particular with respect to access to SAFER individual transaction data for agriculture (with details on arable land, pastureland and land used for permanent crops; see **T2**) and forestry, as he has already accessed them in the past. He will contribute to **T2**, **T4** and **T6**.

Mathilde Fromage, co-investigator

Mathilde Fromage is a State civil servant of the French Ministries of Agriculture and of the Environment ("Ingénieure des Ponts, des Eaux et des Forêts"). Since September 2021, she has been detached to complete a PhD in economics at UMR SMART under the co-supervision of Laurent Piet (INRAE; see Piet et al., 2012, 2021) and Catherine Laroche-Dupraz (Institut Agro, Rennes). In her PhD, Mathilde Fromage combines an agent-based framework with institutional economics to investigate the impacts of climate change on agricultural land markets, accounting for land institutions. Though more qualitative than the works planned in the project (Léger-Bosch and Fromage, 2021), her research is very complementary to ACCLIMATE. Her deep knowledge of French land institutions and existing land regulations will allow ACCLIMATE team members to draw grounded and realistic modelling assumptions in **T1** and **T5**. Her academic and stakeholder networks involved in the study or the design of land regulations (including the national federation of SAFER) will be a major asset for ACCLIMATE, either to help for the demand to access original data (**T2**) or for the organization of the professional workshop (**T6**).

To sum up, the achievement of ACCLIMATE objectives will be facilitated by the complementary knowledge and skills of the different team members involved. Indeed, ACCLIMATE team members together present solid knowledge of land use, adaptation to climate change, land markets and the role of institutions in designing environmental policies. Their complementary skills in econometrics, theoretical analyses and spatially-explicit simulations will allow them to pursue the different tasks, and to identify and implement backup solutions. The scientific coordinator will contribute 61% of the work to the ACCLIMATE project. Given the amount of analysis to be undertaken, the team members will be assisted by a postdoc for two years. François Bareille will also occasionally seek advice related to ACCLIMATE topics from David Lewis, Daniel Bigelow and Carlo Fezzi.

b. Implemented and requested resources to reach the objectives

Partner 1: INRAE - PSAE

Staff expenses

Given the amount of data management and the number of econometric and simulation analyses, we plan to hire a postdoc for 24 months for a total budget of €100,771. The postdoc will be based in PSAE, under the scientific responsibility of François Bareille. The postdoc will be fully involved in tasks **T2** (data management) and **T5** (simulation analysis), as well as in some particular econometric analyses from **T3** and **T4**. The postdoc will contribute considerably to dissemination of ACCLIMATE results (**T6**). Given the planned analyses, the recruitment will target applicants who can demonstrate that they have conducted independent research on topics related to land-use or climate change and that they are fully familiar with econometric analyses using spatial and panel data.

Instruments and material costs

We budget €2,000 for the purchase of a computer as well as mathematical modelling and econometric software for the hired postdoc. As explained, we also budget 1,500 € for the purchase of notarial departmental data from PERVAL (based on an ADNOV estimate).

Building and ground costs

Not applicable.

Outsourcing / subcontracting

Not applicable.

General and administrative costs & other operating expenses

We plan to organize three one-day meetings between the ACCLIMATE team members each year, with an average estimated cost of €500, covering travel costs and catering. €1,000 is budgeted for travel by ACCLIMATE team members, on top of annual meetings. This will cover train tickets between Dijon, Rennes and Paris. In addition, €2,000 is budgeted for a two-week visit to the University of Trento for

François Bareille to work with Carlo Fezzi. The €2,000 will cover the travel and accommodation costs for the period. Finally, €5,000 is budgeted for a one-month visit to the US for François Bareille to work with Daniel Bigelow (Montana State University) and David J. Lewis (Oregon State University). The €5,000 will cover the travel and accommodation costs for the period.

ACCLIMATE will organize two workshops by the end of 2025 (**T6**), one for professionals involved in land market regulations (one day), the other for researchers working on land use and climate change (two days). The combined cost of the two workshops is estimated at €30,000. This includes the cost of the conference room (for the professional workshop) and catering.

For the dissemination of ACCLIMATE results in academia (**T6**), we estimate in addition a total of six conferences with an average budget of €1,000€ each. We also plan to submit three to five papers to journals. Submission to some journals is costly, we therefore budget €2,000 to cover submission costs, purchase of books and editing work to polish submissions.

Consistent with current practice, €19,665, i.e. 12% of the funds, would be used by the research centre to cover administrative costs.

Requested means by item of expenditure and by partner

	Partner: *INRAE (Paris-Saclay Applied Economics)*
Staff expenses	€100,771
Instruments and material costs (including scientific consumables)	€3,500
Building and ground costs	
Outsourcing / subcontracting	
General and administrative costs & other operating expenses	€47,000
Administrative management & structure costs	€19,665
Requested funding	**€170,936**

III. Impact and benefits of the project

The dissemination strategy is fourfold and maximizes ACCLIMATE's impact. First, we aim to publish three to five research articles in top peer-reviewed journals. Specifically, two or three papers will target publications in economics (topics related to the costs of climate change and constraints of land regulations on landowners' adaptation to climate change) and one or two in generalist outlets (topics related to the impacts of climate change on land-use changes). We will make sure that the publications are available in open-access, either by submitting to journals with open access policies or by making pre-prints available in repository websites (e.g. in https://hal.archives-ouvertes.fr/). Second, we plan to disseminate our results in academic circles by organizing a scientific workshop on the assessment of the costs of climate change for the land-use sector (targeting leading international scientists in the field) and by participating, on a regular basis, in leading international environmental economics conferences, such as EAERE and WCERE. More specialized events will also be targeted to make sure that we reach the most interested audience. Third, we want to influence policy making and contribute to reflection on the role of land institutions in shaping landowners' adaptation to climate change. We will reach this objective by (i) writing policy briefs highlighting ACCLIMATE results (in particular results from **T5** on the benefits of potential land policy reforms) and (ii) organizing professional workshops, involving researchers, land institution representatives (including SAFER, CDOA, Agriculture and Environment ministry representatives) and local policymakers involved in the design of land regulations. The contacts that we already have in these institutions and that we will strengthen through the project are very important with respect to this objective. Fourth, vulgarization is an essential component of our work. As described in **T6**, we plan to publish briefs presenting our results, both in French and in English, notably on issues related to the impacts of climate change on land use (particularly induced deforestation, a subject that interests many stakeholders) and the role of institutions in this problem.

At the individual level, ACCLIMATE allows the scientific coordinator to develop and strengthen ties with scientists (i) who are already co-authors (Raja Chakir and Julien Wolfersberger), (ii) who have regular discussions with him on issues related to landowners' adaptation to climate change (Jean-

Sauveur Ay, Carlo Fezzi and Mathilde Fromage) and (iii) who more occasionally exchange with him on similar topics (Daniel Bigelow and David Lewis, who already work together on some aspects related to ACCLIMATE; e.g. Bigelow et al., 2022). These collaborations will in particular allow François Bareille to develop contacts with more international research networks. At a deeper level, this would allow him to participate in the structuring of existing research efforts related to the impacts of climate change on land-use and, ultimately, to establish his scientific legitimacy within the economic and interdisciplinary networks on the topic. The efforts undertaken as part of ACCLIMATE will have a multiplier effect outside the perimeter of the project. First, in the short term, this is an opportunity for François Bareille to supervise a first postdoc on his own. Second, in the medium term, the results of ACCLIMATE may have the potential to participate in the creation of a new sub-field of research on the role of land market functioning in shaping landowners' adaptation to climate change, which has itself the potential to bring new collaborations.

IV. References related to the project

Acharya, A., Blackwell, M., & Sen, M. (2016). Explaining causal findings without bias: Detecting and assessing direct effects. American Political Science Review 110(3), 512-529.

Adamopoulos, T., & Restuccia, D. (2020). Land reform and productivity: A quantitative analysis with micro data. American Economic Journal: Macroeconomics, 12(3), 1-39.

Aragón, F. M., Oteiza, F., & Rud, J. P. (2021). Climate Change and Agriculture: Subsistence Farmers' Response to Extreme Heat. American Economic Journal: Economic Policy 13(1), 1-35.

Auffhammer, M. (2018). Quantifying economic damages from climate change. Journal of Economic Perspectives, 32(4), 33-52.

Ay, J.S., Chakir, R., Doyen, L., Jiguet, F., & Leadley, P. (2014). Integrated models, scenarios and dynamics of climate, land use and common birds. Climatic change 126(1), 13-30.

Ay, J.S., Cavailhès, J., Hilal, M., & Le Gallo, J. (2018). Does issuing building permits reduce the cost of land? An estimation based on the demand for building land in France. Economie et Statistique, 500(1), 45-67.

Bareille, F., & Chakir, R. (2021). Decomposing Weather Impacts on Crop Profits: the Role of Agrochemical Input Adjustments. Working Paper FAERE No. 2021.09, 1-44.

Bareille, F., & Chakir, R. (2022). Estimating Ricardian Models with Repeat-Sales. Working Paper, 1-49.

Bareille, F., Wolfersberger, J. & Zavalloni, M. (2021). "Institutions and Conservation: The Case of Protected Areas." Paper presented at the 26th EAERE Annual Conference. Online, 23-25 June 2021.

Bezabih, M., Di Falco, S., Mekonnen, A., & Kohlin, G. (2021). Land rights and the economic impacts of climatic anomalies on agriculture: evidence from Ethiopia. Environment and Development Economics, 26(5-6), 632-656.

Bigelow, D. P., Lewis, D. J., & Mihiar, C. (2022). A major shift in US land development avoids significant losses in forest and agricultural land. Environmental Research Letters, 17(2), 024007.

Burke, M., & Emerick, K. (2016). Adaptation to climate change: Evidence from US agriculture. American Economic Journal: Economic Policy 8(3), 106-140.

Chakir, R., & Le Gallo, J. (2013). Predicting land use allocation in France: A spatial panel data analysis. Ecological Economics, 92, 114-125.

Chari, A., Liu, E. M., Wang, S. Y., & Wang, Y. (2021). Property rights, land misallocation, and agricultural efficiency in China. Review of Economic Studies 88(4), 1831-1862.

Conley, T. G. (1999). GMM estimation with cross sectional dependence. Journal of econometrics, 92(1), 1-45.

Coisnon, T., Oueslati, W., & Salanié, J. (2014). Agri-environmental Policy and Urban Development Patterns: A General Equilibrium Analysis. American Journal of Agricultural Economics, 96(3), 673-689.

Costinot, A., Donaldson, D., & Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. Journal of Political Economy 124(1), 205-248.

De Cara, S., & Jayet, P. A. (2000). Emissions of greenhouse gases from agriculture: the heterogeneity of abatement costs in France. European Review of Agricultural Economics, 27(3), 281-303.

Deschênes, O., & Greenstone, M. (2007). The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. American Economic Review 97(1), 354-385.

Ekeland, I., Heckman, J. J., & Nesheim, L. (2004). Identification and estimation of hedonic models. Journal of Political Economy, 112(1), 60-109.

Fezzi, C., & Bateman, I. (2015). The impact of climate change on agriculture: nonlinear effects and aggregation bias in Ricardian models of farmland values. Journal of the Association of Environmental and Resource Economists, 2(1), 57-92.

Fezzi, C., Harwood, A. R., Lovett, A. A., & Bateman, I. J. (2015). The environmental impact of climate change adaptation on land use and water quality. Nature Climate Change, 5(3), 255-260.

Fienup, M. J., & Plantinga, A. J. (2021). Unintended effects of environmental policies: the case of urban growth controls and agricultural intensification. Land Economics, 97(2), 261-280.

IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., Leclère, D., Ohrel, S., Ragnauth, S., Schmid, E., Valin, H., van Lipzig, N. & Maertens, M. (2020). Global hunger and climate change adaptation through international trade. Nature Climate Change, 10(9), 829-835.

Kelly, D. L., Kolstad, C. D., & Mitchell, G. T. (2005). Adjustment costs from environmental change. Journal of Environmental Economics and management, 50(3), 468-495.

Lawler, J. J., Lewis, D. J., Nelson, E., Plantinga, A. J., Polasky, S., Withey, J. C., Helmers, D. P., Martinuzzi, S., Pennington, D. & Radeloff, V.C. (2014). Projected Land-Use Change Impacts on Ecosystem Services in the United States. Proceedings of the National Academy of Sciences 111(20): 7492–7497.

Léger-Bosch, C., & Fromage, M. (2021). "Une lecture des nouvelles relations propriété-usage par les arrangements institutionnels et le bouquet de droits." Paper presented at the 14èmes Journées de recherche en Sciences Sociales. Online, 7-8 April 2021.

Lungarska, A., & Chakir, R. (2018). Climate-induced land use change in France: impacts of agricultural adaptation and climate change mitigation. Ecological Economics, 147, 134-154.

Mendelsohn, R. & Massetti, E. (2017). The use of cross-sectional analysis to measure climate impacts on agriculture: theory and evidence. Review of Environmental Economics and Policy, 11(2):280–298.

Mendelsohn, R., Nordhaus, W.D., & Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. American Economic Review 84(4), 753-771.

Mihiar, C. & Lewis, D. J. (2021). Climate, adaptation, and the value of forestland: A national Ricardian analysis of the United States. Land Economics, *Forthcoming.*

Miller, D. J., & Plantinga, A. J. (1999). Modeling land use decisions with aggregate data. American Journal of Agricultural Economics, 81(1), 180-194.

Ortiz-Bobea, A. (2020). The role of nonfarm influences in Ricardian estimates of climate change impacts on US agriculture. American Journal of Agricultural Economics 102(3), 934-959.

Piet, L., Latruffe, L., Le Mouël, C. & Desjeux, Y. (2012). How do agricultural policies influence farm size inequality? The example of France. European Review of Agricultural Economics 39(1), 5–28.

Piet, L., Melot, R., & Diop, S. (2021). What drives competition on the farmland market? A case study in Brittany (France). European Review of Agricultural Economics 48(1), 60-96.

Philippe, M. A., & Polombo, N. (2009). Soixante années de remembrement. Études foncières 140, 43-49.

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. Journal of Political Economy 82(1), 34-55.

Severen, C., Costello, C., & Deschenes, O. (2018). A Forward-Looking Ricardian Approach: Do land markets capitalize climate change forecasts? Journal of Environmental Economics and Management 89, 235-254.

Seo, S. N., & Mendelsohn, R. (2008). An analysis of crop choice: Adapting to climate change in South American farms. Ecological economics, 67(1), 109-116.

Sinha, P., Caulkins, M. L., & Cropper, M. L. (2018). Household location decisions and the value of climate amenities. Journal of Environmental Economics and Management, 92, 608-637.

Timmins, C. (2006). Endogenous land use and the Ricardian valuation of climate change. Environmental and Resource Economics, 33(1), 119-142.

Wolfersberger, J., Amacher, G. S., Delacote, P., & Dragicevic, A. (2021). The dynamics of deforestation and reforestation in a developing economy. Environment and Development Economics, 1-22.

Wolfersberger., J., & Gollin, D. (2021). "Roads, development and deforestation." Paper presented at the 26th EAERE Annual Conference. Online, 23-25 June 2021.