# Adaptation strategies in the Mekong delta

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Chapter 10

# Adaptation strategies in the Mekong delta


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## Abstract

The objective of Chapter 10 is to present how computational models can be used to represent and understand the interactions between adaptation strategies adopted at different spatial and social scales in several climatic scenarios. These models are variations of a basic model called LUCAS (for Land Use Change for Adaptation Strategies), a spatially explicit agent-based model designed as a combination of social, economic, and environmental dynamics with individual land use change decisions. LUCAS simulates the complex interactions between individual and collective strategies, and their combined and cumulative effects on land use over time. Given a set of assumptions, parameters and scenarios, it provides a picture of land use in the Mekong Delta in 2030, with a vision through to 2050. We show that being able to use a model to consider adaptation efforts at the individual level and proposed strategies at the regional level simultaneously enables a very fine evaluation of the effectiveness of the latter, but also that this approach supports the subsequent integration of more specialized models (rice yields, salt and sediment transport, demographic evolution, groundwater dynamics, etc.). Although kept simple for the purposes of this chapter, virtual experiments based on models like LUCAS have the potential to change the way adaptation planning is conducted in the future.



## Tóm tắt

Mục tiêu của Chương 10 nhằm trình bày kết quả ứng dụng mô hình tính toán biểu diễn sự tương tác giữa các chiến lược thích ứng trên phạm vi không gian và xã hội ứng với các điều kiện khí hậu khác nhau. Các mô hình này là các tùy chỉnh của mô hình cơ bản được xây dựng có tên LUCAS (Chiến lược thay đổi sử dụng đất thích ứng). Đây là một mô hình đa tác tử, trong đó dữ liệu không gian được thiết kế kết hợp với các yếu tố kinh tế, xã hội, môi trường và các quyết định thay đổi sử dụng đất của người dân. Mô hình LUCAS mô phỏng các tương tác phức tạp giữa các chiến lược cá nhân người dân và tập thể dưới các tác động tổng hợp và tích lũy của các yếu tố trong sử dụng đất theo thời gian. Dữ liệu đầu vào để hiệu chỉnh và kiểm chứng mô hình được thu thập từ bản đồ hiện trạng sử dụng đất năm 2015 và được giải đoán bổ sung từ ảnh vệ tinh Sentinel 2 cho năm 2020. Dựa trên các giả định, các kịch bản được xây dựng để cung cấp bức tranh về hiện trạng sử dụng đất ở Đồng bằng sông Cửu Long năm 2030 tầm nhìn đến năm 2050. Kết quả đánh giá các chiến lược sử dụng đất thích ứng với biến đổi khí hậu thông qua mô hình cho thấy các chiến lược thích ứng có xem xét đồng thời các nỗ lực thích ứng ở cấp độ người dân và các chiến lược đề xuất ở cấp vùng mang lại hiệu quả tích cực. Ngoài ra, cách tiếp cận mô hình này cũng cho phép tích hợp LUCAS với các mô hình chuyên biệt hơn như mô hình ước đoán năng suất lúa, sự vận chuyển muối và phù sa, phát triển dân số, nước ngầm. Mặc dù được đơn giản hóa cho mục đích của chương này nhưng các thí nghiệm ảo dựa trên LUCAS có khả năng đóng góp trong quá trình lập kế hoạch thích ứng trong tương lai.

# Résumé

L'objectif du chapitre 10 est de présenter comment des modèles informatiques peuvent être utilisés pour représenter et comprendre les interactions entre les stratégies d'adaptation à différentes échelles spatiales et sociales dans plusieurs scénarios climatiques. Ces modèles sont des variations d'un modèle de base appelé LUCAS (pour Land Use Change for Adaptation Strategies), un modèle à base d'agents offrant une combinaison de dynamiques sociales, économiques et environnementales avec des décisions individuelles de changement d'utilisation des terres. LUCAS simule les interactions entre les stratégies individuelles et collectives et leurs effets combinés et cumulatifs sur l'utilisation des terres. Compte tenu d'un ensemble d'hypothèses, de paramètres et de scénarios, il fournit une image de l'utilisation des terres dans le delta du Mékong en 2030, avec une vision jusqu'en 2050. Les données d'entrée pour la vérification et la calibration du modèle sont collectées à partir de la carte d'utilisation des terres pour 2015 et interprétées à partir d'images Sentinel 2 pour 2020. Nous montrons que la possibilité de considérer dans un modèle, simultanément, les efforts d'adaptation au niveau individuel et les stratégies proposées au niveau régional permet une évaluation très fine de l'efficacité de ces dernières, mais aussi que cette approche favorise l'intégration ultérieure de modèles plus spécialisés (rendements rizicoles, transport de sel et de sédiments, évolution démographique, dynamique des eaux souterraines, etc.) Bien qu'elles soient restées simples pour les besoins de ce chapitre, les expériences virtuelles basées sur LUCAS ont le potentiel de changer la façon dont la planification de l'adaptation est menée à l'avenir.

# 1. Introduction

As described in detail in Chapter 1, climate change will affect human communities in Viet Nam by altering environmental conditions such as temperature, precipitation, and sea level, as well as the energy [Chapter 5], water [Chapter 3], food [Chapter 4], and transportation systems on which these communities depend. In the Vietnamese Mekong Delta in particular, this may exacerbate existing local stressors and have a significant impact on the agricultural sector. Indeed, in recent years, the combined effects of fluctuations in profits from agricultural and aquaculture production, changes in management policies, and increases in various environmental stresses have seriously affected agricultural production in the coastal provinces of the Mekong Delta [Nguyen Xuan Hien *et al.*, 2016; Wassmann *et al.*, 2004].

The anticipated impacts of climate change (increased saltwater intrusion due to subsidence and sea level rise [Chapter 9], increased duration of drought periods due to rising temperatures, and decreased availability of freshwater are then going to weigh on farmers' vulnerability in a concerning way. Furthermore, groundwater extraction, which is supposed to partially offset this vulnerability, actually worsens the situation by increasing subsidence throughout the Delta [Minderhoud *et al.*, 2020], which will exacerbate saline intrusion.

To adapt to these unavoidable changes, national and provincial planning authorities are being mobilized to design plans at the regional level to reduce these impacts, and support the sustainable development of the region by promoting resilient adaptation of ecosystems, communities, and infrastructure. As described in Chapter 11, this may involve multiple interventions, such as building new infrastructure, better land and resource use planning, financial incentives, or crop and land use diversification. In parallel to these medium- to long-term planned adaptation strategies, farmers and local communities are not standing still. They are experimenting with individual, sometimes short-term strategies, dictated by their perception of environmental changes (*e.g.* shifting from rice cultivation to aquaculture in response to soil salinization) or economic opportunities (*e.g.* shifting to intensive agriculture to benefit from good market conditions). These individual strategies might differ from those of the planners, and may even be contradictory and barely generalizable at regional scale, yet they are one of the key drivers of the global adaptation process and cannot be overlooked [Chapter 11]. Although land use change in the Mekong Delta is guided by ten-year plans, some models have shown [Drogoul *et al.*, 2016] that actual land use can be explained by a predominance of these individual choices, at the plot or village level, which are constrained by environmental suitability and health and, of course, economic factors such as the existence of a value chain. Encouraged since the early 1990s by an incentive policy, this has led to a gradual intensification of crops, which has accompanied and fuelled the prodigious leap forward in Vietnamese agriculture over the past 20 years. However, this intensification has also had the consequence of weakening both the value chains (over-dependent on monocultures) and the environment (additional inputs, water requirements, etc.) and making them much more vulnerable to climate change, sea level rise, changes in ecosystems and pests [Phan *et al.*, 2010], or extreme weather events caused by climate change.

These different trends are being scrutinized in a growing number of studies measuring or assessing the effects of climate change — primarily sea level rise — on agriculture in the Mekong Delta, and highlighting recommendations for adaptation, both at the local level for farmers and communes and at the global level for the government [ Vu Thuy Linh, 2020 ]. In a number of these studies, the adaptation policies advocated are modelled and evaluated in certain scenarios [ Holman *et al.*, 2019 ], which are themselves derived from the results of numerical simulations of the consequences of climate change. Assuming that the main actors of change were farmers, much work has called for relatively profound changes on their part, inviting them to modify their agricultural practices or land use to minimize the impact of the coming changes on their incomes [ Bong *et al.*, 2018; Vu Thuy Linh, 2020 ]. But this call for the conversion of individual agricultural practices overlooks two fundamental aspects: first, the scaling up or generalization of practices considered virtuous on a small scale is not at all guaranteed to deliver on its promises at larger scales; second, the lack of coordination between individual adaptations risks leading to practices that would only be governed by immediate profit, or that would compete for access to shared resources (water, quality soils, seeds, etc.). These two aspects bear the risk of aggravating an already serious situation.

At the other end of the spectrum, many authors have looked at ways to better help authorities define good adaptation strategies in an increasingly uncertain world, for example by proposing adaptation pathways, notably in Bosomworth *et al.* (2015), Lin *et al.* (2013) or Haasnoot *et al.* (2019). The latter emphasize that traditional planning (a 10-year plan, with a 5-year reassessment), as practiced in land use, is no longer adapted to these new threats and should be replaced by dynamic adaptation pathways, where key steps such as vulnerability assessment, definition of adaptation or investment plans should be reviewed and updated every year, by assessing the current impact of climate change. These new approaches to planning provide welcome capabilities to adapt more quickly and flexibly to changes, some of which are inevitable. However, like their predecessors, they ignore the essential role played by spontaneous adaptation at the individual level, choosing instead to imagine an ideal world in which farmers could change crops at will, according to planned adaptation needs at a higher level.

Research and training efforts are now underway to support the capacity of institutions to plan climate adaptation using model-based or scenario-based resources and tools. They are still far from being routinely used, however, because they cannot embrace all the richness that adaptive practices in this environment cover at multiple scales. But, as is already the case for climate change impact assessment, models are gradually becoming part of the planners' toolbox, simply because the dynamics of interactions between human communities and their environment in a context as complex and changing as the Mekong Delta can no longer be understood by human expertise alone [ Kelly *et al.*, 2013 ]. However, the design of these models raises two challenges: 1 ] they must support multidisciplinary contributions, as their scope extends beyond climate-related issues to encompass social, economic, and ecological issues; and 2 ] they must represent the complexity of socio-ecological processes that must adapt, including individual-level behaviours and decision-making processes, as well as global, nationwide dynamics and constraints [ Chapter 13 ]. So, although all specialists agree that adaptation to the effects of climate change will require a profound change in land use in the Mekong Delta — whether it is decreed by the authorities, decided autonomously by local communities, or the result of the interaction between these two processes — very few tools (an interesting exception being Smajgl *et al.*, 2015b) can really support a scientific approach to this change so far.

The objective of this chapter is therefore to present how one can use computational models to represent and understand the interactions and feedbacks between adaptation strategies adopted at these different levels. By exploring the response of these models in several scenarios, we show how to evaluate large-scale adaptation strategies while simultaneously accounting for the effect of individual decisions. These models are variations of a basic model called LUCAS (for Land Use Change for Adaptation Strategies), a spatially explicit agent-based model designed as a combination of social, economic, and environmental dynamics with individual land use change decisions. LUCAS is programmed to simulate the complex interactions between individual and collective strategies, and their combined and cumulative effects on land use over time. Given a set of assumptions, parameters and scenarios (including climate scenarios, of course), its main objective is to obtain a picture of land use in the Mekong Delta in 2030, with a possible view through to 2050, to effectively support the work of planners.

In the model, farmers and their fields are explicitly represented, and subjected to several processes ranging from large-scale environmental dynamics, socio-economic and climatic changes, to individual decision-making based on local perception of these changes. Input data for model verification and calibration were collected from the existing land use map in 2015, and interpreted from Sentinel 2 satellite imagery in 2020 [ Chapter 4 ]. Among the many climate change scenarios, temperature, precipitation [ Chapter 1 ] from 2015 to 2050 and sea level rise (SLR) data with RCP4.5 and 8.5 scenarios [ Chapter 9 ] were selected. Assuming that understanding the adaptive dynamics at work and proposing adaptation strategies at the scale of the Mekong Delta should be as much about the choice of the individual farmers as it is about the orientations of the government planners, LUCAS relies on an agent-based modelling approach [ Drogoul *et al.*, 2002 ] that supports the exploration, in different scenarios, of dynamic combinations of these bottom-up and top-down practices, in order to best inform the decision-making of the authorities concerned.

Although it proposes to explore the effects of these combinations by immersing them in scenarios running to 2030, with a vision through to 2050, this chapter is not intended to offer predictions on the state of Vietnamese stakeholders' adaptation to climate change at that date. We will indeed introduce models in which humans are not passive actors but can instead adopt options or make choices that will defer impacts, transform vulnerabilities, and ultimately modify the system itself. The consequence of these highly nonlinear characteristics is that the model presented in this chapter allows everyone, by changing the assumptions and parameters, to explore the possible trajectories of the system. It cannot, of course, predict which ones will be the most likely, but it provides clues to decision makers about the impact of their decisions on these trajectories.

After a detailed description of the context of adaptation to climate change in the agricultural sector — in which we review both its vulnerabilities and the policies implemented to address them — this chapter presents the LUCAS (Land Use Change for Adaptation Strategies) model, which was designed as a virtual laboratory, on the scale of the Mekong Delta, to simulate and evaluate the performance of different adaptation strategies and their combinations, at different levels, in different climatic, demographic or economic scenarios. Three simple strategies are presented and evaluated: the first one is based only on individual farmers' choices, without any help or hindrance from the government; the second one is based only on governmental decisions, without spontaneous adaptation by farmers; and the third one is based on a combination of these two approaches, in which the government supports the individual choices that seem relevant to reducing the impacts of climate change. We conclude with a discussion on the interest of better promoting this type of modelling approach in the field of climate change adaptation — as it enables all the contributions of the different stakeholders to be taken into account, thus facilitating the construction of consensual adaptation strategies — and describe the future work we will undertake to develop, disseminate and use LUCAS.

# 2. Environmental change and climate change adaptation in the Mekong Delta

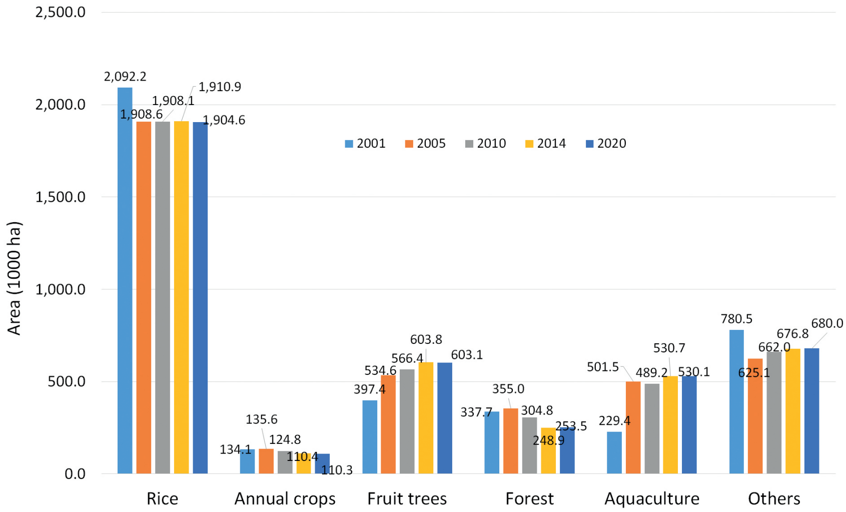
## 2.1 Land use changes in the Mekong Delta

The Mekong Delta is a collection of 13 disparate provinces, which nevertheless have in common the fact of having a predominantly rural population. Although the rural population has tended to decrease since 2008 — following a general dynamic in Viet Nam, accentuated by the rural exodus and the decrease in fertility (according to UNESCO (2016), 34% of Vietnamese live in urban areas: if the growth rate of the general population is 1% per year, that of the urban population is 3.4% per year, and that of the rural population is only 0.4%) — it is still a large majority (74.86% according to General Statistic Office, 2020) in the Mekong Delta. If there is to be adaptation to climate change, it will necessarily involve adaptation of this population and its agricultural practices, in particular its use of land.

The ability to adapt to climate change in rural areas depends on an understanding of its current and future impacts by policy makers and citizens. In that respect, one of the most important tools promoted by the Government to integrate climate change adaptation and disaster risk reduction into farming practices is land-use planning [ Government of Vietnam, 2019; MoNRE, 2021b ].

In recent years, land use change in the Mekong Delta has been analysed in numerous reports, which showed that land use change is affected by socio-economic and environmental factors [ Drogoul *et al.*, 2016 ] in which the changes take place mainly according to the profitability of the farming methods when the environment is favourable [ Nguyen Thanh *et al.*, 2021 ].

[ Figure 10.1 ]
**Land use changes in the Mekong Delta**




Source: MoNRE, 2016, 2021a; Prime Minister of VN, 2001, 2007.

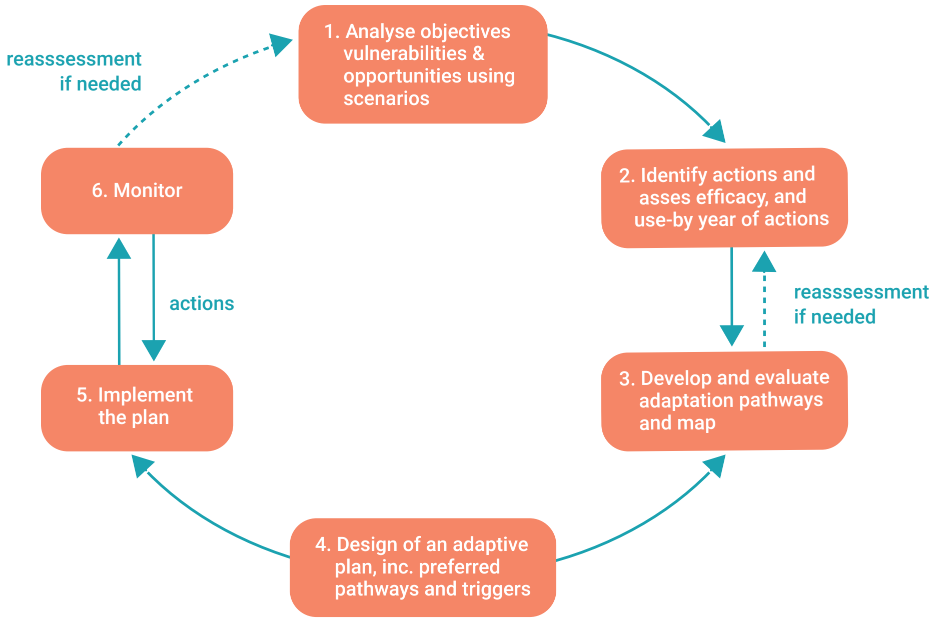
Regarding the statistical data on agricultural land-use of the Mekong Delta during the period 2000–2020 [ Figure 10.1 ], it is easy to see a trend to shift away from rice to other land uses in the first period (2001–2005), a shift representing more than 170,000 ha. At the same time, the surface area dedicated to shrimp aquaculture has doubled from 229,350 ha to 501,500 ha. Young *et al.* (2002) showed that in early 2000, the market price of rice was near or below the production cost, which explains that a huge number of farmers have shifted their land-use away from rice. After that first period, the rice area still remained around 1.9 million hectares for a long time, while a more progressive shift towards fruit trees occurred (doubling over the whole period). After the initial shock increase in 2005, the aquaculture area decreased over the next 5 years, then reverted to an increasing trend from 2014 until 2020. In this period of 20 years, the forest decreased from more than 330,000 ha to 253,500 ha.

Historical data reveal a very difficult management problem: while farmers (sometimes because of governmental production quotas) tend to change their land use to intensive rice production in diked systems or undertake conversions from rice-shrimp to intensive shrimp farming, the consequences of climate change (extreme weather events, soil and water salinity, etc.) are expected to have a significant impact on these very specific crops, potentially turning them into highly unsustainable strategies.

## 2.2 Land use adaptation solutions in the Mekong Delta

It is difficult to draw a clear line between the solutions implemented as a consequence of national adaptation policies — through public investment, for instance — and individual adaptation practices; both, of course, have an

[ Figure 10.2 ]
The dynamic adaptive policy pathways (DAPP) approach




Source: Deltares, 2021, simplified from Haasnoot *et al.*, 2013.

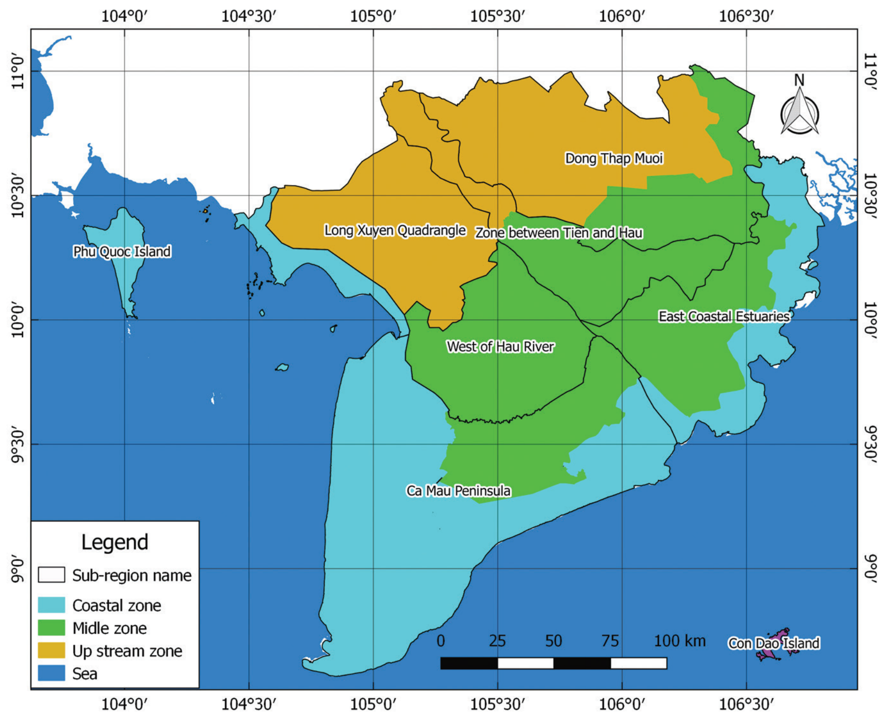
influence on the solutions adopted by farmers and communities.

## National strategies and individual adaptation by farmers

Whether at the national or regional levels, many researchers have been interested in defining adaptation plans for authorities [ Haasnoot *et al.*, 2020; Bosomworth *et al.*, 2015 ]. An adaptation plan specifies actions to be taken immediately, in order to be prepared for the future. Implementing an adaptation plan requires being able to explore different adaptation pathways.

As far as national strategy is concerned, the national plan for adaptation to climate change for the period 2021–2030, with a vision for 2050, signed by the Prime Minister [ Prime Minister of VN, 2020 ], officially puts the focus on improving the effectiveness of climate change adaptation through strengthening state management of climate change, and promoting the integration of climate change adaptation into the strategic system and regional planning. Following the general policies of the government, many authors [ Vu Thuy Linh, 2021 ] suggested strategies for action at government sites to implement the adaptation plans. It emphasizes public investments to support farmers in solutions such as renovating existing irrigation systems, investing in information equipment, automatic monitoring systems, scientific and efficient agricultural management, exploiting freshwater systems,

[ Figure 10.3 ]
**Ecological zoning for agriculture development in the Mekong Delta**




Source: Bong *et al.*, 2018.

and focal sewers to reduce natural hazards (cf. Chapter 11).

Another solution is to manage the conversion using an administrative tool. The departments of Natural Resources and Environment limit land use conversion via adaptation plans and annual land use plans: land registration management offices do not grant conversion permits to people when the conversion takes place spontaneously, according to personal economic interests rather than as part of the government's plan [ The President of S.R. Vietnam, 2013 ]. Besides, especially for shrimp, farmers have to register at the Popular Committee of their parcel commune when they want to establish intensive and semi-intensive farming activities [ Ben Tre Committee, 2016 ]. There is also an attempt to convince people to adopt climate change-adapted farming systems, such as 2 rice seasons and 1 vegetable season [ Bong *et al.*, 2018 ], or 2 rice seasons and 1 rice-shrimp season in vulnerable areas [ Loc *et al.*, 2017 ].

Regarding local government policies for land use conversion in adaptation to Climate change, the local government (An Giang province) has supported farmers who want to convert from 3 rice seasons to 2 rice seasons and 1 freshwater shrimp season, with support on shrimp varieties and technical transfer [ An Giang Committee, 2015 ].

Evers & Pathirana (2018) showed that rural communities can be dynamic and able to continuously adapt to a changing environment. However, rural communities in the Mekong River Basin often lack financial and institutional resources for formal adaptation planning [ Chapter 12 ]. Thus, financial support from government and social resources are also key to adaptation strategies.

## Land use adaptation and farmer decision-making

At the individual scale, many adaptation solutions are a result of agricultural expertise [ Bong *et al.*, 2018; Pongthanapanich *et al.*, 2019 ], including adaptation in aquaculture and agriculture farming systems in line with temperature increases and rainfall decreases: as an example, the transformation of agricultural structures from a single-crop specialization in rice production towards a multiple-crop model with a rotation of rice and crops (vegetables and corn) has been observed. This kind of adaptation has taken place in some provinces of the Long Xuyen Quadrangle, in the intermediate zone between the Tien and Hau rivers, and in the Eastern coastal provinces (Tra Vinh, Ben Tre, Soc Trang) [ Bong *et al.*, 2018 ] [ Figure 10.3 ].

Besides, farmers applied advanced and water-saving irrigation solutions for shallow crops, industrial factories and fruit trees with high commercial and economic value. In coastal areas, people store rainwater in addition to building freshwater settling tanks, which is an economical and effective solution in conditions of saline intrusion [ Vu Thuy Linh, 2021 ]. In aquaculture, farmers need to apply high technology to minimize dependence on natural factors, by controlling the aquatic environment and using roofs to control rainfall and temperature [ Pongthanapanich *et al.*, 2019 ].

## Climate change and sensitivity of farming systems

Climate change effects will strongly impact the different farming systems, but with varying and sometimes opposite effects. Saline intrusion (in part due to sea level rise) will produce suitable conditions for shrimp farming, but the temperature increase will heighten the risk of this system [ IEFP of Vietnam, 2015 ]. Research into tolerance ranges of typical farming systems (rice, shrimp) to salinity level, temperature, and precipitation have shown that the mean temperature increase forecast in climate change scenarios may stay within the tolerance range of catfish, but negatively impact the growth of shrimp [ Hargreaves & Tucker, 2003; Phuc *et al.*, 2017 ]. Bui Quang Te (2003) noted that shrimps are very sensitive to temperature variations. If the temperature exceeds the allowable limit, it can lead to mass decrease or even death of the shrimps. For tiger shrimp, the most suitable temperature is between 28°C and 32°C. When the water temperature in the pond is 37.5°C, only 60% of shrimps survive. The Nutritionists at Kasetsart University [ Banrie, 2012 ] have also suggested that the best temperature for shrimp is between 29 and 31°C.

Precipitation also plays an important role in brackish water shrimp farming: a sudden increase or decrease in precipitation will greatly affect the growth and development of shrimp: heavy rains induce a drop of salinity, and affects pH in ponds, which cause the shrimp to be shocked, die or grow slower.

## 2.3 Vulnerability assessment and adaptation to climate change

As far as adaptation policies are concerned, the identification of exposure and the assessment of vulnerability are very important steps to build adaptive solutions [Smajgl *et al.*, 2015a].

Many approaches have been proposed in the literature to identify vulnerable areas. As an example, Hailegiorgis *et al.* (2018) used an agent-based model of agricultural production and household incomes to identify vulnerable areas depending on their adaptive capacity (among other factors). In their study, Mackay & Russell (2011) used the Comparative Vulnerability and Risk Assessment (CVRA) methodology and framework to estimate overall vulnerability given five factors: population, poverty, agriculture and livelihoods, industry and energy, and urban agglomerations and transport. Vu Thuy Linh (2021) proposed tools to support vulnerability assessment based on GIS, remote sensing and the analytic hierarchy proces. These tools are effective in a specific climate model, but they are difficult to apply in other climate models (there are at least 31 models, Chapter 1).

In addition, it is necessary to determine the vulnerability based on dynamic weather factors, which come from a variety of weather scenarios proposed. With a dynamic of socio-economic data, vulnerability assessment is a big challenge as a result of variable factors, which need to be reassessed every year for annual land-use plans.

Therefore, there is a need for dynamic assessment tools to be applied in flexible climate change adaptation frameworks. Some models propose to formulate the choice of crop rotation as a multi-criteria decision problem: for each plot, the farmer chooses a crop rotation, according to an evaluation at farm level of several criteria (financial risks, expected incomes, workload and farmer habits) [Martel *et al.*, 2017]. Other works focus only on the crop allocation problem. Houet *et al.* (2010) consider the crop allocation problem as an optimization problem, and solve it by computing the maximal flow of the possible transition graph. For the case of Viet Nam, land use change models have been applied in the northern mountainous regions of the country [Castella *et al.*, 2014; Le *et al.*, 2010] and in the central mountainous areas. In the Mekong Delta, Truong *et al.* (2015) showed the interest of using an agent-based model to study land-use changes in a small-scale area at village level.

# 3. Model proposed for climate change adaptation

In this section, we present LUCAS (Land Use Change for Adaptation Strategies), the land use change model we have developed to study and assess adaptation strategies. The purpose of this model is twofold: (i) to compute the land use areas exposed to risks due to climate change effects, and (ii) to simulate the land use changes in the Mekong Delta year by year under the influence of adaptation strategies at various levels. Land use patterns are affected by temperature, precipitation, and salinity intrusion during the dry season.

In recent years, many models have been developed to simulate land use change, in particular in agricultural territories [ Janssen & van Ittersum, 2007 ]. In this context, many works have highlighted the importance of the farm scale for understanding the evolution and dynamics of agricultural landscapes [ Houet *et al.*, 2010; Schaller *et al.*, 2012 ]. Other works have also highlighted the impact of social influences on farm management choices [ Cullen *et al.*, 2020 ].

Agent-based modelling is a particularly suitable approach to study the system at this scale, and the complex interactions between environment and society. This approach consists in explicitly representing the actors composing the system in the form of autonomous and heterogeneous computer entities in interaction, referred to as agents. Agent-based models are useful not only in analysing socio-environmental systems or predicting management outcomes [ Rounsevell *et al.*, 2012; Schulze *et al.*, 2017 ], but also for highlighting emergent behaviours resulting from governance choices [ Bourceret *et al.*, 2021 ].

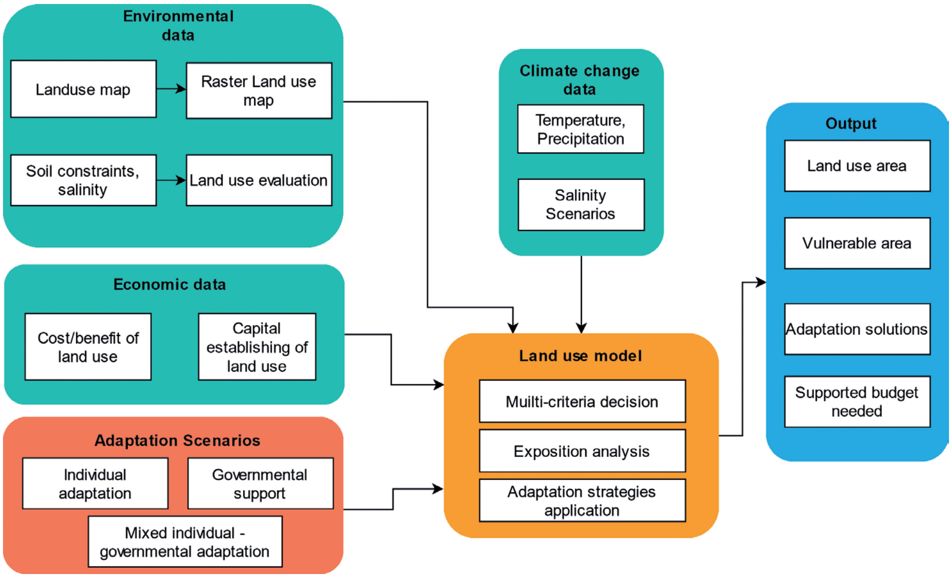
LUCAS is based on this modelling approach. The entities modelled as agents are the farmers who will have to make decisions concerning the type of land-use to implement for their agricultural parcels.

## 3.1 Overview of the model

The conceptual model is presented in Figure 10.4. As mentioned before, the dynamics of the model come from the change in land use of agricultural parcels: each simulation step (representing one year), farmers select the appropriate type of land use using multi-criteria decision-making. Four criteria are used: profitability, land suitability, capacity for conversion to other land uses, and influence of other farmers. Thus, land use decisions are based on socio-economic and environmental factors, which include soil characteristics, salinity, and dyke-protected areas. In the land use change process, the level of exposure of agricultural land use types is assessed considering the influence of temperature and precipitation during the dry months of the year.

For the spatial component, the model is based on a raster representation of the study area, *i.e.* an image made up of pixels. Using LUCAS thus requires importing the raster map of the land use of the area at the date corresponding to the beginning of the simulation. We consider six possible types of land use for the study area: 2 rice crops, 3 rice crops, fruit trees, annual crops, aquaculture, and rice-shrimp rotation.

[ Figure 10.4 ]
Conceptual structure of the LUCAS model



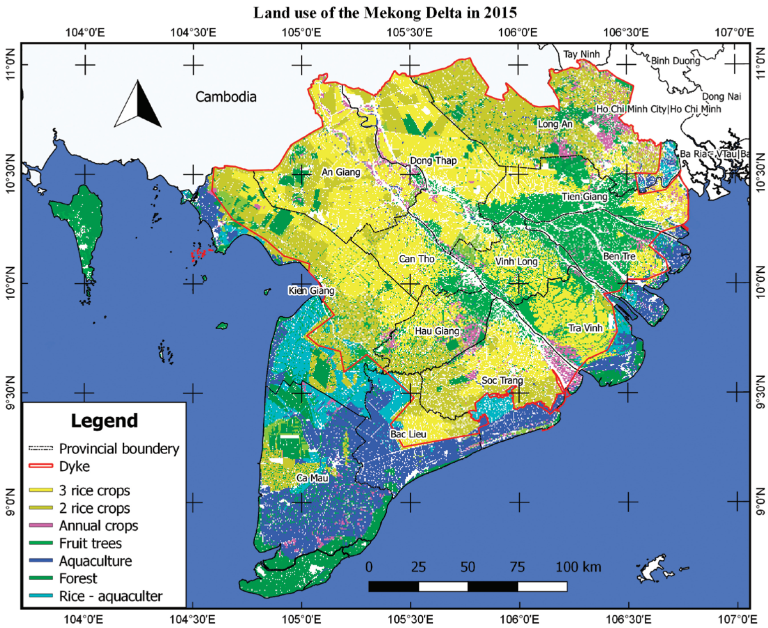

## 3.2 Scales and entities represented

The simulation model has been designed to be executed at the scale of the Mekong Delta region (around 40,500 km$^2$). The smallest spatial units taken into consideration are farmer's agricultural parcels. The simulations are launched from a specific starting year (2015), and last 15 years (to 2030), each simulation step representing one year. Figure 10.5 shows the 2015 land use map for the Mekong Delta.

The data object of the model is shown in Figure 10.6 the main type of agents in the model are farmers. As the model's objective is not precisely representing the geometry of each agricultural parcel, but rather simulating the evolution of the territory on a large scale, we considered that a farmer-agent is characterized by one cell on the map (500 x 500 m). A cell in the map thus represents a farmer and also, at the same time, his/her agricultural parcels with their land use type. In this map, we only select the six dominant land uses: 3 rice (*i.e.* 3 rice crops per year), 2 rice, Vegetables, Aquaculture (Shrimp), Fruit trees, Rice - shrimp.

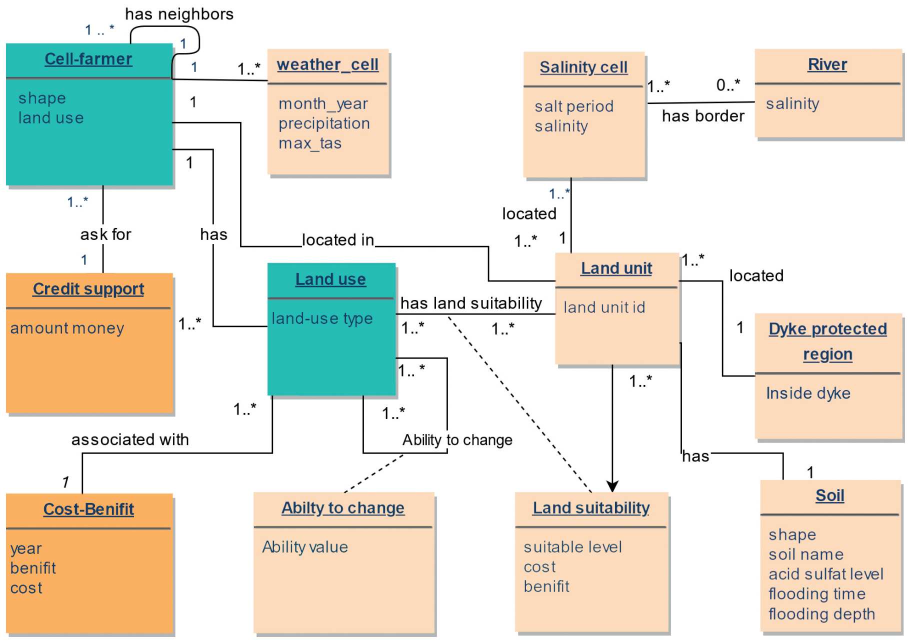
Each cell is located in a land unit region which is a spatial component with soil properties (texture, acid sulphate level, time and depth of flooding), and salinity (salinity level and duration). The land unit map in this study is overlaid with soil and water layers [ Figure 10.7 ], in which each soil object is made up of a soil name, and acid sulphate level (active or potential acid sulphate depth). Also, the water properties of each land unit compose its salinity and salinity duration. Based on land units and land use types, a land suitability table was generated using the land evaluation method, [ FAO, 1981 ] and classified into 4 levels: S1: Highly suitable; S2: suitable; S3: Lightly suitable and N: Not suitable. Thus each Cell can refer to the most suitable land use in the land suitability table.

[ Figure 10.5 ]
**The land use map of the Mekong Delta in 2015**

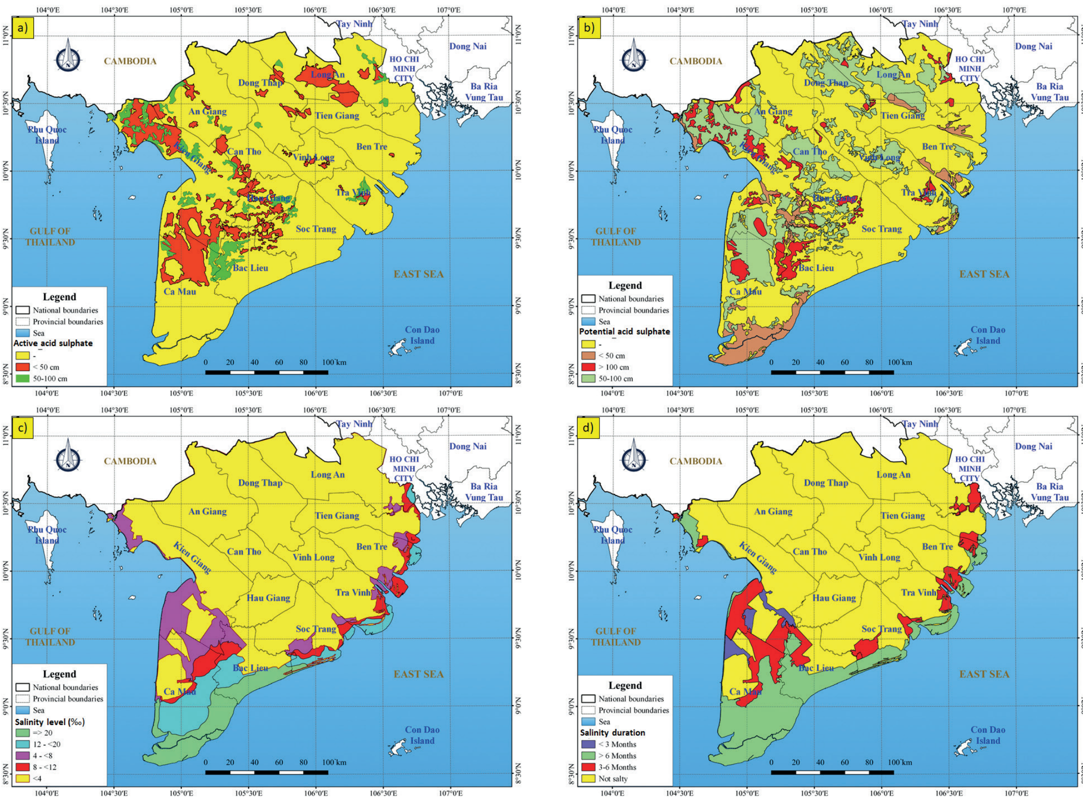



Source: Generated from land use map of 13 provinces in the Mekong Delta, MoNRE, 2015.

[ Figure 10.6 ]
**Entities of the LUCAS model**



[ Figure 10.7 ]
**Property layers of the land unit map**




**a) Active acid sulphate layer**
**c) Salinity level**

**b) Potential acid sulphate layer**
**d) Salinity duration**

Source: Land Resources Department - CTU, 2014.

For each land use, a data table registers the ability to change from each land use to other land use types. This ability measures how easily one land use can change to another land use, in terms of technique and capital. This data table is collected by local agricultural experts as in Table 10.1.

As presented above, individual adaptations are mainly driven by economic factors (in a suitable environmental context). This can be explained by the existing economic benefit of shifting from the dominant land use in the Mekong Delta [Nguyen Hong Thao *et al.*, 2019]. Thus cost and benefit for each land use is coded in a data table in the model, to be used for land use multi-criteria analysis. In this model data is collected as in Table 10.2.

## 3.3 Process overview and scheduling

The model can be summarized by three main dynamics: (i) the annual farmers' decision to change their parcel land use type, (ii) the

[ Table 10.1 ]

**Ability level of changing among the land use types**

| | 3 rice seasons | 2 rice seasons | Vegetables | Shrimp | Fruit trees | Rice - shrimp |
|---|---|---|---|---|---|---|
| 3 rice seasons | 1 | 1 | 0.75 | 0 | 0.5 | 0 |
| 2 rice seasons | 1 | 1 | 0.5 | 0 | 0.75 | 0 |
| Vegetables | 0 | 0.5 | 1 | 0 | 0.5 | 0 |
| Shrimp | 0 | 0 | 0 | 1 | 0 | 0.5 |
| Fruit trees | 0 | 0 | 0 | 0.25 | 1 | 0 |
| Rice - shrimp | 0 | 0 | 0 | 0.75 | 0 | 1 |

Note: 0- Not able to change; 1 - easy to change.

[ Table 10.2 ]

**Benefit of dominant land use types in the Mekong Delta**

| Land use type | Profit (Million VND/ha) | Cost (Million VND/ha) | Labor (Days/ha/year) |
|---|---|---|---|
| 3 rice seasons | 58.48 | 52.31 | 92 |
| 2 rice seasons | 42.42 | 34 | 78 |
| Rice - shrimp | 86.62 | 61.38 | 86 |
| Fruit trees | 184.00 | 62 | 115 |
| Vegetables | 88.07 | 114.24 | 233 |
| Aquaculture (Shrimp) | 277.23 | 308.18 | 217 |

Source: Data survey in Soc Trang Province in 2018, Nguyen, 2021.

computation of exposition to climate change-related risks of the land cells, and (iii) the application of adaptation strategies (if any) based on the risk evaluation. Adaptation strategies can be either no strategy (base scenario), individual-level adaptation (scenario 1), government-level adaptation (scenario 2), or mixed-level adaptation (scenario 3).

## Land use change due to individual decision

At each simulation step (*i.e.* one year), farmer-agents are able to change their land-use type. To this end, each farmer-agent first evaluates the benefits of converting to each existing land-use type using a weighted mean of the 4 criteria, and then selects the land-use type that maximizes it. In order to take the intrinsic inertia of these production change processes into account, we consider that only some of the farmers (randomly selected) will be able to change their land use at each simulation step. This number of farmers will be defined from a conversion rate parameter.

For *i*, a farmer-agent, *l*, their current type of land use, and l' the new land use type to evaluate, the benefit to convert from type *l* to *l'* is calculated as follows:

$$convertibility(i,l,l') = \frac{\sum_{c \in \{profit,suitability,ability,others\}} W_c \times Val_C(i,l,l')}{\sum_{c \in \{profit,suitability,ability,others\}} W_c}$$

– $W_c$ the weight of the criteria *c*. Values are obtained when calibrating the simulated map in 2020 with the land use map in 2020.
– $Val_c(i, l, l')$ the value of the criteria *c* for a conversion from the land-use type *l* to the land use *l'* for the farmer agent *i*.

4 criteria are taken into account:

▸ Profit: The yearly profitability of each land use type is one of the main reasons leading to land use conversion. This factor is an economic adaptation when people try to find a suitable farming model to improve their lives.

▸ (Land) suitability: This criterion represents the adaptation of a land-use type (*i.e.* an agricultural activity) to a specific environment. When environmental conditions change, the adaptation level of land-use types also changes. The suitability evaluation is performed according to the FAO's work [ FAO, 1981 ]. The 4 suitability levels are standardized from 0: non suitable to 1: most suitable.

▸ Ability (to convert): This criterion measures how convenient it is to switch from the current land-use to another one. In farming systems, the transition from one type to another depends on the conditions in which new farming types can be established. In some cases, some switches (*e.g.* from shrimp to fruit trees) will be very difficult, whereas a switch from deep shrimp ponds in intensive shrimp farming to rice cultivation will not be possible. This ability criteria value is computed given a table of values associated to each transition LandUse1 -> LandUse2.

▸ (Influence of) others: As shown by some studies, farmers are influenced in their production choices by their neighbours [ Le Quang Tri *et al.*, 2008 ]. The value of this criterion corresponds to the proportion of farmer agents in the immediate neighbourhood (the 8 cells around the cell representing the farmer) having chosen this type of land use.

## Parameter and indicators of the model

In implementing the adaptation strategies, there are the key factors that should be taken into account in order to measure the impact of climate change in agricultural land use. We first identify the main indicators of climate changes, then define the parameters, so that the model can be used for analysing possible solutions.

▸ Exposure area: In case of temperature and precipitation changes in the dry season, the exposure areas of rice and shrimp would be damaged.

▸ Vulnerability area of rice and aquaculture: The areas of rice and aquaculture still facing risk of damage when the adaptation strategies are applied.

▸ Tolerance parameters for rice: The sensitivity of rice is identified by the maximum temperature of rice or the minimum precipitation tolerated. These are used to identify the exposure area of rice.

▸ Tolerance parameters for shrimp: the two parameters implemented to calculate the exposure of shrimp are the maximum tolerable temperature and maximum rainfall sensitivity.

▸ Adaptation parameters: In this model we try to identify the adaptation percentage parameter for individual farmers and the government. In which there are 4 parameters: percentage of rice farmers self-adapted, percentage of aquaculture farmers self-adapted, percentage of rice farmers and aquaculture farmers supported by the Government. These parameters are detailed in the adaptation strategies.

## Exposure evaluation

In order to inform the adaptation strategies, the model computes the areas that can be exposed to risks from effects of climate change: we consider here only effects of temperature, and precipitation evolution and salinity intrusion by SLR. Two types of crops are distinguished: crop culture (rice, short-term crops, fruit trees) and aquaculture (shrimp).

Concerning crop culture, if the cell concerned is located in an area protected by dyke systems, but the monthly highest temperature in the dry season (December to May) exceeds the crop tolerance threshold and the rainfalls are lower than the tolerance rainfall threshold, the crop is considered risk-exposed. Aquaculture cells are evaluated as risk-exposed when precipitation is above the cut-off threshold (reducing salinity in the ponds). The total area at risk for aquaculture and crop culture is determined by the total area at risk for each type.

## Adaptation strategies

In the base scenario, no adaptation strategy is applied. When one of the following scenarios of adaptation is selected, adaptation is made on the cells at risk. Each of the strategies is characterized by a set of parameters, mainly representing the rate of adoption of adaptation strategies.

We consider three types of adaptation strategies:

▸ Individual-level adaptation: farmers will seek an appropriate land use to eliminate risks. To this end, the ones who have chosen “3 rice crop” land use will change to a more adapted one, *e.g.* “2 rice crop” land use. If the land use is “shrimp”, the farmer will have to invest money to be able to use new techniques to avoid the risk. Two parameters control this scenario: the rates of farmers having 3-rice crops (resp. aquaculture) having adopted this adaptation strategy. The adapted land use types supply less profit than the intensive ones, but in terms of total profit, farmers can avoid a loss of capital for the third crop (for rice), and very heavy capital investment for shrimp.

▸ Government-level adaptation: the government will help farmers eliminate risk; its policy focuses on two axes: investing in infrastructure, such as dykes, sluice gates, irrigation canals (which will help farmers with rice-crops), and helping people with capital (through helping them to access bank loans at low interest rate) and technology to adapt (which will mainly help farmers with shrimp aquaculture). Farmers will keep the same land use, but will have a certain probability of eliminating their risk exposition. Two parameters control this scenario: the rates of farmers having 3-rice crops (resp. aquaculture) that will be helped by this adaptation strategy.

▸ Mixed-level adaptation: this scenario combines individual adaptation and government-based adaptation. The government-based part is also more realistic, as it is based on Decree 35 dated in 2015 [Government of Viet Nam, 2019] and updated by Decree 62/ND-CP dated in 2019 [Government of Viet Nam, 2019]. In these decrees, economic support is invested to convert from 3 rice crops to 2 rice crops and shrimp rice farming with 1,000,000 VND/ha.

For intensive shrimp production, policy support allows people to continue to borrow from banks to continue their activities the following year. Two parameters control this scenario: the rates of farmers having 3-rice crops (resp. aquaculture) that will be helped by this adaptation strategy.

# 4. Climate change adaptation strategies with modelling approach

Based on the approach proposed by [Haasnoot *et al.*, 2013], we have used our proposed dynamic model to assess the adaptation strategies of farmers in land use adaptation. In the following, we first identify a climate and sea level rise scenario, then evaluate the vulnerabilities of the various land uses. Based on these results, adaptive strategies have been proposed and assessed to reduce their impact.

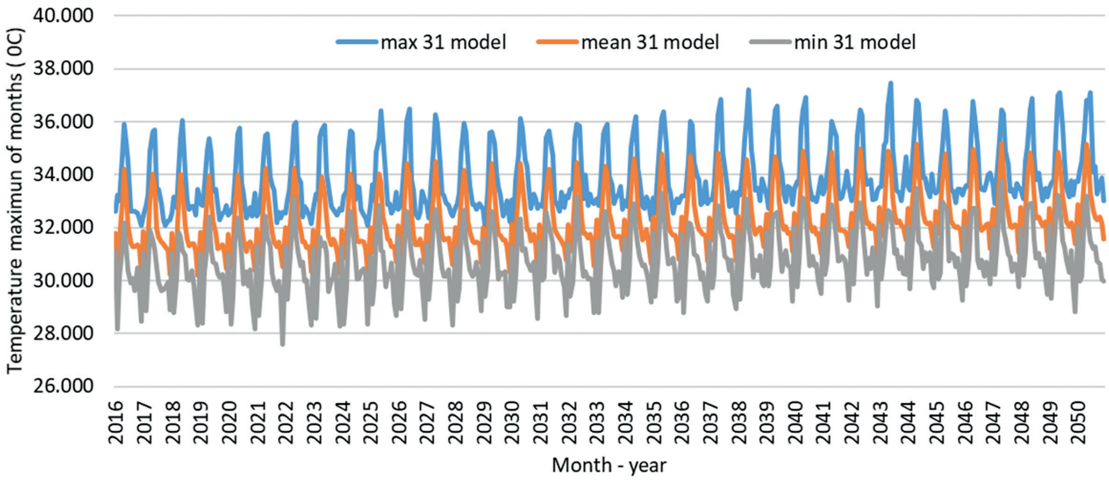
## 4.1 Scenarios of climate change in 2030 and 2050

In order to detect exposure to effects of climate change for different farming systems, 4 scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 have been simulated [Chapter 1]. Under the Paris Agreement on climate change, all countries must take action to keep global temperature rise below 2°C above pre-industrial levels [UNFCCC, 2015]. However, the goal is to make every effort to shift to RCP2.0, which is already almost out of reach. Thus we have chosen to use data from the RCP8.5 scenario as input data in our scenarios. Average, maximum, and minimum temperature per month from 31 climate models [Chapter 1] for the period 2016 to 2050 in the Mekong Delta is plotted in Figure 10.8. We can observe that temperatures have a clear increasing trend. This phenomenon could lead to extreme events like drought and saline water intrusion like those that occurred in 2016 and 2020 in the Mekong Delta.

Precipitation in the Mekong Delta has been calculated using the monthly average of all the pixels in the Mekong Delta mainland. The chart in Figure 10.9 displays the data for maximum, minimum and average precipitation from 31 climate models [Chapter 1] for( the period 2016 to 2050. We can observe that, maximum total precipitation in the rainy season is nearly the same, and that — conversely — rainfall in the dry season should increase. As analysed in Chapter 1, daily temperature variations from one day to the next can be huge, which may strongly impact aquaculture farming systems.

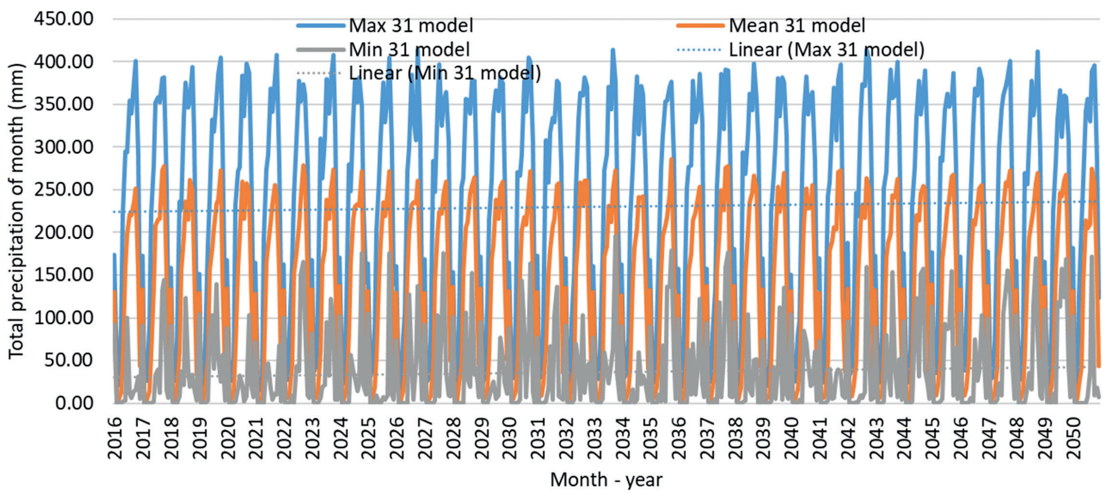
Figure 10.10 shows the salinity intrusion map in 2030 under the scenarios RCP4.5 and 8.5 (cf. Chapter 9), taking into account the dyke and sluice gate systems; it takes into account increase of saline intrusion due to sea level rise and subsidence, and the current salinity in dry season. This kind of map is used to evaluate the exposed land use types impacted by salinity.

[ Figure 10.8 ]
**Monthly maximum temperature of the Mekong Delta until 2050**



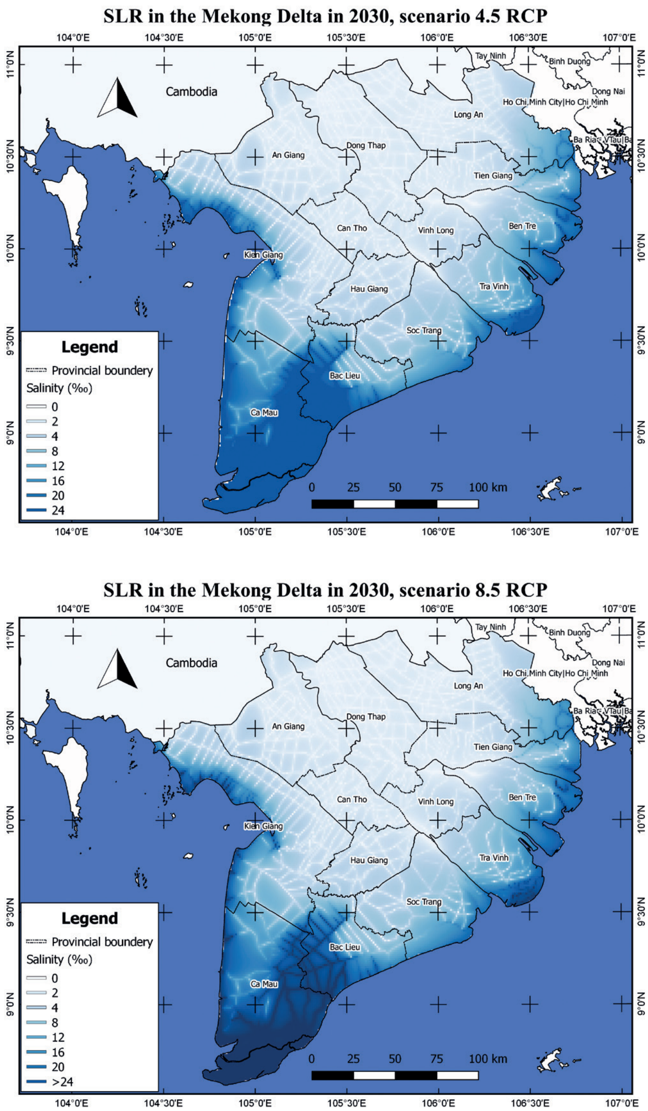

■ Source: Generated from 31 climate models with RCP8.5, Chapter 1.

[ Figure 10.9 ]
**Monthly total precipitation from 2016 to 2050**




■ Source: Chapter 1, RCP8.5.

[ Figure 10.10 ]
**Salinity map of the Mekong Delta in 2030 with RCP4.5 and 8.5 scenarios**

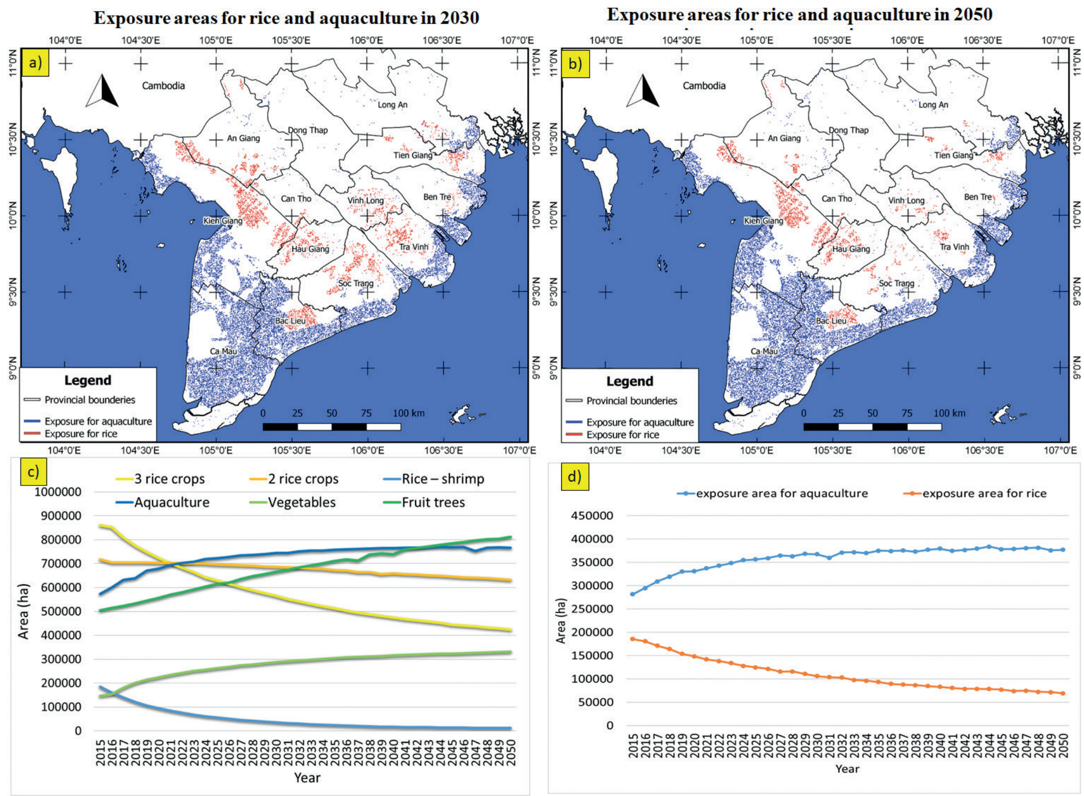



Source: Generated from Chapter 9, RCP4.5 and RCP8.5.

## 4.2 Using model to analyse impacts of climate change on land use

A very important step in the adaptive pathway approach is being able to dynamically assess exposure of land uses to climate change. To evaluate the worst case, we use the presented model to evaluate the affected areas with standard land use types, where the weather scenario is aggregated by taking the highest temperature, and lowest precipitation for each month from 31 climate models, and salt intrusion from the RCP8.5 scenario.

[ Figure 10.11 ]
Land use change and exposure areas for rice and shrimp until 2050




The main land use types in the Mekong Delta are aquaculture and rice, and are sensitive to extreme events caused by climate change. Their impact (and in particular saline intrusion) is stronger during the dry season (from December to end of April). For this reason, we consider this specific period of time to explore possible climate thresholds that could impact agricultural activities.

As far as rice is concerned, temperature and rainfall in the dry season affect the structure of the crop, and saline intrusion affects crop tolerance. When a system of dykes and sluice gates prevents saline intrusion in the fields, the cultivation area is not directly affected. Concerning shrimp farming, saltwater intrusion appears to be favourable for shrimp farming. However, unusual climatic changes during the dry season would affect aquaculture. As described in the section above, a sudden increase in precipitation over several days, or high temperature, affects the growth of shrimps.

Although many studies (c.f. Section 2.2) have studied the tolerance of various crops and aquaculture to effects of climate (in particular thresholds of minimum and maximum temperature and precipitation), it is hard to determine which is the impact threshold. Looking historical precipitation in the dry season in the coastal provinces of the Mekong Delta, Truong

(2018) found that total dry season precipitation for the 8 provinces (Bac Lieu, Ben Tre, Ca Mau, Kien Giang, Long An, Soc Trang, Tra Vinh, Tien Giang) varied from 200 to 400 mm per season. In 2016, the precipitation in this region was lower than 200 mm, which was one of the main causes of the 2016 drought. Associated with risk for shrimps, the high precipitation in 2011–2012 was associated with risk in the Mekong Delta: the shrimp damage of Soc Trang in 2011 was over 20,000 ha, compared with a lower 9,000 ha in other years [DARD Soc Trang, 2012]. As a typical case, we selected a threshold of temperature greater than 33°C and maximum precipitation in a month under 120 mm for rice, and greater than 33°C or maximum precipitation greater than 400 mm for aquaculture, to provide a detailed look at the impacts of climate on land use. Figure 10.11 shows the results when the model takes only the criteria influenced by the weather into account, without considering additional adaptation strategies. The affected areas of rice (red areas) and shrimp (blue areas) are displayed in Figure 10.11 for the years 2030 and 2050. Simultaneously, the surface area for each land use type is plotted; it highlights the fact that the trend of converting from 3 rice crop to other crops (2 rice crops, vegetables, fruit trees), and from cultivated land to shrimp, should continue in the next few years due to saline intrusion from sea level rise.

The results of these initial experiments have illustrated the evolution of land use under the sole influence of multi-criteria selection, without taking adaptation strategies into account. In the following section, we go further by introducing adaptation strategies to face the risks induced by climate change.

## 4.3 Adaptation strategies based on land use adaptation model

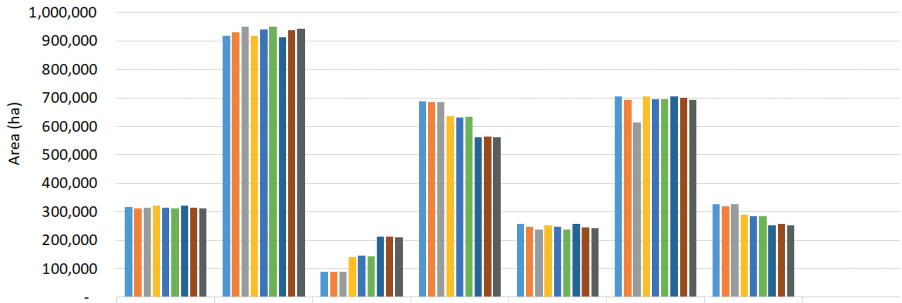
The LUCAS model is used to estimate land use conversion under environmental and socio-economic changes, and to test the adaptation scenarios. The 3 adaptation scenarios are defined in Section 3.3.

### Individual adaptation strategies

The simulations with scenario 1 represent the vulnerable area with reference to the value of the two parameters: the Proportions of crop (resp. rice-shrimp) farmers applying adaptation strategy. Figure 10.12 shows that, when the proportion of households adapting is high, the area of land with 3 rice crops decreased while other crops increased. The rice - shrimp area is still high due to a decrease in conversion to aquaculture, which is reflected in the small aquaculture area. Besides, the vulnerable area for rice and shrimp significantly decreased, which is the basis for convincing people to choose adaptation solutions and choose suitable farming systems to reduce risk.

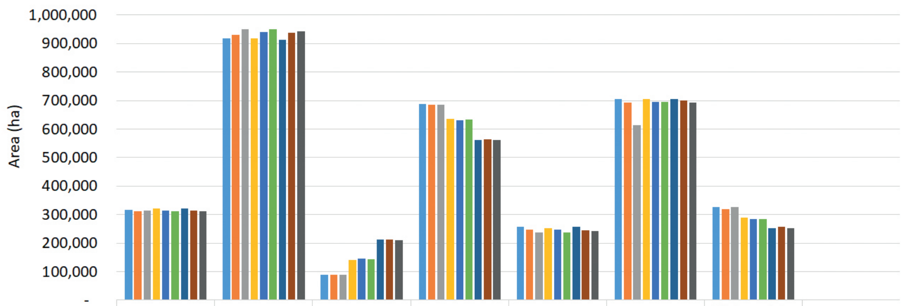
The results show that vulnerable areas will be reduced when farmers select the suitable land use in relation with climate change: for aquaculture households investing in mitigating the impact of weather conditions, farmers stopped converting from rice-shrimp to shrimp. It appears that the higher the number of households applying adaptation measures, the less the remaining exposed area decreases. In addition, we can observe that the most influential parameter is the rate of rice farmers applying adaptation strategies (this could be due to the larger surface area of rice crops in the Delta). Especially when this rate is 90% for both land use groups, the area at

[ Figure 10.12 ]
Land use area in 2030 with different adaptation percentage in scenario 1



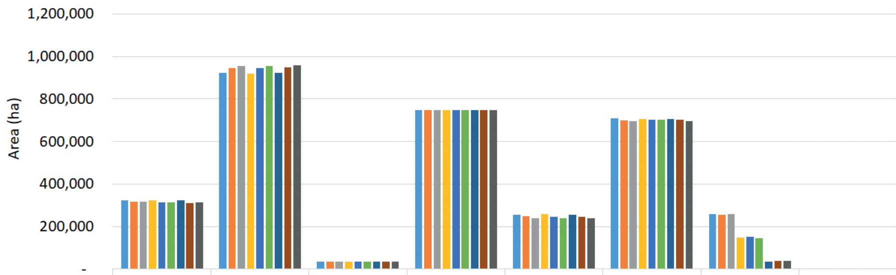

| | 3 rice | 2 rice | Rice – shrimp | Aquaculture | Vegetable | Fruit trees | Vulnerable for aquaculture | Vulnerable for rice |
|---|---|---|---|---|---|---|---|---|
| Agro 0.3- Aqua 0.3 | 316,750 | 917,600 | 88,475 | 688,575 | 256,200 | 706,025 | 325,850 | 1,225 |
| Agro 0.6- Aqua 0.3 | 312,425 | 931,575 | 89,900 | 686,625 | 247,875 | 693,000 | 319,375 | 200 |
| Agro 0.9- Aqua 0.3 | 312,875 | 950,325 | 89,400 | 686,250 | 238,475 | 614,000 | 325,975 | - |
| Agro 0.3- Aqua 0.6 | 320,675 | 917,625 | 141,025 | 635,300 | 251,350 | 705,875 | 290,225 | 1,450 |
| Agro 0.6- Aqua 0.6 | 313,850 | 940,750 | 144,575 | 630,225 | 247,025 | 695,075 | 285,050 | 50 |
| Agro 0.9- Aqua 0.6 | 311,925 | 950,675 | 143,925 | 633,300 | 237,875 | 695,575 | 285,100 | - |
| Agro 0.3- Aqua 0.9 | 321,075 | 914,200 | 212,350 | 560,975 | 255,925 | 705,975 | 252,400 | 1,300 |
| Agro 0.6- Aqua 0.9 | 315,100 | 937,525 | 211,400 | 563,100 | 244,400 | 699,200 | 256,975 | 50 |
| Agro 0.9- Aqua 0.9 | 312,850 | 944,075 | 211,100 | 561,600 | 241,800 | 692,550 | 252,900 | - |

[ Figure 10.13 ]
Land use area in 2030 with different adaptation percentage in scenario 2




| | 3 rice | 2 rice | Rice – shrimp | Aquaculture | Vegetable | Fruit trees | Vulnerable for aquaculture | Vulnerable for rice |
|---|---|---|---|---|---|---|---|---|
| Agro 0.3- Aqua 0.3 | 316,750 | 917,600 | 88,475 | 688,575 | 256,200 | 706,025 | 325,850 | 1,225 |
| Agro 0.6- Aqua 0.3 | 312,425 | 931,575 | 89,900 | 686,625 | 247,875 | 693,000 | 319,375 | 200 |
| Agro 0.9- Aqua 0.3 | 312,875 | 950,325 | 89,400 | 686,250 | 238,475 | 614,000 | 325,975 | - |
| Agro 0.3- Aqua 0.6 | 320,675 | 917,625 | 141,025 | 635,300 | 251,350 | 705,875 | 290,225 | 1,450 |
| Agro 0.6- Aqua 0.6 | 313,850 | 940,750 | 144,575 | 630,225 | 247,025 | 695,075 | 285,050 | 50 |
| Agro 0.9- Aqua 0.6 | 311,925 | 950,675 | 143,925 | 633,300 | 237,875 | 695,575 | 285,100 | - |
| Agro 0.3- Aqua 0.9 | 321,075 | 914,200 | 212,350 | 560,975 | 255,925 | 705,975 | 252,400 | 1,300 |
| Agro 0.6- Aqua 0.9 | 315,100 | 937,525 | 211,400 | 563,100 | 244,400 | 699,200 | 256,975 | 50 |
| Agro 0.9- Aqua 0.9 | 312,850 | 944,075 | 211,100 | 561,600 | 241,800 | 692,550 | 252,900 | - |

[ Figure 10.14 ]
Land use area in 2030 with individual and governmental mixed adaptation in scenario 3




| | 3 rice | 2 rice | Rice – shrimp | Aquaculture | Vegetable | Fruit trees | Vulnerable for aquaculture | Vulnerable for rice |
|---|---|---|---|---|---|---|---|---|
| Agro 0.3- Aqua 0.3 | 322,675 | 922,275 | 35,625 | 747,575 | 255,625 | 707,525 | 257,825 | 1,425 |
| Agro 0.6- Aqua 0.3 | 315,175 | 943,900 | 35,575 | 747,900 | 248,375 | 698,850 | 255,825 | - |
| Agro 0.9- Aqua 0.3 | 315,225 | 954,850 | 35,600 | 747,425 | 240,450 | 695,575 | 256,900 | - |
| Agro 0.3- Aqua 0.6 | 322,925 | 919,100 | 35,550 | 747,150 | 257,300 | 706,800 | 149,325 | 1,300 |
| Agro 0.6- Aqua 0.6 | 312,375 | 945,100 | 35,600 | 747,175 | 246,050 | 701,300 | 151,125 | - |
| Agro 0.9- Aqua 0.6 | 313,775 | 954,475 | 35,650 | 747,875 | 239,925 | 701,225 | 145,125 | - |
| Agro 0.3- Aqua 0.9 | 322,475 | 922,025 | 35,625 | 747,800 | 254,825 | 706,200 | 35,875 | 1,350 |
| Agro 0.6- Aqua 0.9 | 311,425 | 947,775 | 35,650 | 748,700 | 247,050 | 703,375 | 37,575 | 50 |
| Agro 0.9- Aqua 0.9 | 312,875 | 959,775 | 35,625 | 748,250 | 240,350 | 696,125 | 36,825 | - |

risk is reduced to the lowest level. However, in practice, this still depends on the percentage of households able to apply adaptation measures, and the percentage of households that are mainly attracted by the profit factor.

## 4.4 Government strategies for supporting adaptive plans

More generally, Figure 10.13 summarises the analysis of government support for both rice crops and aquaculture, controlled by two parameters: the rates of farmers having 3-rice crops (resp. aquaculture) that will be helped by this adaptation strategy. Also, Figure 10.13 shows the surface area of each land use and the percentage of areas at risk. The results clearly show that the higher the adaptation rate, the smaller the vulnerable area. With government assistance on technical support, infrastructure investment and economic policies, vulnerability will be reduced. This fact helps to support advocacy efforts, integration of recommendations, and training activities on agricultural techniques to limit the impacts of climate change, while the government can maintain the agro-economic development rate thanks to high-profit land-use.

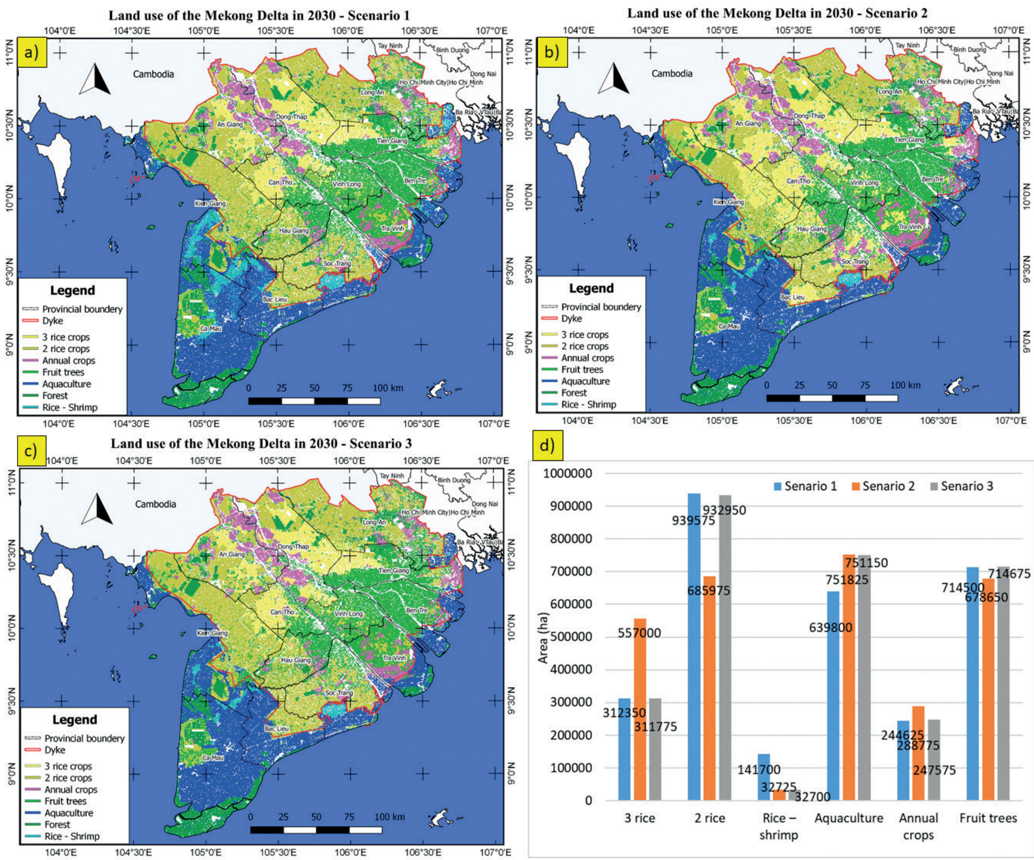
## 4.5 Optimized adaptive scenario

In scenario 3, the support rate and individual adaptation rates were tested with the LUCAS model, which analysed the support rates for rice growers, and rice growers with shrimp. The survey results in Figure 10.14 show that as the rate of government support increases, the area cultivated in 3 rice crops decreases thanks to the support policies. When shrimp farmers get loans and technical support for intensive shrimp farming, the area of shrimp farming increases. On the other hand, the cost of support under Decree 62 [Government of Viet Nam, 2019] for the affected area also increases when the percentage of farmers supported increases (from VND 69 billion to VND 195 billion VND/year).

## 4.6 Comparisons between the three scenarios

In order to compare the effects of each scenario visually via the land use map, we first set all the parameters to an intermediate value (we chose a medium (60%) adaptation percentage for each adaptation type). Figure 10.15 shows the comparison between the 3 scenarios on simulated land use in 2030.

[Figure 10.15]
Land use in 2030 of three adaptation strategies




a) Land use map in 2030 – Scenario 1
b) Land use map in 2030 – Scenario 2
c) Land use map in 2030 – Scenario 3
d) Land use area in 2030

Figure 10.15 shows the land use map in 2030 for 3 adaptation scenarios. The maps of scenario 1 and scenario 2 present a contrast. Aquaculture and 3-rice crop areas in scenario 1 are lower than in scenario 2: in scenario 1, because farmers selected the highly suitable land use, people had to revert from shrimp to shrimp - rice when they saw the risk of climate change. The land use map in scenario 3 [Figure 10.15c] represents a combination of scenario 1 [Figure 10.15a] and scenario 2 [Figure 10.15b]. Here, the 2-rice crop area in scenario 1 and the aquaculture area in scenario 2 were combined in scenario 3. The solution in scenario 3 shows that to maintain high profits and minimize risks due to climate risks, farmers and authorities need to coordinate, with the government advising people to choose an adaptation model, and also providing capital and technical support when people select the suitable farming system.

# 5. Conclusion

Although the impacts of climate change are still uncertain, there is a growing consensus that they will be devastating in regions such as the Mekong Delta, due to a harmful combination of its hydro-geophysical characteristics, ever-increasing anthropogenic pressure, and past choices in favouring intensive agriculture.

Faced with this threat, the effects of which are beginning to be felt, particularly with regard to the increasing salinization of soils, public authorities and farmers are not remaining inactive. The former are thinking about setting up adaptation pathways, which are less rigid than strategies planned over 10 years because they can be revised regularly, but which still presuppose rapid intervention capacities in terms of investment or financial incentives, and which in any case remain top-down strategies, and thus not necessarily always well-adapted to dynamic local conditions. The latter change their land use autonomously, under the pressure of environmental factors or changes in sectors and markets, and begin to diversify local production by also paying more attention to a rational use of the environment and inputs, but these uncoordinated changes in practice make this bottom-up strategy unlikely to scale up easily.

All of these strategies obviously interact and feedback with each other in ways that are highly dependent on local conditions and the environments involved, making any exercise in forecasting or evaluating their future impacts on Delta adaptation very tricky. Nevertheless, in order to carry out foresight exercises, many authors have chosen to focus on only one of the two approaches, providing advice and guidance to farmers or, on the other hand, proposing new planning strategies to governments. These exercises are essential for implementing adaptation policy, but so far have captured only part of the picture.

The chapter we conclude here presents an attempt to carry out the same type of foresight exercises, while making sure not to oversimplify the interrelationships between spontaneous and planned adaptation, which can be sources of innovation or major changes in the dynamics of the system considered. Constructed as a series of simulation experiments using a model called LUCAS (Land Use Change for Adaptation Strategies), this approach makes it possible to represent both individual choices and collective decisions within a single model of the geographical and environmental reality: farmers, like public authorities, are artificial computer agents programmed to perceive their simulated environment, but also to exchange with other agents, and to decide on the best action to take to satisfy a set of objectives (guaranteeing income, not depleting resources, etc.) The simulated environment and artificial agents can then be immersed in different scenarios (climatic, but also demographic, political or economic) and their performance evaluated using statistical tools equivalent to those used in reality.

Three policy scenarios, corresponding to three main management options, have been presented in this chapter, in the framework of the common climate scenario RCP8.5. The first corresponds to a *"laissez-faire"* policy on the part of the government, in which the bulk of the adaptation would rest on the shoulders of farmers, without their choices being hindered or supported by a planned policy. The second is a policy in which no autonomy is granted to farmers, with all decision making being done at the central level and then imposed on individuals. Finally, the third approach presents one way to marry these two approaches in order to maximize their respective benefits and minimize their negative feedback.

The latter is measured, unsurprisingly, as the most beneficial for all actors in the system, and appears to be an interesting way to think about and develop feasible adaptation plans. However, whatever its interest, the lesson to be learned from this chapter does not necessarily lie in this result, but rather in the methodology that made it possible. There are indeed many proposals for adaptation policies that reconcile bottom-up and top-down dynamics, but very few proposals that make it possible to assess their relevance, in advance, in different scenarios. In this respect, the LUCAS model offers a framework and a test bed that should make it possible, in the future, to explore and compare different combinations of adaptation policies, but also to co-construct these combinations and to share these results with users who are not necessarily scientists. The main characteristic of these new approaches is indeed that the dichotomy between scientists, in charge of "measuring", "understanding" or "predicting", and policy-makers who act on this information to "decide" and "act", appears to be out-dated [Edmonds & Moss 2005]. What does this imply for the design of models to support adaptation-planning activities? At least three main points:

- Promoting multidisciplinary model building: the diversity of factors that can contribute to adaptation planning requires a multidisciplinary approach to model design, associating climate scientists with ecologists, social scientists and urban planners [Masson *et al.*, 2014].

- Accepting the "necessary" complexity of adaptation models: to support creative thinking, important features of the target system (*e.g.* spatial or social heterogeneity, multi-scale interactions) must be maintained in the models, so as to provide them with sufficient heuristic power when testing options. The result is complex descriptive models [Edmunds & Moss, 2004] in which it is impossible to predict "most likely" outcomes: they are not meant to be validated and will not provide "solutions"; instead, they must be sufficiently "explorable" to describe outcomes that might be possible under certain system trajectories [ Kelly *et al.*, 2013 ], which stakeholders can then use as a starting point for their deliberations or negotiations.

▸ Supporting stakeholder engagement in model design: this engagement is essential to their effective use in planning [ Reed *et al.*, 2013 ]. It must materialize in a structured, inclusive and iterative cycle of exchanges on shared objects to support a common assessment of adaptation strategies [ Sempé *et al.*, 2006 ]. This requires the use of flexible models, which can be iteratively refined/modified and which are not tied to a given scale, so that they can be effectively manipulated by various stakeholders, each with their own perspectives [ Guyot *et al.*, 2006 ].

In this chapter, we believe we have provided a compelling example, with LUCAS, of the value of these new modelling approaches in planning the adaptation of a system as complex as the Mekong Delta to climate change. LUCAS is an open model, available in open-source[1], and can be programmed, simulated and explored on the GAMA simulation platform [ Taillandier *et al.*, 2019 ], itself the result of a long-standing scientific collaboration between Vietnamese and French researchers. It is also an evolving model, which we hope can serve as a basis for the construction of operational tools for adaptation planning in the Mekong Delta.

1. https://github.com/tcquang/MK_landuse.git

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