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Accounting for Multisectoral Dynamics in Supporting Equitable Adaptation Planning: A Case Study on the Rice Agriculture in the Vietnam Mekong Delta

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Key Points:

- Understanding who wins and who loses under different futures can help planners in anticipating and ameliorating future inequalities
- We show how inequality patterns are sensitive to external uncertainties and adaptation policies
- Exploring inequality patterns requires accounting for multisectoral dynamics, which often has implications for the modeling choices

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract The need for explicitly considering equity in climate change adaptation planning is increasingly being recognized. However, evaluations of adaptation often adopt an aggregated perspective, while disaggregation of results is important to learn about who benefits when and where. A typical example is adaptation of rice agriculture in the Vietnam Mekong Delta (VMD). Efforts focused on flood protection have mainly benefitted large-scale farmers while harming small-scale farmers. To investigate the distributional consequences of adaptation policies in the VMD, we assess both aggregate total output and equity indicators, as well as disaggregated impacts in terms of district-level farming profitability. Doing so requires an adequate representation of the multisectoral dynamics between the human and biophysical systems which influence farming profitability. We develop a spatially explicit integrated assessment model that couples inundation, sedimentation, soil fertility and nutrient dynamics, and behavioral land-use change and farming profitability calculation. We find that inter-district inequality responds in a non-linear way to climatic and socio-economic changes and choices of adaptation policies. The patterns of who wins and who loses could change substantially when a different policy is implemented or if a slightly different uncertain future materializes. We also find that there is no simple ranking of alternative adaptation policies, so one should make trade-offs based on agreed preferences. Accounting for equity implies exploring the distribution of outcomes over different groups over a range of uncertain futures. Only by accounting for multisectoral dynamics can planners anticipate the equity consequences of adaptation and prepare additional measures to aid the worse-off actors.

Plain Language Summary Adaptation planning should strive for not only maximizing welfare outcomes, but also ensuring equitable outcomes among affected people. Supporting equitable adaptation planning requires looking beyond only at aggregated indicators. In this study, we evaluate the distributional outcomes of alternative adaptation policies under various scenarios to the profitability of rice farming in the Vietnam Mekong Delta. To do this, we have to explicitly account for multisectoral dynamics surrounding the agriculture sector. This is because adaptation policies and uncertain factors target different parts of the systems and interact in a non-linear way. Hence, if we zoom in to just one sector (e.g., flood impacts to farmer's profitability), we would overlook the inherent interconnectedness between the different sectors in the system. We therefore develop an integrated assessment model encompassing multiple sectors, including inundation and sedimentation dynamics, soil fertility and nutrient dynamics, and behavioral land-use change and farming profitability. Using this model, we find that even a slight change in uncertain scenarios or implemented adaptation policies could lead to distinctive inequality patterns between farmers across the 23 districts. Our study suggests that to support an equitable adaptation planning, one must incorporate the complex multisectoral dynamics that give shape to inequalities.

1. Introduction

Home to over 500 million people (Kuenzer & Renaud, 2012), the world's deltas are critical for economic activities and global food production. Human activities, such as groundwater abstraction, sand mining,

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and hydropower dam development, have altered the (bio)physical characteristics of deltas through various physical mechanisms including land subsidence, sediment starvation, discharge regime alteration, morphological changes, coastal erosion, and salt intrusion (Minderhoud, Middelkoop, et al., 2020; Renaud et al., 2013; Syvitski et al., 2009; Whitehead et al., 2019). The changes in the (bio)physical character of deltas affect people's vulnerability in multiple ways: Changing hydrological regimes implies increasing flood hazard; reduced sediment supply means less aggradation of land and decreased soil fertility; coastal erosion and salt intrusion reduce the land's suitability for various crops, to mention a few. Vulnerability is further amplified by increasing exposure to natural hazards and weather extremes triggered by climate change and sea level rise (Chen & Mueller, 2018; Giosan et al., 2014; Kuenzer & Renaud, 2012; Moser et al., 2012).

Impacts of climate change and (bio)physical changes of the delta on human vulnerability vary across people, depending on their social, economic, and geographical background (Adger et al., 2009; Below et al., 2012; Call et al., 2017; Füssel, 2010; Thomas et al., 2019). Climate change adaptation planning, however, often uses aggregated indicators, disregarding equity considerations (Kolstad et al., 2014; Stanton et al., 2009). For example, adaptation planning studies by Ahmed et al. (2017), Campos et al. (2016), Radhakrishnan et al. (2017), Ranger et al. (2013), and Smajgl et al. (2015) all report on aggregated indicators such as flooded area, total area having a certain salt concentration, number of people exposed to flooding, total paddy yield, and total economic value in a flood prone area. If little to no attention is given to assessing which groups of the population are more affected, the recommended adaptation policies might fail to target specific vulnerable groups within the population. Such distribution-blind adaptation might reduce the vulnerability of one group of people at the expense of another (Atteridge & Remling, 2018).

There are two important elements that should be included when accounting for equity in climate change adaptation planning: the unit (what is being distributed) and the scope (to whom it is being distributed) of the distribution (Page, 2007). The unit of the distribution varies from physical entities such as flood risk and sediment supply, to socio-economic impacts such as farming profitability (Doorn, 2018; Suckall et al., 2018; Wild et al., 2019). The scope of the distribution is commonly defined by dividing population based on their attributes, such as income level or location (Harrison et al., 2016; Jafino et al., 2019; Sayers et al., 2018; van Ruijven et al., 2015). Explicitly delineating the distribution of units to different groups within the scope allows us to identify which groups benefit and who suffers from adaptation policies. Such information can be useful for decision makers to reduce inequalities, for example, by taking additional compensation policies for worse-off groups.

Several recent studies in model-based adaptation planning in deltas have touched on the issue of equity. Chapman and Darby (2016) distinguish impacts of alternative rice farming practices on the economic performance of small, medium, and large-scale farmers, at a household level. Kind et al. (2017) explore four different aggregation approaches for considering risk aversion and income distribution in flood risk management planning. These two studies, however, do not account for the influence of uncertain external developments. Since inequality can be influenced by both adaptation policies and uncertainties, focusing on just one factor (e.g., adaptation policies) at a time while keeping the other factor (e.g., climate change) constant could result in overlooking the complete picture of possible inequality patterns, resulting in what Juhola et al. (2016) termed "maladaptation." One example of research that accounts for both uncertainties and possible interventions is Ciullo et al. (2020), which explores alternative distributive principles for optimizing flood risk management options, while also considering uncertainties. Their focus, however, is the exploration of the impact of using different principles for aggregating distributional outcomes, rather than on the impacts of the interplay between uncertainties and interventions on inequality patterns.

To adequately support equitable climate change adaptation planning in deltas, a quantitative model needs to satisfy two fundamental requirements. First, the model has to account for the multisectoral dynamics in the delta. This is because uncertainties in climate change adaptation planning come from different systems, including the climatic, hydrological, (bio)physical, and the socioeconomic system (Aerts et al., 2018; Dunn et al., 2019; Kuenzer & Renaud, 2012; Wong et al., 2014). Adaptation measures also come in various forms, targeting different parts of the systems, and potentially benefitting or harming different subgroups within a population (Atteridge & Remling, 2018; Begg et al., 2015; Smajgl et al., 2015; Ward et al., 2020). The co-evolution between these systems may thus give rise to distinctive inequality patterns. The second requirement is that the model has to have an explicit representation of the different subgroups within the scope of the distribution. The specification of the subgroups has to be made on an appropriate dimension, so that the model can provide actionable and targeted recommendations to reduce future inequalities. For instance, if one aims to look at spatial inequalities, then the model needs to be spatially explicit. This allows analysts to look at the robustness of alternative policies not only across scenarios and across dynamics over time (Hadjimichael et al., 2020; Steinmann et al., 2020), but also across people and across space.

The main aim of this study is to investigate how the intricacy of uncertain exogenous developments, internal changes within the delta, and adaptation policies jointly affects future inequality patterns. We investigate future total output and equity performance of the rice agricultural sector in the Vietnam Mekong Delta (VMD) under various realizations of uncertainties and adaptation options as a case study. For the equity part, we observe the spatial distribution of rice farming profitability (the *unit*) across the different districts (the *scope*) in the upper VMD. Being the world's third largest delta, the VMD provides 55% of the total rice production of Vietnam and contributes to more than 85% of the country's rice export (GSO, 2019; Toan, 2014). The VMD faces both uncertain climatic and anthropogenic pressures (Duc et al., 2019; Dung, Merz, Bárdossy, & Apel, 2015; Manh, Dung, Hung, Kummu, et al., 2015), which, in interaction with adaptation policies, affect flood risk, land-use change, land subsidence, and the deposition of nutritious sediments.

To capture the multisectoral dynamics affecting rice farming profitability in the VMD, we develop a spatially explicit integrated assessment model. We combine existing detailed physical models with a cellular automata-based land-use change module and a rice farming profitability module. The model encapsulates the co-evolutionary dynamics influencing the livelihood of the rice farmer. These dynamics include changing flood regime, soil fertility, sedimentation and natural nutrients replenishment, human-induced land subsidence, economic-based fertilizer application, as well as behavioral land-use change. Using the model, we assess the efficacy of alternative adaptation policies using both aggregated and disaggregated indicators. We look at both aggregate total output (i.e., total rice production) and equity (i.e., Gini coefficient) indicators, as well as disaggregated inequality patterns (i.e., rice farming profitability at a district level) under different uncertain futures. Our study shows how equitable climate change adaptation planning in deltas can be supported by systematically exploring the inequality patterns resulting from complex interactions between adaptation options and different futures, enabled by a spatially explicit computational representation of the multiple interacting subsystems in the delta.

In the next section we explain in more details the background of our case study area, which is the VMD. In Section 3 we outline the methodology that we followed in this study; the model conceptualization, the model evaluation, and the experimental setup. The results are presented in Section 4. In Section 5 we reflect on the limitations of our approach and how, despite the limitations, the findings of our study can still be meaningful to the discussion on climate change adaptation planning in the VMD. We conclude with broader implications for supporting equitable climate change adaptation planning in Section 6.

2. Study Area

The large (inter)annual variability in rainfall, river discharge and tidal regime, in combination with human interventions, makes the VMD a physically dynamic delta (Gugliotta et al., 2017; Unverricht et al., 2013). From a biophysical point of view, the VMD is divided into three zones: downstream, midstream, and upstream (see Figure 1). Each zone faces different challenges; salinity intrusion due to sea level rise downstream, annual monsoon flooding upstream, and increasing flood hazard due to increasing runoff and higher river levels midstream (Eslami et al., 2019; Huong & Pathirana, 2013; Smajgl et al., 2015; Tri, 2012; Van et al., 2012). Human interventions including hydropower dam construction, human-induced land subsidence, and sand mining further complicate the dynamics (Hecht et al., 2019; L. P. Hoang et al., 2019; Minderhoud, Coumou, Erkens, Middelkoop, & Stouthamer, 2019; Triet, Dung, Fujii, et al., 2017).

Most rice farming activities take place in the upstream zone where salt influence is minimal and freshwater availability is higher. We therefore focus our analysis to the two provinces in the upstream zone: Dong Thap and An Giang. The choice is motivated by three reasons. First, unlike provinces in the downstream zone, farmers in Dong Thap and An Giang do not face significant salt intrusion from the sea. Therefore, it is foreseen that these provinces will still be the main rice production hub in the delta in the foreseeable future (Mekong Delta Plan Consortium, 2013). Second, unlike provinces in the middle stream zone, farmers in

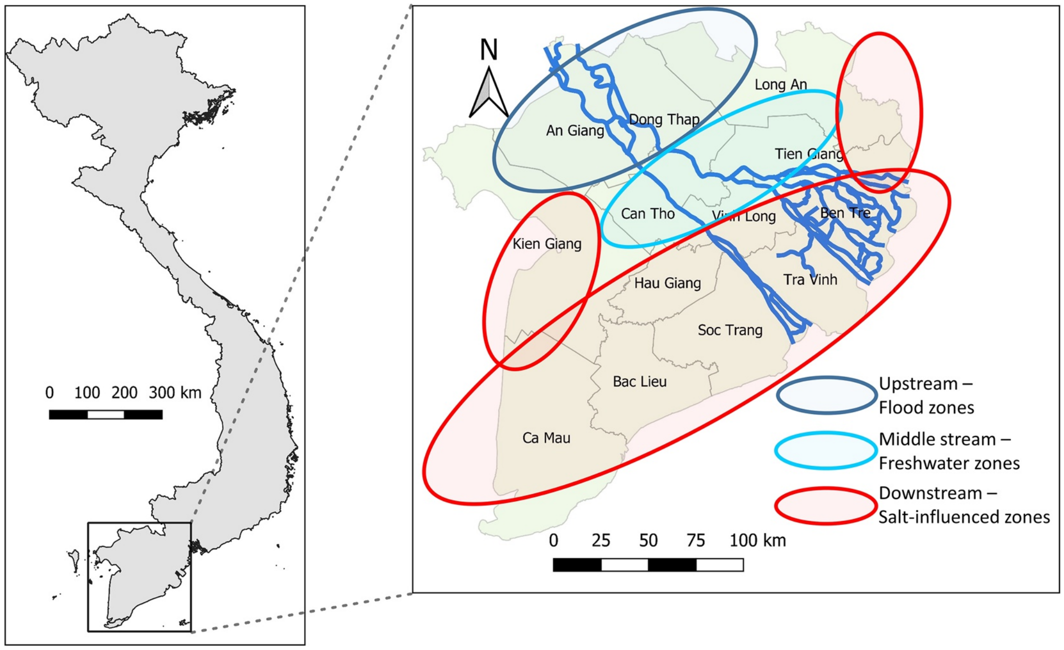

Figure 1. Left panel: Map of Vietnam. Right panel: three different hydrological zones and 13 provinces in the Vietnam Mekong Delta (VMD). The blue lines are the branches of the Mekong river. In this study we focus on the upstream zone.

Dong Thap and An Giang still have to face annual flooding in the monsoon season. This makes the biophysical aspect of the upstream zone more dynamic compared to the middle stream zone. Third, these provinces are the first areas where high dikes were constructed and triple-rice crops were adopted. The land-use change in these provinces is among the most dynamic ones in the region (Ngan et al., 2018).

Rice farming in Dong Thap and An Giang has undergone a major transition in the past decades. This transition started after the establishment of the "Doi Moi" policy in 1986, when the government pushed investments for agricultural intensification (Garschagen et al., 2012; Käkönen, 2008). Before 1986, farmers mainly relied on rain-fed rice where the paddy fields were cultivated only once per year. Later, water management infrastructure, especially low dikes and irrigation channels, enabled farmers to adopt double-rice cropping. The winter-spring crop starts in December right after the monsoon season while the summer-autumn crop is grown between April and July (Ngan et al., 2018; Son et al., 2013). The monsoon season starting in July brings annual flooding so the paddy fields are inundated from August through October. Since the early 2000s, the government has been pushing further intensification by upgrading the low dikes (about 2 m high) to high dikes (about 4.5 m). High dikes prevent fluvial flooding of the paddy fields during the annual monsoon. So, farmers can grow a third crop between August and October, often called the autumn-winter crop.

Today, there is growing evidence that the increase in total rice production, thanks to the high dikes, comes at the expense of sustainability and exacerbates inequalities among farmers (Chapman & Darby, 2016; Chapman et al., 2016; Käkönen, 2008; D. D. Tran, van Halsema, et al., 2018). Preventing annual floods from entering the paddy fields reduces the natural supply of nutrients to the field. Over time, this means that farmers have to buy ever larger quantities of fertilizer for the same yield. Previous study has assessed the distributional implications of the high dike policy to a single illustrative farmer with different farm sizes (Chapman & Darby, 2016). A regional plan, however, requires more than just a single farmer assessment. Hence, in this study we center our attention to the spatial inequalities resulting from different scenarios. This enables us to provide a spatially explicit and more targeted recommendations on how to reduce future inequalities. In addition to calculating spatially distributed impacts, we also assess the delta's total agricultural output and equity through aggregated indicators.

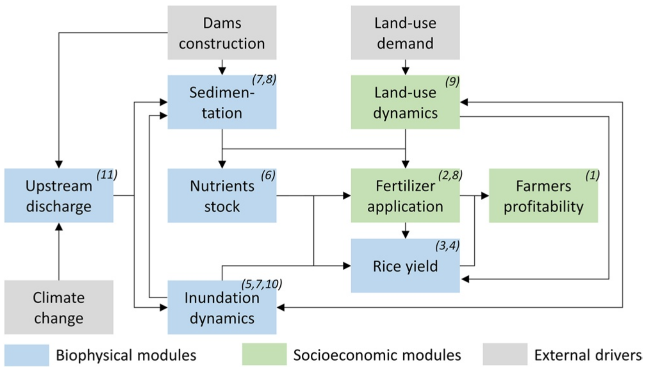

Figure 2. Conceptualization of the integrated assessment model. The numbers correspond to modules described in Table 1.

3. Methodology

To explore both aggregated and distributional impacts of adaptation policies under different futures, we need to ensure that the relevant dynamics that give rise to distributed impacts to rice farming profitability are taken into account. Failure to include multisectoral dynamics and the interactions between them may lead to under- (or sometimes, over-) estimation of the impacts of policies and uncertainties (Jafino et al., 2019; Wagner et al., 2017). Therefore, we need a model that captures both the (bio)physical and the socioeconomic aspects of the delta. In the case of rice agriculture in the VMD, the relevant (bio)physical aspects include, among others, the changing flooding regime, future sediment budget, as well as the various (bio)physical-focused adaptation policies (Chapman et al., 2016; L. P. Hoang et al., 2019; Triet, Dung, Merz, & Apel, 2018). The socioeconomic aspects include land-use change decisions of the farmers, societal preferences of future farming practices, as well as farming profitability accounting (Ngan et al., 2018; D. D. Tran, Huu, et al., 2021; D. D. Tran, van Halsema, et al., 2018).

The model we develop follows a theory informed meta-modeling approach (Davis & Bigelow, 2003; Haasnoot, Middelkoop, et al., 2012; Haasnoot, van Deursen, et al., 2014). This approach aims at simplifying and coupling detailed physical models while maintaining the performance of the original models. We combine both statistical and process-based approaches to meta-modeling (Razavi et al., 2012). The choice of the approach to represent the different systems depends on the availability of the complex model and statistical relationships, the possibility of simplifying physical processes, and the fitness to our model purposes.

Meta-modeling has been used for supporting climate change adaptation planning especially when the intention is to explore uncertain futures and alternative adaptation policies (Haasnoot, van Deursen, et al., 2014; Hamilton et al., 2015; Lempert et al., 2003). The integrative nature of the meta-modeling approach makes it highly suited for representing the complexity of the agricultural sector in the VMD and its interdependencies with other sectors such as hydrology, land-use change, and nutrient cycling. Furthermore, the meta-model developed in this study has a spatially explicit representation of the system, so that it fits for the purpose of exploring future spatial inequality among farmers in different areas.

3.1. Model Conceptualization

The integrated assessment model comprises two groups of modules as shown in Figure 2. The biophysical modules include the main pressures on the agricultural sector, namely sedimentation and inundation dynamics, as well as the main response variable, namely rice yield. The socio-economic modules include the calculation of farming profitability, which is aggregated at a district level, and the dynamics of land-use change due to the farmers' response to the changing environment. Table 1 lists each individual module.

Farming profitability, which is the final output of the model, is calculated based on the farmers' income from selling rice and cost of purchasing fertilizer. The rice yield is determined by how much nutrients are available, both from fertilizer and from sedimentation. Therefore, letting the rice fields flood brings the benefit of replenishing the natural nutrients in the soil, although it prevents farmer for having a third crop throughout the year. The sediment budget that enters the VMD is determined by the magnitude of river discharge and the presence of upstream dams in Cambodia. A higher degree of upstream dam development traps more sediment upstream, thus reducing the expected benefits of intentional flooding in the VMD. Dam construction could also offset the climate change impacts of increasing discharge of the Mekong river (Triet, Dung, Hoang, et al., 2020). Furthermore, we include a behavioral land-use change component where farmers can decide what kind of farming practices they want to adopt. However, different land-use classes induce varying rates of land subsidence, which in turn increase the flood risk in the delta. A more detailed explanation of the model is provided in supporting information S1.

Table 1
Modules of the Integrated Assessment Model, and the Applied Modeling Approaches

Number	Processes	Modeling approach	Description	Source of model equations and parameter values
1	Rice farming profitability calculation	Process-based	Simple equation of income and cost	D. D. Tran, van Halsema, et al. (2018)
2	Fertilizer application	Statistical + Process-based	Statistical modeling of average fertilizer use + cause-effect relations of yield deficit	Chapman et al. (2016) and D. D. Tran, van Halsema, et al. (2018)
3	Rice yield	Statistical	QUEFTS rice yield model	Witt et al. (1999)
4	Rice yield damage due to inundation	Statistical	Cause-effect relations + lookup function	Triet, Dung, Merz, and Apel (2018)
5	Inundation dynamics	Statistical	Simplification of complex physical-based hydrological model in the Mekong Delta	Dung, Merz, Bárdossy, Thang, and Apel (2011) and Triet, Dung, Merz, and Apel (2018)
6	Nutrients stock dynamics	Process-based	Stock and flows structure	Chapman and Darby (2016)
7	Floodplain sedimentation	Statistical	Simplification of complex physical-based sedimentation model in the Mekong Delta	Manh, Dung, Hung, Kummu, et al. (2015) and Manh, Dung, Hung, Merz, and Apel (2014)
8	Nutrients contents in sediment and fertilizer	Statistical	Statistical information from experiments	Manh, Dung, Hung, Merz, and Apel (2014) and Tan et al. (2004)
9	Land-use dynamics	Process-based	Cellular automata land-use change model	Van Delden and Hurkens (2011) and White et al. (1997)
10	Land subsidence	Statistical	Statistical observation of past land subsidence in the Mekong Delta	Minderhoud, Coumou, Erban, Middelkoop, Stouthamer, and Addink (2018)
11	Upstream discharge	Statistical + Process-based	Synthetic hydrographs from global model PCR-GLOBWB + correction for upstream dam development scenarios	Lauri et al. (2012) and Sutanudjaja et al. (2018)

All processes except for maximum annual upstream discharge generation are spatially explicit with a cell size of 200 × 200 m and a time step of one year. We consider the presence of monoculture rice farming, but also other forms of land-use such as aquaculture, fruits plantation, mixed shrimp-rice farming, and urban area. However, as displayed in Figure 3, rice farming dominates the land-use of the upstream VMD. The model is run for a period of 38 years from 2012 to 2050, while the period between 2002 and 2012 is used for model evaluation.

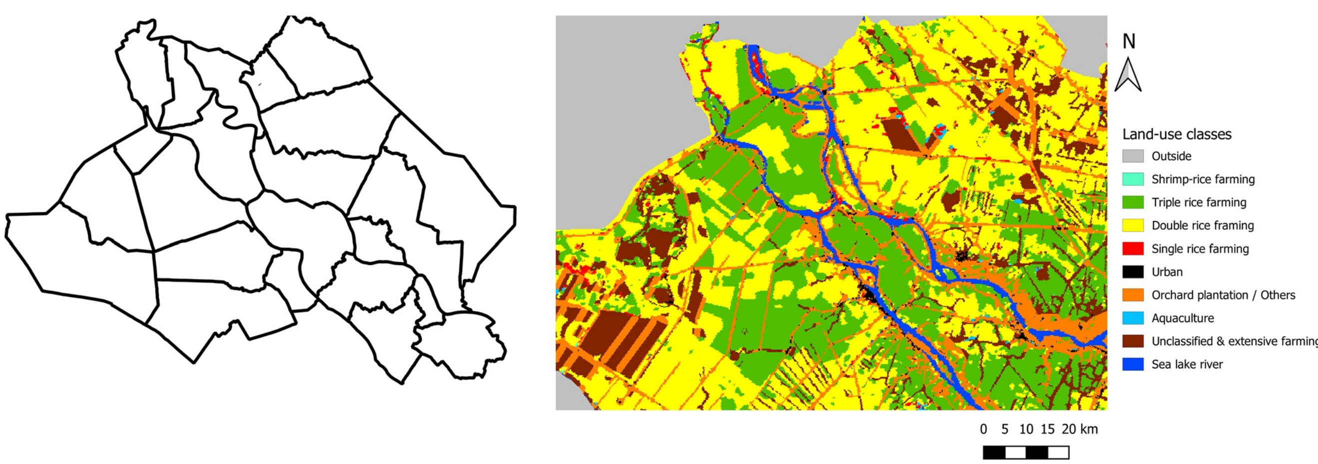

Figure 3. Left panel: Boundaries of districts in Dong Thap and An Giang, two provinces in the upper VMD. Right panel: land-use map of the case study area in 2011 (GAEN-View, 2013; Sakamoto et al., 2009). The two branches of the Mekong river stretch from the northwest to the southeast.

3.2. Model Evaluation

To evaluate the adequacy of the model, we focus on whether the model is fit for its purpose of exploring inequality patterns. The fit for purpose approach begins by reflecting on the intended use of the model and continues with formulating evaluative questions that guide the adequacy of the model in fulfilling its purpose (Gramelsberger et al., 2020; Haasnoot, van Deursen, et al., 2014). Given that the model will be used for exploring the total output of the agricultural sector and the emerging inequality among farmers under different scenarios, the main evaluative question for the model is: Does the model produce credible outcomes and responses to external drivers that are within the boundary of past studies and historical data?

There are two elements to the main evaluative question. The first relates to the realism of the model, that is, the agreement between the model outcomes with past studies and historical data. The second element is to evaluate the structural adequacy of the model through investigating if the model produces reasonable outcomes given changes in inputs. We adapted the behavior testing procedure in Van Delden et al. (2010) for this. This involves varying the inputs to the model, formulating hypotheses on how the model would behave, and evaluate if the model behaves accordingly. The guiding questions for both model realism and structural adequacy assessments as well as the results to these questions are presented in Table 2.

In light of Table 2, we conclude that the model is sufficiently fit for purpose. Regarding realism, we see that the model sufficiently mimics historical behavior. However, the full spectrum of farming profitability is not captured by the model. One explanation is that the market price dynamics for rice are not accounted for. Regarding structural adequacy, we observe that the model behaves as hypothesized. The impacts of increase in annual peak discharge amplify stronger than the impacts of sediment starvation and triple-rice expansion. A higher peak discharge results in wider inundation extent, and this directly affects the observed outcomes (i.e., flood-induced damage to crops). Reduction in sediment supply does not have direct consequences to farming profitability, as nutrients are supplied by not only sediment deposition but also by artificial fertilizer.

3.3. Experimental Setup

We consider three uncertain factors that also have been accounted for in earlier studies related to climate change adaptation planning for the upper VMD (Manh, Dung, Hung, Kummu, et al., 2015; Manh, Dung, Hung, Merz, & Apel, 2014; Triet, Dung, Hoang, et al., 2020; Triet, Dung, Merz, & Apel, 2018). Table 3 lists these factors as well as the adaptation policies considered in this study. For river discharge, two hydrographs are generated based on two moderate and high-end global emission trajectories of RCP4.5 and RCP8.5 from the Representative Concentration Pathways (RCPs) framework (van Vuuren et al., 2011). Although the plausibility of RCP8.5 has been questioned (Hausfather & Peters, 2020; Ritchie & Dowlatabadi, 2017), these two RCP scenarios have been often used for climate impact assessment in the VMD as they cover both expected and worst-case emission scenarios (Dang et al., 2020; L. P. Hoang et al., 2019; Lee & Dang, 2018; Tan Yen et al., 2019).

For upstream dam development, we consider three degrees of development: Small, medium, and large. A higher level of dam development reduces both the annual sediment budget and the peak river discharge (Lauri et al., 2012; Manh, Dung, Hung, Kummu, et al., 2015). The large dam development, for instance, assumes that all 136 currently planned dams are constructed. For societal preference about different farming practices, we follow recent discussions on this topic (Nguyen et al., 2020; D. D. Tran, van Halsema, et al., 2018; T. A. Tran & Rodela, 2019). We consider two possibilities: Continued agricultural expansion (triple-rice farming systems), and a shift to less intensive agricultural practices (double-rice farming combined with aquaculture and shrimp). These possibilities affect future land-use demand and development.

We consider three policies in addition to a baseline do-nothing policy: Two different hard infrastructural adaptation policies, and one soft subsidy policy. The hard policies follow the different views as expressed in the recent debates on flood control: Either more construction of high dikes (in accordance to the "Food Production Scenario" in the Mekong Delta Plan) or instead lowering them (Mekong Delta Plan Consortium, 2013; Triet, Dung, Merz, & Apel, 2018). In the former we assume that all dikes are upgraded into high dikes, while in the latter we assume that all dikes are downgraded to low dikes. The soft policy is supporting farmers whose paddy field is far from the main branch of the Mekong river, as the sedimentation rate

Table 2
Summary of Fit for Purpose Evaluation of the Model

Evaluation elements	Guiding questions/hypotheses	Results
Main question: Does the model produce credible outcomes and responses to external drivers that are within the boundary of past studies and historical data?		
Model realism; to what extent the outcomes of the model comply with past studies and observations	Does the model produce the heterogeneity of rice farming profitability?	Although not the entire range of surveyed annual profitability is captured, farm profits calculated from the model (40–70 million Dong) are still within the boundary of surveyed profit (20–80 million Dong)
	Does the model capture the variation of rice yield between the different cropping seasons?	The averages of the modeled yield of each cropping season corresponds well to the historical observation (7 ton/ha for winter-spring crop, 5 ton/ha for summer-autumn crop, 4 ton/ha for autumn-winter crop), although the range of the modeled yield is generally larger than the observation
	Does the model produce a reasonable magnitude of annual floodplain sedimentation?	The floodplain sedimentation rate is adequately captured with an average deviation of less than 10%. An exception is for large flood events, where the maximum sedimentation is slightly underestimated by the model
	Does the model yield a similar pattern of annual maximum water level in the study area?	Historical observations reported in previous studies and the model show a comparable temporal behavior of annual maximum water level at Tan Chau and Chau Doc hydrological stations between 2002 and 2012. In most of the years, the deviation from historical data is less than 10%
	Does the model capture a sufficient location and pattern accuracy of land-use change processes?	The model simulates land-use change with high pattern accuracy, as measured by clumpiness index. The overall location accuracy is also relatively high (Kappa statistics of 0.793). Lower accuracy is observed for marginal land-use classes such as aquaculture
Structural adequacy; to what extent changes in model outcomes given changes in model inputs are reasonable	Increase in annual peak discharge would increase the number of flood-induced damaged crops	At an extreme scenario where the annual peak discharge increases by 60%, around 263% increase of damaged crop is observed
	Reduction in sediment supply from upstream would also reduce rice farming profitability	At an extreme scenario where upstream sediment supply decreases by 60%, average profitability of all farms also decreases by 8%. Double-rice farmers experience a bigger lose with an average of 11%, while triple-rice farmers are barely affected
	Rapid expansion of triple-rice cropping without adequate dikes construction would increase the flood-induced damaged crops	A rapid expansion of triple-rice cropping system while maintaining the standard dikes construction leads to 26% increase in total flood-induced damage to crops

Note. Detailed results for each guiding question are discussed in supporting information S1.

decreases with the distance to the river (Manh, Dung, Hung, Merz, & Apel, 2014). We assume that this support is not in cash, but directly in the form of fertilizers: farmers receive 50 kilograms of fertilizer for each cropping season. Such farmers-targeted support is not new in the region. In the past 10 years, three subsidy policies (Decree 42/2012/ND-CP, Decision 62/2013/ND-CP, and Decree 36/2015/ND-CP) have been enacted by the central government (Nguyen et al., 2020). All adaptation policies are assumed to be enacted from 2025 onwards.

Table 3
Uncertain Factors and Adaptation Policies Considered in the Experimental Setup

Uncertainty and policy variables		Possibilities	Internal variables affected
Uncertain factors	Climate-induced river discharge	- RCP 4.5 - RCP 8.5	Inundation dynamics (affecting inundation extent) and sedimentation (affecting total annual sediment budget)
	Upstream hydropower dam development	- Large development - Medium development - Small development	Sedimentation (reducing total annual sedimentation budget) and upstream discharge (reducing discharge)
	Societal preference over farming practices	- Expansion of triple rice - Shift back to double rice	Future land-use demand, affecting land-use dynamics
Adaptation policies	Hard infrastructural policies	- Further construction of high dikes - Deconstructing high dikes into low dikes	Inundation dynamics (high dikes prevent water level of up to 4.5 m) and land-use dynamics (low dikes are not suitable for triple-rice farming)
	Soft policy	- Fertilizer subsidies	Fertilizer application (increasing seasonal fertilizer supply)

Note. The detailed explanation of how uncertain factors affect internal variables is provided in supporting information S1.

We use a full factorial experimental design through which we explore all permutations of the uncertain factors and adaptation policies. The design results in 48 simulation experiments (two river discharge scenarios, three dam development scenarios, two farming practices preference scenarios, and four alternative adaptation policies).

3.4. Analysis of Model Results

From the model we calculate two types of performance indicators. The first type is disaggregated indicators, that is, district level farming profitability. From this indicator, we can observe the emerging spatial inequalities under different scenarios. Accordingly, farming profitability is aggregated for each of the 23 districts in Dong Thap and An Giang. As our aim is to assess farming profitability in a district relative to other districts in each individual scenario, while also understanding the degree of inequality in each scenario, the district level profitability in each scenario is scaled to the median. Specifically, in each scenario, we calculate the percentage deviation of each district's farming profitability from the median profitability in that scenario. The second type is aggregated indicators: total rice production as an indicator of total agricultural output and Gini coefficient among farmers as a proxy for equity. Total agricultural output is the sum of all rice production in the two provinces. This indicator is of importance to the regional government in order to ensure the adequate supply of rice. The Gini coefficient is calculated from the distribution of district-level average farming profitability.

4. Results

4.1. Disaggregated Performance: Inter-District Inequality Patterns

We began our analysis with the observation of spatial inequality, in terms of farming profitability, across the 23 districts in An Giang and Dong Thap under different dam development, land-use demand, and river discharge scenarios, as well as under four alternative policies. The spatial inequality is presented in Figure 4.

First, we focus on the inequality that results from external developments without adaptation policies (baseline column in Figures 4a–4d). Large upstream dam development (lower left maps in Figures 4a–4d) benefits districts located in the middle of the two branches of the Mekong river. In contrast, a small degree of dam development (upper left maps in Figures 4a–4d) makes these districts relatively less profitable compared to other districts. There are three districts located to the north and three districts located to the south of the river that have relatively higher profitability under small dam development. Most paddy fields in these six districts are protected by low dikes only. Since low dike areas are regularly flooded, they receive nutrients

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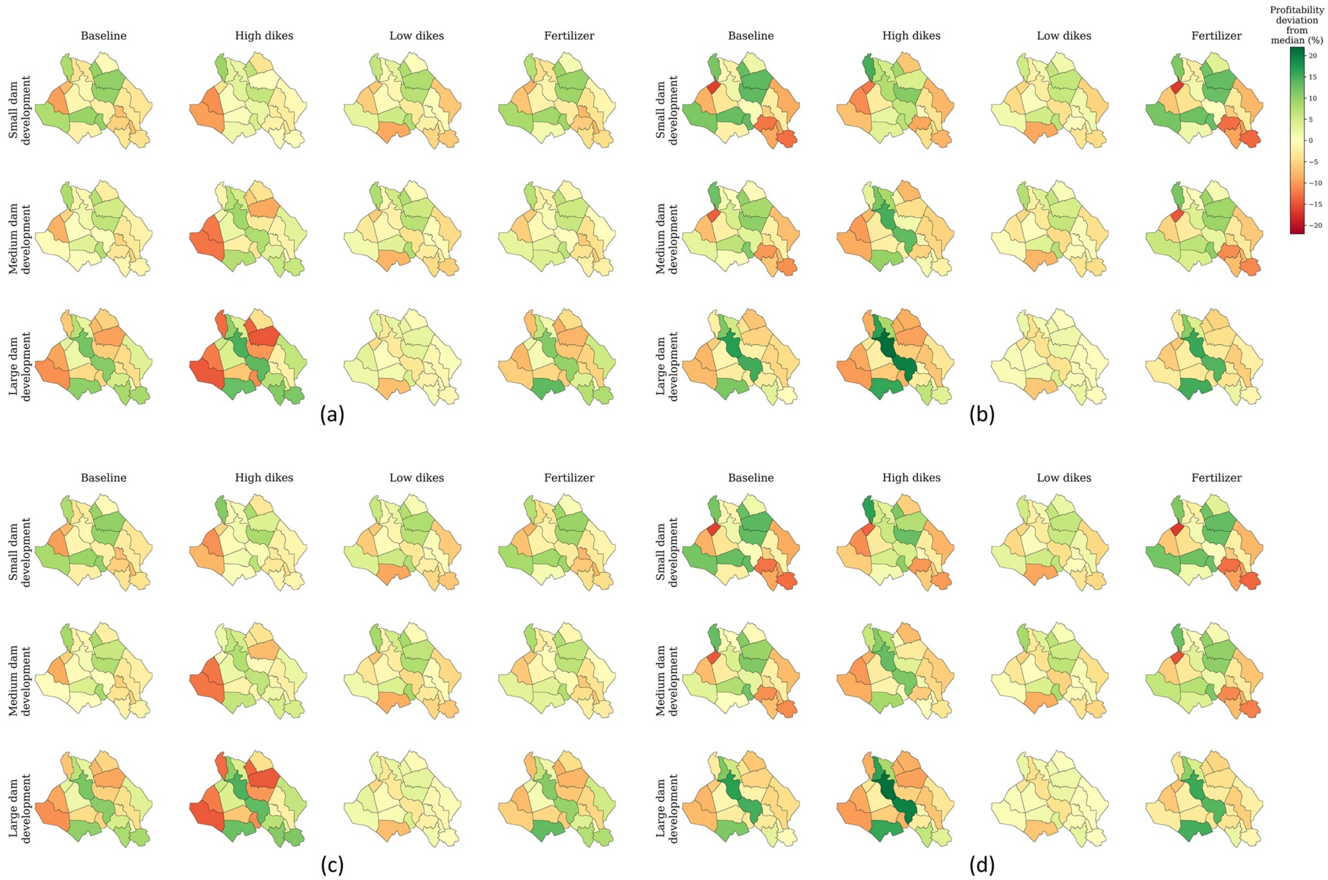

Figure 4. Relative profitability of rice farming at district level by 2050 under different scenarios and adaptation policies: (a) RCP 4.5 and expansion of triple rice, (b) RCP 4.5 and shift back to double rice, (c) RCP 8.5 and expansion of triple rice, and (d) RCP 8.5 and shift back to double rice.

from floodplain sedimentation during the monsoon. In combination with a small degree of upstream dam development, these six districts receive a relatively higher amount of nutrients from sedimentation. The constant large supply of natural nutrients (under the small dam development) along with the less exploitative double-rice system allow districts with low dike systems to outperform districts with high dikes because high dike districts tend to deplete their nutrient stock at a higher rate due to the triple-rice cropping.

The effect of different river discharge scenarios on inequality patterns can be seen by comparing Figure 4a with Figure 4c (RCP 4.5 vs. RCP 8.5 with triple rice expansion) and by comparing Figure 4b with Figure 4d (RCP 4.5 vs. RCP 8.5 with shift back to double rice). We see that the effect of different river discharge scenarios to altering the inequality patterns is relatively small. For instance, the six districts with the highest profitability under the small dam development and baseline scenarios (top left maps in Figures 4a–4d) remain the most profitable ones irrespective of the river discharge scenario. The reason for this is that the annual maximum discharges under RCP 4.5 and 8.5 do not differ much during the simulated period of 2012–2050 (see supporting information S1 for details). Previous studies support this, as they show almost the same change in precipitation and evaporation, which are the two main drivers of river discharge, up to 2050 under both RCP 4.5 and 8.5 in Cambodia and the VMD (Lee & Dang, 2018; van Oldenborgh et al., 2013). This also aligns with a recent study that finds that in the short to medium term, climate-induced discharge changes do not substantially increase flood risks in the delta (Triet, Dung, Hoang, et al., 2020).

To assess the impacts of societal preference and land-use demand on inequality patterns, we compare Figure 4a with Figure 4b (different societal preferences under RCP 4.5), and Figure 4c with Figure 4d (different societal preferences under RCP 8.5). The effect is particularly noticeable for districts in the southeast and far east part of the case study area. For instance, under small dam development and RCP 4.5 river discharge, the relative profitability of these districts decreases when a shift back to double-rice happens (top left maps

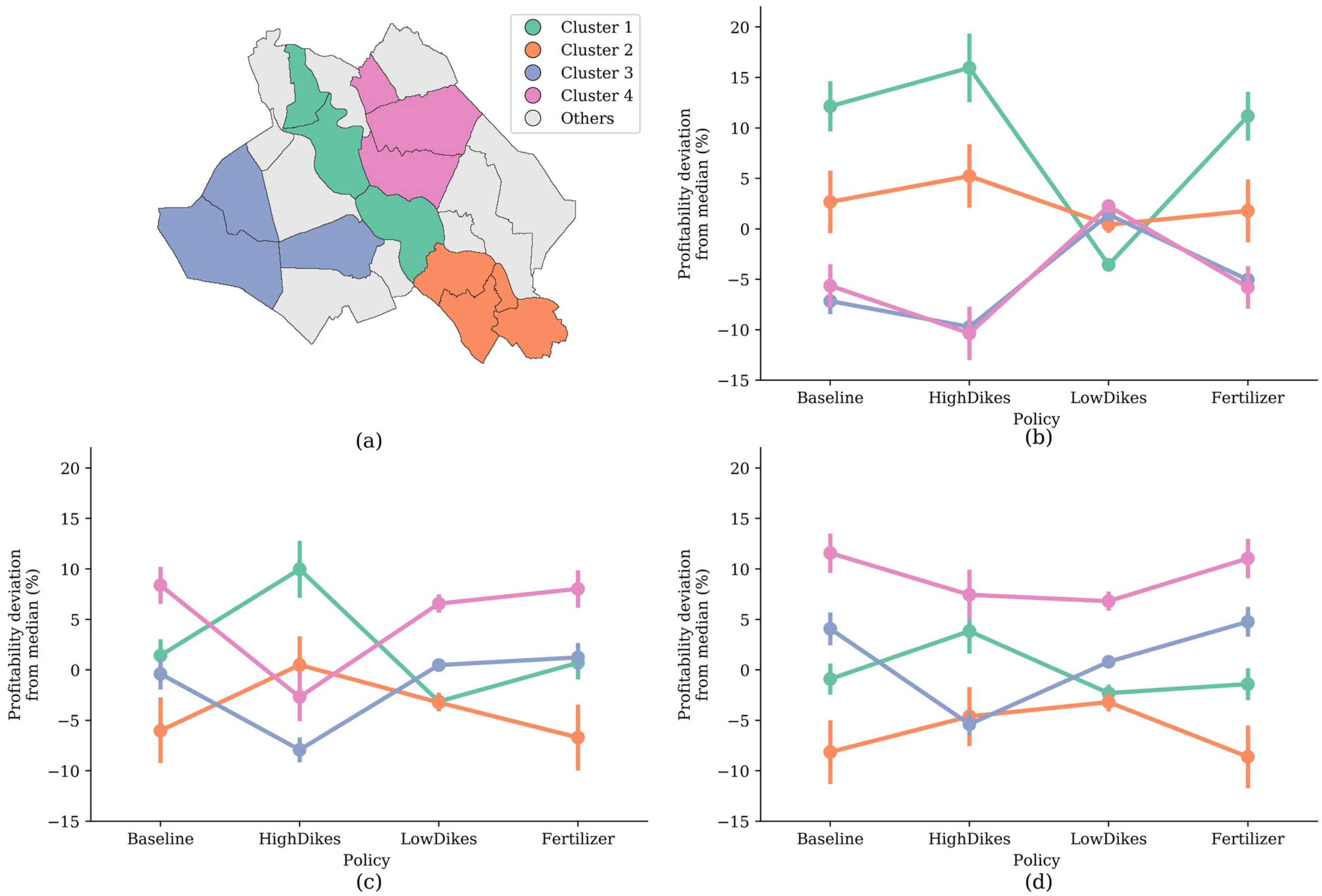

Figure 5. Average profitability deviation of four different clusters of districts. Panel (a) shows the four representative clusters of districts. Panel (b–d) show average profitability deviation under large, medium, and small dam development scenarios, respectively. The colors in panel (b–d) correspond to clusters of districts specified in panel (a).

in Figures 4a and 4b). The effect of societal preference scenarios is less pronounced for districts alongside the river. The presence of low or high dikes in a district explains the different effects of the societal preference scenarios. Districts whose relative profitability is less affected are fully enclosed by high dikes, whereas districts with large relative profitability changes are only partially protected by high dikes. Land-use change is hence more subdued in high dike areas, since the suitability of a place for triple-rice farming is highly reliant on the presence of high dikes. Accordingly, the difference in spatial allocation of triple- and double-rice farming from the two societal preference scenarios is mainly seen in districts that currently still have low dikes (e.g., districts in the south east and far east part of the case study area).

Looking at the impact of each external development on inequality patterns under the do-nothing policy shows that upstream dam development has the largest influence. The inequality patterns change and differ substantially between the three dam development possibilities. The two different societal preferences affect only the land-use pattern of some districts while leaving the land-use pattern of other districts, especially those where triple-rice system is very dominant and has long been established, intact. The two river discharge scenarios also hardly affect the inequality patterns, as the discharges in both scenarios have similar magnitude and dynamics.

To illustrate the impacts of alternative adaptation policies to the inequality patterns, we first assume other factors to be the same (ceteris paribus principle). We look at the river discharge scenario from RCP 4.5, small dam development, and a continued expansion of triple-rice (top row in Figure 4a, also represented in Figure 5d). The high dikes policy prevents annual flooding from entering all rice fields. This in turn precludes sedimentation on double-rice paddy fields and without this free natural nutrient supply this reduces the

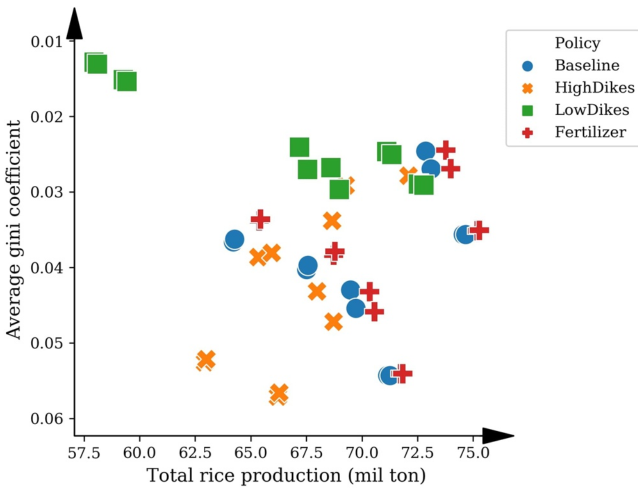

Figure 6. Equity (expressed by the district-level Gini coefficient) and total output (expressed by the total rice production) of the agricultural sector under different scenarios. The arrows on the axes represent the direction of desirability (low Gini implies high equity performance and high total production implies high total output performance).

relative profitability of the six most profitable districts under the baseline adaptation scenario (districts in Cluster 3 and 4 in Figure 5). The low dikes policy has the opposite effect. This policy is detrimental to districts which rely on high dikes for triple-rice farming (e.g., districts in Cluster 1 in Figure 5). The fertilizer subsidy policy, as expected, slightly raises the relative profitability of districts located far from the river. The fertilizer policy slightly reduces the relative profitability of districts between the river branches (as visible by comparing the fertilizer policy and the baseline policy in the top row of Figure 4a, also in as observed in districts in Cluster 1 and 2 in Figure 5d).

The simulation results suggest that the impacts of external developments and adaptation policies cannot simply be analyzed in isolation from each other as the model shows non-linear responses of inequality patterns. For example, the high dikes policy yields relatively equal profitability across districts under small dam development scenarios, as seen through the convergence of the average profitability deviation in Figure 5d. In contrast, districts along the river largely benefit when a larger number of upstream dams is constructed (Figure 5b). If we specifically look at the average profitability deviation of districts in cluster 4, the low dikes policy benefits these districts under large dam development scenarios (Figure 5b), while it yields opposite impacts in medium and small dam development scenarios (Figures 5c and 5d). The difference in relative profitability of districts along the river and the other districts is even larger under the shift back to double rice scenario (Figure 4b, high dikes—large dam development).

4.2. Aggregated Performance: Total Output and Equity

We use total rice production as an indicator for total output and the inter-district Gini coefficient as an indicator for equity (Figure 6). We find neither a large correspondence nor a clear trade-off between these two indicators, as the effectiveness of the policies depends on the scenario. Some scenarios result in low total output but high equity performance, such as in case of the outcomes of the low dikes policy in the top-left part of Figure 6. Other scenarios lead to synergies of high total output and equity performance, such as those on the top-right part of Figure 6. Figure 6 also indicates which adaptation policies perform better than the others. For instance, in many scenarios the low dikes policy performs better than other adaptation policies in terms of equity, whereas the fertilizer subsidy policy performs better on the total output axis.

We summarize the total output and equity performance of the alternative policies in Table 4. This table reveals four important things. First, upstream dam development is the most influential uncertain factor, with large upstream dam development generally worsens both total output and equity. Most scenarios (68.75%) involving large upstream dam development have relatively low total output and equity performance, while most scenarios (62.5%) involving small upstream dam development score better on both total output and equity. Hence, upstream dam development is a critical variable to be monitored continuously in order to ensure timely adaptation within the region. There are some exceptions to this observation. For instance, the equity performance of the fertilizer subsidy policy given RCP4.5 discharge and triple-rice expansion in case of medium upstream dam development is larger than in case of low upstream dam development. But it worsens again in case of large upstream dam development. A second exception is that the equity performance of the low dikes policy is largest in case of large upstream dam development, but at the expense of total rice production.

Second, climate scenarios which affect the river's peak discharges have only small impacts on the performance of the adaptation policies within the considered time horizon until 2050. For instance, under small upstream dam development and triple-rice expansion, the shift from RCP 4.5 to RCP 8.5 only marginally changes the total output of the high dikes policy. Uncertainties about farmers' preferences, expressed as land-use scenarios, have a larger effect than the climate change induced river discharge scenarios, although not as large as upstream dam development. This implies that uncertainty about future human interventions

Table 4
Summary of Aggregated Total Output and Equity Indicators by 2050 Across all Scenarios

		Small dam				Medium dam				Large dam			
		Baseline	High dikes	Low dikes	Fertilizer	Baseline	High dikes	Low dikes	Fertilizer	Baseline	High dikes	Low dikes	Fertilizer
RCP4.5 + expansion triple-rice	Inter-district Gini	0	++	+	0	++	0	+	++	−	−−	++	−
	Rice production	++	+	++	++	++	0	0	++	−	−	−−	0
RCP4.5 + back to double-rice	Inter-district Gini	−−	−	++	−−	−	−	++	−	0	−−	++	0
	Rice production	+	−	+	+	0	−−	−	0	−−	−−	−−	−−
RCP8.5 + expansion triple-rice	Inter-district Gini	0	+	+	0	+	+	+	+	−	−−	++	0
	Rice production	++	+	++	++	++	0	0	++	−	−	−−	0
RCP8.5 + back to double-rice	Inter-district Gini	−−	−−	++	−−	−	−	+	−−	0	−−	++	0
	Rice production	+	0	+	+	0	−	−	+	−−	−−	−−	−

Note. Scoring is presented on a relative scale where "−−" refers to the 20% lowest performance while "++" refers to the 20% highest performance across all scenarios.

such as upstream dam developments and future societal preference are more important for the performance of the agricultural sector than uncertainty about climate change impacts to river discharge.

Third, trade-offs between total output and equity turn out to be very dependent on the external development scenario that materializes. The low dikes policy under the large dam development scenario exemplifies a very strong trade-off: there is a very low Gini coefficient (high equity performance) but at the expense of a very low total rice production (low total output performance). The performance of the adaptation policies under the medium dam, RCP4.5, and triple-rice expansion scenario exemplifies a very weak trade-off instead. Here, a higher total output is always accompanied by a larger equity performance as well.

Fourth, the low dikes policy is found to be the most robust alternative across all scenarios. It always has high equity performance in all scenarios, although it yields relatively smaller total output especially in the large dam scenarios. The low dikes policy can be seen as a no-regret alternative since, unlike the high dikes policy, it does not lead to a lock-in. The fertilizer subsidies policy is not as robust as the low dikes policy, but it can still be a preferred alternative due to its adaptability and flexibility—the government can decide in each year if they are going to employ the subsidies.

Overall, we find there is no simple preference nor ranking of alternative adaptation policies. A simple example here is the ranking of policies based on its equity indicator under the RCP4.5 and triple-rice expansion scenario (top rows in Table 4). Under small upstream dam development, the high dikes policy yields the best performance, followed by the low dikes policy. However, under medium upstream dam development, the baseline and fertilizer subsidy policy become the most preferable ones, followed by the low dikes policy, while the high dikes policy performs worst on equity. If dam development turns out to be even more intense, the low dikes policy takes the first place. This finding implies that which policy should be preferred depends on which external developments are materialized as well as on which performance indicator (either total output or equity) would be given priority by the decision makers. This emphasizes the need for an adaptive plan for coping with uncertain climatic and socioeconomic changes.

5. Discussion

5.1. Computational Model to Support Equitable Climate Change Adaptation Planning

In climate change adaptation planning, future inequality is affected both by how uncertain factors play out and what adaptation measures are taken, requiring one to incorporate multisectoral dynamics. Including multisectoral dynamics requires one to expand the conceptual boundary of the model being used for analysis. This often comes at the cost of reducing the details and resolution of some of the systems through simplifications (Audsley et al., 2008; Davis & Bigelow, 2003). The model we develop in this study is no exception. As we try to make use of existing complex physical models and statistical relations, the integrated assessment model has some limitations worth noting.

The first limitation concerns the dynamics between the double-rice and triple-rice farming. The total demand of each farming type is fully exogenous. One improvement could be to make this demand internal in the model, as this demand in reality might react to factors such as average profitability over time. Furthermore, there also exists the possibility of changing land-use transition rules in the future. Such behavioral changes could be induced by, for instance, change in societal values or improvement in socioeconomic conditions (Malek & Verburg, 2020; van de Poel, 2018). A second simplification relates to the deterioration of soil quality over time. The model approximates the deterioration through the depletion of soil nutrients stock. In reality, soil quality reduction is also triggered by other means such as increase in sulfite concentration and acidity (Tong, 2017; Tran Ba et al., 2016). A third potential improvement is to look beyond rice agriculture, and consider other higher value livelihoods such as aquaculture, fisheries, and fruits and vegetables (V. V. Hoang & Tran, 2019; Pham et al., 2020). However, since these livelihoods have only been promoted and adopted recently (D. D. Tran, Huu, et al., 2021), existing models and information regarding their impacts on the biophysical environment and the impacts of biophysical change to their productivity are limited.

Although including multisectoral dynamics unavoidably leads to simplifications in how subsystem are represented because of computational tractability and spatiotemporal alignment of the relevant processes, we still have to ensure that the resulting multisectoral dynamics model is suitable for answering the policy question at hand. For this purpose, we follow the fit for purpose approach for model evaluation. This approach has been promoted as an alternative to standard model validation approaches under three conditions (Haasnoot, van Deursen, et al., 2014; Oreskes, 1998; Oreskes et al., 1994; Schwanitz, 2013). The first condition is when the phenomenon being modeled concerns an open loop system, that is, a system in which we have no ground truth to validate the model against. The second condition is when the model is being used to simulate situations that have not existed nor observed in the past. The third condition is when the model is being used to rapidly screen alternative policies under various uncertainties in a strategic decision-making context, rather than for detailed technical planning purposes. These conditions suit the nature of exploration of inequalities under different scenarios. We sometimes do not have exact historical data on some of the sectoral dynamics (e.g., measurement of soil fertility over time), while we need simulate scenarios that have not occurred in the past (e.g., people prefer to shift back to double rice) to investigate the emerging inequality patterns under different scenarios.

An important direction for future research in modeling multisectoral dynamics is improving the way in which model simplifications are accounted for in the entire analysis. One promising, but underappreciated, direction is that of the multi-resolution modeling (Davis & Bigelow, 1998; Davis & Tolk, 2007; Hong & Kim, 2013). The core idea is to describe a system with a single model or a family of models involving different levels of resolution. Resolution here can encompass various dimensions of the system, such as process (e.g., detailed physical processes or stylized processes), spatial scale (e.g., small gridded cells or aggregate district area), and time (e.g., monthly or annual). The goal is to enable users to zoom in and out, allowing them to specify and explore parameters at the resolution suitable for their purposes. Adopting multi-resolution modeling to the present context of exploring inequality patterns allows us to identify interesting combinations of adaptation measures and futures that could be analyzed in more detail using a sectoral model with higher resolution. For example, on the temporal dimension, we can explore the impacts of changing monthly temperature and precipitation pattern and how an alternative cropping calendar might be used to adapt to such changes. On the process dimension, we can explore how power asymmetry between farmers within the same dike ring could shape the decision of (de)constructing high dikes, eventually affecting the inequality in the entire region.

5.2. Insights for the VMD

This study provides two important insights for agricultural adaptation to climate change planning in the upper VMD. First, we explore how inter-district spatial inequalities vary across scenarios. The variety is mainly observed between two groups of districts: those located along the two branches of the Mekong (districts in the diagonal line from the northwest to the southeast) and those located just to the north and to the south of the river branches. Districts in the first group are fully protected by high dikes since the late 2000s. Local farmers in these districts have adopted triple-rice farming, which is more exploitative in nature. Districts in the second group is only partially protected by high dikes, making swapping between triple and double-rice cropping easier. There are two conditions where districts in the first group become relatively better-off compared to districts in the second group: further construction of high dikes and large upstream dam development. Further construction of high dikes would nudge farmers in other districts to shift to triple-rice farming. However, since the transition would take some time, districts in the first category have an advantage to other districts as they already have adopted triple-rice farming. Large upstream dam development induces sediment starvation which reduces the relative advantage floodplain sedimentation in the monsoon season.

The second important insight is that upstream dam development is the most influential driver whereas climate-induced river discharge is less influential in affecting the VMD's agricultural sector. A negative correlation is observed here: the more upstream dams, the lower the total rice production in the VMD. The relationship between upstream dam development and equity is more complicated as this strongly depends on other uncertain factors and the adaptation policy. For instance, in case of a low dikes policy, increased upstream dam development reduces inequality in the VMD. For the fertilizer subsidy policy, medium upstream dam development results in the largest equity compared to either small or large upstream dam development. While upstream dam development is treated as fully uncertain in this study, in reality it can be a subject of negotiation with the Cambodian government. This emphasizes the importance of pursuing a catchment-wide approach to climate change adaptation planning in deltas through coordination with upstream countries. As for climate-induced river discharge, the temporal dynamics of the two RCPs do not differ much during the time horizon of our analysis. This variable might become more influential if we look at a longer time horizon, for instance until the end of the century.

6. Concluding Remarks

In this study, we demonstrate the importance of accounting for multisectoral dynamics in model-based support for equitable climate change adaptation planning. This necessity comes from the fact that the interactions between future uncertainties and adaptation policies give rise to distinctive inequality patterns, and that uncertainties and adaptation may originate from multiple sectors. We reflect on how including multisectoral dynamics often comes at the expense of sacrificing details in modeling some parts of the system. Further, we describe how the fit for purpose approach can be useful in assessing the adequacy of such a quantitative model for decision support. Climate change adaptation planning of the agricultural sector in the upper VMD is used as a case study. We explore the consequences of different scenarios of river discharge, upstream dam development, societal land-use preference, and adaptation policies to spatial inequalities as well as aggregated total output and equity performance. While previous studies mostly focus on either the aggregate total output of the agricultural sector in the entire region, or equity issues at an individual farm, in this study we assess both disaggregate equity and aggregate total output at a regional level.

We recognize three broader insights for model-based support for equitable climate change adaptation planning in deltas. First, the relationships between uncertainties and adaptation policies with equity and total output are complicated and non-linear. Different combinations of uncertain future developments and adaptation policies may lead to different inequality patterns. We also present how small changes in an uncertain factor, when compounded with different adaptation policies, can lead to different inequality patterns with different "winners" and "losers." This implies that when offering model-based support for climate change adaptation planning, varying only one factor at a time (e.g., degree of upstream dam development) while keeping other factors constant would risk overlooking non-linear interactions effects. This again emphasizes that in the quantitative models, one needs to incorporate relevant multisectoral dynamics as well as interactions between the different systems that give rise to distinctive inequality patterns.

Second, equitable climate change adaptation planning should involve the consideration of not only total output but also equity indicators. Equity performance should be assessed both at an aggregate (e.g., using the Gini coefficient or other aggregation procedures) and at a disaggregate (e.g., the spatial inequality patterns) level. This is because, similar to Anscombe's quartet (Anscombe, 1973), the same statistical summary (Gini coefficient) can result from completely different inequality patterns. Further, while the aggregated indicators are more practical for comparing the performance of alternative policies, the disaggregate indicators are useful to help in identifying "winners" and "losers" under each combination of adaptation measures and scenarios. Such information is valuable for planners to anticipate changing inequality patterns in advance and to prepare additional policies, such as redistribution measures, to ameliorate inequality. When doing equity analysis, it is important to carefully deliberate the choice of the *unit* and the *scope* of the distribution. In this study, we choose to look at spatial equity of socioeconomic variables. In other circumstances, one might need to look at other variables such as distribution of flood safety or environmental degradations.

Finally, given the non-linearity and interaction effects, static strategies are unlikely to have satisfactory performance across multiple scenarios. Instead, strategies that can be adapted over time in response to changing conditions and new information are likely to perform better across the ensemble of scenarios (Maier et al., 2016; Walker et al., 2013). Such adaptive strategies are often conceptualized as adaptation pathways (Haasnoot, Kwakkel, et al., 2013). It involves the identification and implementation of short-term no-regret actions while continuously monitoring critical variables and system performance and adapting in response to this to avoid maladaptation. However, in order to make an adaptive delta plan equitable, one needs to move beyond looking only at aggregate indicators. The findings of this study have shown that one needs to also continuously monitor the distributional impacts to the different population subgroups.

Data Availability Statement

Supporting data behind the figures is included in supporting information S1. Model and analysis codes, as well as simulation results data, can be accessed at https://doi.org/10.5281/zenodo.4588499. Please cite the model and data as: Bramka Arga Jafino (March 8, 2021). bramkaarga/VietnamModel: Earth's Future article v1.0 (Version v1.0). Zenodo. http://doi.org/10.5281/zenodo.4588499.

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