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Evaluating the distributional fairness of alternative adaptation policies: a case study in Vietnam's upper Mekong Delta

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Abstract

To support equitable adaptation planning, quantitative assessments should consider the fairness of the distribution of outcomes to different people. What constitutes a fair distribution, however, is a normative question. In this study, we explore the use of different moral principles drawn from theories of distributive justice to evaluate fairness. We use adaptation planning in Vietnam Mekong Delta as a case study. We evaluate the preference ranking of six alternative policies for seven moral principles across an ensemble of scenarios. Under the baseline scenario, each principle yields distinctive preference rankings, though most principles identify the same policy as the most preferred one. Across the ensemble of scenarios, the commonly used utilitarian principle yields the most stable ranking, while rankings from other principles are more sensitive to uncertainty. The sufficientarian and the envy-free principles yield the most distinctive ranking of policies, with a median ranking correlation of only 0.07 across all scenarios. Finally, we identify scenarios under which using these two principles results in reversed policy preference rankings. Our study highlights the importance of considering multiple moral principles in evaluating the fairness of adaptation policies, as this would reduce the possibility of maladaptation.

Keywords Adaptation · Distributional outcomes · Equity · Normative · Justice · Ethical principle

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1 Introduction

Attention to justice in climate change adaptation planning has increased in the past years (Byskov et al. 2019; Pelling and Garschagen 2019). There are several reasons for this. First, physical consequences of climate change vary across space, resulting in different exposure and impact on people in different places (Green 2016). Second, people exposed to the same degree of climate change may experience different actual impacts because of differences in vulnerability and adaptive capacity (Thomas et al. 2019). Third, adaptation policies are likely to unequally affect different people, thus reinforcing existing or introducing new inequalities (Atteridge and Remling 2018). Despite all this, the assessment of adaptation alternatives often still uses aggregated indicators where the costs and benefits of alternatives are aggregated across people, space, and time (Kolstad et al. 2014). Such blind aggregative assessments obfuscate the distributional impacts on different groups of people.

Adaptation policies inevitably have distributional effects for different groups within the population (Atteridge and Remling 2018). These can be intentional consequences or unintended side effects. Deliberately planned distributional effects are profound in the domain of flood risk adaptation, where various compensation mechanisms have long been an inseparable element of adaptation policies, as physical measures such as levee heightening often have adverse consequences for some subgroups of the population (van Doorn-Hoekveld et al. 2016). Yet, even in such an established domain, unforeseen distributional impacts still abound. In the Vietnam Mekong Delta, reducing flood risk by constructing higher dikes turned out to be harmful to small-scale farmers (Chapman and Darby 2016), while also transferring flood risk downstream (Triet et al. 2017). This inherent complexity of adaptation planning emphasizes the importance of *ex-ante* accounting for distributive justice in adaptation policy planning.

Assessing distributive justice requires specifying the *unit* (what is being distributed?), *scope* (to whom is it being distributed?), and *shape* (what pattern of distribution is just?) of the distribution (Bell 2004; Page 2007). The *unit* of the distribution depends on context and application domain. For example, in flood risk management, the *unit* of the distribution typically is the expected annual damage or exposure to flood hazard. In adaptation planning for deltas, the *unit* ranges from physical variables such as flood risk (e.g., expected annual damage or expected casualties) to socioeconomic variables such as farmers' annual income (Suckall et al. 2018). The *scope* of the distribution is defined by partitioning the population into relevant (sub)groups, for example, by dividing the population based on their income (Hallegatte and Rozenberg 2017), or based on where they live (Ciullo et al. 2019; Jafino et al. 2019). The *shape* is relevant for assessing the resulting distributional effects of alternative policies in comparison to what is considered just given a preferred distributive moral principle.

Two dimensions of justice are relevant: procedural and distributive justice. Procedural justice is concerned with how decision-making processes are organized (Bulkeley et al. 2013; Schlosberg 2009). In procedural justice, higher degrees of recognition, inclusion, participation, and transparency in decision-making processes are advocated for (Chu et al. 2016; Hügel and Davies 2020). Procedural justice reflects on how institutional arrangements for adaptation governance could be improved to realize a more inclusive decision-making process (Holland, 2017). Distributive justice is concerned with how the benefits and costs of adaptation policies are distributed across stakeholders (Grasso 2010; Paavola and Adger 2006). The questions here include: how are the burdens and benefits of climate change currently distributed? Who gains and who loses from adaptation? How could burdens and benefits of adaptation policies be distributed more fairly?

Distributive justice research can be further divided into explorative and normative. Explorative studies assess how burdens and benefits of adaptation *will be* distributed by identifying who gains and who loses, and how this is affected by climatic and socioeconomic uncertainties (see e.g., Chapman and Darby 2016; Gold et al. 2019; Triet et al. 2020). Explorative analysis can guide planners and/or policy makers in anticipating unintended distributional impacts and designing corrective actions. In contrast, normative studies are concerned with how burdens and benefits *should be* distributed and to what extent alternative policies meet standards (Grasso and Markowitz 2015; Muller 2001). Here, moral principles are used as guidance to design requirements for (prescriptive) and to assess the fairness of (evaluative) adaptation policies. Explorative and normative analyses are complementary. While an explorative analysis identifies "winners" and "losers," normative analysis generates a preference ranking of adaptation policies based on a preselected moral principle.

While both prescriptive and evaluative normative analyses are paramount in mitigation studies (Dooley et al. 2021; Klinsky et al. 2017), this is not yet the case in adaptation studies. Normative studies in the adaptation domain are largely prescriptive, i.e., aiming to prescribe what a just adaptation policy should look like (Graham et al. 2015; Paavola and Adger 2006; Pelling and Garschagen 2019). It is, therefore, an open question how to use multiple moral principles as yardsticks in evaluating the projected outcomes of adaptation policies. Moreover, how does uncertainty affect the policy preference rankings as produced by different moral principles? Except for a few recent studies, model-based quantitative analyses for supporting adaptation planning barely consider distributional effects and seldom reflect on the moral principle that implicitly underlies the aggregation of outcomes across people (Beck and Krueger 2016; Rao et al. 2017).

In this paper, we show how to use multiple moral principles in performing a normative assessment of distributional outcomes in model-based adaptation planning under uncertainty. We first operationalize seven distributive moral principles often found in climate studies. Next, using agricultural adaptation planning in the upper Vietnam Mekong Delta (VMD) as a case study, we evaluate the performance of six alternative adaptation policies using these moral principles and analyze the change in rankings across them. Then, we evaluate the robustness of the rankings for each principle. Finally, we demonstrate how to identify scenarios in which two moral principles give reversed preference ranking.

The remainder of this paper is structured as follows. We introduce the theoretical background of this study in more detail in "Sect. 2." Next, we introduce the distributive moral principles that we consider as well as the case study we apply these principles on. "Sect. 4" presents the results of the case study, while in "Sect. 5" we provide a more general reflection and conclusions.

2 Methods

2.1 Alternative principles for distributive justice

Various distributive moral principles have been proposed for the specific context of planning for climate change. Many cost–benefit analyses of adaptation projects adopt a utilitarian principle (André et al. 2016; Watkiss et al. 2015), where the goal is to maximize the total benefits irrespective of how they are distributed across people. The “putting the most vulnerable first” principle is often applied in studies that focus on fair adaptation to climate change (Burton et al. 2002; Paavola and Adger 2006). Other moral principles which are gaining prominence in the climate justice domain include egalitarianism, prioritarianism, and Rawlsian difference (Adler and Treich 2015; Ciullo et al. 2020; Johnson et al. 2007). These principles are, however, mainly applied only in the mitigation domain. For adaptation, these principles are being used but primarily to prescribe how adaptation strategies should be designed (e.g., more resources should be put for flood protection should for worse-off regions), but not to ex-ante evaluate the expected outcomes of concrete adaptation measures under different scenarios.

In this study, we use seven moral principles that have been previously used or proposed in climate change research (Table 1). The set of principles was selected to cover three criteria: (i) the default principle applied in most climate change studies (i.e., the utilitarian principle); (ii) principles that have been formalized only in either climate mitigation and adaptation studies or both (the strict egalitarian, the prioritarian, and the envy-free principles); and (iii) principles that have been argued to be useful for planning for climate change but have never been formalized for simulation and/or numerical studies as far as we know (the Rawlsian difference and the sufficientarian principles).

We operationalize these principles by deriving aggregation functions based on the normative ideas underpinning them. For example, the Rawlsian difference principle of bringing benefits to the least advantaged members of the society implies an aggregation function that looks at the outcome for the worst-off (Rawls 2009). Strict egalitarianism demands total equality of outcomes across all individuals (Nielsen 1979); hence, the aggregation function concerns the discrepancy between the outcomes of the worst-off and best-off individuals. These aggregation functions compare the distributional outcomes of the alternative adaptation policies to produce a preference ranking among them. When available, we derive the aggregation functions based on previous studies in the climate change domain.

There are two important things to note about the operationalization of the principles. First, the absolute values of the aggregated outcomes are incommensurable across the different principles. Comparison across principles can only be performed by comparing the preference rankings produced by a principle. Second, the original conception of each principle might have specific units for which the principle is deemed applicable. For example, the utilitarian principle is concerned with utility (Posner 1979). But utility is an abstract concept, and it is not necessarily a linear function of other measurable units. Nevertheless, applications of this principle often use the unit of interest in the planning context (e.g., expected annual damage) directly as utility (Du et al. 2020), whereas other studies transform the unit of interest into utility by using a concave function (Adler et al. 2017; Kind et al. 2017). The envy-free principle, in contrast, cares about the consumption bundle owned by individuals but not about the utility gained from consuming the bundle (Varian 1974). In this study, we interpret the principles more liberally; we use our unit of interest directly as the subject of the distribution.

2.2 Case study: Adaptation planning for rice farming in the upper Vietnam Mekong Delta

The VMD, often called the granary of Vietnam, contributes to around 85% of the country’s rice export and 55% of the country’s rice supply (GSO 2019). Most households in the upstream part of the delta, especially in An Giang and Dong Thap provinces (see

Table 1 Distributive moral principles accounted in this study. The aggregation function column shows whether to maximize or minimize the aggregated welfare outcomes

Principles	Description	Aggregation function	Theoretical underpinnings	Examples of application in the climate change domain
Utilitarian	An action should maximize well-being and/or welfare of all affected individuals	Maximize: $\sum_{i=1}^{n} u(x_i)$	Posner (1979)	Anthoff and Emmerling (2018); Fankhauser et al. (1997); Shardul and Samuel (2008); Thaler et al. (2018)
Strict egalitarian	Equality of outcomes—each individual should have the same level of welfare. An action should strive for such equal distribution of outcomes	Minimize: $\max\left(u\left(x_i\right)\right) - \min(u(x_i))$	Konow (2003); Nielsen (1979)	Ciullo et al. (2020); Ikeme (2003); Johnson et al. (2007); Kaufmann et al. (2018); Thaler and Hartmann (2016)
Rawlsian difference principle	An action should bring benefits for the least advantaged individuals	Maximize: $\min(u(x_i))$	Rawls (2009)	Johnson et al. (2007); Kaufmann et al. (2018)
Prioritarian	The outcome of an action is a function of an aggregation of overall welfare with extra weights given to worse-off individuals	Maximize: $\frac{1}{1-\gamma} \sum_{i=1}^{n} u(\frac{u(x_i)}{u(\overline{x})})^{1-\gamma}$	Arneson (2000); Parfit (1997)	Adler et al. (2017); Anthoff et al. (2009); Ciullo et al. (2020); Gourevitch et al. (2020); Paavola and Adger (2006)
Sufficientarian	An action should ensure that all individuals have secured enough welfare	Maximize: $\left\|\left\{i \in n \,:\, u\left(x_i\right) \geq u(s)\right\}\right\|$	Shields (2012)	Ikeme (2003); Meyer and Roser (2010)
Envy-free	An action is morally just if no individuals prefer another individual's achievements and/or welfare	Minimize: $\sum_{i=1}^{n} \sum_{j=1}^{n} \max\{u(x_j) - u(x_i), 0\}$	Bosmans and Öztürk (2018); Konow (2003); Varian (1974)	Tol (2001); Grasso (2007); Ikeme (2003)
Composite principles	The outcome of an action should be evaluated against several moral principles (in this case, between utilitarian and egalitarian)	Maximize: $w * f\left(\sum_{i=1}^{n} u\left(x_i\right)\right) + (1-w) * f(\max\left(u\left(x_i\right)\right) - \min(u(x_i)))$	Frohlich and Oppenheimer (1993); Konow (2003)	Schlosberg (2013); Wood et al. (2018)

where:

$u(x_i)$, welfare of individual i

$u(\overline{x})$, average welfare of all individuals

γ, inequality aversion factor

$u(s)$, minimum welfare threshold deemed sufficient

w, preference factor for utilitarianism compared to egalitarianism

$f(.)$, min–max linear normalization

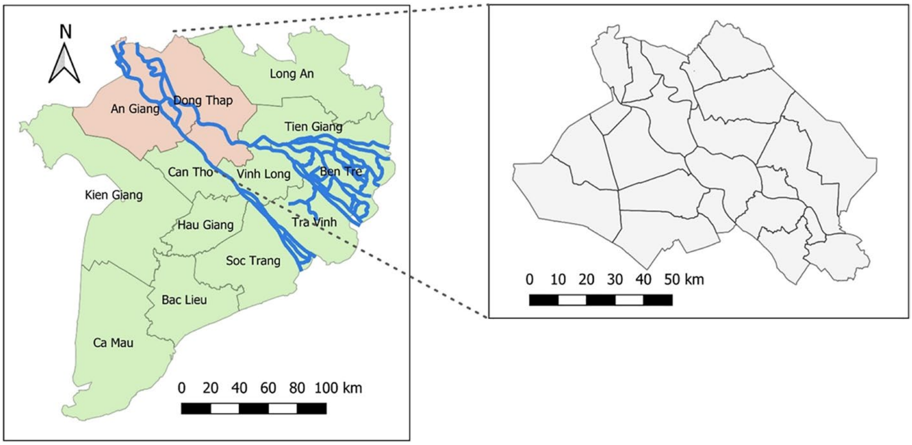

Fig. 1 Map of the case study area. Left panel: provinces in the Vietnam Mekong Delta, right panel: 23 districts in An Giang and Dong Thap

Fig. 1), rely primarily on rice farming since their location is safe from salt intrusion (Ngan et al. 2018). There are two main types of rice farming: double-rice farming (two harvests a year outside the monsoon season) and triple rice farming (an additional planting season during the monsoon). As the delta is regularly flooded during the monsoon, triple rice farming is only possible in areas protected by high dikes. The construction of high dikes began in the early 2000s to boost rice production in the delta (Garschagen et al. 2012).

Rice farming in the upper VMD suffers from various climatic and anthropogenic pressures. Climate change is expected to increase the intensity of annual flooding during the monsoon season (Triet et al. 2020). If high peak floods happen earlier in the year, they damage not only the monsoon harvest but also the summer-autumn harvest. Continuous land subsidence with a rate of up to 17 mm/year further raises flood risk (Minderhoud et al. 2018). Sediment starvation is a related problem. Sediment transported by the river supplies nutrients for rice cultivation in the VMD. The amount of sediment entering the VMD is anticipated to decrease in the future due to upstream hydropower dam construction (Lauri et al. 2012; Manh et al. 2015). The construction of high dikes in the VMD exacerbates the problem of sediment starvation, as high dikes prevent annual floods from entering the rice fields and thus reduce the supply of nutrients brought by the sediment. Consequently, farmers need to apply more fertilizer to maintain agricultural productivity. While large-scale farmers benefit from economies of scale to overcome this drawback, this is not the case for small-scale farmers (Chapman and Darby 2016). Hence, the current strategy of continuing intensification of the agricultural sector, while successfully increasing overall rice production, raises equity concerns as it jeopardizes small farmers. This motivates the selection of this planning problem as our case study.

In this study, we assess the distributional outcomes of six alternative adaptation policies for Dong Thap and An Giang, two provinces in the upper VMD (see Fig. 1). More precisely, we evaluate the spatial distribution of farm profitability among farmers in the 23 districts in these two provinces. Farm profitability is determined by the cost of purchasing fertilizer and income from selling rice, whereas rice yield is calculated through an integrated impact assessment metamodel (see Fig. 2). The model assumes

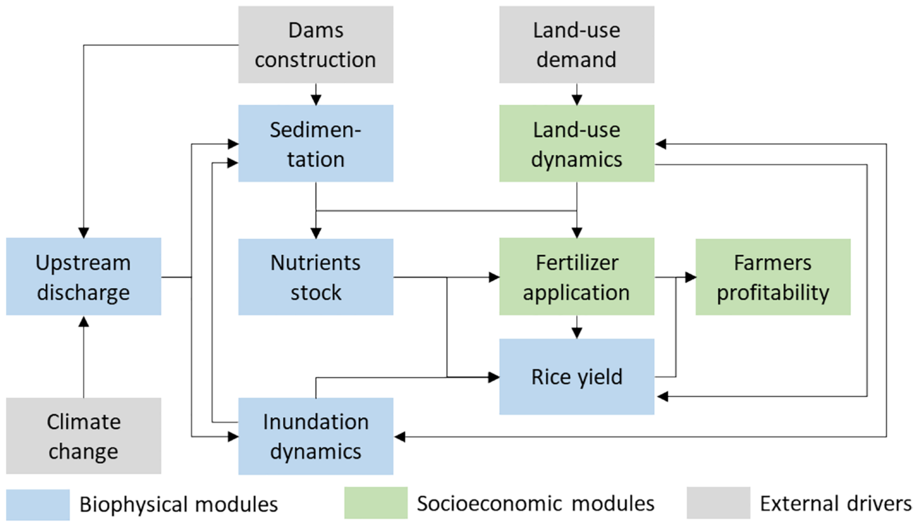

Fig. 2 Modules in the integrated impact assessment metamodel. Taken from Jafino et al (2021)

that maximum potential rice yield is constrained by nutrient availability, which is supplied either through natural floodplain sedimentation or artificial fertilizers. At the same time, rice crops can be damaged by the occurrence of extreme flooding, which is worsened by climate change and local land subsidence. Hence, the model combines flooding and sedimentation dynamics, soil nutrient stock dynamics, crop yield calculation, land subsidence, land use change dynamics, and a farm profitability calculation module (see Jafino et al. (2021) for details of the model). The model is spatially explicit with a parcel resolution of 200 m and has a simulation time horizon of 38 years, from 2012 to 2050.

The spatially explicit model initially calculates farm profitability based on rice yield at the parcel level. Farm profitability from all parcels in a district is then added up to obtain farm profitability at the district level. This results in a total of 23 outcome variables representing farmers in the 23 districts in the case study area. To calculate the principle-based performance of policies, we aggregate the 23 outcome variables based on the aggregation functions listed in Table 1. The main ingredient of all aggregation functions is the welfare of individual i ($u(x_i)$). Here, the individual i described in Table 1 refers to all farmers in each district, while farm profitability is a direct measure of welfare ($u(x_i)$).

Several moral principles require further parameterization. First, the prioritarian principle involves an inequality aversion factor γ, with larger values implying more weight to prioritize the worse-off. Previous studies took a value between 0 and 3 with 0.5 and 1 the most frequently used (Adler et al. 2017; Anthoff et al. 2009). In this study, we take a value of $\gamma = 0.5$. Second, the sufficientarian principle requires setting a minimum threshold of farm profitability. We use an optimistic threshold of 70 million Vietnam Dong (VND), which is the highest average annual profit as surveyed by Tran et al. (2018). Third, the composite principle requires setting the weighting factor w, which indicates the preference given to the utilitarian principle compared to the egalitarian principle. We use a value of 0.33 here, implying less emphasis on the utilitarian principle. With this parameterization, we calculate the principle-based aggregated performance of each policy and then calculate the preference ranking of the policies based on each principle.

2.2.1 Alternative adaptation policies

In this study, we consider four hard infrastructural and two "soft" policies. The infrastructural policies are related to dikes (de)construction: either further construction of high dikes in the areas currently protected by low dikes, or deconstruction of all high dikes into low dikes. Each policy is applied in both An Giang and Dong Thap independently. These policies are inspired by recent discussions on sustainable flood control in the region (Tran et al. 2018; Triet et al. 2020). The soft policies are upgrading seed and fertilizer subsidy. In the former policy, we assume that by using a higher quality seed variety, crops are more resilient to flooding. This policy thus reduces the steepness of the stage-damage curve (Triet et al. 2018), so that the same flood depth results in a lower fraction of damaged yield. In the latter policy, we distribute 50 kg of free fertilizer to farmers who are located far from the Mekong River. The motivation behind this is that the sediment concentration in the river declines proportionately to the distance from the main river. Hence, farmers located far from the river receive significantly fewer nutrients from the floodplain sedimentation process (Manh et al. 2015). In the past 10 years, similar subsidy policies have been implemented in the region (Nguyen et al. 2020). All policies are assumed to be implemented from 2025 onwards.

2.2.2 Uncertainties

We consider five future uncertain developments that have a substantial influence on the agricultural sector in the upper VMD. Firstly, the river discharge is changing due to climate change. We use synthetic hydrographs generated by a global hydrological model to obtain annual maximum upstream discharge at Kratie, Cambodia, under climate scenarios RCP 4.5 and 8.5 (Sutanudjaja et al. 2018). The second uncertainty is hydropower dam development in Cambodia, which reduces the total sediment supply entering Vietnam and the annual maximum peak discharge. We use five upstream dam development scenarios developed by Lauri et al. (2012) and Manh et al. (2015). The third and the fourth uncertainties are the productivity gaps between the three different harvesting seasons. The winter-spring season after the monsoon (December–April) is the most productive season, followed by the summer-autumn season (April–July) and the autumn–winter season (July–December). In 2016, the yields in the summer-autumn season and the autumn–winter season were, on average, 26% and 35% lower than that of the winter-spring season. Here, we consider a wider bandwidth of productivity gaps of 15–45%. The fifth uncertain development is land use change dynamics. Based on recent reports and studies (Mekong Delta Plan Consortium 2013; Triet et al. 2018), we consider four scenarios: continuing intensification of the triple rice farming system, shifting back to double rice, an increase of alternative agricultural livelihoods (e.g., orchard and aquaculture), and large-scale urbanization.

2.3 Experiment and analysis setup

To systematically explore the uncertainty space, we use Latin Hypercube Sampling to generate 1200 future scenarios. Each scenario corresponds to a unique combination of values for each uncertain variable. We then evaluate each policy against the set of 1200 scenarios, resulting in a total of 7200 simulation runs (1200 uncertainty scenarios times six policies). We then perform four analyses. In the first analysis, we analyze the policy preference ranking under a baseline scenario (future river discharge based on RCP4.5, small upstream dam development, and continuation of triple rice expansion) to illustrate how the choice of different moral principles affects this ranking. The rank of each policy is determined by aggregating district-level farm profitability using the functions specified in Table 1.

The other analyses look at the impacts of scenarios. In the second analysis, we evaluate the robustness of the ranking across all scenarios. Specifically, we look at how the rankings vary under each principle across all 1200 scenarios. In the third analysis, we assess the agreement of rankings between each pair of principles across all scenarios using Kendall's Tau-*b* coefficient (Kendall 1938; Agresti 2010). For each pair of principles, Kendall's Tau-*b* coefficient equates the rankings from all pairs of alternative policies. It takes a value between 1 (completely similar rankings between the two principles) and − 1 (completely opposite rankings). The fourth analysis aims to identify the uncertain conditions under which two moral principles yield conflicting results, i.e., when Kendall's Tau-*b* coefficients between them are negative. We use dimensional stacking (Kwakkel 2017; Molina-Perez 2016), a scenario discovery technique (Bryant and Lempert 2010), to identify uncertainty subspaces with a high concentration of scenarios with negative ranking correlations between any pair of moral principles.

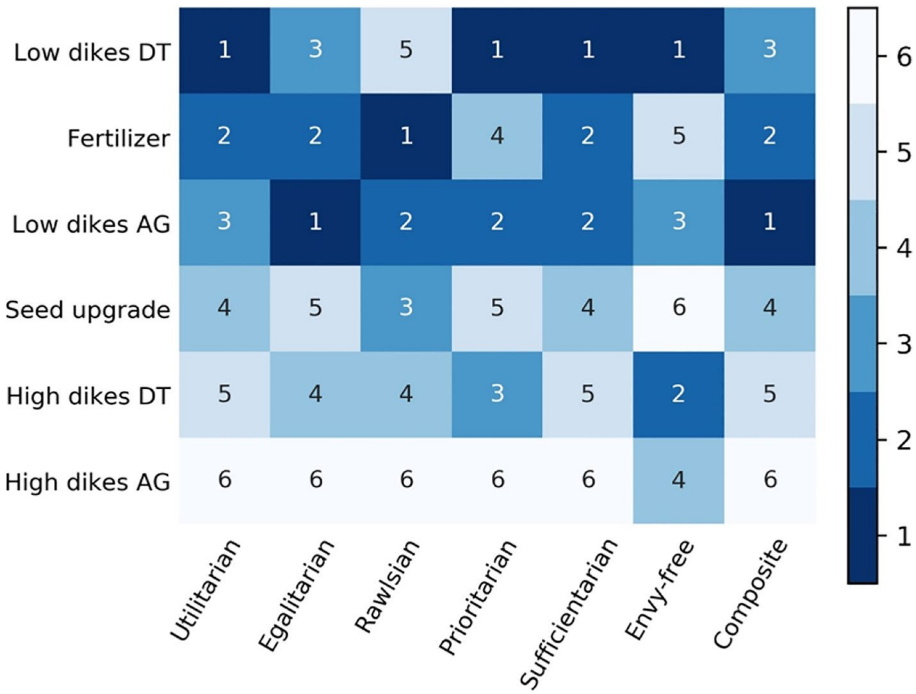

Fig. 3 Preference ranking of alternative policies under a single scenario, with 1 as the most preferred and 6 as the least preferred. DT stands for Dong Thap while AG stands for An Giang

3 Results

3.1 Policy preference ranking under a baseline scenario

To what extent do policy preference ranking change when different distributive moral principles are used? To answer this question, we compare the ranking of the policies under a baseline scenario. The result is presented in Fig. 3.

We first investigate the result in Fig. 3 by looking at the performance of a policy across the different principles. Further expanding high dikes in An Giang is the least preferred policy, except for the envy-free principle. In contrast, low dikes in Dong Thap performs the best in most principles, making it one of the most promising policies to pursue. However, when viewed from the Rawlsian difference principle, this policy is the second worst performing policy. The policy with low dikes in An Giang, despite ranking first in only two principles, does not rank lower than third when we look at all other principles. These rankings thus indicate which policies perform well (or bad) under different distributive perspectives.

Overall, there are no pairs of principles that yield identical rankings. Also, there is no pair of principles with completely reversed rankings. Some pairs of principles do have quite dissimilar preference rankings, despite having the same most preferred policy (e.g., utilitarian and the envy-free principle). Other pairs of principles have a relatively large degree of ranking agreement (e.g., utilitarian and sufficientarian principles). The egalitarian and composite principles also result in a quite similar ranking, although the policies with seed upgrade and high dikes in Dong Thap are ranked in reversed order. This is explained by the fact that in the composite principle, we assigned a substantial weight to the egalitarian principle (i.e., 0.67).

3.2 Robustness of ranking across future scenarios

How do uncertainties influence the ranking of policies for the different distributive moral principles? To answer this question, in Fig. 4, we vertically stack the rankings of the policies across all the 1200 scenarios. Each vertical line shows the ranking of the policies under one scenario. Figure 4 shows that no policy is always ranked the same across all scenarios for any of the principles. For example, the policy that performs best according to the prioritarian principle in the largest number of scenarios is the policy with low dikes in Dong Thap. However, this policy is ranked first in only 61% of the scenarios and ranked last in about 14%. According to the egalitarian and the Rawlsian principle, the policy ranked first under the baseline scenario (low dikes in An Giang and fertilizer subsidy, respectively) is ranked first in just over a third of all scenarios (around 35% and 38%, respectively). According to the sufficientarian principle, all policies have comparable performance in 15% of the future scenarios.

From Fig. 4, we can draw more general conclusions about the ranking stability of each distributive principle. For example, the results for the utilitarian principle can be classified into two groups. The first group contains 640 scenarios in which low dikes in Dong Thap performs best. In contrast, in the second group of scenarios (the other 560 scenarios), the fertilizer subsidy performs best. Within the first group, the fertilizer subsidy ranks second in 47% of the 640 scenarios, while low dikes in An Giang ranks second in the rest of the scenarios. In the second group, the seed upgrade policy ranks second in most (88%) of the

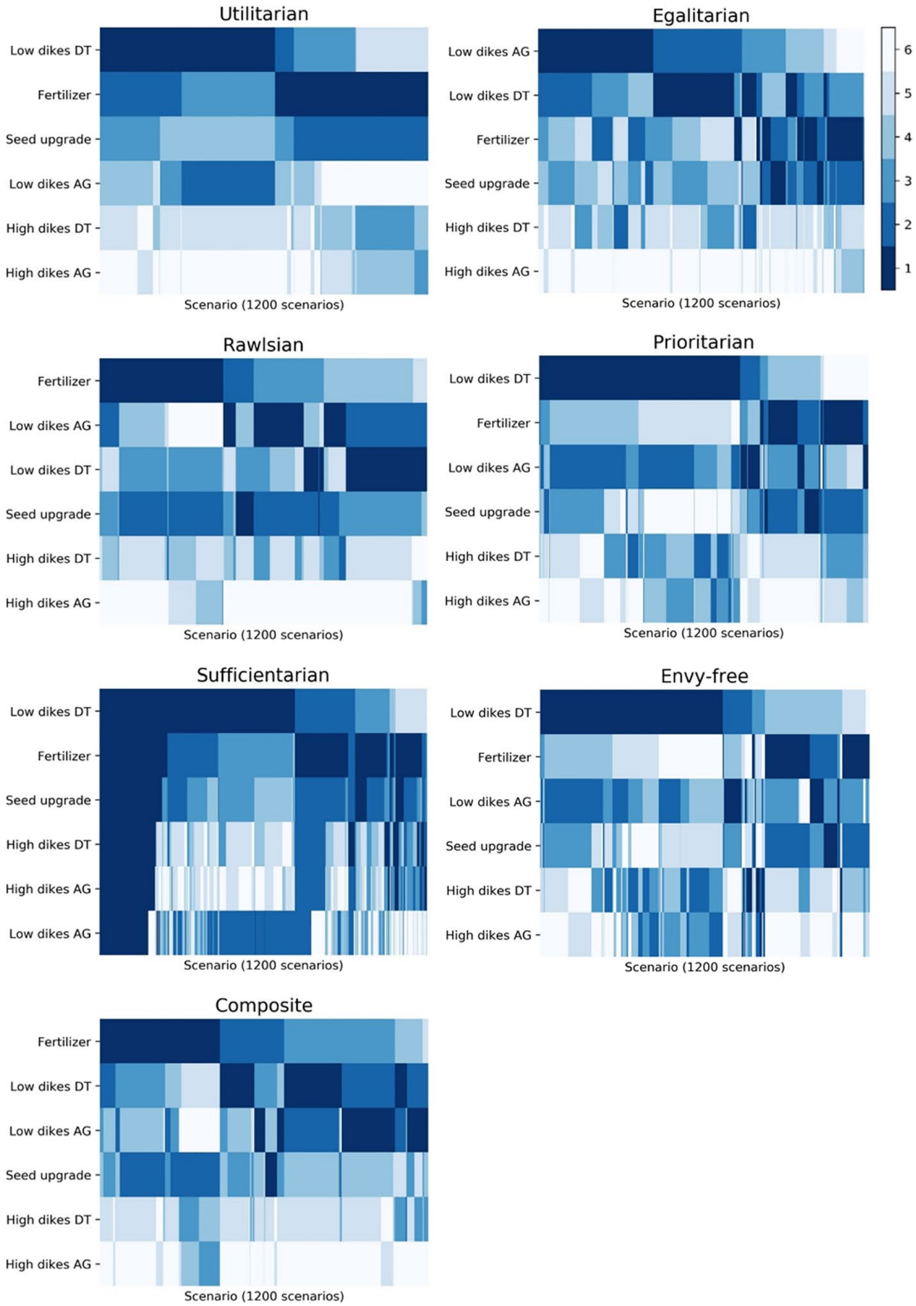

Fig. 4 Ranking of policies across all 1200 scenarios based on seven distributive moral principles. All rankings are illustrated as stacked color lines, with each vertical line designating the ranking of policies under one specific scenario. For each principle, the policies are ordered based on how often they perform the best across the scenarios. DT stands for Dong Thap and AG stands for An Giang

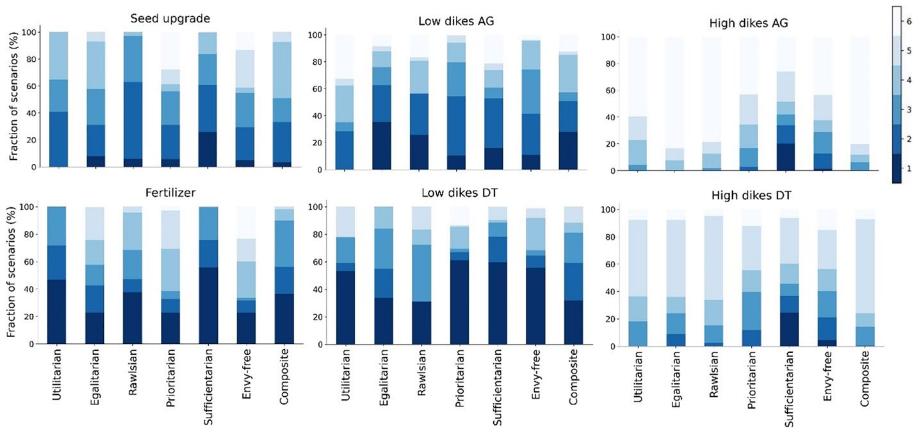

Fig. 5 Histogram of rankings of each policy across all 1200 scenarios

560 scenarios. In this second group, low dikes in Dong Thap (which is the most preferred option in the first group) ranks fifth in almost half the cases (47%).

Overall, the utilitarian principle has the most stable ranking. This is evidenced by the fact that the results for the utilitarian principle show the least changes in ranking compared to the other principles (see Fig. 4). As a comparison, for the envy-free principle, in scenarios where the policy with low dikes in Dong Thap performs best (56% of all scenarios), the second most preferred policy varies widely across the scenarios. In the remaining 44% of scenarios, the best-performing policy is any of the other five policies. This underscores that, when we move away from a strictly utilitarian perspective, the preference ranking of the policy is strongly affected by uncertainties.

We can also analyze the results from the perspective of the policies (Fig. 5). The policy with low dikes in Dong Thap, although performing best according to many distributive principles under the baseline scenario (Fig. 3), ranks first in 53%, 61%, 60%, and 56% of the scenarios according to the utilitarian, prioritarian, sufficientarian, and envy-free principles, respectively (Fig. 5). The next policy that ranks first in many scenarios across all principles is the fertilizer subsidy and low dikes in An Giang. However, these policies do not perform well according to the prioritarian and the envy-free principle. High dikes policies rank low in most scenarios across all principles. From the perspective of the policies, we can identify the most robust performer across all moral principles and scenarios, which is the policy with low dikes in Dong Thap.

3.3 Agreement of ranking across scenarios

To what extent are the policy preference rankings according to each principle correlated, in the sense that they are in agreement with the rankings according to all other principles? To answer this, Fig. 6a presents the distribution of Kendall's Tau-*b* coefficients across all 1200 scenarios as kernel density for each pair of principles. To facilitate a more direct

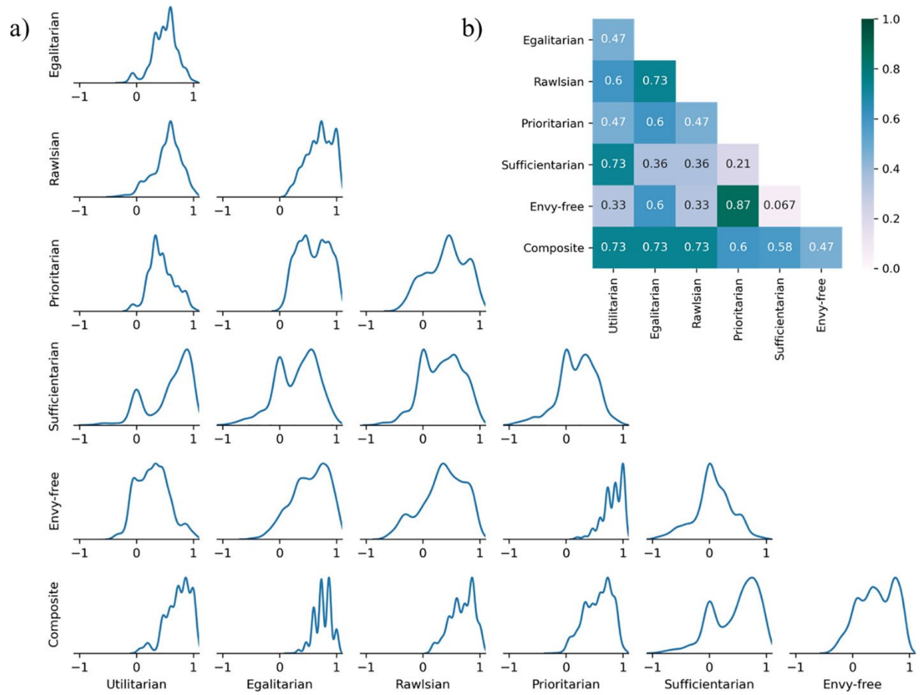

Fig. 6 **a** The distribution of Kendall Tau-b across all 1200 scenarios for each pair of distributive moral principles. The median value of the distribution is printed at the top left of each subplot. **b** The same median values of the Kendall Tau-*b*, presented as a heatmap

comparison across all pairs of principles, Fig. 6b highlights the median values of the Kendall Tau-*b*.

There are some observations given Fig. 6. First, there are only a few pairs of principles that have relatively high median Kendall Tau-*b* coefficients. For instance, there are only six pairs whose median coefficient is larger than 0.7.[1] Two of these pairs are the composite principle with the utilitarian and the egalitarian principle, which is to be expected because the composite principle was defined as a combination of the utilitarian (33%) and the egalitarian (67%) principle. Preference rankings from the prioritarian and the envy-free principle, despite being dissimilar in the baseline scenario (see Fig. 3), are quite homogeneous across all scenarios (median Kendall Tau-*b* coefficient of 0.87). In many pairs of principles (10 out of 21), the median ranking similarity is relatively low (less than 0.5), with the envy-free and sufficientarian principles yielding the lowest median Kendall Tau-*b* coefficient.

Second, distributive moral principles that have similar prescription for what is just have a high Kendall Tau-*b* coefficient across the scenarios. This is the case for the envy-free, egalitarian, and prioritarian principles—the three principles that aim to minimize inequality. The results for pairs of principles founded on different imperatives are more mixed. For example, the utilitarian and the sufficientarian principles have a fairly high-rank similarity, while the envy-free and Rawlsian principles have a low-rank similarity.

Third, in general, the Kendall Tau-*b* coefficients are positive. For some scenarios, however, the coefficients are negative. For example, Kendall Tau-*b* coefficients between the envy-free and the egalitarian principles have a negative value in 6.1% of the scenarios.

[1] Note that setting 0.7 as a threshold to classify a Kendall Tau-*b* coefficient as relatively high is a context-dependent and subjective choice.

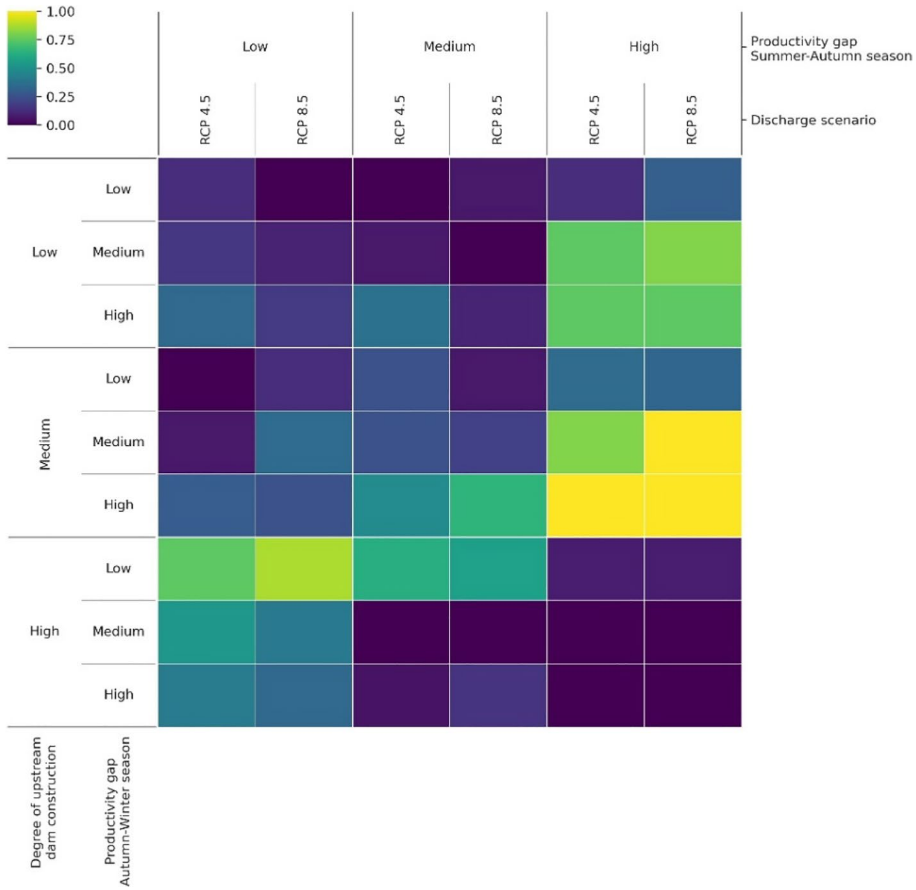

Fig. 7 Identification of scenarios leading to negative ranking correlations between the sufficientarian and the envy-free principles. The colormap indicates the fraction of scenarios which ranking correlation is negative. For example, scenarios with high productivity gap in both summer-autumn and autumn–winter seasons, medium degree of dam construction, and discharge from RCP 8.5, result in negative Kendall Tau-*b* coefficients between rankings from the two principles. Note that the results are based on the six policies assessed in this study

In some scenarios, the Kendall Tau-*b* coefficients between the sufficientarian principle and the egalitarian, prioritarian, and envy-free principles even take a value of − 0.93. This implies an almost reverse preference ranking when the distribution of the profitability is evaluated by either of the two principles.

3.4 Identification of scenarios with conflicting results

What, if anything, do the scenarios with negative Kentall Tau-*b* have in common? We take the sufficientarian and the envy-free principles as an illustration for answering this question. Rankings from these principles have negative Kendall Tau-*b* correlations in around 28% of the scenarios. Figure 7 shows the results of the dimensional stacking analysis of these scenarios. The brighter color indicates a higher concentration of scenarios with negative ranking correlations. Negative correlations occur in scenarios with a high productivity gap in the Summer-Autumn crop, medium-to-high productivity gap in the Autumn–Winter crop, and medium degree of upstream dam development. In contrast, the rankings from both principles tend to have non-negative correlations under scenarios with a high degree of both dam construction and productivity gap in the Summer-Autumn crop, and scenarios with a low degree of dam construction and productivity gap in the Summer-Autumn crop.

Overall, this analysis shows that the realization of upstream dams in Cambodia and the decrease in agricultural productivity of the Summer-Autumn and Autumn–Winter crops are two critical variables to be monitored. These variables strongly influence the preference ranking agreement between the sufficientarian and the envy-free principle. This analysis also underscores the complex interplay between productivity reduction and dam construction. A high degree of productivity reduction for the Summer-Autumn crop causes conflicting ranking when upstream dam construction is low or medium. However, if most dams are eventually constructed, it would lead to similar rankings for both principles. In such scenarios, conflicting ranking would only emerge if the productivity gap is low both for the Summer-Autumn and for the Autumn–Winter crop.

4 Discussion and conclusion

Adaptation policies almost unavoidably have distributional consequences. Therefore, the assessment of adaptation policies needs to consider distributional outcomes. While many quantitative model–based adaptation studies focus on exploring the distributional consequences, research on normatively assessing the distributional outcomes is still limited. In this study, we evaluated the distributional outcomes of policies using seven moral principles. We operationalized these principles to create a preference ranking of alternative policies. We used the adaptation planning challenge of the upper VMD as a case study, for which we evaluated the distributional outcomes of district-level farm profitability. We evaluated how the preference ranking of the policies changes when different principles are being adopted and how these rankings vary across scenarios.

There are various reasons for including multiple distributive principles when performing a normative analysis. Firstly, there is a growing acknowledgment of the plurality of the conception of justice, i.e., there is no single justice principle that is universally applicable in all circumstances and across all generations (Konow 2003; Taebi et al. 2020). Furthermore, by accounting for multiple principles, one also enlarges the information base upon which adaptation decisions are taken (Sen 2001). This reduces the possibility of creating unintended distributional consequences where certain people are unintentionally harmed by adaptation, which could be qualified as a form of "maladaptation" (Juhola et al. 2016).

When looking at the principles, we observed that preference rankings for the utilitarian principle are not heavily influenced by uncertainties. In contrast, preference rankings from the egalitarian and the sufficientarian principles are strongly affected by uncertainties. Further, we investigated ranking agreement resulting from each pair of distributive principles across the 1200 scenarios. In general, principles that are derived from similar ethical imperatives (e.g., prioritarian, egalitarian, and envy-free principles, all to some extent aimed at reducing the gap between the worse-off and the better-off) have a high agreement in ranking across scenarios. The agreement of rankings from principles derived from different imperatives is more mixed. Some pairs of principles were found to have high ranking similarity (e.g., utilitarian and sufficientarian principles), while others had a low similarity (e.g., sufficientarian and envy-free principles). However, it is important to acknowledge that this observation is based solely on the case study without guaranteeing generalization to other planning problems.

Given that our findings may be case-study specific, what can we conclude and recommend? A first recommendation is to explicitly reflect on the distributive moral principle used to aggregate distributional outcomes, as well as the possible implications of using that principle. The utilitarian principle is often adopted without due consideration of its possible flaws. To identify which distributive principle is appropriate in a given case, participatory, qualitative, and survey methods can be used which aim to reveal the preference of affected stakeholders, for example, as done by Lau et al. (2021) and Van Hootegem et al. (2020). The second recommendation is to understand whether using two (or more) different principles would produce different preference rankings and under what scenarios they give such divergent outcomes. The Kendall Tau-*b* and scenario discovery technique demonstrated in this study are useful approaches for this purpose. Third, because societal norms could evolve over time, the second recommendation is to evaluate the robustness of the policies across different principles, in addition to assessing robustness across scenarios (McPhail et al. 2020). Finally, since even the most robust policy might not be the most preferable under all principles, knowledge of which principles a selected policy does not perform well could be very informative in reports about model-based policy analyses. This would warrant that decision makers are aware of the potential shortcomings of their policy from the perspective of certain principles.

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Declarations

Conflict of interest The authors declare no competing interests.

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