25th International Congress on Modelling and Simulation, Darwin, NT, Australia, 9 to 14 July 2023
mssanz.org.au/modsim2023

Exploring the impact of modelling assumptions on distributive justice using JUSTICE

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Abstract: Integrated Assessment Models (IAMs) vary widely in complexity and underlying assumptions. There have been considerable efforts to increase the complexity of IAMs for improved representation of socioeconomic and environmental outcomes. However, less attention has been given to the foundational assumptions of these models and their distributional consequences. These assumptions are fraught with deep and normative uncertainty and can significantly impact IAM projections. If these assumptions are not explicit, IAMs can perpetuate existing mistakes and exacerbate inequalities due to their black-box nature. This paper introduces a novel IAM called JUSTICE (Justice Universality Spatial Temporal Integrated Climate Economy) to explore the influence on distributive justice outcomes due to underlying modelling assumptions across model components and functions: the economy and climate components, and the damage and social welfare functions. JUSTICE is a simple IAM inspired by the long-established RICE and is designed to be a surrogate for more complex IAMs for eliciting normative insights.

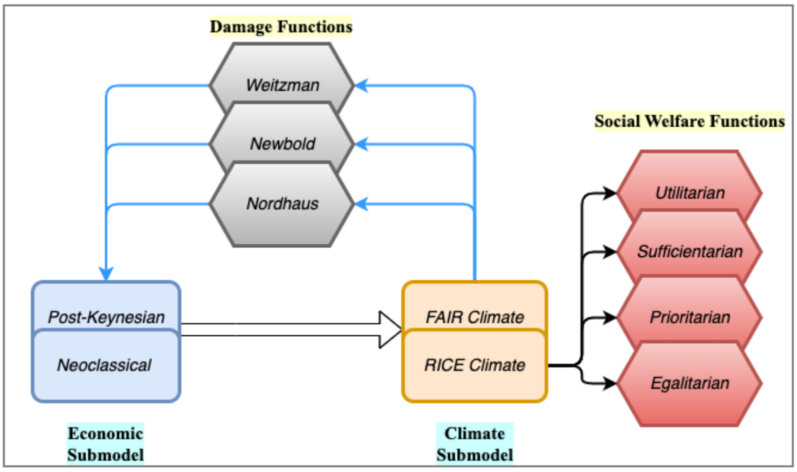

Figure 1. Schematic of the JUSTICE IAM consisting of sub-models and functions

As illustrated in Figure 1, JUSTICE contains two distinct economic and climate sub-models, three damage functions, and four social welfare functions (SWFs), each based on fundamentally different assumptions. This modular structure enables JUSTICE to uncover assumptions with nontrivial normative and distributional consequences. Also, the simplicity of JUSTICE makes it suitable for assessing the consequences of these modelling assumptions under deep and normative uncertainty using MS-MORDM and EMODPS frameworks, promoting a more equitable approach to decision-making.

Using JUSTICE, we investigate the effects of three SWFs—Utilitarianism, Egalitarianism, and Prioritarianism—on global temperature rise, with two levels of aggregation. We also explore the sensitivity of distributional outcomes for two different climate models. Our findings reveal that different assumptions lead to significantly distinct optimal abatement pathways, underscoring the importance of explicating assumptions and exploring their uncertainties to facilitate deliberation and identify common ground among policymakers with diverse perspectives.

Keywords: *Integrated assessment model, distributive justice, normative uncertainty, deep uncertainty*

1. INTRODUCTION

Climate change disproportionately affects disadvantaged and marginalised communities (Faus Onbargi, 2022), highlighting the importance of distributive justice in climate negotiations. Distributive justice focuses on the fair allocation of benefits and burdens, while equity addresses the just distribution of climate policy costs and benefits across dimensions like income, geography, and time. Fairness involves the perception of impartiality in the processes and outcomes of these policies. Distributive justice is increasingly becoming a central focus in climate negotiations, as demonstrated by its prominence in discussions during the 2022 United Nations Climate Change Conference (COP27, 2022). Integrated assessment models (IAMs) play a pivotal role in designing climate policies and generating insights used in climate negotiations, as reflected in the Intergovernmental Panel on Climate Change (IPCC) reports. However, IAMs have been criticised for perpetuating inequalities and not considering equity and justice perspectives (Gambhir, Ganguly, & Mittal, 2022; Tavoni & Valente, 2022). IAMs overlook distributional outcomes that worsen inequality and risk pushing millions into poverty by 2030 (Soergel et al., 2021). Moreover, these distributional outcomes of IAMs are susceptible to modelling assumptions, ranging from scientific, economic, and normative. These assumptions include the choice of the ethical premise, premature aggregation, choice of scientific and economic models, and poor treatment of entangled uncertainties.

There is no universally correct principle of distributive justice to determine fairness in climate policies (Robiou du Pont et al., 2017). Usually IAMs presuppose only one principle of justice, Utilitarianism, which overlook stakeholders' diverse preferences and perpetuate inequality (Budolfson et al., 2021; Gazzotti et al., 2021). Howard and Sylvan (2020) demonstrated that different normative assumptions in the DICE model significantly affect the Social Cost of Carbon (SCC) calculations. Ethical concerns also arise regarding the aggregation of incommensurate objectives in the social welfare function (SWF), and aggregating actors over space and time (Kasprzyk, Reed, & Hadka, 2016; Oehmen & Kwakkel, 2021).

The choice of economic and climate submodels has distributional consequences since it predicts future economic growth and damages. Two primary approaches of the economy submodule are neoclassical optimisation and post-Keynesian simulation (Nieto, Carpintero, Miguel, & de Blas, 2020), with neoclassical models projecting a decrease and post-Keynesian models projecting an increase in economic growth under climate policy interventions (Tavoni & Valente, 2022). Additionally, RICE's climate model has significant distributional implications since it fails to capture all complex feedback and interactions within the climate system. FAIR (Finite Amplitude Impulse Response) climate model, on the other hand, can accurately capture the non-linearities and uncertainties of the climate system.

Furthermore, IAMs face both deep and normative uncertainties, making evaluating the consequences of different modelling assumptions challenging. Deep uncertainty arises from the inability to accurately predict future scenarios due to inherent irreducible uncertainties and an inability to rank possibilities (Kwakkel & Pruyt, 2013). Normative uncertainty arises from the uncertainty surrounding which moral theories are correct and how to navigate conflicting moral options (Taebi, Kwakkel, & Kermisch, 2020). Disentangling uncertainties is crucial for analysing distributional outcomes, as demonstrated by Lamontagne, Reed, Marangoni, Keller, and Garner (2019), who found that the growth rate of global abatement is the primary driver of long-term warming and future warming is driven by earlier abatement actions.

2. MODEL DESCRIPTION

The JUSTICE IAM is an optimal growth model that falls under simplified and highly aggregated models, designed to provide insights into climatic and economic interactions. Such models are well-suited for analysing distributive justice, which is a high-level concept for distributing the benefits and burdens of climate change. The development of JUSTICE is motivated by the need for climate change policy models to be objective, transparent, and reflect different social values while considering the impacts of policy decisions at different spatial scales and over different time horizons (Pot, Scherpenisse, & 't Hart, 2022). It is crucial to explicitly represent the heterogeneity of actors and incorporate values in IAMs to increase credibility, public support and reduce political polarization towards climate change issues (Victor, Lumkowsky, & Dannenberg, 2022). The JUSTICE IAM expands RICE by Nordhaus and Yang (1996) to elicit distributive justice insights about climate policies. The JUSTICE framework, as described below, explicitly states assumptions for normative analysis using the following questions.

- J: *Justice* – Which theories of justice?
- U: *Universality* – Are the insights generalizable?
- S: *Spatial* – What resolution of intragenerational equity is being considered?
- T: *Temporal* – How is intergenerational equity considered?

- I: *Integrated* – How are different components integrated for the assessment?
- C: *Climate* – What climate assumptions are used?
- E: *Economy* – What economic assumptions are used?

Justice refers to the principle of distributive justice adopted in the modelling process. The principle chosen shapes the normative components of the IAM, namely the SWF and normative parameters like the discount rate. The principles also affect the spatial and temporal aspects of the analysis regarding how the present and future generations are valued. In this study, we incorporate Utilitarianism, Egalitarianism, Sufficientarianism, and Prioritarianism principles of distributive justice (Jafino, Kwakkel, & Klijn, 2022) into the JUSTICE IAM. Utilitarianism proposes that the right course of action is the one that distributes the resources and benefits in a way that maximizes the overall well-being of all members of society. Egalitarianism advocates for the complete elimination of social and economic inequalities by distributing resources and benefits equally among all members of society. Prioritarianism supports the prioritization of the worst-off individuals in society when distributing resources and benefits. Sufficientarianism advocates for providing sufficient resources and benefits to all members of society rather than an equal distribution.

Universality means the transferability of the normative insights from JUSTICE to other various IAMs. IAMs have faced criticism for oversimplifying climate change and misrepresenting distributional consequences (Rivadeneira & Carton, 2022). Increasing model complexity does not always increase the accuracy or relevancy of the results (Rising, Tedesco, Piontek, & Stainforth, 2022). Especially in situations involving deep and normative uncertainty, improving the model may compound and exacerbate controversies, reduce transparency, and hinder participation (Taebi et al., 2020). Therefore, it is imperative to understand IAM's purpose and its spatial and temporal scope of the analysis. Simple models are preferred because of faster computational times and the ability to test assumptions across multiple realizations of deep and normative uncertainties.

Spatial and Temporal distribution of benefits and burdens of climate change, i.e., amongst regions and generations, is a key focus of distributive justice. Therefore, JUSTICE IAM allows a flexible analysis of climate change's spatial and temporal distribution of benefits and burdens. For the spatial analysis, different countries can be grouped based on their economic, climatic, or geographic characteristics depending on the aim of the analysis. Similarly, the temporal resolution or the timestep of the analysis can be adjusted to assess the intergenerational impact of climate. Additionally, JUSTICE addresses the limited ability of RICE to explore regional decarbonization strategies due to the lack of consideration of energy and the use of a single constant global carbon decline rate. Incorporating the EDGAR (Emissions Database for Global Atmospheric Research) CO2 dataset into the JUSTICE model improves the model's accuracy and policy relevance by providing a more detailed understanding of decarbonization spatially.

Integrated refers to the transparent coupling of different sub-models and functions, allowing for easy visualization of which economic and climate sub-models and damage and social welfare functions are interconnected. It also refers to the different datasets used to integrate the different parts of the model. The RICE-2010 model, for instance, lacks transparency in data processing and uses outdated economic and political similarities for regional classification. JUSTICE IAM improves upon these limitations of the RICE model by using updated datasets and transparent mapping of the regions.

Climate sub-model projects the temperature rise due to emissions which determines the economic damage and distributional outcomes. The relationship between climate and economy is nonlinear. The climate sub-model of RICE-2010 fails to capture this nonlinearity and can significantly underestimate damages from climate change and delay climate action (Burke, Hsiang, & Miguel, 2015). To accurately capture the nonlinearities and uncertainties of the climate system, the FAIR (Finite Amplitude Impulse Response) model is incorporated in JUSTICE. FAIR captures the climate system's essential physics, and the results align with the AR5-IR model (Millar, Nicholls, Friedlingstein, & Allen, 2017). Temperature projections closely align with other well-established climate models, such as AR5-IR, PI-IR, and MAGICC. FAIR is also computationally efficient, making it valuable for robust climate change pathway analysis, which typically requires millions of runs.

Economic sub-model refers to the growth model embedded in IAMs. Typically, the neoclassical growth model is used in optimization models and post-Keynesian in simulation models. The choice of the economic growth model has important implications for addressing climate change (Nieto et al., 2020). Neoclassical growth theory assumes the infinite expansion of economic growth without negative environmental impacts. In contrast, post-Keynesian growth theory recognizes the limitations of market mechanisms and the need for government intervention to promote sustainable economic growth. Optimization models focus on reaching a general equilibrium and prescribing solutions, while simulation models pay attention to income distribution and demand-led growth for policy evaluation. The different assumptions of these models highlight the importance of considering a range of economic perspectives in addressing the complex problem of climate change. Therefore, we adopt both the original neoclassical economic sub-model of RICE by Nordhaus and Yang (1996) and a post-Keynesian economic sub model based on DEFINE by Dafermos and Nikolaidi (2022).

3. METHODS FOR JUST POLICY DESIGN

IAMs are affected by intertwined deep and normative uncertainties arising from Climate Science, Climate Economics, and Climate Ethics (Tavoni & Valente, 2022). Decision-making under these circumstances requires disentangling the uncertainties and exploring the outcomes of different scientific and normative assumptions in a simulation-optimisation setup using methods described in this section.

Reformulating Social Welfare Functions involves reframing the objectives in light of different principles of distributive justice and disaggregating incommensurate objectives. Rival ethical framings incorporate different approaches to distributive justice, such as Utilitarian, Prioritarian, Sufficientarian, and Egalitarian principles in the SWF. It provides a collaborative and ethical approach to policy evaluation and decision-making, enabling the consideration of diverse moral principles and the involvement of multiple stakeholders. Disaggregation of objectives in IAMs involves separating disutility from the utility in the SWF. It is a more ethical approach to decision-making because it avoids injustices that arise from premature aggregation (Oehmen & Kwakkel, 2021). Disaggregation promotes a fair evaluation of all available options, allowing policymakers to make morally informed decisions and allowing for fair consideration of diverse preferences. The set of objectives after applying different rival ethical framings and aggregation levels is shown in Table 1.

Multi-Scenario Multi-Objective Robust Decision-Making (MS-MORDM) framework is an updated version of MORDM that searches for Pareto-optimal policies over multiple reference scenarios (Kasprzyk et al., 2016). Exploring multiple scenarios enhances the overall robustness of the policies across multiple realizations of deep and normative uncertainties. This exploration of multiple objectives makes MS-MORDM a more ethical approach that aligns with Amartya Sen's principles of ethical reasoning and prevents decisions that subject people to undue risks (Lempert, Groves, & Fischbach, 2013; Rising et al., 2022).

Table 1. Set of objectives for the four framings of Distributive Justice with two levels of aggregation

	Rival ethical framings			
	Utilitarian	***Sufficientarian***	***Egalitarian***	***Prioritarian***
Aggregated	Welfare Temperature overshoots	Welfare Temperature overshoots Max distance to consumption threshold Population below consumption threshold	Welfare Temperature Overshoots Consumption Gini	Welfare Temperature overshoots Lowest income per capita
Disaggregated	Welfare Temperature overshoots Welfare loss	Welfare Temperature overshoots Welfare loss Max distance to consumption threshold Population below consumption threshold Max distance to damage threshold Population above damage threshold	Welfare Temperature overshoots Welfare Loss Consumption Gini Damage Gini	Welfare Temperature overshoots Welfare loss Lowest income per capita Highest damage per capita

Evolutionary Multi-Objective Direct Policy Search (EMODPS) is a decision-making framework that generates adaptive Pareto-optimal strategies for multiple conflicting objectives, providing robust policies and a comprehensive understanding of policy consequences (Giuliani, Castelletti, Pianosi, Mason, & Reed, 2016). The adaptivity enables policymakers to update and revise emission reduction goals and promote transparent and effective decision-making based on observations of their parameters of choice (Marangoni, Lamontagne, Quinn, Reed, & Keller, 2021). The EMODPS framework employs nonlinear approximating networks to condition the outcomes on policy control levers. It provides the flexibility to prevent lock-ins and keep options open for future generations, thereby addressing intergenerational justice (Teodoro, Doorn, Kwakkel, & Comes, 2022). Using a similar approach as Marangoni et al. (2021), we integrate the average global temperature as feedback to define the emission control rate policy lever, as shown in Figure 2.

Multi-Objective Evolutionary Algorithms (MOEAs) are used in the MS-MORDM and EMODPS frameworks to search for Pareto-optimal policies. MOEAs provide several advantages, including generating a set of Pareto-optimal solutions that allow decision-makers to understand the trade-offs between solutions. They allow stakeholders to explore problem formulations with different objectives, which can address Arrow's Paradox and reduce decision biases (Kasprzyk et al., 2016).

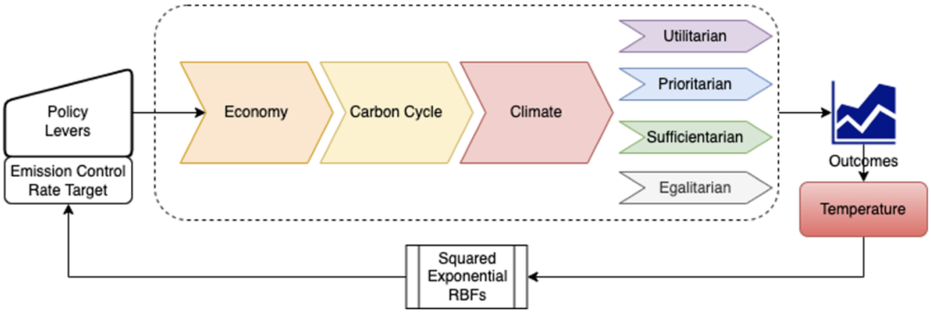

Figure 2. JUSTICE converted into a closed loop control problem using the global temperature output as a feedback for adaptive Emission Control Rate Target policy lever

4. RESULTS AND DISCUSSION

The impact of various assumptions on the JUSTICE IAM's temperature pathways is illustrated in Figure 3, which examines the normative assumptions behind the SWF, namely the three principles of distributive justice and disaggregation of disutility and utility, and the assumptions behind the two climate models in RICE-2010 and FAIR. Plot (A) shows aggregated SWF with the RICE climate sub-model, plot (B) shows aggregated SWF with the FAIR climate sub-model, and plot (C) shows disaggregated SWF with the RICE climate sub-model. The Utilitarian principle (blue) focuses purely on maximising welfare for all regions while disregarding distributional outcomes. The Egalitarian principle (green) utilises the Gini coefficient to ensure equal distribution of the burdens of climate change across regions. The Prioritarian (yellow) principle prioritises worse-off regions, i.e. regions with low emissions and low economic development facing adverse impacts of climate change.

The results indicate that different modelling assumptions lead to drastically different consequences, as demonstrated in the three graphs. Firstly, we compare the differences between different climate sub-models while using the same aggregated SWF to test the impact of different climate assumptions. JUSTICE with the FAIR sub-model predicts higher temperature rise in the future, with all the pathways for the three principles reaching 4°C or more. On the other hand, the RICE climate sub-model produces a lower long-term temperature rise for Utilitarian and Prioritarian principles, staying way below 2.5°C, except for Egalitarian principle, which projects a temperature rise of 12°C. All three principles result in different temperature rises; however, Egalitarian principle projects the maximum temperature rise for the RICE climate sub-model, whereas for FAIR, the Utilitarian principle produces the maximum temperature rise. Secondly, we compare the difference in temperature pathways between aggregated and disaggregated SWF, keeping the default RICE climate sub-model. In the disaggregated version, the Utilitarian principle produces the maximum temperature rise in the future, whereas in aggregated, the Egalitarian principle produces the maximum temperature rise. The temperature rise for Prioritarian and Egalitarian principles for the disaggregated version also shows future temperature rising to 2°C and above, with Prioritarian principle predicting higher temperature rise than Egalitarian principle. On the contrary, for the aggregated version, Prioritarian principle produces the lowest temperature rise of only 0.5°C.

These results show that the extra feedback loop between the carbon and climate module in FAIR improves its ability to capture carbon mass, temperature, and emission dynamics, indicating a more realistic representation of climate dynamics than the climate sub-model of RICE. Additionally, the stark contrast between the pathways in each subplot demonstrates how the choice of ethical premise and level of aggregation strongly affect the

Pareto optimal policies, highlighting the importance of understanding the complexity of climate justice, clarifying responsibilities, and facilitating public deliberation in climate policymaking.

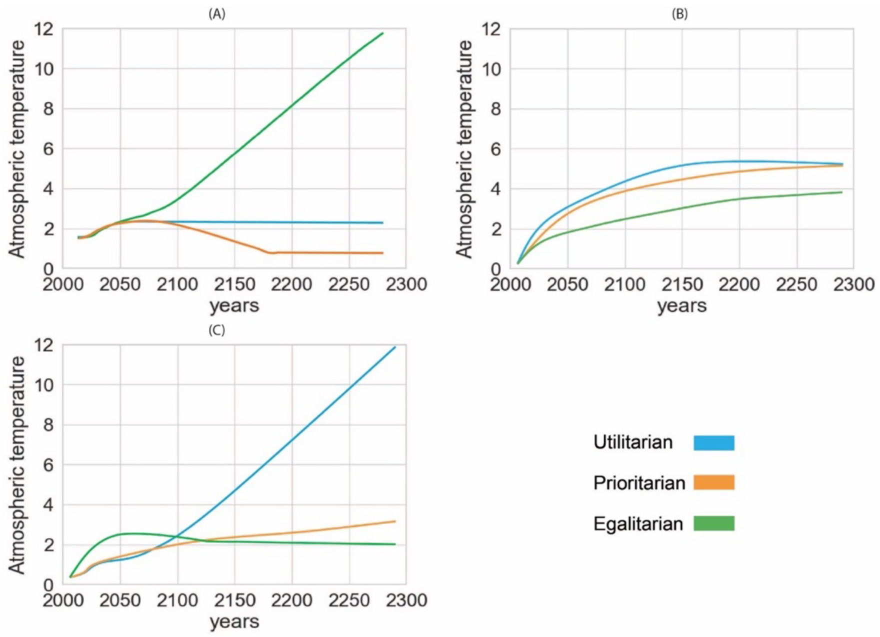

Figure 3. Pathways of global atmospheric temperature until the year 2300 under different modelling assumptions for three principles of distributive justice. Plot (A) shows pathways under aggregated SWF and default RICE climate model. Plot (B) shows pathways under aggregated SWF with FAIR Climate model. Plot (C) shows pathways under disaggregated SWF with default RICE climate model.

5. CONCLUSION

The JUSTICE IAM allows the evaluation of climate policies through the lens of distributive justice by incorporating various principles and assessing their distributional effects on societal groups. As a result, the model promotes a more comprehensive and equitable approach to climate policy analysis. The proposed simulation-optimization methods for just policy design utilize a temperature feedback loop to achieve intra- and inter-generational justice through adaptive mitigation pathways. The methods also encourage inclusive and adaptive decision-making to address the multifaceted challenges of climate change.

Future research and development of the JUSTICE IAM should focus on expanding the model to include more distributive justice principles, incorporating international dimensions of distributive justice such as historical responsibility for emissions and the impacts of climate change on vulnerable populations across the globe, and refining the model to adapt to new knowledge and perspectives. Further analysis is required to address some of the limitations of our analysis, particularly the impact of different economic sub-models and damage functions on the distributional outcomes, examining potential overlaps between different principles of distributive justice, the role of technological progress, and the implications of intra- and inter-generational justice.

These developments would enable a more comprehensive assessment of the fairness and equity of global climate policies and facilitate international cooperation in addressing the multifaceted challenge of climate change. By fostering a more transparent, flexible, and democratic approach to climate policy evaluation, the JUSTICE IAM contributes to the pursuit of just and sustainable climate policies, ultimately supporting the global effort to combat climate change effectively and equitably.

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