Disutility of climate change damages warrants much stricter climate targets

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Abstract

Cost-benefit integrated assessment models (IAMs) inform the policy deliberation process by determining cost-optimal greenhouse gas emission reduction pathways based on economic considerations. These models seek to maximise economic utility and treat estimates of climate impacts (damages) and mitigation costs at par as GDP losses, having the same impact on utility reduction. However, prospect theory suggests that a certain level of climate damages could be valued higher by society than the same level of mitigation costs, as climate damages often occur as sudden unexpected events. In this paper, we show how this concept could be taken into account in cost-benefit IAMs and explore possible consequences on optimal mitigation pathways. Our results suggest that compared to the standard utility approach, capturing explicit aversion to climate impact incidence shows optimal pathways with earlier and deeper emission reduction, lowering both net-negative emissions and mid-century temperature peaks in line with stringent Paris Agreement targets.

Introduction

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was established with the overall aim to prevent dangerous human interference with the climate system. In the Paris Agreement, the aim was made more concrete by the objective to keep the increase of global mean temperature change well below 2°C by 2100 and to pursue efforts to limit it to 1.5°C. Setting such a target and choosing appropriate mitigation strategies are extremely difficult given the complex web of socio-economic, technical, geophysical and ethical aspects that play a role and the multiple perspectives and interests. Integrated Assessment Models (IAMs) have played a key role in exploring the interplay of several of these factors to derive useful insights for policymaking. Broadly speaking, two main types of IAMs can be distinguished: process-based IAMs which focus on the required changes in technologies and behaviours to achieve certain climate targets and cost-benefit IAMs which focus on evaluating the costs and benefits of climate policy[1].

Many studies using cost-benefit IAMs have shown that cost-optimal climate targets are sensitive to damage estimates[2] and the social discount rate[3,4]. All these cost-benefit studies assume that the impact of climate change damage on utility can be assessed directly at par with the impact of mitigation costs – or economic loss due to any other reason – on utility. There are arguments why these costs should not be evaluated the same, as literature on prospect theory has shown that the disutility of losses is larger than the utility of the same value of gains[5]. Mitigation measures are planned and borne by the investor; the costs associated with these measures therefore do not come as a sudden surprise. 194 countries have submitted their mitigation plans through the mechanism of Nationally Determined Contributions in the UNFCC process[6]. Additionally, 136 countries, 235 cities, and 683 companies have committed themselves to a net-zero emissions target by 2050[7,8]. Damages resulting from climate change, however, often come as a sudden loss with a large impact on local communities (think of storms, floods, droughts, wildfire). In this paper, we show what the impact on cost-optimal and cost-effective emission pathways would be if losses of damages are valued higher according to prospect theory.

For this, we use the MIMOSA model, based on a simple Ramsey economic growth model[9]. A production function is calibrated to socio-economic variables obtained from the Shared Socio-economic Pathways (SSPs). Estimates on mitigation costs and climate damage costs from recent literature are subtracted from this SSP-consistent baseline GDP as losses. The damage function developed in the COACCH project (hereafter the “COACCH damage function”) is employed for damage cost estimates. It accounts for uncertainty by defining the damage function to fit increasing quantiles of a broad range of sectoral estimates. The mitigation costs are calibrated to IPCC AR5 data. The utility of consumption in each period is derived from the GDP after mitigation and damage losses. Since mitigation (emission reduction) reduces expected damages, and both costs influence the utility equivalently at a given time, the model determines the least-cost trade-off between the two that maximises the discounted utility (welfare). The utility maximising model can be run either with a fixed cumulative end-of-century emission budget (or temperature target), or without. The first case represents a cost-benefit setting deriving the optimal pathway for a given temperature target, while the second constitutes a traditional cost-benefit analysis without any external temperature constraints.

Using this model, we implement a disutility that captures the loss aversion towards estimated climate damage costs. To do so, we first disaggregate the prospective loss of utility attributed to the estimated damage costs in each period. The disutility of damage is then calculated by multiplying it with a parametrised damage loss aversion factor. A loss aversion factor to 1 implies no additional disutility from climate damage similar to the standard utility approach, while values of 2 to 3 are analogous to mean loss aversion factors according to Prospect Theory literature[10,11]. While in standard cost-benefit analysis utility is derived from consumption only, our approach adds an extra dimension of disutility which does not depend on GDP or consumption, but on damages only. As in standard cost-benefit analysis, utility is then discounted to the present, and is optimised by the model as before. We analyse the relative impact of the damage aversion factor, as well as varying discount rates and damage estimates on the optimised temperature, emission, and carbon price pathway.

A more detailed description of the MIMOSA model and the disutility modelling is given in the Methods section.

Results

Cost-optimal outcomes (i.e. without a carbon budget) with the standard utility approach using a discount rate of 1.5% and the median (50th percentile) COACCH damage estimates are shown in blue in Fig. 1. The global mean temperature rises throughout the century, reaching 1.89°C by 2100, as also shown by van der Wijst et al.[12]. The corresponding optimal cumulative emissions reach 1269 $GtCO_2$, with a greater reduction of annual net emissions up to 2035, and a more gradual reduction after. Net-zero emissions are achieved only in the first half of the 22nd century in this optimal pathway, i.e. beyond the modelled timeframe.

The orange lines in Fig. 1 show the impact of valuing the disutility of damages higher than the disutility of mitigation costs by a factor 2. Optimal cumulative emissions up to 2100 are halved with the disutility approach without carbon budget constraints. Net annual emissions follows a smoother reduction pathway compared to the standard approach with deeper initial mitigation until 2040. This corresponds to a drop in temperature rise at 2100 from 1.89°C to 1.49°C, with a temperature peak at 1.53°C.

For a loss aversion factor of 3 (Fig. 1, outcomes in green), cumulative emissions are reduced even further to 266 $GtCO_2$. Temperature rise by the end of century is 1.26°C, reducing from a peak of 1.42°C in 2060. Net-zero CO_2 emissions are achieved in 2060 in this case, compared to 2080 for an aversion factor of 2.

The effect is further emphasised with higher estimates for uncertain damages implemented via the COACCH damage function using a set of quantile specifications (Fig. 2). The 5th percentile of this independently derived function closely resembles the low range of damage functions in literature (such as the DICE 2016R2 damage function[13]), the median 50th percentile resembles the medium range (based on a meta-analysis by Howard et al. of empirical and traditional IAM estimates[2]), while the 95th percentile nears the high range of estimates in literature (long-run empirical damage function from Burke, Hsiang and Miguel[14]). This allows us to capture the range of possibilities by varying the specifications for a single function[12].

For low estimates of damages (the 5th percentile of the COACCH damage function), optimal end-of-century temperature change is reduced from 3.1°C in the standard utility approach to 2.9°C in the disutility approach (aversion factor 2). However, a similar aversion towards medium to high damage estimates leads to a sharp advancement in the optimum timing of zero annual emissions, leading to end of century temperature rise of 1.5°C and 1.2°C respectively. The impact of the disutility approach is highlighted by similar optimal temperature outcomes for the 95th percentile of the damage estimate using an aversion factor 2, as for the 50th percentile of the damage estimate optimising for the standard utility.

The impact of disutility can also be illustrated by analysing its effect on temperature-constrained cost-optimal emission pathways. If the carbon budget is fixed at 633 $GtCO_2$, implying a peak temperature increase of 1.49°C in line with Paris Agreement targets, the disutility approach leads to deeper short-term emission reductions compared to the standard approach for the same cumulative target (Fig. 3), leading to lower peak emissions; with correspondingly lower peak temperature rise and earlier net-zero targets.

The optimal mitigation pathways using the disutility approach is reflected by higher initial rates of increase in the global carbon-price followed by a slower rate culminating in a peak or level price by 2100 (Fig. 3c, in orange). In comparison, the standard utility approach (Fig. 3c, in blue) shows a preference for delayed deep mitigation. Correspondingly, a lower initial increase in the carbon price is followed by a steeply increasing rate across the century. This culminates in a carbon price at 2100 that is higher than with the disutility approach, and which continues to peak beyond the modelled timeframe.

The above illustrates that taking into account the possibility that disutility of damages valued more strongly than the disutility of mitigation costs can have a strong impact on the optimal peak temperature and emission pathway. A simple sensitivity analysis (methodological details and results presented in Supplementary Information) confirms that this impact from capturing loss aversion preferences is comparable to that from varying rates of time preference through discounting.

Discussion

Cost-benefit IAMs inform the policy deliberation process by determining optimal emission pathways based on economic considerations and estimates of climate impacts and mitigation costs. The utilitarian cost-benefit approach hinges critically on the evaluation of economic consequences of potential climate change impacts, which are always treated at par with the costs of mitigating them. While this parity has been unchallenged as of yet, it is intuitively and – increasingly – empirically clear that increasing the pace of climate mitigation efforts would be preferable to experiencing increasing climate change impacts[15–18]. An important reason for this is that the costs and impact of mitigating climate change are more predictable than the impact of damages.

The disutility approach described in this article offers a method to express the trade-offs between mitigation costs and damages in an intuitive, comparable way in a quantitative economic cost-benefit paradigm. It provides a mechanism to express social preferences specifically towards averting climate impacts (such as those reflected in the Paris Agreement or net-zero pledges by 2050), and to determine acceptable trade-offs. This work does not give a new generalised formulation for the welfare utility function. Instead, it highlights that economic notions of utility depend not just on monetary costs, but assumptions on social preferences towards the outcomes. The most commonly accepted form of the utility function is modified to accommodate aversion preferences towards the incidence of climate change impacts within the purpose of cost-benefit IAMs.

The implementation presented follows a conservative approach, using elicited preferences from literature based on relatively low-stakes choices presented to individual actors, whereas the present application deals with the choices made by a hypothetical social planner regarding the economic value of the timing and value of investments to mitigate climate change impacts. However, it offers us a plausible, stylised parametrisation to test the impact of the hypothesis that sudden and extreme impacts of climate change have a greater negative impact to utility than the expected loss of utility from the planned mitigation.

Although mitigation costs come less sudden and are more planned than damages, actors may indeed experience a loss of utility from specific mitigation measures (e.g. closure of coal mines, increased household energy expenditure). However, these losses could be anticipated, and individuals could be compensated via social protection programs, re-skilling, etc. Expected mitigation costs could thus be internalised, which is not the case for the deeply uncertain incidence of damages.

Capturing loss aversion to climate impact incidence shows optimal emission pathways with deeper front-loaded emission cuts, and consequentially, a reduced dependence on negative emissions towards the end of the 21st century compared to the standard utility approach. This reduced dependence is particularly significant given the nascent technological know-how and capability to implement the negative emissions at the required time and scale per the standard approach. Optimal emission pathways using the disutility approach also lead to a lower peak temperature rise over the century and thereby lower unmitigated climate change damages. The temperature outcomes are consistent with the most stringent objective of the Paris Agreement for reasonable aversion factors and median damage estimates.

Further research could also explore the consequences of applying the disutility approach on regions, and further on within regions. It is well known that poorer countries are more vulnerable to climate damage compared to richer countries[18–21], and further disproportionately on the poorest within countries[22]. Apart from the aggregated assessments of optimal emissions pathways, the disutility approach can also be used to address distributional concerns by incorporating the unequal incidence of climate impacts as seen in Denning et al.[23], with explicit representation of aversion towards them.

Finally, alternative functional formulations of the disutility may also be explored further, such as by a concave (marginally increasing) function of accumulated damages with appropriate parametrisation of preferences to define its elasticity. Such a formulation may be better suited for the assessment of long term, intergenerational “endowments” of climate impacts from choices made in the present, in addition to the resource and capital endowments associated typically with discounted utility-growth models.

Methods

The model.

Fig. 5 shows a schematic overview of the MIMOSA model modified to implement the disutility from damages. It consists of an economic module (top grey box) and an energy-emissions module (bottom grey box) that interact via the mechanisms of damage costs (middle, left), and mitigation costs (middle, right).

A standard Cobb-Douglas production function derives the GDP in the period, calibrated using total factor productivity and labour inputs derived from SSPs. This economic output is split into consumption and savings via a fixed savings rate. Savings are fully invested in the next time step as capital input to the production function. In the standard approach, utility is derived solely from the consumption in each time step, and is discounted to the present. The objective of the model is set to maximise the sum of the discounted utility, i.e. welfare, in each time step.

In parallel, the emissions module derives the CO_2 emissions as a function of endogenous GDP and exogenous baseline carbon intensity of the energy systems fuelling it. Emissions in each time step accumulate in the earth's atmosphere. Cumulative emissions cause a rise in the global mean temperature (GMT) modelled via a linear Transient Climate Response to Emissions (TCRE) relationship. The economic impact of rising GMT is modelled as a damage function, and is treated as a GDP loss in the time step. These climate change impacts are mitigated by reducing annual emissions. A global carbon price is applied at each time step. An exogenous Marginal Abatement Cost (MAC) curve is used to determine the corresponding reduction in emissions and quantify the mitigation costs in the time step. These costs are treated as a GDP loss similar to damages, reducing the net GDP and consumption in the time step, and causing a drop in the utility. For a more detailed description of the model without the disutility option, including the data sources, parametrization choices and other assumptions, see van der Wijst et al., (2021).

Fig. 6 shows a stylised representation of the disutility of damage with respect to the standard concave utility function with respect to GDP (assuming a fixed savings rate). 'U_{md}' is the utility derived from GDP less the mitigation and damage costs, equivalent to the net utility in the standard approach. Analogously, 'U_m' is the utility derived from the baseline GDP minus mitigation costs alone. The disutility of damage is calculated as the prospective loss of utility attributed to the estimated damage costs (i.e., $U_m - U_{md}$) times a parametrised damage loss aversion factor (f_d). The net utility is then given by:

$$U_{net,t} = U_m - f_d (U_m - U_{md})$$

Modifications to the model to implement the disutility approach involve deriving this net utility which is discounted and optimised as with the standard approach.

When the model is run with the standard utility approach, the drop in the net utility is the same irrespective of the source of GDP loss. When the model is run with the disutility setting, both damages and mitigation costs still have the same effect on the GDP itself. However, their respective impacts on the net utility are disaggregated. Mitigation costs continue to have the same effect on consumption utility as in the standard approach, while damages affect net utility through the separate disutility.

The damage loss aversion factor represents the degree of loss aversion towards climate damage. Since a loss aversion factor set to 1 implies no additional disutility from climate damage, model experiments are carried out by parametrizing its value to 2 and 3 for analysis in this paper (Table 1), reflecting the range of the mean loss aversion factor in Prospect Theory literature[10,11]. Further research can experiment with different values for the damage aversion factor.

Experimental methods and setup

We run the model with welfare functions specified to include the disutility approach and with the standard utility approach of the predecessor model. Additionally, model runs are also performed by varying the damage loss aversion factor as well as with different values for the carbon budget, damage function specification and discount rate – or more specifically, the pure rate of time preference (PRTP). A summary of the variables and values is shown in Table 1 below. Outcomes are retained for analysis for the full factorial of these input combinations.

Table 1: Model inputs and their value ranges over which the model runs are performed

Input variable	Range	Units
Welfare function	[without disutility, with disutility]	n/a
Damage loss aversion factor (when run with disutility)	[2, 3]	n/a
Carbon budget	[None, 1344, 633]	$GtCO_2$
COACCH damage function specification	[5, 25, 50, 75, 95]	Percentile
Pure rate of time preference	[0.1, 1.5, 3]	% per year

This allows an analysis of the outcomes under different input combinations, as well as determining the influence of the disutility approach and its parametrisation on the outcomes relative to those from higher damage estimates and a range of discount rates.

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Figures

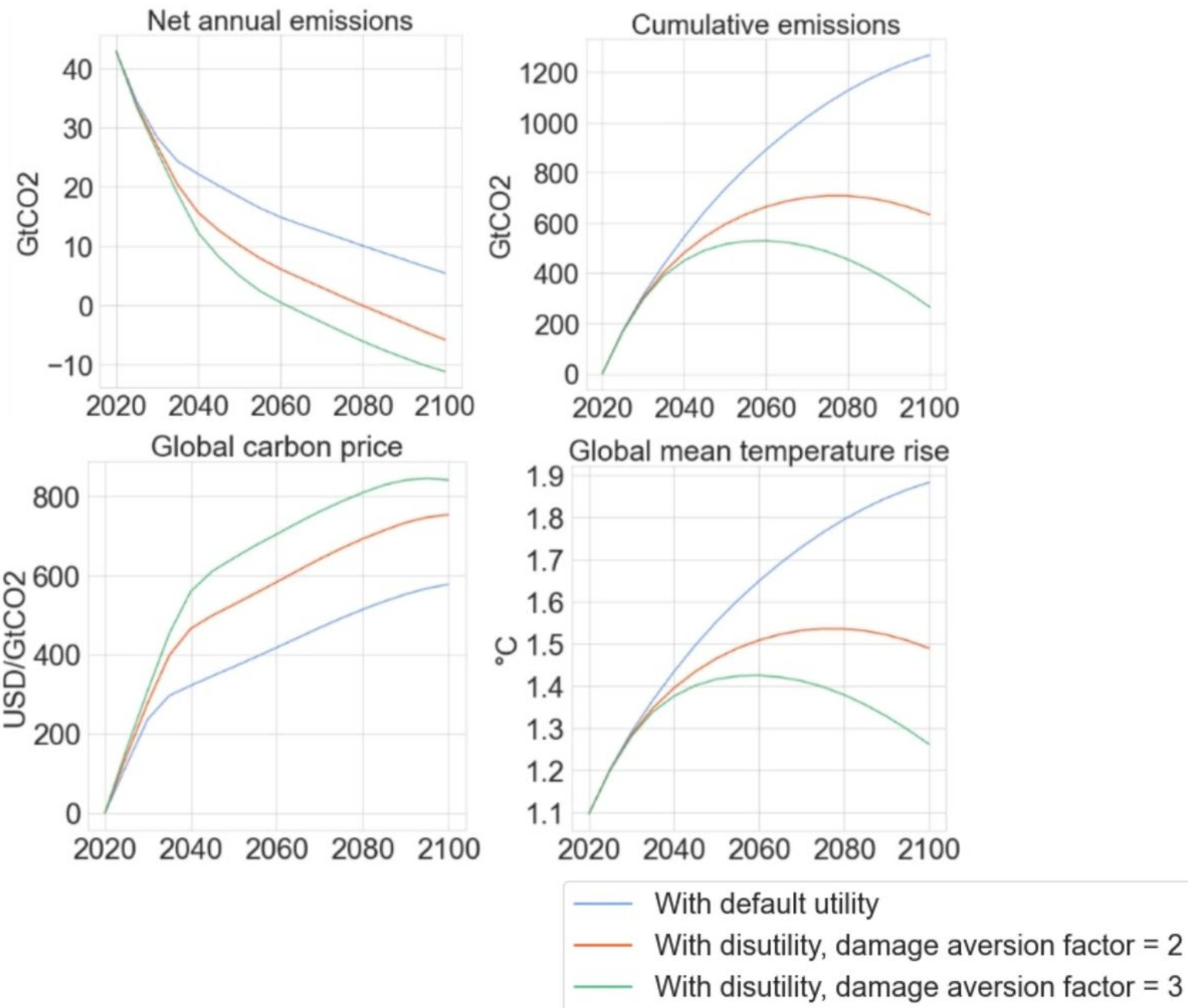

Figure 1

Optimal pathways without carbon budget constraints with and without the disutility approach. Panels, a: net annual emissions, b: cumulative emissions, c: population-weighted global carbon price, d: global mean temperature rise

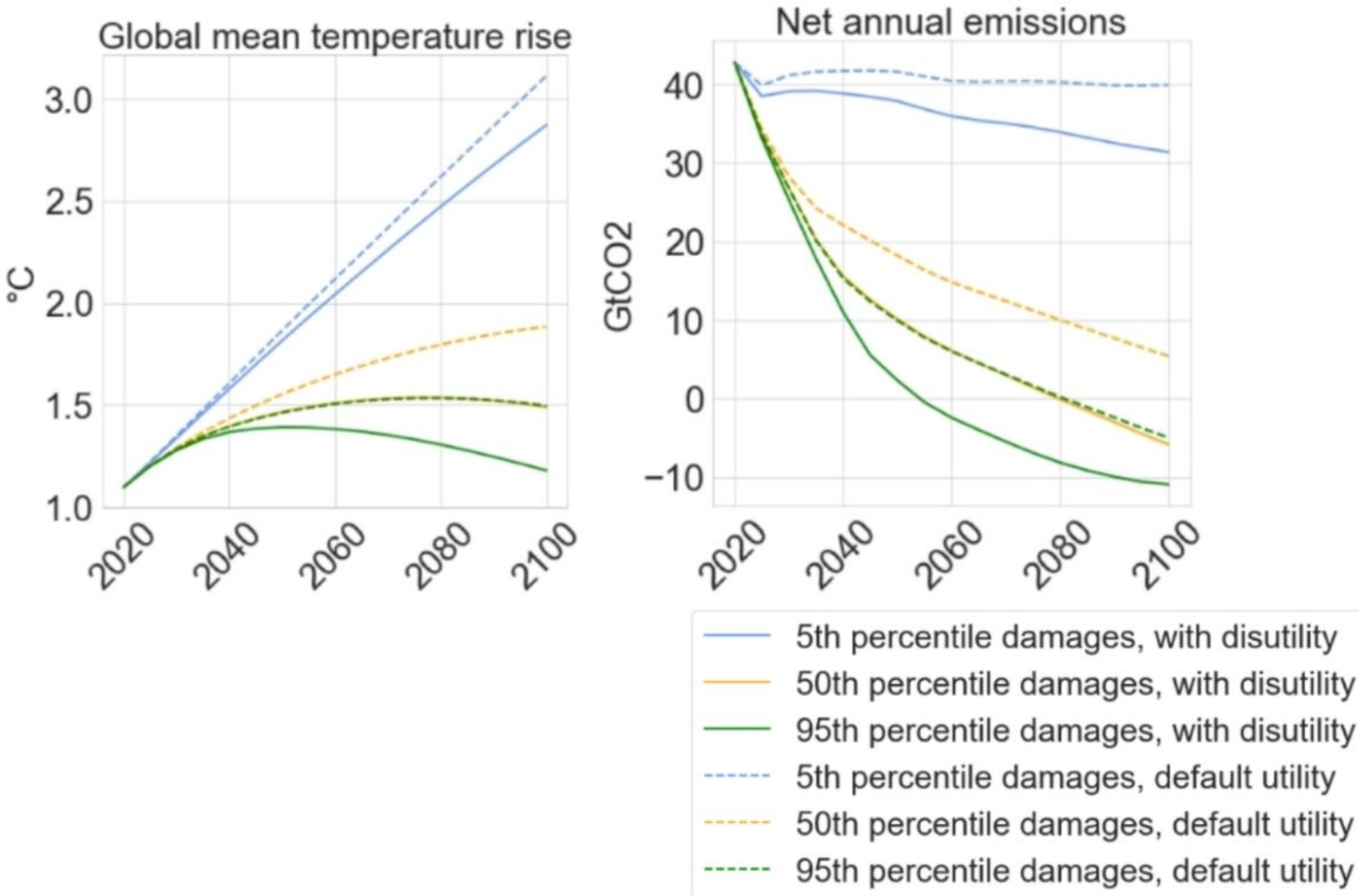

Figure 2

Optimal pathways with different damage estimates with and without the disutility approach. Panels, a: temperature, b: annual emissions. See SI.3 in Supplementary Information for optimum pathways constrained with a carbon budget across damage estimates.

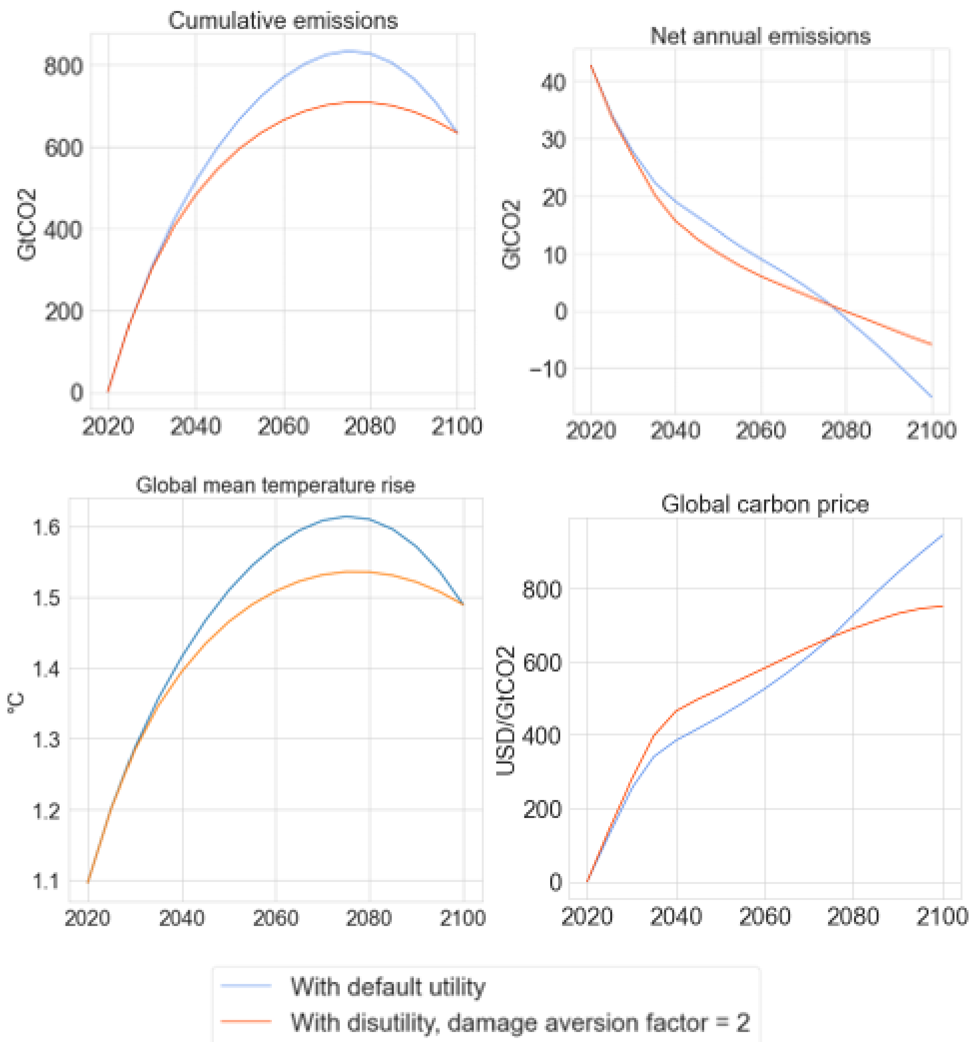

Figure 3

Optimal pathways with a fixed carbon budget of 633 $GtCO_2$. Panels, a: net annual emissions, b: cumulative emissions, c: population-weighted global carbon price, d: global mean temperature rise. See SI.2 in Supplementary Information for optimal pathways including with an aversion factor 3, and also with a carbon budget of 1344 $GtCO_2$.

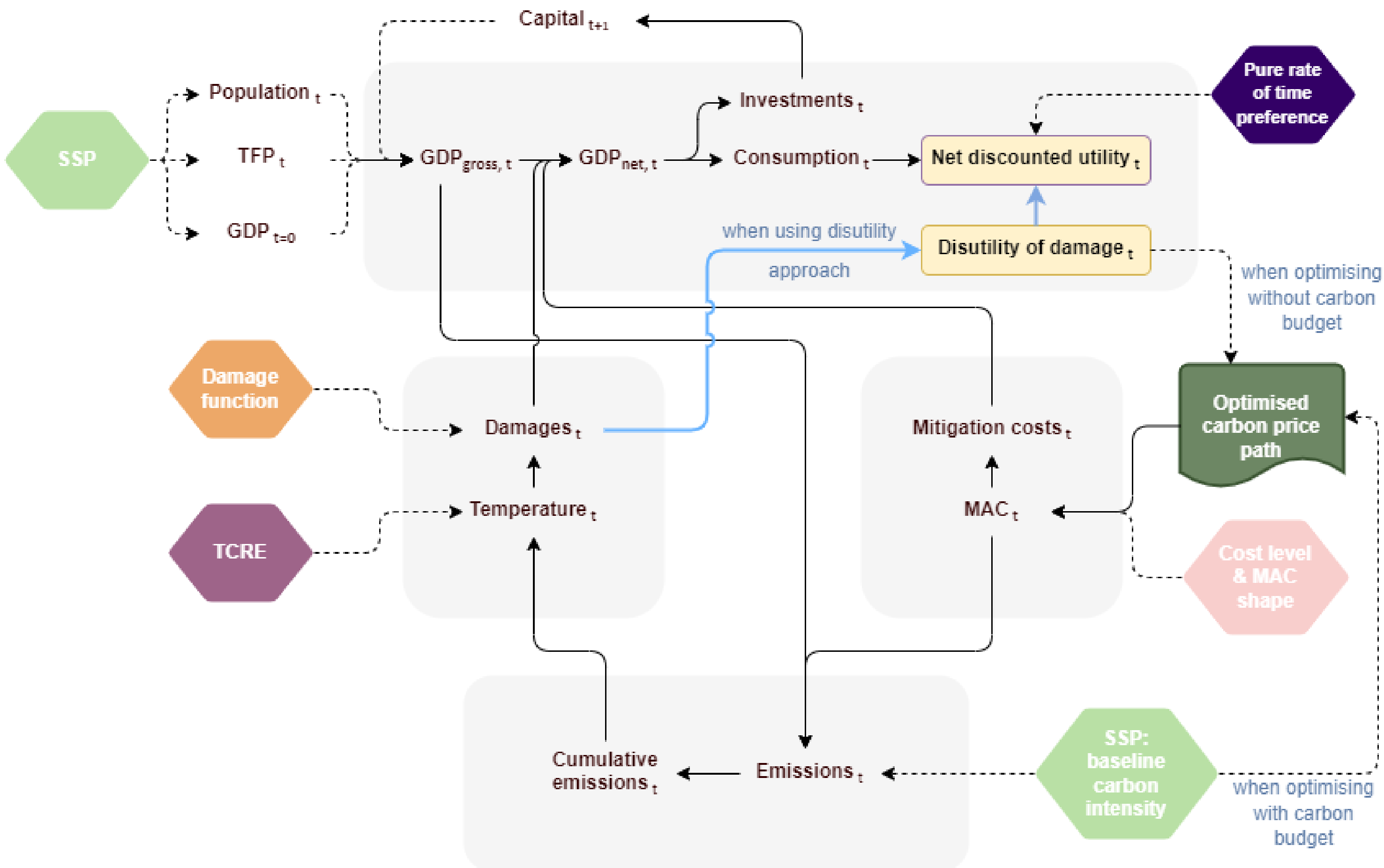

Figure 4

Schematic overview of the MIMOSA model with the novel disutility approach, adapted from van der Wijst et al., (2021)

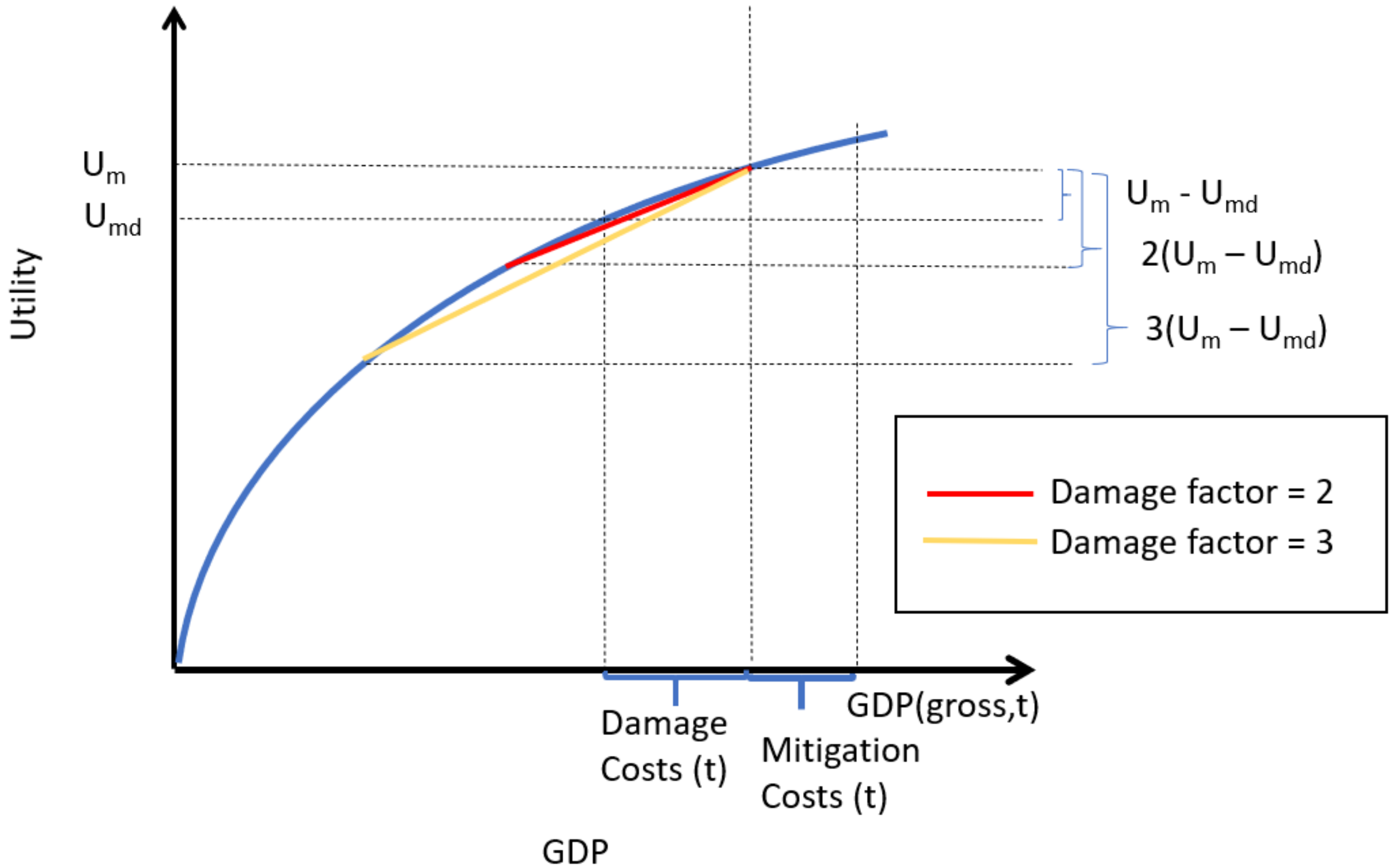

Figure 5

Stylised representation of unequal utility of consumption and disutility of damage

Supplementary Files

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- disutilitysupplementary.docx