Climate change challange: Free-riders and geo-engineering

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Abstract

In this work an agent-based model with computable general equilibrium integrated assessment models is used to determine if the availability to geo-engineering has an influence on climate negotiations. With a combination of FAIR-DICE and an alternative energy sector an optimal path is calibrated for policymakers which can either invest in green energy or aerosol injections to combat climate change. The altered DICE-model integrates economics, carbon cycle, climate science, and the weighing of costs, resulting in agents guessing benefits of taking steps to slow down climate change. Geo-engineering is seen as a possible cheap alternative solution to slow down global warming, which could mean a slower transition to green energy. This model results show no significant influence on the timing of the green transition in both a competitive and altruistic scenario.

1 Introduction

CO2 reduction is currently limited by "free-riding" problems: Countries who are not reducing CO2 emissions or investing in renewable energy do still benefit from others who put in effort. This does not create incentive to be the first who takes action, causing general inaction. Geoengineering, large-scale interference with the climate system, has alternatives that are considered cheap enough for individual countries to implement. With stratospheric aerosol injection, global warming could be slowed down at a relatively low cost. On one hand it is feared that the application of geo-engineering would reduce the incentive to decarbonize, on the other hand unilateral Geoengineering might incentivize policymakers that are opposed to aerosol injection to decarbonize. Using an agent-based integrated assessment model (IAM) the optimal climate response policy is generated for how regions should react to optimize their welfare.

2 Methods

2.1 GeoDICE: Dice model including SRM

The code used is similar to DICE2013 used in [[1]] with adjustments to the climate model from [[3]] and the energysector as in [2].

2.2 Climate model

The geophysical model describing the climate state is the so called FAIR model. Extending the IPCC AR5 Earth system model with a constraint following the 100-year integrated impulse response function. (refJoos et al.) Contrary to DICE where carbon is distributed between atmospheric, upper and lower ocean reservoirs in FAIR the carbon reservoirs do not have a direct physical interpretation. The carbon related equations are given as

$$\frac{dR_i(t)}{dt} = a_i E(t) - \frac{R_i(t)}{\alpha(t)\tau_i}, i = 1, ..., 4. \tag{1}$$

Constants and their meaning can be found in table [**??**]. Here E(t) is emissions in GtC per year, a_i is the quantity of Emissions inserted in reservoir i and τ_i is the decay time constant for each reservoir respectively. Scaling term $\alpha(t)$ expands AR5-IR to the FAIR.

The introduction to describe the algebraic expression for the scaling term is simplified by first defining the temperature states by using:

$$T_j(t+1) = (T_j(t) - q_j F(t)) \exp(-\frac{\Delta}{d_j}) + q_j F(t) \tag{2}$$

. $T_j, j = 1, 2$ are temperature states used to describe the mean surface temperature by $T_{AT} = T_1 + T_2$. The atmospheric CO_2 concentration is described by:

$$C_{AT}(t) = C_0 + \sum_i R_i(t). \tag{3}$$

And finally the accumulated carbon perturbation in land and ocean

$$C_{acc}(t+1) = C_{acc}(t) + \Delta \sum_i \frac{R_i(t)}{\alpha(t)\tau_i}. \tag{4}$$

The radiative forcing at the top of the atmosphere is given by

$$F(t) = F_{2x} \log_2(\frac{C_{AT}}{C_0}) - \eta \alpha_{SO_2} * \exp[-(\beta_{SO_2}/I_S)^{\gamma_{SO_2}}] \equiv F_{CO_2} - F_{SO_2} \tag{5}$$

Model parameters are shown in Table The scaling factor is determined by solving the governing equation for $\alpha(t_{k+1})$

$$\sum_{i=1}^{4} \alpha(t_{k+1}) a_i \tau_i [1 - \exp(\frac{-100}{\alpha(t_{k+1})\tau_i})] = r_0 + r_C C_{acc}(t_{k+1}) + r_T T(t_{k+1}) \quad (6)$$

Equations (1 - 6) are used to represent the climate model.

2.3 Negotiations

To reach the equilibria an iterative process is used, the design of the climate negotiations is taken from [[2]]. Over a set of negotiation rounds each country continuously adapts their policy based on results from the previous round.
With $N_{regions} > 1$ having decision vectors $X_i(t) = (\sigma_g, \sigma_{SRM})$
and $t = 0, ..., T_{end}$. The decisions of region R_i at negotiation round k are X_i^k. The succeeding decisions at $k+1$ are gathered by optimizing the welfare function W_i using that other regions $j \neq i$ use their policy $X_{j \neq i}^k$. This process is repeated for each region until no more progress can be made in improving the policies.

2.4 Damages and welfare

Damages are similar to Helwegen et al.

$$D(T, P, C, I_S) = \psi_T T^2 + \psi_P P^2 + \psi_C C^2 + \psi_s I_S^2 \quad (7)$$

T,C,P and C are the changes with respect to pre-industrial levels in temperature, precipitation and atmospheric CO_2 concentration and I_S is the annual sulfur injection rate in megatonnes sulphur. Resulting in the net ouput per region:

$$Y_{net} = \frac{1}{1+D} Y_{gross} - \lambda_S I_S \quad (8)$$

Where $\lambda_s I_S$ represents the cost of solar radiation management.

2.5 Energy Model

The abatement cost equation in the DICE-model assumes that abatement costs are proportional to a power function of the reduction rate and to the output. Where the scaling factor declines exogenously over time. This infers that the cost of cutting emissions is independent of previous emission levels: it neither reflects history or inertia. [5]

Instead to represent the To represent the energy sector in the model, a derivative of the Dystopian Schumpeter meeting Keynes (DSK)[6] combined with the system described in Brede, De Vries (2012) is used.[2] To realize the desired production ,energy is required. This desired energy can be generated by brown or green power plants. Brown power plants use fossil-fuel and green powerplants represent renewable energy. The activities of the energy sector lead to CO_2 emissions. Learning and innovation determines the cost of energy produced by power plants. Initially brown power plants are cheaper to build with respect to green plants. By building more plants of either type their price to constructs lowers, doubling the capacity lowers the building costs by 20%. [4]. Brown energy has additional costs in the form of fossil fuel required to keep the plant running. Each region starts with 5% of their initial capacity of energy plants to be green.

Energy demand is based on desired

production:

$$Y_{des} = A(t)K^{\gamma}L^{\gamma-1} \tag{9}$$

With the energy demand (ED) described as:

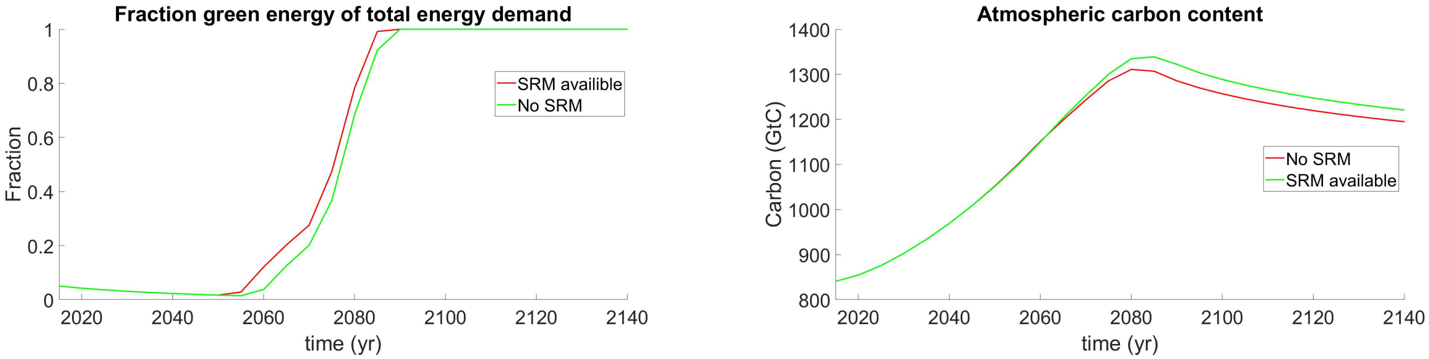
$$ED = Y_{des} * \sigma(t) \tag{10}$$

Where σ represents the efficiency of the plants by dropping with 1% each year. In this simulation ED is always fulfilled. The availability to fossil-fuel is different to Brede, De Vries in that the fuel is always fully accessible to all regions. Additionally the supply never runs out completely, having an increasing difficulty (price) to obtain.

3 Results

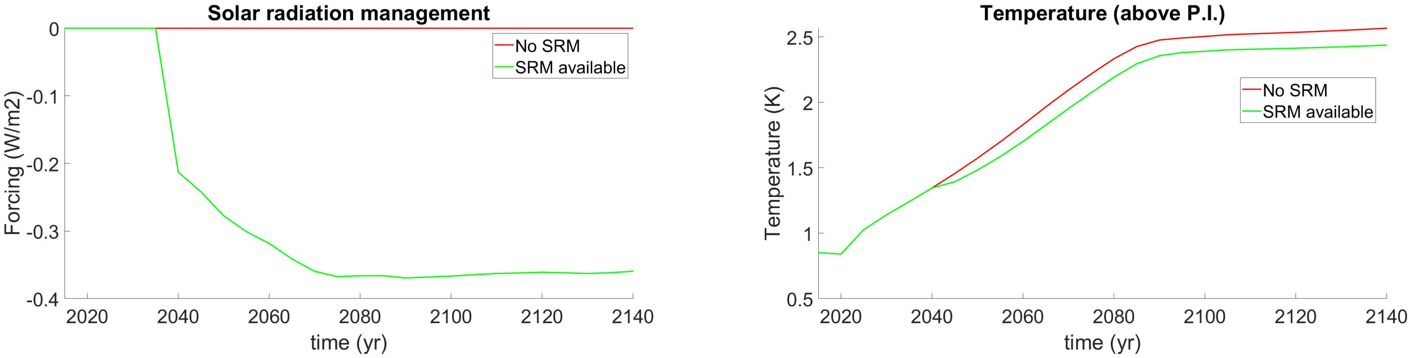
3.1 Cooperative world

At first in the ideal scenario where countries freely trade information and care for each-others welfare the influence of SRM on the climate negotiations and the resulting climate response is shown in figure (1). The green transition starts one time step earlier with SRM available at 2055, with 50% of the total energy generated by green plants at 2075 in both cases. Their atmospheric carbon content peaks at 1340 and 1310 GtC respectively. The total forcing done by SRM converges to -0.37 W/m^2 .



(a) aaa

(b)



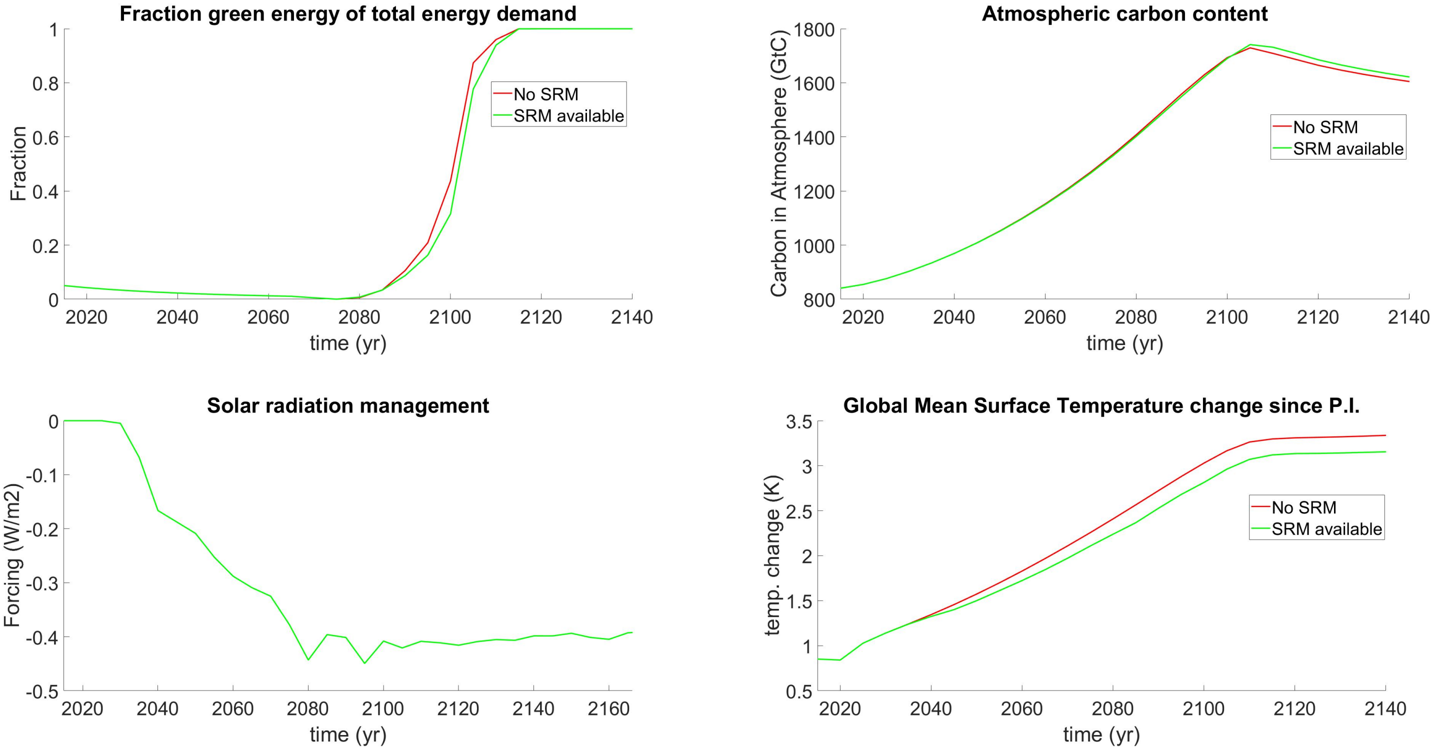
(c)

(d)

Figure 1: Altruistic scenario where between regions information is freely traded and the welfare of other regions is weighed equally. In figure **(1a)** the fraction of total green energy generated by green plants, **(1b)** represents the atmospheric carbon content, **(1c)** represents the total forcing done by SRM and **(1d)** represents the temperature change with respect to pre-industrial levels.

3.2 Competitive world

[H] In the non altruistic competitive scenario there is no single converging policy reached. Instead after 20 rounds the policies started a repeating pattern of different scenarios. The average of these patterns is used as a representation to measure the impact of SRM on the negotiations. In figure **??** the resulting scenario is shown for a model with 2 regions in a non altruistic case. The abatement shows a slightly faster green transition when no SRM is allowed. In both cases a full green transition is realized at 2115. The transition is later than in the altruistic case, since the regions can benefit from waiting and letting the other do the initial investment. The availability to SRM is consistent with the altruistic scenario: the impact on total emissions is too narrow and does not result in a significant difference in accumulated emissions in the atmosphere: their peaks in GtC are 1740 and 1730 respectively. This results in a temperature change of more than 3K since P.I. In both scenarios the policy with no SRM is marginally earlier with the transition.


Fraction green energy of total energy demand

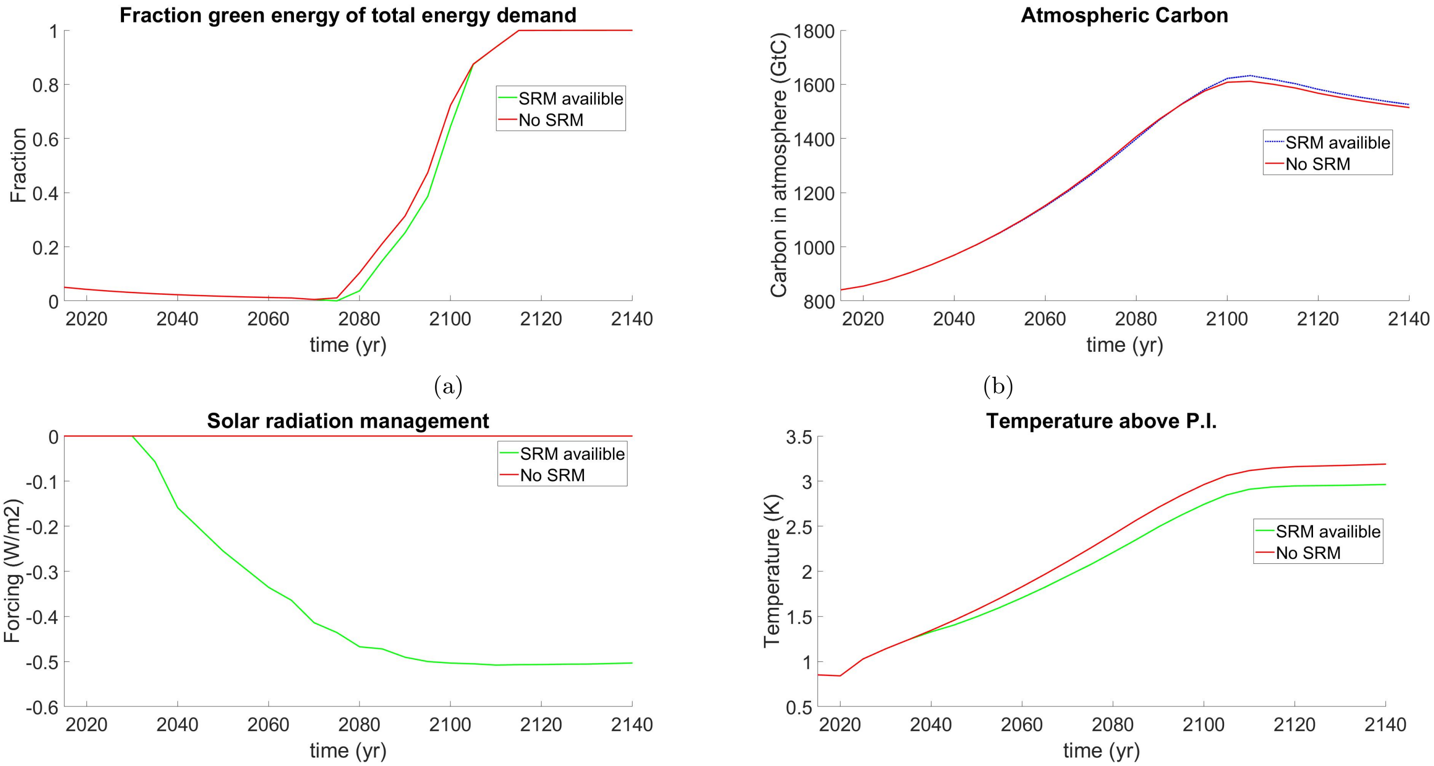
Atmospheric carbon content

Solar radiation management

Global Mean Surface Temperature change since P.I.

Figure 2: Competitive scenario, where each region only optimizes for its own welfare.

To combat the waiting problem that was present in the competitive scenario, the last case has an adjustment such that regions only benefited from learning by building their own plants. In this case regions are more individual actors since they do not have the advantage of cheaper green plants if others build them first. They would still benefit from less emissions if other regions did build green plants. This optimal policy did converge to an equilibrium for both regions. This resulted in an earlier start to the energy transition with respect to the competitive case with shared learning. However, 50% and 100% green production was reached at the same time. As a result their atmospheric carbon peaked at 1640 and 1610 GtC respectively. Also more SRM was used in this scenario which peaked and remained at $-0.5W/m2$.



(a) (b)

(c) (d)

Figure 3: Independent learning competitive scenario.

Symbol	meaning	Value
q_1	Constant forcing FAIR-DICE	0.33 KW^{-1}/m^2
q_2	Constant forcing FAIR-DICE	$0.41KW^{-1}/m^2$
d_1	Time constant FAIR-DICE	239 year
d_2	Time constant FAIR-DICE	4.1 year
r_0	Time scaling constant FAIR-DICE	32.40 year
r_C	Time scaling constant carbon FAIR-DICE	0.019 year GtC^{-1}
r_T	Time scaling constant Temperature FAIR-DICE	4.165 year K^{-1}
F_{2x}	Forcing constant FAIR-DICE	3.74 Wm^{-2}
a_1	FAIR constant	0.2173
a_2	FAIR constant	0.2240
a_3	Fair constant	0.2824
a_4	Fair constant	0.2763
τ_1	Time scale FAIR	10^6 year
τ_2	Time scale FAIR	394.4 year
τ_3	Time scale FAIR	36.54 year
τ_4	Time scale FAIR	4.304 year
α_{CO_2}	scales sulfate radiative forcing	65 W m^-2
β_{SO_2}	scales sulfate radiative forcing	2246 $Mt(S)yr^{-1}$
γSO_2	Sulfate radiative forcing	0.23
η	Sulfate rad. forcing correction	0.742
ψ_C	damage from CO_2	$3.31 * 10^{-8}(ppmv)^{-2}$
ψ_T	damage from warming	$1.703 * 10^{-3}K^{-2}$
ψ_P	damage from change in precipitation	$0.4(mmd^{-1})^{-2}$
ψ_S	damage from SRM	$9.27 * 10^{-5}(Mt(S)yr^{-1})^{-2}$
λ_S	Cost of implementing SRM	USD 14 billion per megatonne sulfur

Table 1: Table of constants.

4 Summary and discussion

In conclusion, the availability to solar radiation management does not impact climate negotiations significantly. Each scenario had a tendency to start slightly later on the green transition with geo-engineering available, however this did not result in large atmospheric carbon concentration differences. In comparison to earlier studies [1] , which implements exogenous abatement instead of a more explicit energy production representation to represent investing in green energy. This result shows that a different representation of the energy sector has a large impact on the time-frame of the green transition. However, the damages done by global-warming are still optimizable, damage function of sulfur injections and temperature are not yet realistically represented and could give better insight on how climate negotiations might develop.

References

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