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Social discounting, social costs of carbon, and their use in energy system models

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Abstract

Discounting plays a large role in cost-optimization models, but is nevertheless often only covered in little detail in energy system models. The aim of this paper is to highlight the effects of varying discount rates and social costs of carbon in energy system models with the example of the Global Energy System (GENeSYS-MOD), propagating open debate and transparency about chosen parameters for model applications. In doing so, this paper adds to the academic discourse on socio-economic factors in energy system models and gives an outline to modelers in the field by providing example results. The results show that close-to-zero discount rates that factor in intergenerational equality, total emissions could be reduced by up to 41% until 2050 compared to the baseline discount rate of 5%. This effect is even increased when a carbon price akin to the actual social costs of carbon is chosen. This underlines the importance of the topic, which is, up to now, seldom covered in cost-optimizing energy system models.

1. Introduction

Climate change is one of the most challenging topics of the 21st century (IPCC 2014, 2018, UNFCCC 2015a). While the existence of adverse effects accompanied with this climate change is generally agreed upon, the concrete steps and measures, as well as their timing, are still heavily debated. Thus, the task often arises for modelers to provide well-founded answers to these questions—to *optimally* provide a single, least-cost, welfare-optimizing path into the future. With the energy sector being one of the largest contributors to global greenhouse gas emissions, a large part of this burden falls to the decarbonization of the energy system, and thus the modeling and quantitative analysis of energy systems. These cost-optimizing energy system models try to give insights into future energy scenarios by computing investments in a multitude of technologies across various sectors, as well as their respective dispatch and energy flows[1]. Since the models are cost-driven, a large importance falls onto the valuation of costs and benefits over time, therefore relying on discounting to maintain comparability. While the issue of discounting is generally well discussed in economics and other model types (such as e.g. integrated assessment models (IAMs)), there is little literature on the topic regarding energy system models specifically (García-Gusano *et al* 2016)[2]. However, since climate issues and their damages inevitably fall into the far-distant future, the implementation and choice of discount rate(s) and costs for negative externalities of greenhouse gases is of high importance.

The purpose of this paper is not to find an optimal choice of discount rate or carbon costs to be implemented into energy system models. As Dasgupta (2008) suitably put it: ‘Intergenerational welfare economics raises more questions than it is able to answer satisfactorily’, summarizing the Herculean

[1] While there are also other forms of energy system models, e.g. market-oriented equilibrium models or pure dispatch models that do not include capacity investments, I refer to bottom-up cost-optimizing energy system models in this paper, since they are most commonly used for long-term analyses of the energy system (Herbst *et al* 2012).

[2] In fact, García-Gusano *et al* (2016) and Steinbach and Staniaszek (2015) are the only two papers published on the topic at the time of this writing.

task that this would pose. Instead, the aim is to highlight the effects of varying discount rates and social costs of carbon in energy system models with the example of the Global Energy System (GENeSYS-MOD), propagating open debate and transparency about chosen parameters for model applications. In doing so, this paper adds to the academic discourse on socio-economic factors in energy system models and gives an outline to modelers in the field by providing example results.

2. Discounting, social costs of carbon, and energy system models: an overview

Discounting is a valuable tool to compare fiscal values across time. As such, the concept has been present for thousands of years, already being used by Babylonian mathematicians for the valuation of money flows (Neugebauer 1969). Its usage and implications have been heavily and extensively discussed in economics over the years (Cline *et al* 1992, Hanley 2001, Zhuang *et al* 2007, Bottero *et al* 2013, Pollitt and Billington 2015). Especially in recent economic history, discounting has once again seen large attention, specifically in the context of climate change. This culminated in the 2018 Nobel Prize in economics given to William D. Nordhaus for his work on discounting and the economics of climate change. But even there, the choice of discount rate is not quite unproblematic, with the famous Stern-Nordhaus debate focusing on the topic of finding the *right* discount rate for climate damages (Nordhaus 2007, 2008, Stern 2007).

A large issue with damages related to climate change is that they mostly fall far into the future, likely beyond our own life expectancy. Thus, these potential damages will mainly affect the life of coming generations instead. The question of discounting becomes a very ethical one here—while in usual business applications, the discount rate merely represents a tool based on market investment returns to compare different financial options for both now and the future. In the context of climate damages, one has to weigh the damages for future generations against the benefits of the current generation. This quickly becomes very problematic, since unlike money flows, where one can quite easily determine the opportunity costs for each investment, putting a diminishing value to future human life would be a quite controversial point of view.

To give a better understanding of this issue, it is best to decompose the discount rate into its different elements to showcase how it is determined and constructed. The famous Ramsay rule of discounting (Ramsey 1928) portrays the discount rate as follows:

$$\rho = \delta + \eta g$$

where the discount rate ρ (used as the social discount rate within this paper) is the sum of the the rate of pure time preference δ and the product of the elasticity of marginal utility of consumption η and growth factor g. The latter part describes the intertemporal risk aversion of the individual or group, with positive values for η describing a preference in consumption today in light of the uncertainty of the future (also described as an 'impatience factor' in Anthoff *et al* (2009b)). The main element of contention in the Stern-Nordhaus-Debate, however, is the rate of pure time preference δ. This rate describes the discrepancy between today's benefits compared to those of tomorrow. Since a sum of money could be invested today and provide net positive returns, the same sum of money would be worth more today to the investor than it would be in, e.g. a year. The rate of pure time preference would thus mimic the gains of the investment opportunity. However, in the case of climate damages, the concrete value is not as easily determined, since the trade-off here lies between money spent on climate mitigation now, versus, among others, damages in the form of potential health and environmental issues that would arise with unhindered global warming, some of which can already be experienced today (although those damages occurring at a later stage might be substantially more severe than those experienced today). Thus, Stern (2007) proposes a rate of pure time preference close to zero, with the only reason for a nonzero value given in the (unlikely but not impossible) event of total extinction of the human species, which would thus make any benefit analysis moot (a concept described and introduced as the so-called 'hazard rate' in Yaari (1965)). Therefore, social discount rates commonly display low discount factors and are applied in cases where a purely monetary valuation is not possible. Anthoff *et al* Anthoff *et al* (2009b), however, pointed out that the risk-aversion part of the Ramsay discounting formula is just as important as the rate of pure time preference. Commonly, positive discount rates are applied, because economic growth is assumed to be positive. This assumption is not necessarily true, as climate damages might very well lead to negative growth, especially in the Global South, making the product of η and g, and thus potentially the entire discount rate, negative (Dasgupta 2008, Anthoff *et al* 2009b, Fleurbaey and Zuber 2012).

Since quantitative models aim to give insights into possible future developments, they make use of discounting as a tool to compare model options (e.g. to compare investments across different time periods). Macroeconomic models also often differentiate between general and social discount rates in order to incorporate the previously discussed elements into their analysis (García-Gusano *et al* 2016, Emmerling *et al* 2019). However, in energy system modeling, there is a distinct lack of such differentiation, as well as a lack of literature on the topic. At the time of this manuscript, only two papers focusing on social discounting and energy system models were able to be found, Steinbach and Staniaszek (2015) and García-Gusano *et al* (2016), only one of which is published in a peer-reviewed journal. Instead, most literature that focuses on discounting in energy system models purely analyzes the technical side, e.g. regarding carbon-capture and storage (CCS) (Sano *et al* 2013) or effects on certain technology options (Østergaard and Andersen 2018, Rady *et al* 2018, Islam *et al* 2019).

Steinbach and Staniaszek (2015) give an overview over different perspectives and use-cases for discounting, and review applications of energy system models with regard to their discounting. They thereby aim to give some 'best-practice' advice for modelers, coming to the conclusion that there should be a differentiation between social and individual (actor-specific) discount rates, since they are used for a different forms of evaluation. While social discount rates are used to evaluate total costs and benefits from a societal perspective, individual discount rates at a market-actor level are instead used to model 'investment decision making reflecting the expected return of an investor' (Steinbach and Staniaszek 2015). García-Gusano *et al* (2016) underline that finding, claiming that since optimization models are cost-driven, and discount rates are used for cost-evaluation, the choice of discount rates must be well-founded and differentiated. They find a distinct 'lack of sensitivity analysis and discussions concerning the discount rates' of energy system models (García-Gusano *et al* 2016). Their findings showcase a meaningful change in model results, however their chosen discount rates were significantly higher than those recommended in (Steinbach and Staniaszek 2015).

Another frequently asked question in both science and policy is that of damages caused by carbon dioxide emissions. These damages to society as a whole, including environmental damages and increased healthcare costs, are summed up as social costs of carbon. The German Environmental Agency released a methodological convention for the assessment of environmental costs (Matthey and Bünger 2019) in which they reach a social cost of carbon of 180€ per ton of CO_2 emitted. This value is in line with other studies in the field that conducted a social cost analysis on carbon (Anthoff *et al* 2009a, Weitzman 2013, IPCC 2014, van den Bergh and Botzen 2014). Since the discussion about social costs of carbon is also heavily entangled in that of discounting (and in particular social discount rates and the rate of pure time preference since they heavily influence the outcomes of such cost analyses (Anthoff *et al* 2009a)), social costs of carbon will be implemented in GENeSYS-MOD as a sensitivity to review their effect on the energy system development.

3. Implementing social discounting in GENeSYS-MOD

The GENeSYS-MOD is an open-source, multi-sectoral energy system model based on the Open-Source Energy Modeling Framework (OSeMOSYS) (Howells *et al* 2011, Löffler *et al* 2017). It encompasses the sectors electricity, buildings, industry, and transport, providing a multitude of technologies for the model, including sector-coupling and storage options. GENeSYS-MOD usually focuses on long-term energy pathways in the context of deep decarbonization until 2050, including the sectors electricity, heat, transport, and industry. To achieve this, the model minimizes the net present value of total system costs across the modeled time horizon, while also fulfilling the exogenously defined demands and other constraints (e.g. carbon budgets, capacity expansion limits, etc)[3]. In order to provide comparable fiscal units for the cost optimization, all investments and other direct and indirect costs are discounted towards the base year. The GENeSYS-MOD/OSeMOSYS framework in its original form only allows for one general discount rate to be set, with the default value set to 5% per annum. For more information on GENeSYS-MOD, its core functionalities, as well as source code and technical documentation, please refer to Löffler *et al* (2017), Burandt *et al* (2018, 2019), and the GENeSYS-MOD Git repository.

For the purpose of this study, the European version of GENeSYS-MOD developed in the EU Horizon 2020 project openENTRANCE (see Auer *et al* (2020)) has been expanded with new and improved discounting functionalities. This pan-European application includes the 27 EU member states (with the exception of Cyprus and Malta), as well as the United Kingdom, Switzerland, Norway, an aggregated Balkan region, and Turkey. In total, the model covers 30 nodes for the timeframe 2015 to 2050, computed in 5-year-steps. To fully compare the effects of discounting on energy pathways, there is no carbon budget implemented in this study. Instead, two different carbon price assumptions are compared: (a) a conservative EU ETS carbon price, starting at roughly 15€ per ton CO_2 in 2015 and reaching 85€ in 2050, and (b) a carbon price that endogenizes negative external effects of CO_2 in a social-costs-of-carbon-approach. This social cost of carbon of 180€ per ton of CO_2 in 2016, increasing to 240€ in 2050, is taken from the 'Methodological Convention for the Assessment of Environmental Costs' of the German Environment Agency (Matthey and Bünger 2019). Matthey and Bünger (2019) reach this value by including various damaging aspects of

[3] Other, non-energy sectors are not covered by the model. Therefore, only energy-related emissions are covered in the budget calculations.

Table 1. Choice of social discount rate parameter options.

Parameter values for SocialDiscountRate$_r$ analyzed in this study								
−3%	−1%	0%	0.1%	1%	3%	5%	7%	9%

carbon dioxide, including air pollutants, land use change, or noise, and using a rate of pure time preference of 1%. A variation, using a rate of time preference of 0%, reaches a social cost value of 640€ per ton of CO_2 in 2016. Also, to account for negative externalities of nuclear power plants (since they would not be included with a pure focus on CO_2), an environmental cost akin to von Hirschhausen (2017) has been implemented.

To allow for a more distinct and precise use of discounting in GENeSYS-MOD, multiple new parameters have been included and introduced to the mathematical formulation. The parameter DiscountRate$_r$ has been removed and replaced by the parameters GeneralDiscountRate$_r$, TechnologyDiscountRate$_{r,t}$, and SocialDiscountRate$_r$, where r is the model region and t is the set of technologies. This differentiation allows for a largely improved granularity regarding discounting: the GeneralDiscountRate$_r$ applies to infrastructure investments and non-technology specific costs, the TechnologyDiscountRate$_{r,t}$ applies for technology-specific costs and investments, and the SocialDiscountRate$_r$ applies for the costs of carbon, or EmissionsPenalty in GENeSYS-MOD. While not the focus of this study, the inclusion of the Technology dimension in the technology-specific discount rate also allows for different hurdle rates for each technology, or could be used to differentiate between different sectors or investors (e.g. households and industry, which might possess different discount rates) if the user wishes to do so. All discount rates are accounted for in the objective function of GENeSYS-MOD, which minimizes the aggregate discounted costs towards the base year (see equation (1) for a stylized version of the updated objective function). The detailed equations and their changes can be found in appendix A (available online at stacks.iop.org/ERL/16/104005/mmedia).

$$\begin{aligned}\min z = &\sum \mathrm{CombinedGeneralCosts}^{\mathrm{GeneralDiscountRate}_r}\\ &+\sum \mathrm{CombinedTechnologyCosts}^{\mathrm{TechnologyDiscountRate}_{r,t}}\\ &+\sum (\mathrm{TotalEmissions}\times \mathrm{EmissionsPenalty})^{\mathrm{SocialDiscountRate}_r}\end{aligned}$$

Equation 1. Stylized objective function of GENeSYS-MOD.

To properly analyze the effects of a social discount rate on the outcomes of energy system models, all other values remain unchanged (this includes the other types of discount rates, which remain at their base value of 5%). The chosen values for the social discount rate comparison are shown in table 1.

Table 2. Assumptions for the different ranges of social discount rates. o represents values close to zero, while + and – represent positive and negative values, respectively, with the number of symbols used highlighting their intensity.

Social discount rate ρ	Pure rate of time preference δ	Elasticity of marginal utility and growth factor ηg
−3% to −1%	o	− to −−
0% to 0.1%	o	o
1% to 3%	o or +	+ or o
4% to 5%	+	+
7% to 9%	++	++

The negative discount rates, −3% and −1%, represent a world where climate damages are assumed to cause negative economic growth (Burke *et al* 2015, Newell *et al* 2021), thus leading to below-zero discount rates (Dasgupta 2008). The rates 0% and 0.1% represent the approach to discount at a rate of pure time preference akin to Cline *et al* (1992), Stern (2007), and Weitzman (1998), placing (almost) equal weight to future generations as to today's population, while keeping the values for g and η close to zero. The range from 1% to 3% represents social discount rates commonly found in policies in the EU, as well as a median range found in a survey of over 200 experts by Drupp *et al* (2018). Five percent is the default value of the original version of GENeSYS-MOD, and 7% and 9% represent a more business-compliant discount rate, commonly found in techno-economic models (Steinbach and Staniaszek 2015). The fringe cases of −3% and 9% social discount rate both cover the extremes of the imaginable range for social discount rates. In fact, both of there rates are quite unlikely, since e.g. climate damages leading to such high GDP losses would be avoided in a mitigation pathway, which is a common application for GENeSYS-MOD and other energy system models. However, both of the social discount rates fall within the range observed in the survey by Drupp *et al* (2018), promoting their theoretical use case. Since the goal of this paper is to showcase the effects of varying social discount rates, these extreme cases have been selected to fully span the range of variation in pathway results. Table 2 lists the assumptions for each range of social discount rate.

Figure 1 displays the effects of the chosen discount rates over the 35 year time-period of the GENeSYS-MOD application.

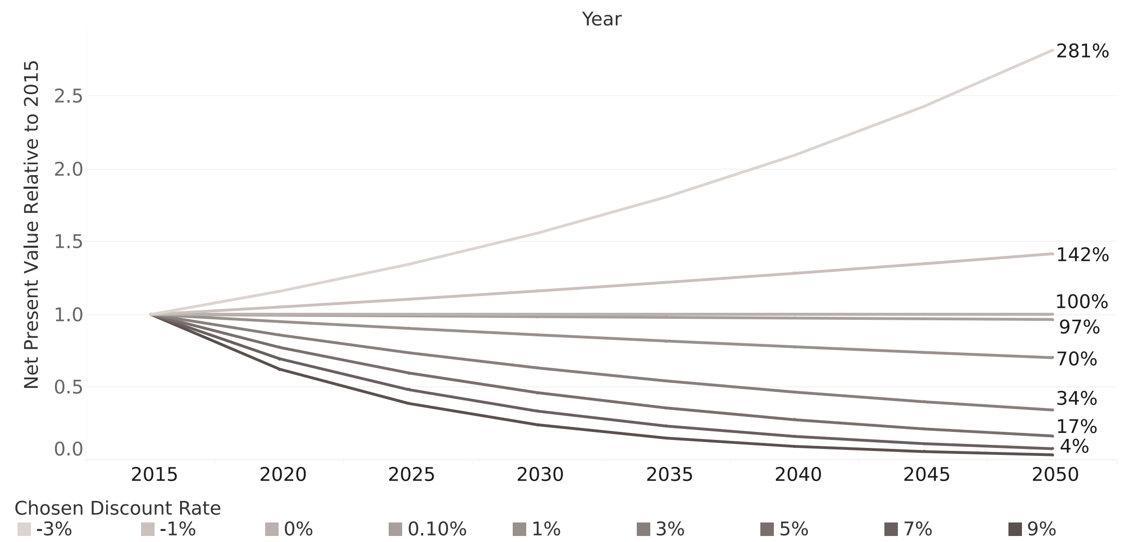

Figure 1. Effects of chosen annual discount rates on discount factor over time.

4. Results

The results show a significant effect of both the choice of social discount rate, as well as the carbon price sensitivity on the model results. The inclusion of a social discount rate of 0.1%, thus representing a very low discount rate that assumes an intergenerationally just rate of pure time preference, reduces cumulative emissions in 2050 by 31% compared to the base value of 5% discounting, and even 40% compared to the maximum 9% discount rate (see figure 2). The European carbon budget corresponding to limiting global warming to 2 °C of 51.6 $GtCO_2$ is taken from Hainsch *et al* (2021). The exact calculation of the carbon budget is detailed in appendix B.

Interestingly enough, once the applied social discount rate approaches intergenerational equality (which would happen at a discount rate of 0%), the model reduces the CO_2 emissions significantly, reaching almost a compliance with a 2 °C target. The introduction of negative discount rates, representing a shrinking economy due to climate damages in the future, lowers the cumulative emissions even more. When considering social costs of carbon according to Matthey and Bünger (2019), the CO_2 budget roughly corresponding to limiting global warming to 2 °C is actually reached for all social discount rates below 6%, showing the strong effect on emissions[4]. Also, the reduction in emissions occurs sooner than in the base case of 5% discount rate. While the choice of discount rate mainly affects the choices that lie the furthest in the future, the implementation of a carbon price has a more immediate effect on decarbonization, leading to reduced accumulated carbon emissions.

[4] Since the model results only encompass Europe as a region, the results for global warming are therefore approximations assuming similar developments in the rest of the world.

This effect also shows in the electricity mix and the usage thereof. Figures 3 and 4 show the electricity mix in 2050 and the use of electricity per sector in 2050, respectively. In line with previous research (Löffler *et al* 2017, Hainsch *et al* 2018, Burandt *et al* 2019), the electricity sector is the first sector to decarbonize and thus sees no change in renewable share below 3% discount rate in the base case and below 7% in the social costs of carbon sensitivity. This is, however, counteracted by increased electrification in the other sectors, clearly shown in figure 4. An increased use of electricity in other sectors leads to a different electricity mix, with mostly an increase in on- and offshore wind for lower social discount rates. This is explained by the exhaustion of available and commercially favorable solar potentials, which then drive other variable renewables into the mix.

The industrial sector, as well as hydrogen use (shown here as renewable hydrogen generated via electrolysis) increase significantly in electrification when very low social discount rates are considered. Hydrogen is especially valuable in difficult-to-decarbonize sectors such as industry and freight transportation, explaining the strong increase in its usage. With the inclusion of carbon costs in line with the actual social costs of carbon, one can observe that the social discount rate does not change the electric sector in a meaningful way. Instead, most of it is covered via the drastically higher CO_2 price. The remaining effect of the social discount rate in combination with social costs of carbon (as seen in figure 2) can thus be attributed to other sectors of the energy system.

The installed capacities paint a similar picture (shown in figure 5). In accordance with the generation of electricity, the installed capacities show an increase in generation capacity with lower social

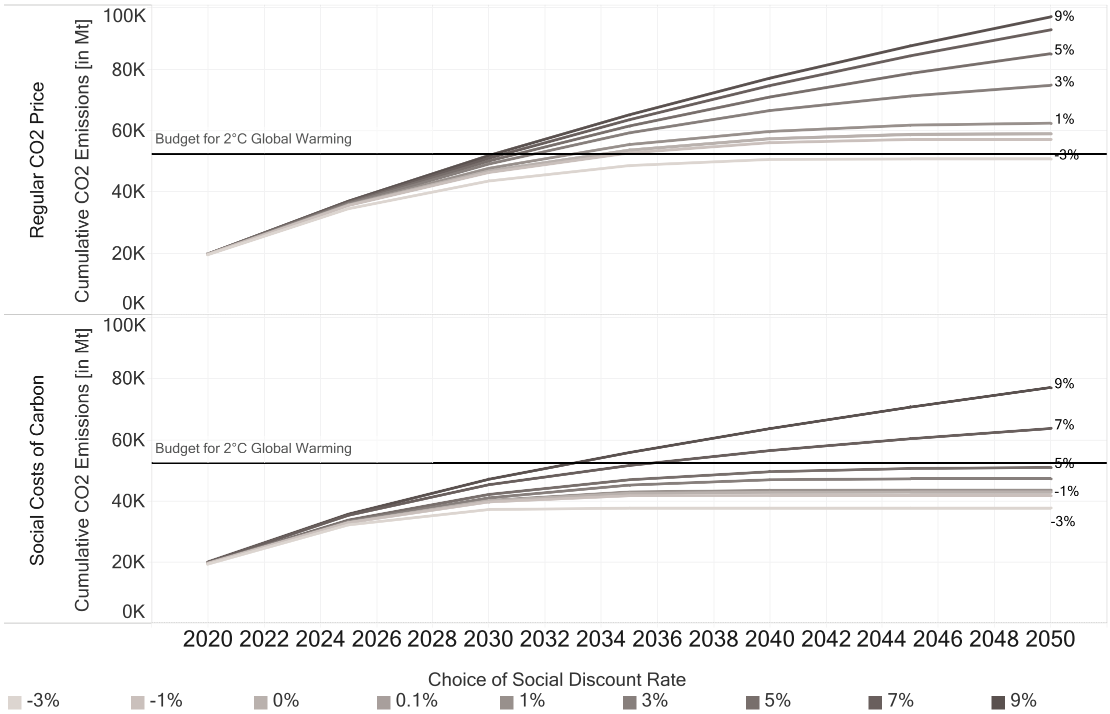

Figure 2. Comparison of cumulative CO_2 emissions from Europe over the modeled period in Mt CO_2.

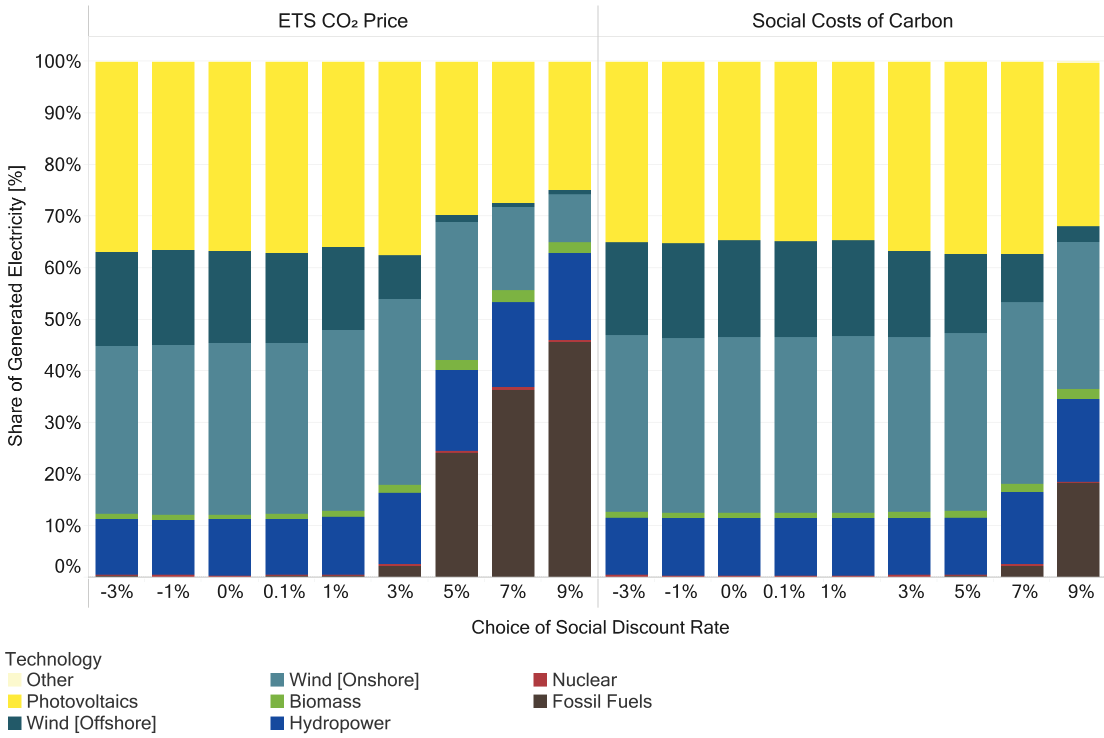

Figure 3. Electricity mix in Europe in the year 2050 for different choices of social discount rate, for both ETS carbon price and social costs of carbon sensitivity.

discount rates, reaching almost double the installed capacity in the cases below 1% compared to the base value of 5%. While solar is steadily increasing in usage in the ETS CO_2 costs sensitivity, the constantly high electrification volumes in the social costs of carbon model runs show a very steady capacity mix, with solar reaching the limits of it is technical and economical potential.

For the EU ETS CO_2 price, the electricity generation costs in 2050 span from roughly 31 € Megawatthour $(MWh)^{-1}$ for -3% social discounting, to 38 € MWh^{-1} for 9% discounting,

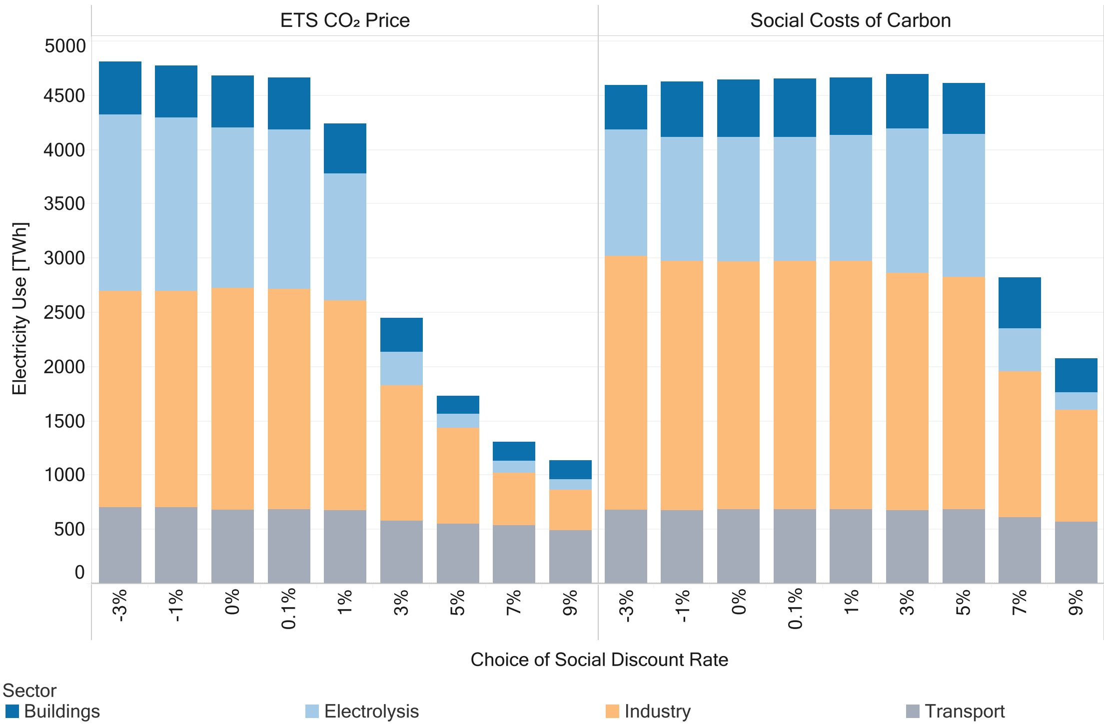

Figure 4. Electricity use per sector in TWh per sector for Europe in the year 2050. Displayed for each choice of social discount rate and carbon price sensitivity. The exogenous final energy demand for electricity has been excluded from this graph, as it remains the same across all model runs.

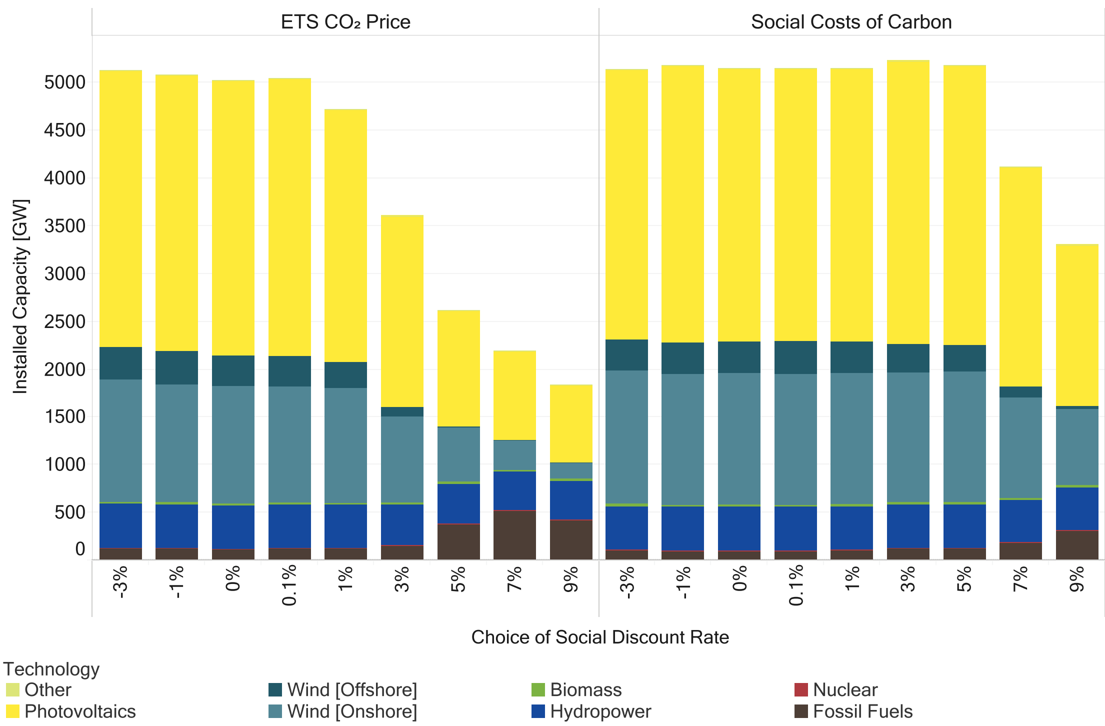

Figure 5. Installed capacities in the year 2050 for different choices of social discount rate and carbon price sensitivities in GENeSYS-MOD Europe.

with 35 €$\,$MWh^{-1} in the 5% discounting base case. For the social costs of carbon case, the range of electricity generation costs in 2050 spans from 31 €$\,$MWh^{-1} (-3% social discount rate) to 46 €$\,$MWh^{-1} (9%), with the 5% discounting base case reaching 31 €$\,$MWh^{-1}. The average generation cost of electricity is therefore very much in line with the similarity in electricity mixes for the different sensitivities. A full table of electricity generation costs can be found in appendix C.

The high shares of variable renewables, especially present at lower discount rates, introduce higher requirements for storages and other flexibility options. The amount of electricity storage required in the mix increases by almost 480% in the ETS CO_2 price sensitivity (135 GW at 9% social discount rate vs. 647 GW at −3% social discount rate), and by more than 300% in the social costs of carbon case (267 GW at 9% social discount rate vs. 831 GW at −3% social discount rate). Especially the high share of sector-coupling of the other sectors with the electricity sector leads to this drastic increase of electricity usage, mainly covered by intermittent renewable energy sources.

5. Implications and discussion

It can be shown that by simply either including a social discount rate that favors intergenerational equality, or by including carbon costs that represent actual negative externalities of carbon dioxide emissions, the model runs of GENeSYS-MOD reach an emission volume that would comply with the Paris Agreement (UNFCCC 2015b, BP 2017), even in a scenario featuring a conservative carbon price. Combining these two measures yields even lower total emissions, showing a further emission decrease of up to 17% by 2050. Thus, by including social, ethical, and environmental aspects in the scope of the optimization, the model outputs drastically change, since the model changes its valuation of investments and damages—and thereby its recommendations. This is in line with Emmerling *et al* (2019), who also determined this effect in their study, coming to the conclusion that lower discount rates lead to earlier emission reduction.

These findings heavily underline the significance of a social discount rate when climate policy is in focus. Since any discussion about climate is always long-term (usually at least until 2050, regularly even until the next century), the choice of discount rate drastically changes the way that future damages are evaluated (compare figure 1). It is thus paramount to openly discuss the choice of discount rates and internalization of negative external effects of carbon dioxide in any modeling that is aimed to inform decision makers on future policy. The energy sector is a major contributor to CO_2 emissions and thus to global warming. Energy system models, trying to emulate the workings of this entire sector—and often optimizing in the role of a social planner, should therefore include a social discount rate to account for the difference in valuation of short- to medium-term investments and long-term damages to the environment.

That said, the choice of the applied discount rate(s) is a challenging one, as the determination of a properly fitting social discount rate often includes many ethical and philosophical considerations, essentially leading to an arbitrary number of possible realizations. However, this makes an open discussion and transparency of the choice of discount rates in the applied models all the more important. Various discount rates should at least be considered in a sensitivity analysis for any long-term energy pathway.

As only the time frame until 2050 was considered for this study, further research should also look into the effects until the end of the century. Since 2100 is often a target for climate analysis, the choice of discount rate is all the more relevant there. This, coupled with an analysis of negative emission technologies, could give additional insights on possible mitigation pathways[5].

6. Conclusion

In order to successfully avert the dangers of global climate change, an immense reduction of greenhouse gas emissions needs to happen over the next few decades. While this fact is generally agreed upon, the distribution of the efforts involved is a point of contention. While a part of the studies advocates for a swift change towards renewable energy sources and immediate emission reductions (Löffler *et al* 2017, Ram *et al* 2017, Bogdanov *et al* 2019), others promote a slower, steady decline of fossil fuels, often offset by negative emission technologies later in the century, trying to remove the accrued overshoot, or by heavy investments into nuclear energy (Paltsev *et al* 2018, World Energy Council 2019, Int. Energy Agency 2020). However, not only these technologies themselves (von Hippel *et al* 2010, Hirschhausen *et al* 2012), but also the feasibility of such ex-post compensation methods is disputed and hugely uncertain (IPCC 2018). It is thus of utmost importance for quantitative models to be properly calibrated in order to be able to generate meaningful insights for policy- and decision-makers. With the energy system being a major contributor of global carbon emissions, energy system models have the obligation to take these uncertainties into account when performing their cost optimization. The results of this paper show that the introduction and choice of a social discount rate, as well as that of social costs of carbon, have a huge impact on model results. Just the choice of discount rate can lead to a decrease of cumulative emissions until 2050 by more than 41% compared to the baseline of 5% discount rate. Therefore, the issue of discounting should be more prominently discussed and evaluated in the field of energy system analysis. Only by properly including the discussed aspects into the application and evaluation of said

[5] Negative emission technologies were not considered in this study, since their large-scale deployment and effectiveness is still unclear (von Hippel *et al* 2010, Hirschhausen *et al* 2012). However, especially looking at longer time horizons than 2050, the inclusion of such technologies, at least as a sensitivity, could give an outlook for different slopes of abatement curves under varying scenario assumptions on technology availability.

models, meaningful and robust results that properly include socio-economic issues such as intergenerational equality can be provided.

Data availability statement

The data that support the findings of this study will be openly available on the public GENeSYS-MOD GitLab repository in October 2021. The repository can be accessed under https://git.tu-berlin.de/genesysmod/genesys-mod-public.

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