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Regional and Sectoral Estimates of the Social Cost of Carbon: An Application of FUND

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Abstract The social cost of carbon is an estimate of the benefit of reducing CO_2 emissions by one ton today. As such it is a key input into cost-benefit analysis of climate policy and regulation. We provide a set of new estimates of the social cost of carbon from the integrated assessment model FUND 3.5 and present a regional and sectoral decomposition of our new estimate. China, Western Europe and the United States have the highest share of harmful impacts, with the precise order depending on the discount rate. The most important sectors in terms of impacts are agriculture and increased energy use for cooling. We present an extensive sensitivity analysis with respect to the discount rate, equity weights, different socio economic scenarios and values for the climate sensitivity parameter.

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1. Introduction

The social cost of carbon (SCC) is an estimate of the desired intensity of climate policy. The SCC specifies the level at which greenhouse gas emissions should be priced in order to account for the externalities associated with CO_2 emissions. Unsurprisingly, given the challenges associated with modeling the global and centuries long effects of CO_2 emissions, the literature has many (>300) estimates of the social cost of carbon covering a wide span (Tol 2009). This paper offers a sectoral and regional decomposition of newer and, we argue, better estimates. Our goal is to facilitate understanding and discourse about the relative contribution of each region and sector and the state of climate change impacts science.

The estimates in this paper are based on version 3.5 of the FUND model. FUND has a more detailed representation of the impacts of climate change than other models producing SCC estimates (Hope et al. 1993;Hope 2006;Hope 2008;Nordhaus 1994;Nordhaus 2008;Nordhaus and Boyer 2000;Plamberk et al. 1997). In particular, FUND has more regional and sectoral detail. The results presented in this paper focus on that detail. (Tol 1999) presented disaggregated results for FUND 1.6, a version that is very different from the current version: FUND 3.5 offers a complete update of the impact estimates (Tol 2002a;Tol 2002b) and includes additional impacts (Narita et al. 2009;Narita et al. 2010).

The social cost of carbon is, to a first approximation, equal to the tax that a benevolent, global planner would apply to greenhouse gas emissions in order to fully internalize the externalities of those emissions (Pigou 1920). It is less clear how a regional planner would set the social cost of carbon (Anthoff and Tol 2010). One reason is that questions of strategic interactions between different regions complicate the analysis (Barrett 1994). A regionally disaggregated estimate of the social cost of carbon is of interest for two reasons: First, it gives insight how a global estimate is distributed between different regions; and second, it can inform game theoretic analysis of strategic interactions between different world regions with respect to greenhouse gas mitigation options.

The paper also disaggregates the social costs of carbon by impact "sector". This reveals regional patterns of marginal impacts and identifies the more vulnerable sectors (at the margin) as well as priorities for research.

The paper proceeds as follows. Section 2 presents the model. Section 3 discusses the results. Although best guess are shown, the discussion focuses on the sensitivity analyses. Section 4 concludes.

2. The model

This paper uses version 3.5 of the *Climate Framework for Uncertainty, Negotiation and Distribution* (*FUND*). FUND is an integrated assessment model of projections of populations, economic activity and emissions, carbon cycle and climate model responses, and estimates of the monetized welfare impacts of climate change.[1] Climate change impacts are monetized in 1995 dollars and are modelled over 16 regions. Modelled impacts include agriculture, forestry, sea level rise, cardiovascular and respiratory disorders influenced by cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources, unmanaged ecosystems and tropical and

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[1] FUND is one of the few integrated assessment models that produce SCC estimates. Other models include DICE (Nordhaus 2008) and PAGE (Hope 2008).

extratropical storm impacts. The source code, data, and a technical description of the model can be found at http://www.fund-model.org.

The model distinguishes 16 major regions of the world, viz. the United States of America, Canada, Western Europe, Japan and South Korea, Australia and New Zealand, Central and Eastern Europe, the former Soviet Union, the Middle East, Central America, South America, South Asia, Southeast Asia, China, North Africa, Sub-Saharan Africa, and Small Island States. The model runs from 1950 to 3000 in time steps of one year. The prime reason for starting in 1950 is to initialize the climate change impact module. In *FUND*, some of the impacts of climate change are assumed to depend on the impact of the previous year, this way reflecting the process of adjustment to climate change. Because the initial values to be used for the year 1950 cannot be approximated very well, both physical and monetized impacts of climate change tend to be misrepresented in the first few decades of the model runs.[2] The centuries after the 21st are included to assess the long-term implications of climate change. Previous versions of the model stopped at 2300.

2.1. Scenarios and Climate Module

The scenarios are defined by the rates of population growth, economic growth, autonomous energy efficiency improvements as well as the rate of decarbonization of the energy use (autonomous carbon efficiency improvements), and emissions of carbon dioxide from land use change, methane and nitrous oxide. The scenarios of economic and population growth are perturbed by the impact of climatic change. Market impacts are a

[2] The period of 1950–2000 is used for the calibration of the model, which is based on the *IMAGE* 100-year database (Batjes and Goldewijk 1994). The scenario for the period 2010–2100 is based on the EMF14 Standardized Scenario, which lies in between IS92a and IS92f (Leggett et al. 1992). The 2000–2010 period is interpolated from the immediate past (http://earthtrends.wri.org), and the period 2100–3000 extrapolated.

deadweight loss to the economy. Population decreases with increasing climate change related deaths that result from changes in heat stress, cold stress, malaria, and storms. Heat and cold stress are assumed to have an effect only on the elderly, non-reproductive population. In contrast, the other sources of mortality also affect the reproductive population. Heat stress only affects the urban population. The share of the urban population among the total population is based on the World Resources Databases (http://earthtrends.wri.org). It is extrapolated based on the statistical relationship between urbanization and per capita income, which are estimated from a cross-section of countries in 1995. Climate-induced migration between the regions of the world also causes the population sizes to change. Immigrants are assumed to assimilate immediately and completely with the respective host population.

The endogenous parts of *FUND* consist of the atmospheric concentrations of carbon dioxide, methane, nitrous oxide and sulphur hexafluoride, the global mean temperature, the impact of carbon dioxide emission reductions on the economy and on emissions, and the impact of the damages to the economy and the population caused by climate change. Methane and nitrous oxide are taken up in the atmosphere, and then geometrically depleted. The atmospheric concentration of carbon dioxide, measured in parts per million by volume, is represented by the five-box model (Hammitt et al. 1992;Maier-Reimer and Hasselmann 1987). The model also contains sulphur emissions (Tol 2006).

The radiative forcing of carbon dioxide, methane, nitrous oxide, sulphur hexafluoride and sulphur aerosols is as in the IPCC (Ramaswamy et al. 2001). The global mean temperature T is governed by a geometric build-up to its equilibrium (determined by the radiative forcing RF), with an e-folding time of 66 years. In the base case, the global mean temperature rises in equilibrium by 3.0°C for a doubling of carbon dioxide equivalents. Regional temperatures follow from multiplying the global mean temperature by a fixed factor, which corresponds to the spatial climate change pattern averaged over 14 General Circulation Models (Mendelsohn et al. 2000). The dynamics of the global mean sea level are also geometric, with its equilibrium level determined by the temperature and an e-folding time of 500 years. Both temperature and sea level are calibrated to correspond to the best guess temperature and sea level for the IS92a scenario (Kattenberg et al. 1996).

2.2. Impacts and Damages

The climate impact module includes the following categories: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, energy consumption, water resources, unmanaged ecosystems (Tol 2002a;Tol 2002b), diarrhoea (Link and Tol 2004), and tropical and extra tropical storms (Narita et al. 2009;Narita et al. 2010). Climate change related damages can be attributed to either the rate of change (where damages are calibrated at 0.04°C/yr) or the level of change (with damage functions calibrated at 1.0°C). Damages from the rate of temperature change slowly fade, reflecting adaptation (Tol 2002b).

People can die prematurely due to climate change, or they can migrate because of sea level rise. Like all impacts of climate change in FUND, these effects are monetized. The value of a statistical life is set to be 200 times the annual per capita income. The resulting value of a statistical life lies in the middle of the range of values in the literature (Cline 1992). The value of emigration is set to be 3 times the per capita income (Tol 1995), the value of immigration is 40 per cent of the per capita income in the host region (Cline

1992). Losses of dryland and wetlands due to sea level rise are modeled explicitly. The monetary value of a loss of one square kilometre of dryland was on average $4 million in OECD countries in 1990 (Fankhauser 1994). Dryland value is assumed to be proportional to GDP per square kilometre. Wetland losses are valued at $2 million per square kilometre on average in the OECD in 1990 (Fankhauser 1994). The wetland value is assumed to have logistic relation to per capita income. The level of coastal protection is based on an internal cost-benefit analysis that includes the value of additional wetland lost due to the construction of dikes and subsequent coastal squeeze.

Other impact categories, such as agriculture, forestry, energy, water, storm damage, and ecosystems, are directly expressed in monetary values without an first estimating impacts in ‘natural’ units (Tol 2002a). Impacts of climate change on energy consumption, agriculture, and cardiovascular and respiratory diseases explicitly recognize that there is a climatic optimum, which is determined by a variety of factors, including plant physiology and the behaviour of farmers. Impacts are positive or negative depending on whether the actual climate conditions are moving closer to or away from that optimum climate. Impacts are larger if the initial climate conditions are further away from the optimum climate. The optimum climate is of importance with regard to the potential impacts. The actual impacts lag behind the potential impacts, depending on the speed of adaptation. The impacts of not being fully adapted to new climate conditions are always negative (Tol 2002b).

The impacts of climate change on coastal zones, forestry, tropical and extratropical storm damage, unmanaged ecosystems, water resources, diarrhoea, malaria, dengue fever, and schistosomiasis are modelled as power functions. Impacts are either negative or positive with greater climate change, and they do not change sign (Tol 2002b).

Vulnerability to a given climate change is a function of population growth, economic growth, and technological progress. Some systems are expected to become more vulnerable with increases in these factors, such as water resources (with population growth), heat-related disorders (with urbanization), and ecosystems and health (with higher per capita incomes). Other systems such as energy consumption (with technological progress), agriculture (with economic growth) and vector- and water-borne diseases (with improved health care) are projected to become less vulnerable at least over the long term (Tol 2002b). The income elasticities (Tol 2002b) are estimated from cross-sectional data or taken from the literature.

2.3. Calculation of the Social Cost of Carbon

We estimated the SCC cost of carbon by computing the difference between the projected total monetised impact of climate change along a business as usual path and those along a path with an incremental increase in emissions between 2010 and 2019.[3] The differences in projected impacts are discounted back to the year 2010, and normalised by the difference in emissions. The SCC is thereby an estimate of the marginal additional damages of additional carbon at a point in time expressed in dollars per tonne. Because the estimate is at the margin, it is also a conceptually appropriate measure for the avoided damages from reducing emissions by one tonne. That is,

[3] The social cost of carbon of emissions in future or past periods is not the focus of this paper.

$$SCC_{r,s} = \sum_{t=2010}^{3000} \frac{D_{t,r,s}\left(E_{1950}+\delta_{1950},...,E_t+\delta_t\right) - D_{t,r,s}\left(E_{1950},...,E_t\right)}{\prod_{i=2010}^{t} 1+\rho+\eta g_{i,r}} \Bigg/ \sum_{t=1950}^{3000} \delta_t \tag{1}$$

$$\delta_t = \begin{cases} \omega & \text{for } 2010 \le t < 2020 \\ 0 & \text{for all other cases} \end{cases}$$

where

- $SCC_{r,s}$ is the regional, sector specific social cost of carbon (in 1995 US dollars per tonne of carbon);
- r denotes region;
- s denotes sector/impact type;
- t and i denote time (in years);
- D are monetised impacts (in 1995 US dollars per year);
- E are carbon emissions (in metric tonnes of carbon);
- δ are incremental emissions (in metric tonnes of carbon);
- ω is the marginal amount of extra emissions;
- ρ is the pure rate of time preference (in fraction per year);
- η is the elasticity of marginal utility with respect to consumption; and
- g is the growth rate of per capita consumption (in fraction per year).

To compute the SCC for a specific region, we add up the sector specific estimates for that region:

$$SCC_r = \sum_s SCC_{r,s}$$

We then aggregate, as follows to compute the global social cost of carbon:

$$SCC = \sum_r \left(\frac{c_{2010,ref}}{c_{2010,r}}\right)^{\varepsilon} SCC_r \tag{2}$$

where

- SCC is the global social cost of carbon (in 1995 US dollar per tonne of carbon);
- SCC_r is the regional social cost of carbon (in 1995 US dollar per tonne of carbon);

- *r* denotes region;
- c_{ref} is the average per capita consumption in the reference region (in 1995 US dollars per person per year); the reference region may be the world (Fankhauser et al. 1997) or one of the regions (Anthoff et al. 2009);
- c_r is the regional average per capita consumption (in 1995 US dollars per person per year); and
- ε is the rate of inequity aversion; $\varepsilon = 0$ in the case without equity weighing; $\varepsilon = \eta$ in the case with equity weighing.

3. Core results and sensitivity analysis

3.1. Time preference

Figure 1 shows the social cost of carbon for three alternative pure rates of time preference (0.1%, 1%, 3% per year) for the world as a whole (simple summation) and for the individual regions.

The social cost of carbon rises as the pure rate of time preference falls: For a 3% rate, the SCC is $1.33/tC; it is $30.3/tC for 1%; and $186/tC for 0.1%. The same pattern is observed for the regional social costs of carbon, but there are sign changes as well. Six regions have a negative social cost of carbon for a 3% rate: Australia and New Zealand; Central America; Eastern Europe; Japan and South Korea; Middle East; and South Asia. For a 1% rate, only Japan and South Korea benefit at the margin from higher emissions. For a 0.1% rate, all regions face negative marginal impacts. This suggests that some regions see short-term benefits of climate change. However, all regions are projected to experience damages in the long run that surpass the short-term impacts in undiscounted terms. The sectoral decomposition shows that these are primarily in agriculture due to carbon dioxide fertilization (see below).

For a 3% rate, some regions benefit from a marginal emission of carbon today. Of these regions, Japan and South Korea have the largest share of benefits with 77% of estimated benefits, followed by the Middle East with 11%. Of the regions with harmful impacts, the USA has by far the largest share of the social cost of carbon (33%), followed by Western Europe (18%), the former Soviet Union (16%), sub-Saharan Africa (15%) and North Africa (12%). For a 1% rate, only Japan and South Korea benefit from marginal emissions. China has the largest share of harmful impacts (31%), followed by Western Europe (21%) and the USA (13%). For a 0.1% rate, China has the largest share (48%) with Western Europe the only other region with a share above 10% (14%). Increased demand for air conditioning is one of the largest impacts in China. This illustrates both the vulnerability of China to climate change and its projected rise to economic prominence.

Figure 2 shows the social cost of carbon by "sector". For a 0.1% pure rate of time preference, agriculture contributes 68% of the harmful marginal impact and cooling energy another 27%. For a 1% rate, the roles are reversed, with cooling making up 64% of the harmful marginal impact and agriculture 21%. For a 3% rate, agriculture and cooling are roughly equal in size but opposite in sign: -$6.5/tC and $6.8/tC.

Cooling energy and agriculture are the two most important marginal impacts. Heating energy is less important because this benefit is capped by the expenditure in the absence of climate change. Forestry is a small sector in the economy, and tropical and extratropical storms do, on average, little damage. The marginal impacts of sea level rise are relatively small because the level of the sea responds with a lag to changes in temperature. For ecosystem impacts, the value of the impact (and hence per capita income) is more important than the impact itself. Infectious diseases are brought under control (in the model) with rapid economic growth. For cardiovascular and respiratory disorders, positive and negative impacts tend to balance.

The impact of climate change on forestry and heating energy are always positive at the margin. The other impacts are always negative, except for agriculture which is positive in the short run (and for a high discount rate) but negative in the long run (and for a low discount rate). The sign of the marginal impacts follow immediately from the assumed signs of the total impacts.

3.2. Equity weighting

Figure 3 repeats the results of Figure 1 and adds equity weighting. Equity weighting corrects for the fact that a dollar to a poor person is worth more than a dollar to a rich person. Figure 3 shows results for equity weights from the perspective of a global planner (Fankhauser et al. 1997), and from the perspective of two regional planners (Anthoff et al. 2009): USA (with the highest per capita income) and sub-Saharan Africa (with the lowest per capita income).

Global equity weights increase the global social cost of carbon by a factor of 3.0 to 4.5, depending on the discount rate. Equity weights themselves are independent of the discount rate. The distribution of regional social costs is not, however. As we first discount impacts to the present, and then aggregate them, equity weights have a different effect depending on the discount rate.

If impacts are equity-weighted from the perspective of the USA, the social cost of carbon increases by a factor of 18.6 to 27.6. Because the USA is one of the richest regions, the impacts in all other regions (with a lower income) get an equity weight larger than 1, thus increasing the social cost of carbon estimate compared to a situation without equity weights. If impacts are equity-weighted from a sub-Saharan African perspective, the social cost of carbon falls by a factor of 0.29 to 0.43. Sub-Saharan Africa is one of the poorest regions in the world. Impacts in all regions with higher incomes (essentially all other regions) therefore get an equity weight <1 when a Sub-Saharan perspective is used, thereby decreasing the social cost of carbon estimate compared to a situation without equity weights.

Global and two regional equity weighting schemes use a different normalization constant. Therefore, the regional share in the equity-weighted global social cost of carbon is independent of equity weight. Generally, poorer regions are more important and richer regions less important with equity weighting. For a 3% pure rate of time preference, 60% of the harmful share of the social cost of carbon is in sub-Saharan Africa, with another 18% in North Africa and 16% in the former Soviet Union. 36% of the beneficial impacts are in South Asia, 27% in the Middle East and 13% in China and Japan each. For a 1% rate, China has the largest share (46%) of harmful impacts, followed by sub-Saharan Africa (17%) and South Asia (12%). Only Japan has beneficial impacts from a 1% pure time preference rate. For a 0.1% rate, China has the largest share (66%), followed by South Asia (10%) and sub-Saharan Africa (7%). Figure 4 shows the social cost of carbon per sector with and without equity weighing. Equity weighing discounts the marginal impact on cooling energy, and puts more emphasis on the marginal impact on agriculture. Cooling costs are higher in richer regions, and impacts in those regions are given less weight with equity weights. Agricultural impacts are more important in poorer, less developed regions and impacts in those regions receive more weight with equity weights.

3.3. Scenarios

We use the FUND scenario as the baseline. We use the four SRES baseline scenarios as a sensitivity analysis. The A1 scenario assumes low population growth, rapid economic growth, and rapid technological progress. A2 assumes high population growth, slow economic growth, and slow technological progress. B1 assumes low population, rapid economic growth, and very rapid technological progress particularly in energy supply and use. B2 assumes moderate population growth, moderate economic growth, and moderate technological progress.

Figure 5 shows the social cost of carbon as a function of the socio-economic and emissions scenario. For a 3% pure rate of time preference, the social cost of carbon is highest in the FUND scenario (used in the results presented above). The values for the SRES scenarios range from -$2.29/tC (B1) to $1.55 (A2). For a 1% rate, the FUND scenario is in the middle; the SRES values range from $8.09/tC (B1) to $45.4/tC (A2). For a 0.1% rate, FUND is again in the middle; the SRES values range from $58.1/tC (B1) to $1880/tC (A2).

Figure 6 again shows the social cost of carbon (assuming a 1% pure rate of time preference) for the five scenarios, but now as a function of the size of the population in 2100, the average per capita income in 2100, and the global mean surface air temperature in 2100.[4] The social cost of carbon increases with the temperature, but more so with the population. The dominant effect, however, is per capita income: The social cost of carbon

[4] Note that population, income, emissions, and temperature are not independent of one another.

tends to fall with income in FUND. Therefore, the relatively poor-but-hot A2 scenario has high marginal impacts whereas the rich-but-cool B1 scenario has low marginal impacts.

For a 3% rate, the global social cost of carbon changes sign between scenarios. So does the regional social cost of carbon for China, South America, Southeast Asia, Small Island States and Western Europe. In these regions, negative and positive impacts are roughly balanced, and different assumptions will change the sign of the aggregate impact. The regional social cost of carbon of Canada, former Soviet Union, North Africa, sub-Saharan Africa and USA is always positive independent of the chosen scenario; and it is always negative for Australia and New Zealand, Central America, Eastern Europe, Japan and South Korea, Middle East, and South Asia.

Figure 7 shows the social cost of carbon per sector as a function of the socio-economic and emissions scenario. For three of the four SRES scenarios, the pattern is the same as for the FUND scenario: Agriculture dominates the marginal impacts in the long run, and cooling energy in the short run. The A2 scenario is the exception to this. For a 0.1% pure rate of time preference, agriculture is the biggest contributor (55%) to the social cost of carbon, followed by mortality (42%) and cooling energy (3.2%). The A2 scenario has the lowest per capita income growth. Air conditioning is therefore less widespread, and infectious diseases more common.

3.4. Climate sensitivity

Figure 8 shows the social cost of carbon for three alternative climate sensitivities: 2.0°C equilibrium warming for doubling of atmospheric carbon dioxide, 3.0°C (the value used in the runs above) and 4.5°C. The higher the climate sensitivity, the greater the social cost of carbon. For a 3% pure rate of time preference, the social cost of carbon is -$0.708/tC for a climate sensitivity of 2.0°C; this increases to $1.33/tC for 3.0°C; and to $2.92/tC for 4.5°C. For a 1% rate, the estimates are $11.5/tC, $30.3/tC and $64.5/tC, respectively. For a 0.1% rate, the estimates are $52.8/tC, $186/tC, and $1,510/tC. The social cost of carbon is non-linear in the climate sensitivity (increasing at an increasing rate). The results for the lower pure rate of time preference reveal that this non-linearity becomes more important over time, because the difference in warming grows over time.

The same pattern is observed for the estimates of the regional social cost of carbon. Two regions stand out: the social cost of carbon for China and the Small Island States is consistently more non-linear than the global estimate, because in these regions agriculture is one of the larger impacts (see below).

Figure 9 shows the social cost of carbon per sector for three alternative climate sensitivities. Agriculture net damages are more non-linear in the long-run than in the short-run, and considerably more non-linear than cooling energy. This is because agricultural impacts are assumed to be quadratic in warming while cooling is proportional to temperature to the power 1.5. Mortality is even more non-linear in the long run. Cooling energy dominates mortality for all but one combination of climate sensitivity and pure rate of time preference. However, for a 0.1% rate and a 4.5°C sensitivity, the marginal impact on mortality is almost five times higher than the marginal impact on cooling energy. This is because, in the long run, all regions are assumed to become rich and old enough to suffer from cardiovascular and respiratory disorders, while the positive incremental impacts of reduced cold stress disappear if it gets warm enough.

4. Discussion and conclusion

We present new estimates of the social cost of carbon, and split them by region and by sector. As is known from previous studies (Kuik et al. 2008), estimates vary greatly with the pure rate of time preference, equity weighting, scenario, and climate sensitivity. For a high pure rate of time preference, the social cost of carbon is dominated by the currently rich regions. For a low pure rate of time preference, China is the dominant region with low per capita income and significant agricultural and cooling requirement exposure. However, all regions exhibit significantly more damages in the future with greater climate change than in the near-term. Differences in economic growth are a key determinant to differences in the social cost of carbon between scenarios. Slower income growth and greater income differences across regions, combined with higher emissions, results in larger regional damages. The social cost of carbon is increasing and accelerating in climate sensitivity, and more so if the pure rate of time preference is lower due the acceleration of damages over time with higher climate sensitivity. Agriculture and cooling energy are the largest impacts in the near- and long-term (at the margin), as well as extremely responsive to socioeconomic conditions, emissions, and climate sensitivity. However, human mortality could be significant in the distant future under poor global socioeconomic and emissions conditions or high climate sensitivity.

These results come with a number of caveats. Primary among them is the fact that SCC estimates are only as good as the impacts research literature. To date there is limited knowledge regarding potentially important impacts, such as with respect to biodiversity, air pollution, extreme weather events, catastrophic events, ecosystem thresholds, variability, geophysical irreversibilities, non-market values, and interactions between sectors and regions. This has led some to characterize estimates of the SCC as underestimates (Schneider et al. 2007). In addition, it is important to be reminded that the SCC is an estimate of marginal damages and therefore suitable for evaluating marginal global emissions changes. An incremental change in emissions has little effect on the probability of events that may be caused by climate change, such as hurricanes, ice sheet collapse, massive methane release from melting permafrost, and large-scale migration.

Finally, the analysis presented does not attempt to represent uncertainty, only partial ranges of possible outcomes. Nor do we reflect the value of risk, other greenhouse gases, or changes in the SCC over time. These topics are discussed in companion papers. Furthermore, the estimates are sensitive to more than the sensitivities considered in this paper, e.g., specification of carbon cycle and climate model, the impact categories included and their functional form with respect to development and climate change, and their monetization. We do not present these results as definitive regional and sectoral estimates, but instead to enhance understanding of marginal impacts and the SCC from one model, and to stimulate discussion and impacts research on global regions and sectors.

Acknowledgements

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Figures

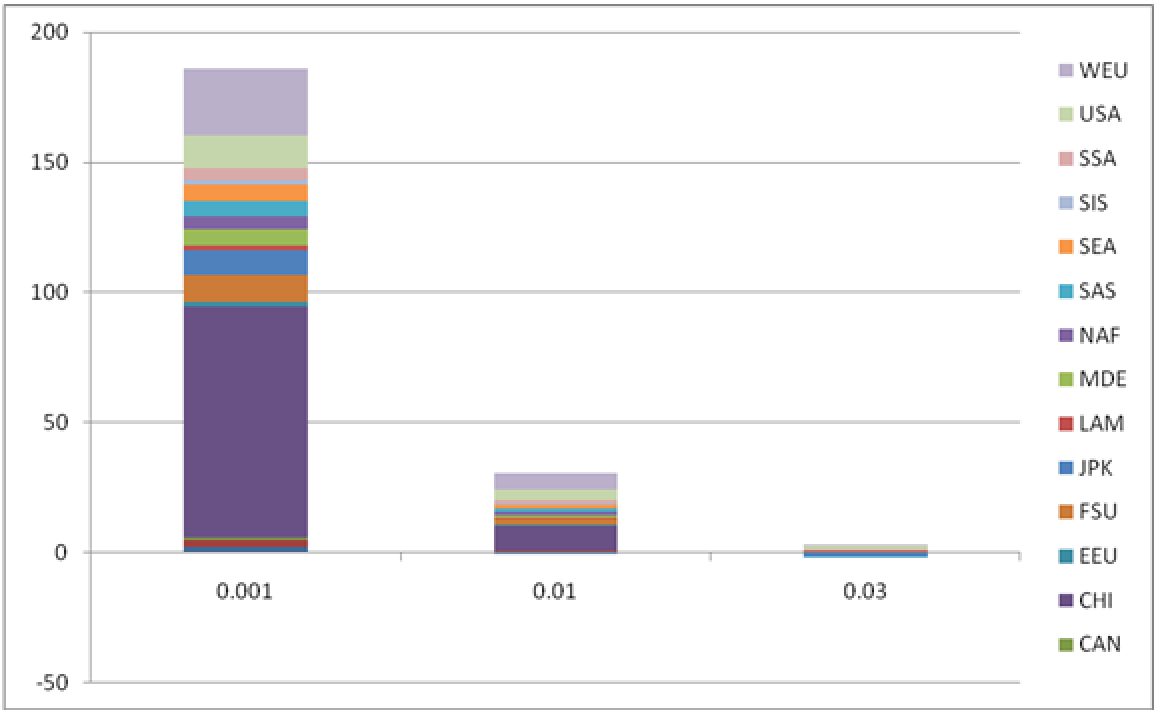

Figure 1. Social cost of carbon per region as a function of the rate of pure time preference.

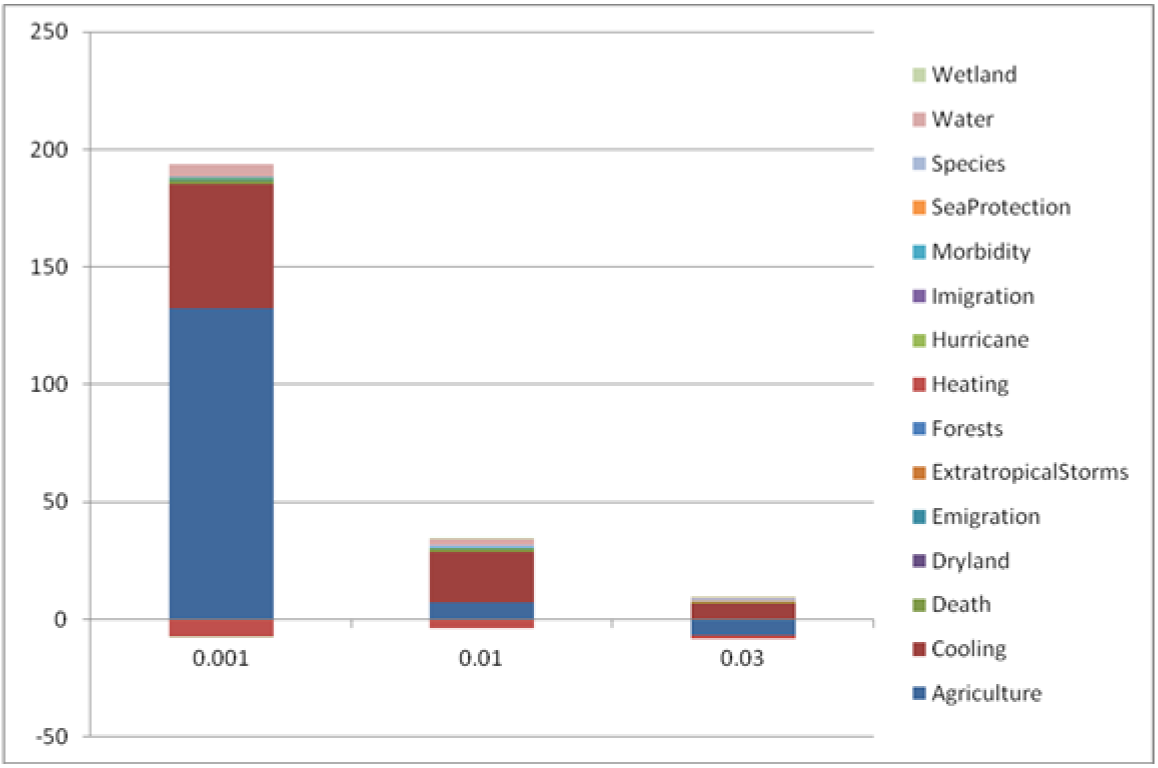

Figure 2. Social cost of carbon per sector as a function of the rate of pure time preference.

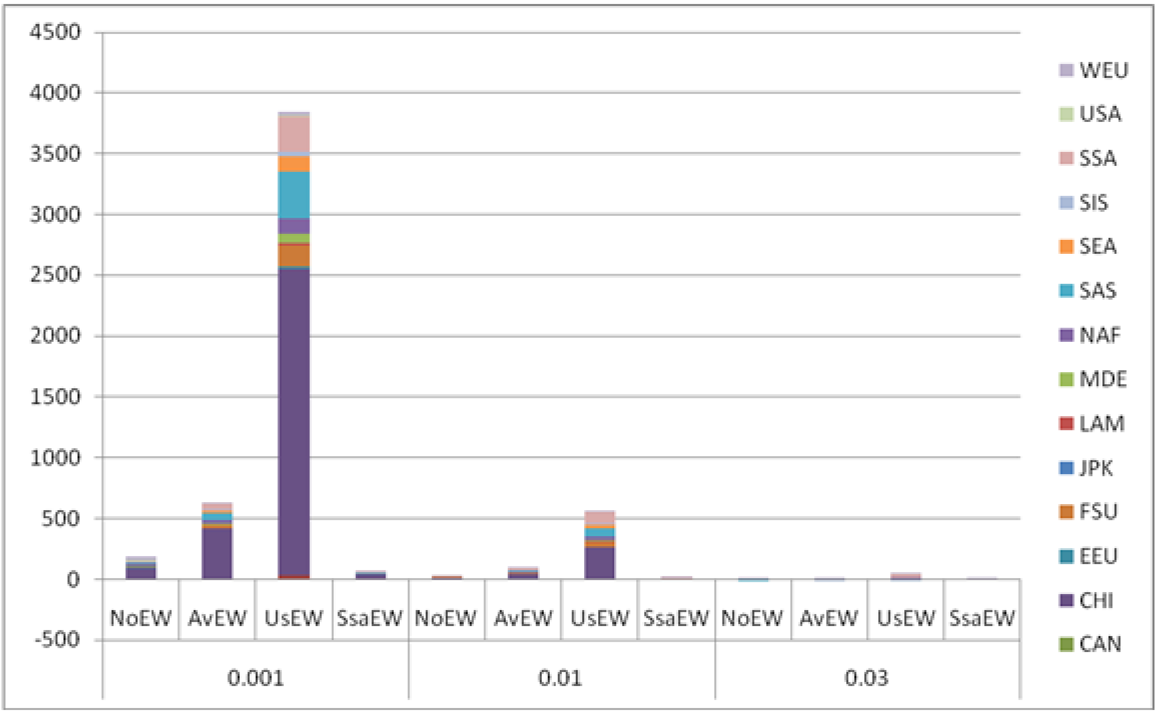

Figure 3. Social cost of carbon per region with and without equity weighing.

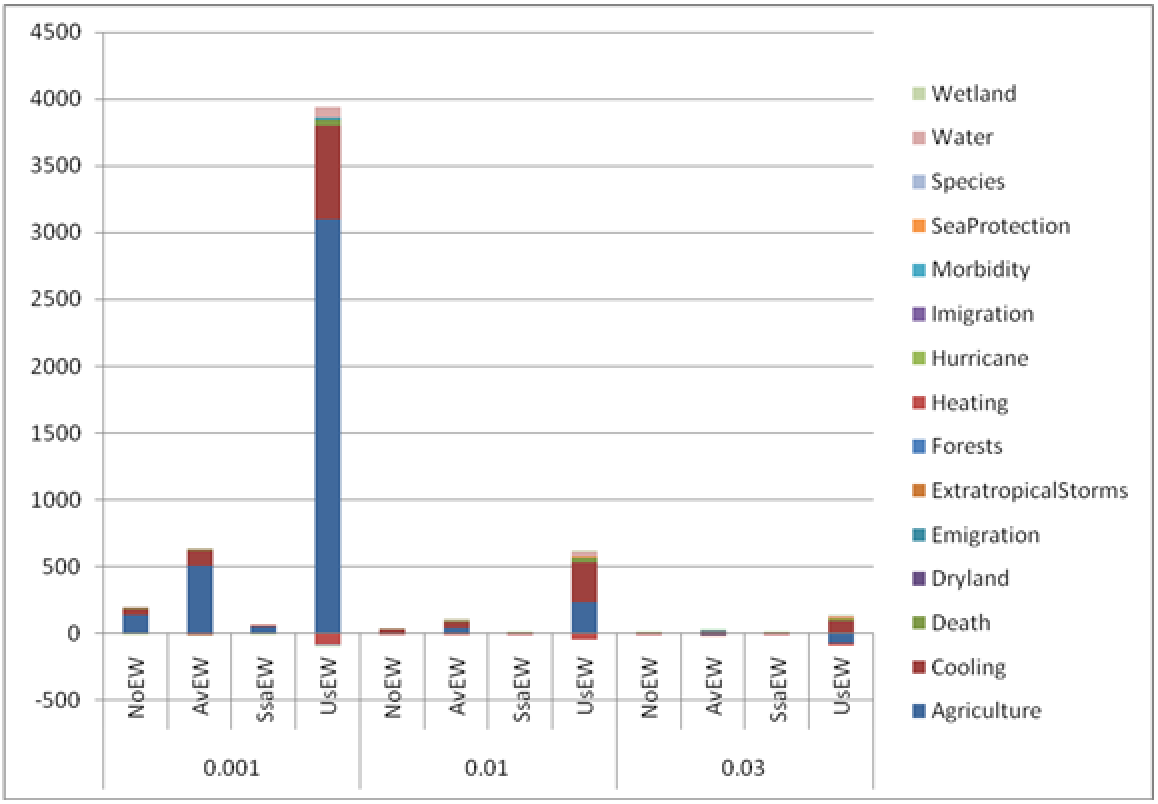

Figure 4. Social cost of carbon per sector with and without equity weighing.

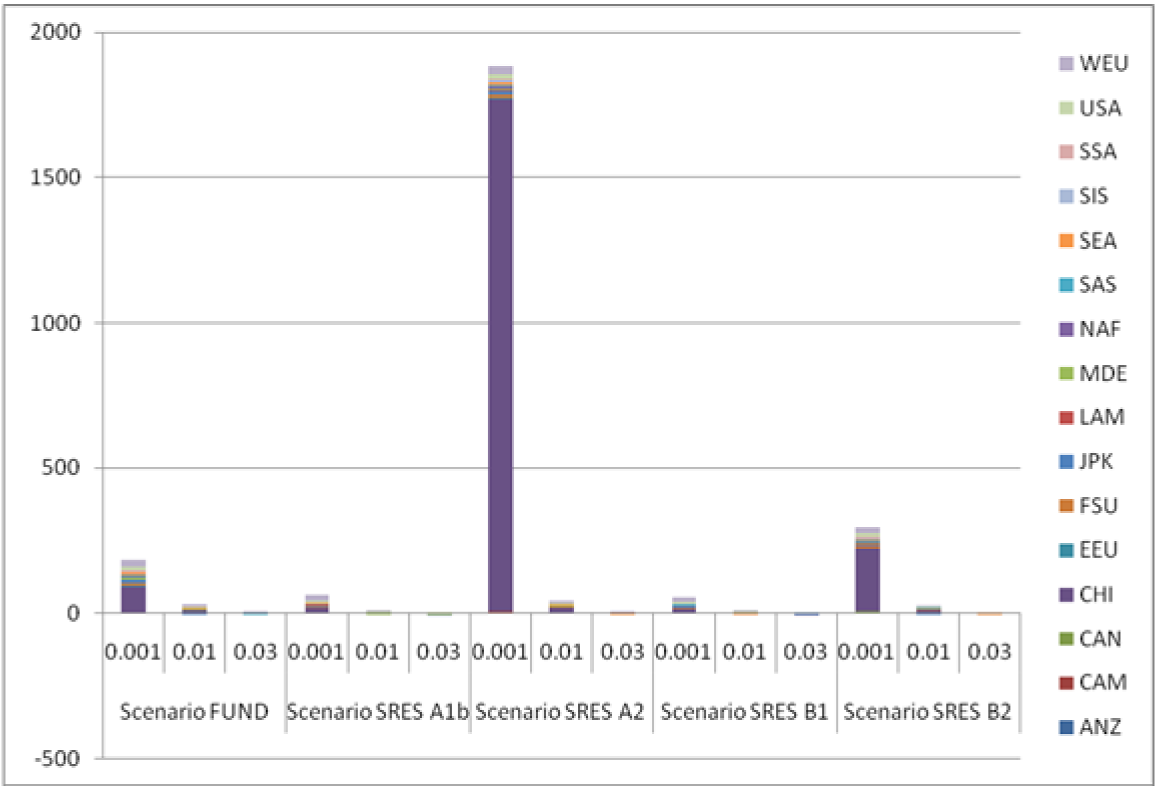

Figure 5. Social cost of carbon per region for alternative socio-economic scenarios.

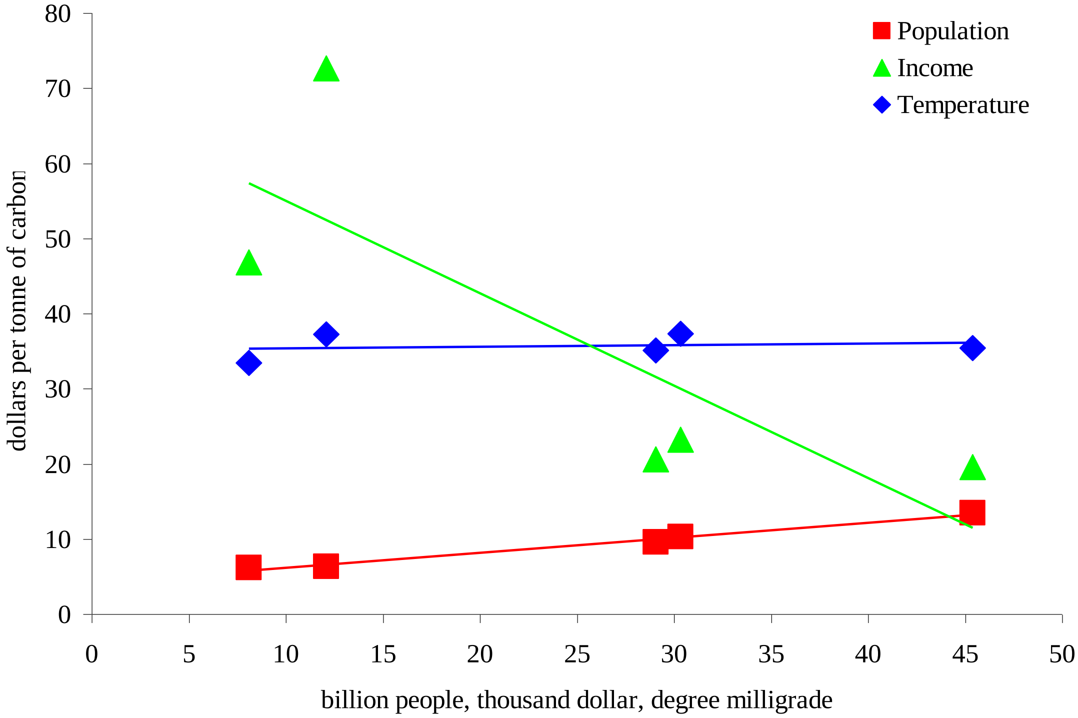

Figure 6. The social cost of carbon for alternative scenarios.

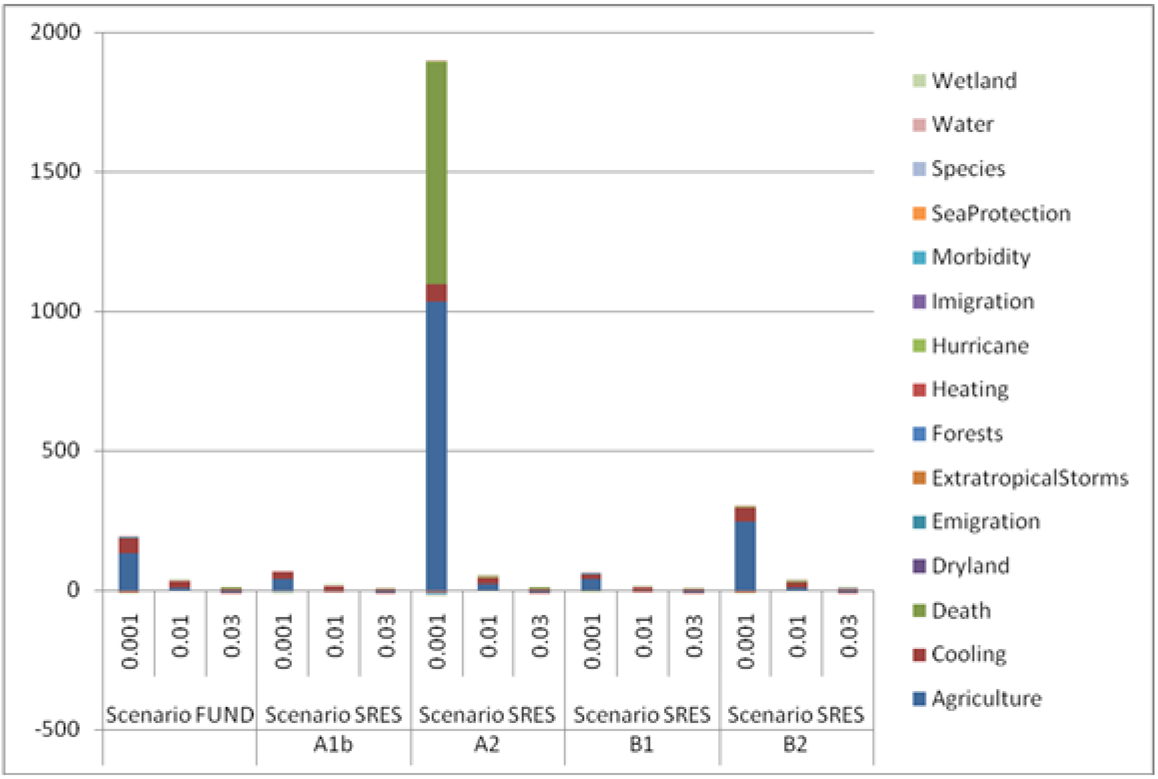

Figure 7. Social cost of carbon per sector for alternative socio-economic scenarios.

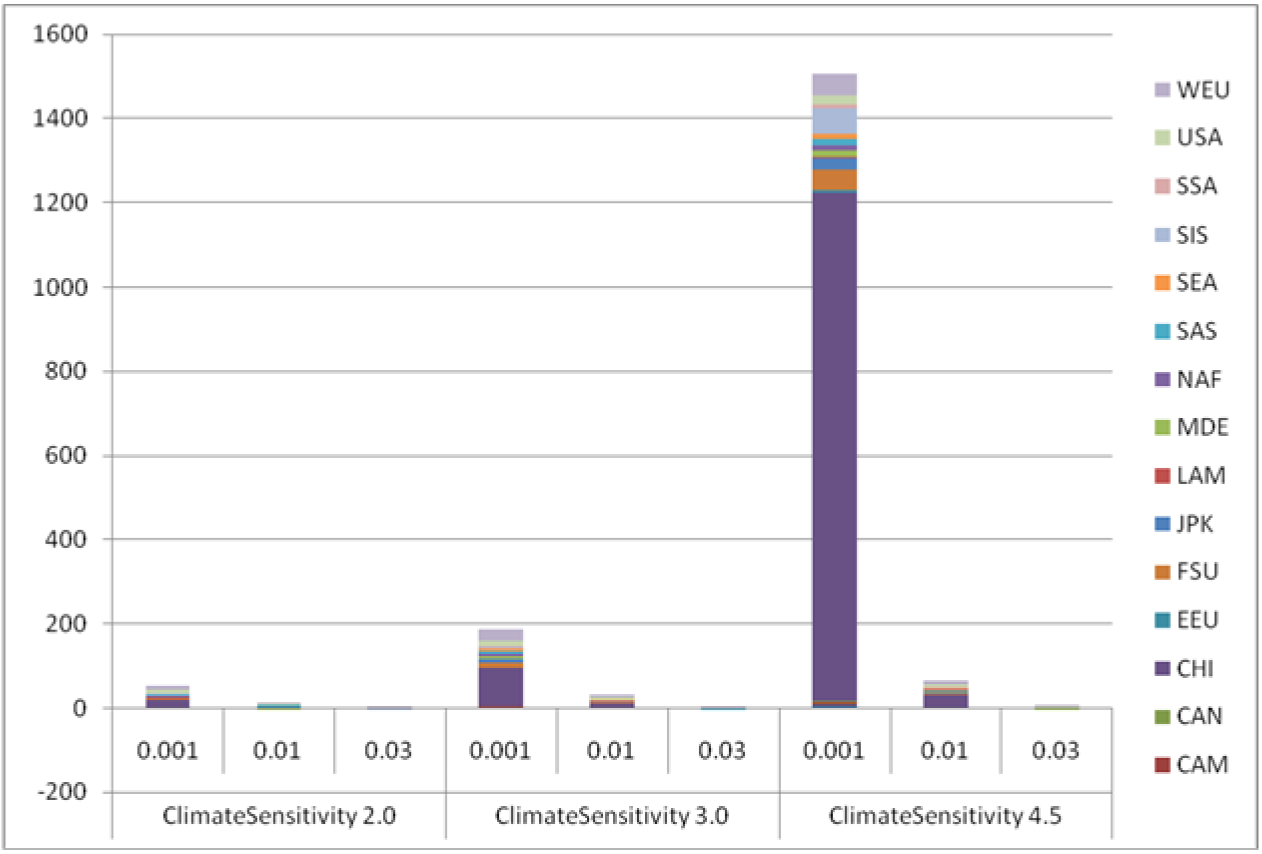

Figure 8. Social cost of carbon per region as a function of the climate sensitivity.

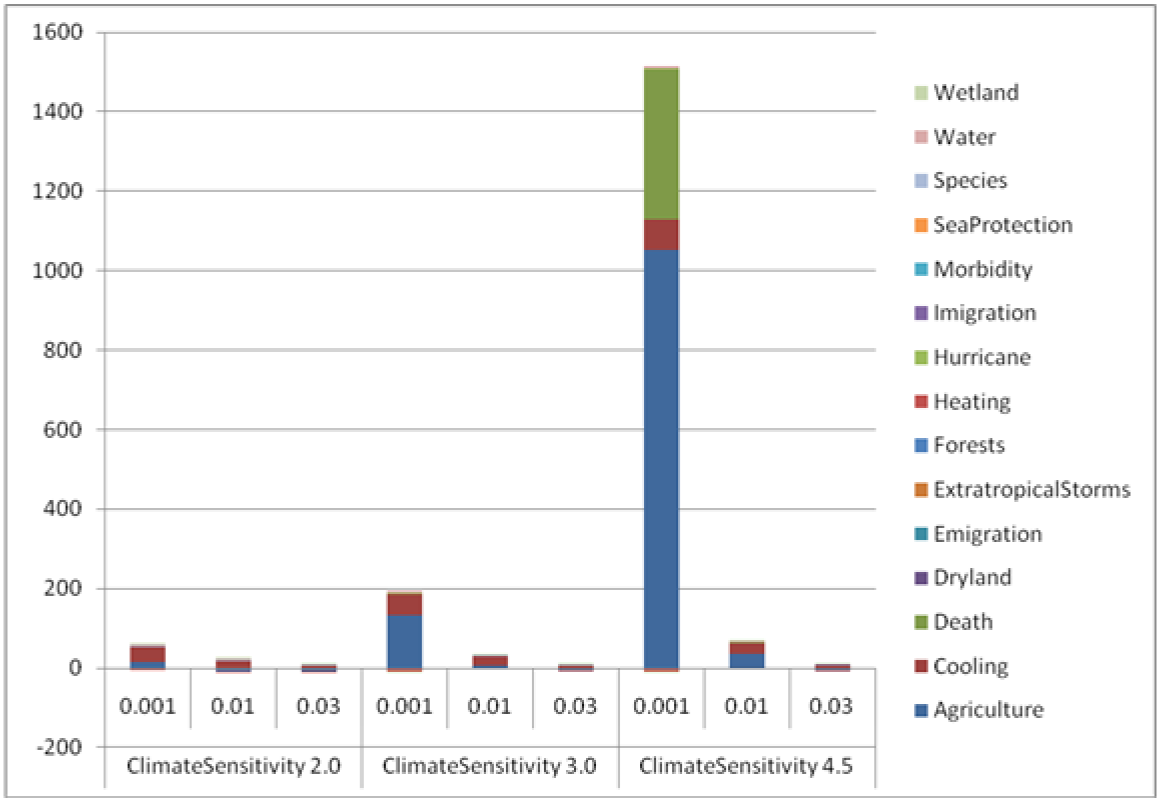

Figure 9. Social cost of carbon per sector as a function of the climate sensitivity.

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