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Whither climate change post-Paris?

Roy Thompson

Abstract

The Paris Climate Agreement has been welcomed by many as providing a remarkably strong basis for global action on anthropogenically mediated climate change, by underpinning a highly ambitious, very clever and forward-looking political process. On the other hand the sum total of the fresh emission reductions pledged is very small. A new climate-economics model is explored to help focus on two key points remaining at issue post-Paris, namely where are we now? and where are we headed? The output reinforces the unpalatable finding that in the absence of even stronger carbon-pricing policies, temperatures and sea-level will, this century, rise significantly beyond what are currently deemed to be ‘dangerous’ levels. Pigouvian taxes have long been championed by economists as providing a simple, down-to-earth corrective remedy for market failures, such as excessive carbon emissions. The Wilsonian modification, or ‘*feebate*’, provides an attractive modern variant that could easily be implemented post-Paris.

Keywords

Abatement costs, Anthropocene, climate change, climate sensitivity, damage function, discount rate, integrated assessment model, Pigouvian tax.

The phrase ‘Anthropogenic Climate Change’ is considered by Rahmstorf (2008) to involve two slightly different ideas. The first, he suggests, is a statement about the future which can be summed up as follows “*anthropogenic emissions of greenhouse gases will lead to significant global warming*”. The second, he proposes, is an affirmation about what we can observe now, that is to say “*human activities already have noticeably changed global climate*”. In this short article I reflect on these two facets of Anthropogenic Climate Change within the context of the process of the adoption, signing and ratification of the Paris Climate Agreement. In particular, by making use of a straightforward energy-balance model and a stripped-down integrated assessment model, I focus on the two questions: where are we now? and where are we headed?

The Paris Agreement, negotiated by 195 countries plus the European Union, was formally adopted on Dec 12 2015. Over 34,000 words, with 1,600 bracketed passages, had been successfully resolved by the 21st session of the Conference of the Parties (COP21)¹. The Paris Agreement sets a long-term goal of restricting the average global temperature increase to “...*well below 2°C above pre-industrial levels...*” with all countries pursuing efforts “...*to limit the temperature increase to 1.5 °C...*” What are we to make of the Paris Agreement and the COP process? Paris was the latest of the series of United Nation (UN) meetings that form part of the global environmental treaty, negotiated in 1992, that seeks to prevent dangerous climate change. However, international climate governance has transpired to be a particularly intractable affair. So despite the best efforts of the long sequence of Climate Conferences stretching back over 50 years via Paris, Kyoto and Rio through to President Lyndon B. Johnson's Science Advisory Committee in 1965, greenhouse gas (GHG) concentrations have exhibited a trend of ever-accelerating rise. Hansen (2015), for example, reports that global fossil-fuel GHG emissions have increased by about 3% per year since the adoption of the Kyoto Protocol in 1997, compared to a growth rate of only 1.5% in the preceding decades.

The starting point for the modelling work used here is the minimal, but practical, energy-balance model of the Earth's climate system developed by Thompson (2015) in order to estimate the Earth's climate sensitivity² and to make projections of future warming. The simplicity and parsimony of the model readily allow it also to be used to back-project temperatures to pre-industrial times. Surprisingly the Paris Agreement does not concern itself with what the phrase ‘*pre-industrial levels*’ actually means. In broad terms the UN normally follows the science of the most recent assessment report of the IPCC. But the Fifth Assessment Report (AR5) does not define the pre-industrial.

Roughly speaking there are three approaches that might be used to try to determine pre-industrial temperatures: (i) direct observation, (ii) proxy data and (iii) modelling. All have technical difficulties. The first suffers from the problem that the geographical distribution of direct measurements was rather sparse before the mid-1800s. The second has worries over climate-proxy calibration, standardization, bias and variable geographical coverage. The third approach (used here) aims to hindcast a pre-industrial temperature level by linking direct measurements of global (or land + sea) temperatures made through the industrial period, with synchronous measures of greenhouse gas concentrations (direct + ice-core data) and aerosol forcings (direct + ice-core data). It simultaneously allows for the concurrent effects of volcanic eruptions and ENSO variations, and for the non-steady state situation which results from ocean heat-flux damping. With this approach the pre-industrial temperature is simply the constant in the energy-balance equation (i.e., the constant represents the value predicted for the dependent variable when all the independent variables are simultaneously equal to zero³).

By using the energy-balance approach to project backwards I find the 1951-1980 base-period of the GISS temperature series to lie 0.65 °C above pre-industrial. In addition the mean monthly global temperatures of each month from December 2015 to April 2016 have all turned out to lie between 1.1 and 1.3 °C above the GISS baseline. So if the phrase “*well below 2 °C*” in the Paris Agreement is taken to mean in the region of 1.7 to 1.8 °C (as opposed to, say, 1.9 °C as denoting “*just below 2 °C*”) then ironically the five months between the adoption and the signing ceremony of the Climate Agreement coincides very closely with recent global temperatures first breaking through the Paris aspiration and limit (of respectively 1.5 and 1.7-1.8 °C above pre-industrial).

Turning to the second question of ‘*where are we headed?*’ the minimal energy-balance approach can again be put to use. The energy-balance equation (Eq. 3 and 4 in Thompson, 2015) is easily embedded within a climate-economics model (i.e. a basic integrated assessment model, IAM). IAMs date back to the pioneering work of Nordhaus (1992). Today’s state-of-the-art IAMs have become rather complex, and so can be difficult to interrogate (Stanton et al., 2009). Anthoff (2004), for example, describes an IAM (FUND2.8) with some 7,000 lines of computer code and more than 700 parameters. Without a firm understanding of the individual model components and without close experience of their circuitous interactions, an appreciation of the subtleties of their output can be problematic. An alternative approach is used here - namely to employ a sparse model, but one which captures the key aspects of climate economics. Maddison’s 1995 study developed a good, simple example of a sparse IAM. Here a dynamic, welfare-optimizing scheme was selected for use (in essence a cost-benefit scheme). The model depends on just four central ingredients. These are the damage function (Fig. 1a), the cost function (Fig. 1b), the climate sensitivity and the discount rate. Let us consider each component in turn.

The damage function of Fig. 1a builds on Tol (2009) in plotting damage (the costs to society of changing climate) as a quadratic of temperature. The quadratic serves to remind us of how the world, for millennia, has been operating near an optimum temperature; how a fall of a few degrees would result in an ice age with severe economic consequences; or how a rise of a few degrees would also cause acute economic stress. In Fig. 1a, the least-squares quadratic fit to the 21 currently available data points is constrained to pass through the origin. The location of the downward curvature of the quadratic curve (Fig. 1a, right-hand side) can be seen to be of vital concern for estimating future climate damage.

Next we turn to the cost function (Fig. 1b). Marginal abatement costs for reducing the world’s dependence on fossil fuels (Fig. 1b), although not without controversy, are reasonably well agreed as involving a few percent per year of projected gross world product (GWP). The simplest approach to estimating abatement costings (of changing from fossil to non-fossil fuels) is to order different technologies (from left to right across Fig. 1b) according to their emission-reduction costs. A typical sequence might be: improving building insulation, energy-efficiency measures, afforestation, nuclear power, renewables, adding carbon capture at coal-fired power stations and so on. As ever there are difficulties in determining detailed costs. Grubb et al. (1993) point out that economic approaches using “top-down” models based on price indices and elasticities tend to overestimate costs, whereas technology-orientated explorations with their “bottom-up” cost and

performance models tend to underestimate. Nevertheless a steep rise in costs is to be expected for deeper emission cuts. A further critical question is how the cost curve will evolve over time. Briefly, for Paris to be effective, today's cost curve (long-dash curve in Fig. 1b) will somehow need to be shifted substantially down, or to the right. To date, market forces alone have proved to be inadequate to the task. Lord Stern captured this grave situation with the memorable aphorism, "*Climate change is a result of the greatest market failure the world has seen*".

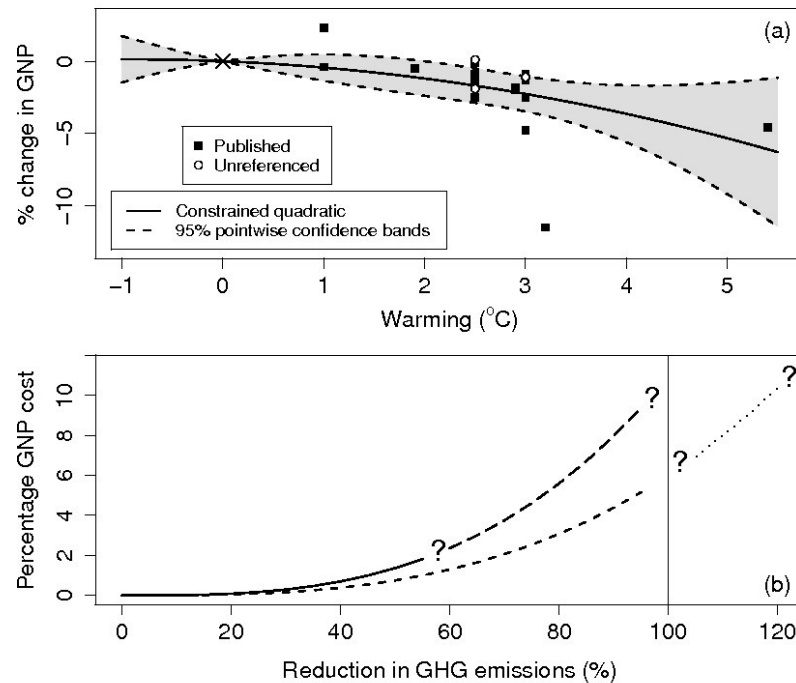


Figure 1. Schematic damage and cost functions. (a) Damage curve. Constrained (no constant) quadratic fit to the 21 currently available data points, as garnered by Tol (2015). Damage expressed as percentage of global GNP. (b) Marginal abatement costs expressed as percentage of global GNP. Costs (solid curve), for emission reductions up to 60%, put together from Morris et al. (2012), Maddison (1995) and Grubb et al. (1993). Costs of achieving higher emission reductions (longdash curve) are very uncertain. The dashed curve indicates hoped-for reduced abatement costs with technological advancement through the 21st century. The dotted line is illustrative of the even stronger technological advances that would be needed to make scenarios such as RCP2.6 (van Vuuren et al., 2011b), which aim to limit the temperature increase to 2 °C, become economically feasible. Note how damage (plotted in panel a) is regressed against temperature (units °C) whereas for costs (plotted in panel b) the independent variable is emission reduction (units %). Climate sensitivity (units °C per GHG doubling) provides the mathematical link that allows the two to be combined.

Thirdly we have the climate system. Here the dominant terms we need are the thermal inertia of the ocean response (which regulates how swiftly surface temperatures will react to a climate forcing), the masking effect of aerosols and the climate sensitivity. The parameter values adopted are those found by the energy-balance model described in Thompson (2015). The climate system (especially the principal parameter of climate sensitivity) provides the crucial scaling linkage between damages (Fig. 1a) and costs (Fig. 1b) in the cost-benefit optimization.

Finally we need to address the time dimension. The profound difficulties and uncertainties associated with the distant time-horizons of climate change can cause problems for ethical and economic enquiries. Here a utilitarian approach is used in order to capture the time-issues of climate change, specifically within a welfare-optimization scheme. The potentially troublesome dilemma, of the choice of discount rate (i.e. the conversion rate needed to translate future monetary transactions into today's monetary values), is overcome numerically by analysing all reasonable rates (see Fig. 2).

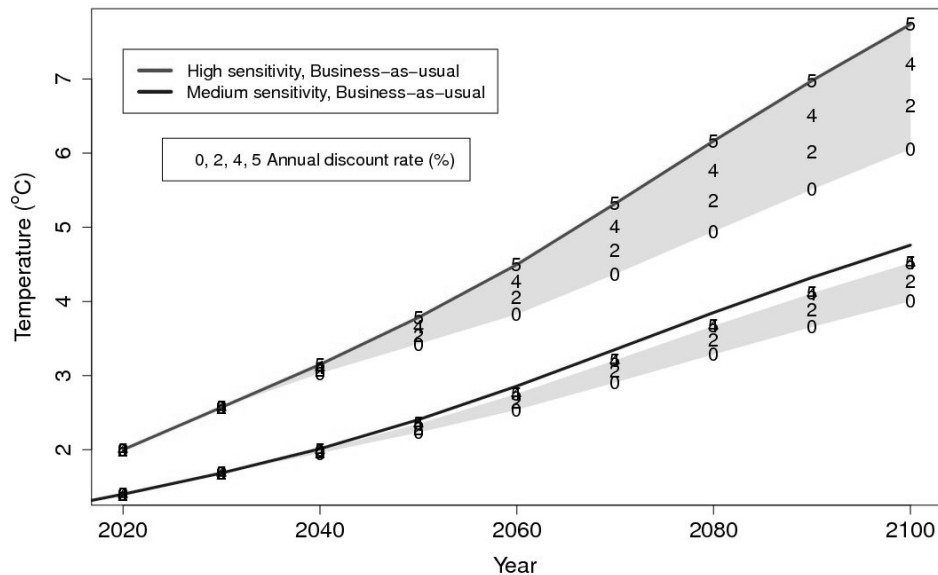


Figure 2. Simplified diagram showing global temperature change as modelled for a selection of the two key climate-economics parameters of discount rate and climate sensitivity. The dotted line plots the temperature trajectory for the business-as-usual scenario (RCP8.5) and a high sensitivity. The associated grey polygon shows the temperature trajectories found when RCP8.5 greenhouse emissions are reduced in the most cost effective way (for annual discount rates of 0, 2, 4, & 5%). Note how high temperatures are reached, by 2100, even assuming behaviour commensurate with a discount rate of zero. The solid black line, and associated grey polygon, show the same results but this time using a mid-range climate sensitivity. In this case the discount rate has a rather modest effect on the optimum cost-balance strategy and hence on the peak temperature reached by the end of the century. Also note how overall the predominant determinant of the rate of global warming is climate sensitivity rather than discount rate.

The new, least-cost climate-economics model combines the above four components. It works by testing different prognoses of future greenhouse emissions. It begins by taking a reference prognosis (e.g. business-as-usual⁴, Nakicenovic et al., 2006) and then calculates the change in total utility for various emission-reduction scenarios. It ends by plotting the temperature change revealed for optimum (maximum) utility.

Fig. 2 shows the results for a range of combinations of the two key climate-economics parameters of discount rate and climate sensitivity. In all cases the economic optimization generates high temperature increases by the century end. With a high (4 °C per CO₂ doubling) climate sensitivity, global temperatures reach around 5 to 7 °C, whereas with a mid-range (2.5 °C per CO₂ doubling) sensitivity temperatures reach 3.5 to 4.5 °C. Very briefly the high temperatures arise because, although the best welfare outcomes are found to involve some reduction in GHG emissions (from abatement and improved low-carbon technologies), the reductions never become large as then the abatement costs would far outweigh any future saving to be accrued from diminished climate-induced damage. The model results confirm that in practical terms the only way out of the predicament that the world finds itself in, i.e. the double bind of seeking global prosperity alongside an annulment of human-induced climate change (Garrett, 2011), is for society to rapidly engineer a large downward shift in abatement costs (cf. shortdash line in Fig. 1b), or to engage in a much more substantial carbon-sequestration programme (cf. dotted line in Fig. 1b). Looking more closely at Fig. 2, its left hand side is found to be quite revealing. Little effect on global warming temperatures is found before 2045 (for any of the economic scenarios) as the long-lag times inherent in the climate-economics system serve to delay any impact from emission reductions until mid-century.

A check that the findings of the sparse climate-economics model, used here, are credible despite the model minimalism is provided by a comparison with results from more complex IAMs. Typically more computer intensive IAMs have not been used to cover the full range of the combinations of variables shown in Fig. 2. However where the two procedures overlap, such as an assessment of the effect of discount rate on end-of-

the-century temperatures when adopting a modest climate sensitivity, excellent agreement is found. In this specific instance both approaches reveal the same modest discount-rate effect (compare the thin grey polygon in the lower half of Fig. 2 with its equivalent depiction in Fig. 23 on page 64 of Bosello et al., 2012).

As a last climate-economics point, it is worth emphasising that the new architecture for global climate policy, as enshrined in the Paris Agreement, brings together very disparate national pledges. As these NDCs (Nationally Determined Contributions) are voluntary (and therefore non-binding) and are being set, monitored and enforced by individual countries they are naturally sub-optimal (in a global sense). Consequently the Paris Agreement is primed to generate feebler temperature reductions than those unearthed by the cost-benefit optimisation of Fig. 2, and will lead to less satisfactory welfare outcomes.

Finally, in closing, what about the question of policy instruments? While nations are free to set their own post-Paris (post-COP 21) emission-reduction policies, the dominant approaches are most likely to involve cap-and-trade and command-and-control (Kossoy et al., 2015). It remains to be seen if the COP/UNFCCC process can build a demand for low-carbon products and so spur innovation into new ‘renewable’ technologies with a focus on the de-carbonisation of the global economy. Briefly the British economist Arthur Pigou came up with the policy instrument of choice decades ago when developing his concept of economic externalities (Pigou, 1920). His simple, down-to-earth remedy for market failure was the imposition of the corrective measure of a Pigouvian tax. This market-based mechanism works by taxing people (using a flat, across-the-board fee) so that they pay the full cost of a specific good or service, i.e. at a cost that takes into account the harm caused to innocent bystanders. People respond to such a tax by changing their behaviour: buyers by reducing their consumption, sellers by striving to improve their product or to lower their costs. Thus the primary benefit of the tax is that it provides, through classic market economics (Smith, 1976), an incentive for companies to create cleaner, greener technologies. In effect it serves to reduce the economic inertia for change, thereby allowing the market place to select the winning technologies. An attractive modern variant is the Wilsonian modification⁵ which involves recycling 100% of the revenues generated directly to taxpayers.

The Wilsonian approach, to carbon and energy taxation, through a combination of fee and rebate or “*feebate*” (an idea much championed by Hansen, 2015), could well achieve substantial public endorsement as it is a free-market solution which requires no significant increase in administrative bureaucracy. British Columbia has given the world a first-rate example of this textbook approach to a carbon tax (Murray and Rivers, 2015). The Pigou/Wilsonian arrangement has been in place since 2008 (Carl and Fedor, 2016). Carbon fees are imposed on fossil fuels burned for transport, home heating, and electricity, but a balance is achieved by rebate or by personal income taxes and corporate taxes being reduced by an equivalent amount. Murray and Rivers (2015) and Metcalf (2016) report that the British Columbian scheme has been a great success. Fossil-fuel consumption has reduced by 5-15% while at the same time no negative effect has been observed on economic performance. For instance, British Columbia’s rate of economic growth has kept pace with that of the rest of Canada, while many jobs have been generated in sectors like healthcare and retail where people spend their newfound disposable income Murray and Rivers (2015). In all emission reduction stratagems designed to produce an economically efficient phase-out of fossil fuels a key concern is the optimal price of carbon. As described above, and as summarised by Fig. 2, climate sensitivity is found to prevail as the pivotal climate/economics parameter for setting the price correctly.

In short while it would be naïve to expect the Paris Agreement to be a miraculous cure for all the maladies arising from global warming (Savarese, 2016), the Paris stratagems are nevertheless found to be distinctly sub-optimal on account of the lack of a strong carbon-pricing policy, i.e. of failing to follow a Pigouvian line of attack. The stratagems encoded within the Paris Agreement will turn out to be especially ineffectual and unfit for purpose if historical aerosol emissions (Hansen et al., 2013) have been serving to mask a high climate sensitivity (Thompson, 2015; Kaya et al., 2016).

Notes

1. The Conference of the Parties (COP), which is the “supreme body” of the United Nations Framework Convention on Climate Change (UNFCCC) meets annually. A key task for the COP is to review the national communications and emission inventories submitted by Parties (Member States). By making use of this information, the COP assesses the effects of the measures taken by Parties and the overall progress made.
2. In practical terms climate sensitivity is the temperature rise that will result following a doubling of atmospheric CO₂.
3. The date when the independent variables are zero in the sparse IAM is 1750 AD, as this marks the start of the rise in atmospheric levels of the main greenhouse gases as used in RCPs (Representative Concentration Pathways), i.e. in the latest generation of scenarios that provide time-dependent projections of atmospheric greenhouse gas concentrations for input into climate models.
4. The RCP8.5 scenario (Van Vuuren et al., 2011a) is most commonly used as representing business-as-usual (BaU). It combines a continuing high population growth (to a peak value of 12 billion) with modest income growth alongside steadily improving technological development and increasing improvements in energy-intensity efficiency. BaU scenarios have withstood the test of time amazingly well. Over the last quarter of a century, for example, global CO₂ emissions have closely tracked the original BaU projection, SA90-A-High in the 1st IPCC Scientific Assessment Report (published in 1990), of a 0.53 GtCO₂ increase year-on-year (Nakicenovic, 2015).
5. David Wilson, Professor Emeritus of Mechanical Engineering at the Massachusetts Institute of Technology: the unsung inventor of the carbon tax. [Accessed 31-12-2015 <http://www.bostonglobe.com/ideas/2014/08/09/the-unsung-inventor-carbon-tax/f1xHyWmaXf2XzW3nVxrNJK/story.html>]

References

- Anthoff D (2004) *Social cost of carbon: Equity weighting*. MSc thesis, Oxford University. pp 33-34.
- Bosello F, Carraro C and De Cian E (2012) Market and Policy Driven Adaptation to Climate Change [Accessed on 5-5-2016 <http://www.copenhagenconsensus.com/sites/default/files/climateadaptation.pdf>]
- Carl J, and Fedor D (2016) Tracking global carbon revenues: A survey of carbon taxes versus cap-and-trade in the real world. *Energy Policy*, 96: 50-77.
- Garrett TJ (2011) No way out? The double-bind in seeking global prosperity along with mitigated climate change. *Earth System Dynamics Discussion* 2: 315-354.
- Grubb M, Edmonds J, ten Brink P and Morrison M (1993) The costs of limiting fossil-fuel CO₂ emissions: a survey and analysis. *Annual Review of Energy and the environment* 18(1): 397-478.
- Hansen JE (2015) Environment and development challenges: the imperative of a carbon fee and dividend. In the Oxford Handbook of the Macroeconomics of Global Warming ed. L Bernard and W Semmler (Oxford: Oxford University Press) doi:10.1093/oxfordhb/9780199856978.001.000 Chapter 26, 639-647.
- Hansen J, Sato M, Russell G and Kharecha P (2013) Climate sensitivity, sea level and atmospheric carbon dioxide. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering*, 371(2001): 20120294.
- Kaya Y, Yamaguchi M and Akimoto K (2016) The uncertainty of climate sensitivity and its implication for the Paris negotiation. *Sustainability Science*, 11(3): 515-518.

- Kossoy A, Peszko G, Oppermann K, Prytz N, Klein N, Blok K, Lam L, Wong L and Borkent B (2015) State and trends of carbon pricing 2015 (September), by World Bank, Washington, DC. Doi: 10.1596/978-1-4648-0725-1 License: Creative Commons Attribution CC BY 3.0 IGO
- Maddison D (1995) A cost-benefit analysis of slowing climate change. *Energy Policy* 23(4): 337-346.
- Metcalf GE (2016) A Conceptual Framework for Measuring the Effectiveness of Green Fiscal Reforms. *International Journal of Green Growth and Development* 2(02): 87-126.
- Morris J, Paltsev S and Reilly J (2012) Marginal abatement costs and marginal welfare costs for greenhouse gas emissions reductions: results from the EPPA model. *Environmental Modeling & Assessment* 17(4): 325-336.
- Murray B and Rivers N (2015) British Columbia's revenue-neutral carbon tax: A review of the latest "grand experiment" in environmental policy. *Energy Policy*, 86: 674-683.
- Nakicenovic N (2015) Conceptualizing our Future: Storylines and Scenarios of Future Climate Change. Our Common Future Under Climate Change, International Scientific Conference 7-10 July 2015 Paris, France. [Accessed on 31-12-2015 <http://www.slideshare.net/CFCC15/nakicenovic-n-201507080900unescofontenoyroomi>]
- Nakicenovic N, Kolp P, Riahi K, Kainuma M and Hanaoka T (2006) Assessment of emissions scenarios revisited. *Environmental Economics and Policy Studies* 7(3): 137-173.
- Nordhaus WD (1992) An optimal transition path for controlling greenhouse gases. *Science* 258: 1315-1315.
- Pigou AC (1920) *The Economics of Welfare*. London: Macmillan.
- Rahmstorf S (2008) Anthropogenic Climate Change: Revisiting the Facts. In: Global Warming: Looking Beyond Kyoto. E. Zedillo, Ed., Brookings Institution Press, Washington, pp. 34-53.
- Savarese A (2016) The Paris Agreement: a new beginning? *Journal of Energy & Natural Resources Law*, 34(1): 16-26. DOI: 10.1080/02646811.2016.1133983
- Smith A (1976) An Inquiry Into the Nature and Causes of the Wealth of Nations, Vol. II. In: Campbell RH, Skinner AS and Todd WB (eds) *Glasgow Edition of the Works and Correspondence of Adam Smith [1776]*, Oxford: Oxford University Press, 2 vols., 1162 pp.
- Stanton EA, Ackerman F and Kartha S (2009) Inside the integrated assessment models: Four issues in climate economics. *Climate and Development* 1(2): 166-184.
- Thompson R (2015) Climate sensitivity. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh* 106(01): 1-10.
- Tol RS (2009) The Economic Effects of Climate Change. *Journal of Economic Perspectives* 23(2): 29-51.
- Tol RS (2015) Who Benefits and Who Loses from Climate Change? Handbook of Climate Change Mitigation and Adaptation Springer: New York doi 10.1007/978-1-4614-6431-0_58-1
- Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram, T, Krey V, Lamarque JF and Masui T (2011a) The representative concentration pathways: an overview. *Climatic Change* 109: 5-31.
- Van Vuuren DP, Stehfest E, den Elzen MG, Kram T, van Vliet J, Deetman S, Isaac M, Goldewijk KK, Hof A, Beltran AM, and Oostenrijk R (2011b) RCP2.6: Exploring the possibility to keep global mean temperature increase below 2°C. *Climatic Change* 109: 95-116.