Safe Climate Policy is Affordable – 14 Reasons

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Abstract
There is a widespread sentiment that a sufficiently stringent climate policy, i.e. considerable reduction of greenhouse gas emissions to avoid extreme climate change, will go along with tremendous economic costs for society. Various climate cost-benefit analyses and climate policy cost assessments have calculated these costs, but all of them are characterized by debatable assumptions. Moreover, cost-benefit analyses have excluded relevant damage cost categories. This paper argues that safe climate policy is not excessively expensive. To this end, fourteen perspectives on the costs of climate policy are offered.

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1. Introduction

It is generally felt that climate policy stabilizing greenhouse gas (GHG) emissions at a 'safe' level will be extremely expensive, whether in terms of monetary costs, lower GDP growth or forgone welfare. This is supported by a number of influential economic cost-benefit analyses (CBA) of climate policy (for overviews, see Kelly and Kolstad, 1999; and Tol, 2008a,b). As will be extensively motivated in Section 2, application of CBA to climate change and policy can be judged as being overly ambitious. To avoid the many fundamental and practical problems associated with CBA and the associated notion of optimal climate policy, it will be argued here that one can instead better adopt a more modest and practical approach, namely examining the cost of a safe climate policy. This reflects a policy that realizes a stable and safe level of atmospheric GHG concentrations. The combination of risk aversion, pervasive uncertainty and extreme climate events and trends suggests a focus on a safe or precautionary instead of an optimal climate policy. In fact, avoiding extreme climate change may be regarded as the ultimate motivation for us humans to worry about climate change, study it, and respond to it. Even two confirmed applicants of CBA to climate change like Tol and Yohe (2007, pp. 153-154) state: "A cost–benefit analysis cannot be the whole argument for abatement. Uncertainty, equity, and responsibility are other, perhaps better reasons to act." Taking safe GHG concentration and derived emission targets as a starting point, this paper will consider the cost of climate policy from a range of perspectives, thus going beyond the limits provided by existing policy cost models. Indeed, the case will be made that the cost of climate policy has so far been approached from a too narrow perspective. Spash (2007) simply concludes that "cost effectiveness is not better" (than CBA). It is true indeed that studies which have tried to assess the monetary cost of climate policy involve many debatable assumptions about future progress concerning energy technologies, instrument design and economy-wide effects, as will be discussed in Section 3, even though the shortcomings arguably are less serious than in the case of climate CBA studies.

As some of the shortcomings of CBA and cost assessment of climate policy cannot be resolved, one cannot hope for a single model analysis of climate policy to give the definite answer regarding its cost let alone its optimality. Instead, as it will be proposed here, one would do better to approach the cost of climate policy from multiple, complementary perspectives, and see whether the various insights arrived at provide reasons for an optimistic or pessimistic overall picture. In particular, fourteen different perspectives on the cost of climate policy are offered here. These deliver an optimistic conclusion: climate policy is not excessively expensive. In other words, our (global) society can afford to invest in a safe climate policy. This should serve as relevant information for politicians who fear economic despair due to stringent regulation of GHG emissions.[2]

The remainder of this paper is organized as follows. Section 2 briefly argues the failure of cost-benefit-analysis of climate policy. Section 3 discusses the meaning of the cost of climate policy, and reviews the methods and assumptions that have been used to produce the main estimates. Section 4 contains the main thrust of the paper, presenting the fourteen different perspectives on, and interpretations of, climate policy costs that go beyond current model assumptions and limitations. Section 5 provides conclusions.

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[2] B. Lomborg also has suggested that climate policy is overly expensive, most recently through his Copenhagen Consensus initiative. This simplifies the choice of climate policy to allocating a fixed, static budget among very different policies areas, so as to reach maximum policy effectiveness. In doing so, these areas are treated as if they were independent. However, climate change, health, contagious diseases, poverty, development, food availability, conflict over resources, biodiversity loss, etc. are interlinked in complex ways and cannot be freely traded-off against one another. Lomborg's policy conceptualization further fails to account for the cumulative and irreversible features of climate change as well as for extreme climate scenarios.

2. The failure of cost-benefit analysis of climate policy

The assumptions made by the various economic cost-benefit analyses of climate change and policy have received a great deal of (fundamental) criticism which is difficult to resolve (e.g., Ayres and Walters, 1991; Daily et al., 1991; Broome, 1992; Barker, 1996; Azar, 1998; Neumayer, 1999; Spash, 2002; DeCanio, 2003; van den Bergh, 2004; Padilla, 2004; Ackerman and Finlayson, 2007; Maréchal, 2007; Gowdy, 2008; Tol, 2008b; in addition, various responses to the Stern Review express criticism on CBA). Criticism has been directed, among others, at the behavior of economic agents assumed, the social welfare objective used, discounting and discount rate value, monetary valuation of a human life, and the neglect or incomplete treatment of certain cost categories. A main criticism is that the analysis of climate policy should not be conceptualized as a problem suitable for quantitative cost-benefit analysis but as one of risk analysis, since the cost of climate damage cannot be assessed with any acceptable degree of certainty (e.g., Azar and Schneider, 2003; van den Bergh, 2004; Stern et al., 2006). Particularly, the combination of small probabilities and large impacts associated with extreme climate change and climate events poses problems for an expected value approach to cost-benefit analysis, and does moreover not reflect the way humans generally tend to evaluate such problems (Kahneman and Tversky, 1979; Diecidue and Wakker, 2001; Botzen and van den Bergh, 2008b; Quiggin, 2008). This can partly be understood through different treatments of risk-aversion in expected and non-expected utility approaches (Cohen, 1995). Low-probability, high-impact costs have a small expected value and as a consequence receive a relatively low weight in CBA analysis. Nevertheless, individuals may perceive such costs as very undesirable and hence place a considerable value on preventing low-probability high-impact events from occurring, especially when such events are irreversible and involve the loss of non-substitutable goods or service, as is the case with climate change.

In line with this view, Loulou and Kanudia (1999) and van den Bergh (2004) have proposed to study climate change using a precautionary principle formalized via a minmax regret goal. This represents more risk aversion than expected value approaches and less risk aversion than, for example, maximin net benefits.[3] Tol (2008b, p.10), a fervent believer in climate CBA, supports the precautionary approach to climate policy evaluation implicitly by stating that in view of the strongly right-skewed distribution of climate change damage costs (median \$14/tC, mean \$93/Tc, 95 percentile \$350/tC; Tol, 2005): “The policy implication is that emission reduction should err on the ambitious side”. Dietz et al. (2007, p. 250) make a convincing plea for precaution in climate policy as well: “Those who deny the importance of strong and early action should explicitly propose at least one of three arguments: (i) there are no serious risks; (ii) we can adapt successfully to whatever comes our way, however big the changes; (iii) the future is of little importance. The first is absurd, the second reckless, and the third unethical.”

What is perhaps most surprising of all is that environmental economists have since long thought about uncertainty and irreversibility which has given rise to option value theory (Arrow and Fisher, 1974). But they have nevertheless refrained from systematically applying this to the most relevant case of irreversible environmental change, namely climate change (an exception is Schimmelpfennig, 1995). In brief, this would entail that the foregone benefits of a certain ‘preservation scenario’ (i.e. safe climate policy) are included as a cost category of the ‘development scenario’ (i.e. no policy, leading to climate change). The resulting option value can be interpreted as the value of flexibility to either or not accept climate change at a later date, where the flexibility is due to investing in GHG emissions reduction to avoiding irreversible climate change (or more precisely avoiding irreversible build-up of greenhouse gases in the atmosphere in the short run). Ha-Duong (1998) applies the notion of quasi-option to climate

[3] An alternative social welfare specification to the discounted utility framework is the Chichilnisky (1996) criterion: maximizing a weighted average of a discounted sum of utilities plus the terminal utility value (thus assuming a finite time horizon).

policy, which reflects that precaution allows for learning about climate change, in terms of risks, costs and adaptation opportunities. Admittedly, a main weakness of applying (quasi-)option value theory to climate change policy is that it takes expected utility theory as a basis, which, as argued above, is problematic in view of low-probability, high-impact events or trends associated with climate change.[4]

In the face of extreme uncertainty a quantitative analysis will not necessarily be able to offer more informative insight than a mere qualitative analysis. The reason is that the extreme uncertainty does not disappear by adding more quantitative sophistication to the method of analysis. All existing models including uncertainty somehow apply arbitrary probability distributions to extreme climate events and changes (surveyed by van den Bergh, 2004). These models regard investments in emissions reduction as a decision on risky investments, but insufficiently reflect the irreversibility of climate change, the extreme uncertainty associated with certain scenarios and events (both precise content and probability are uncertain), and the uninsurability against extreme climate change and events due to risks being highly correlated for all regions in the world.

There are several other fundamental issues that can be raised in relation to social welfare evaluation in the context of climate change. Woodward and Bishop (2000) argue that current economic analysis of climate policy falls short as it focuses on economic efficiency while the underlying concerns about climate change are driven by intergenerational allocation of economic endowments. They show using a simple model that efficiency does not guarantee environmental sustainability. Tol (2008b) mentions population being endogenous to climate change as the latter will influence mortality and migration, and indirectly affect long term birth, mortality and migration rates through climate impacts on poverty and economic development. As a result, welfare optimization may involve ethically debatable implications for population size. More recently, Llavador et al. (2008) reject discounted utilitarianism as a normative criterion for intergenerational public decision making, and instead examine climate strategies under intergenerational maximin criterion[5] and maximization of a Quality of Life (human development) indicator. Indeed, there is a large literature on happiness and economics which finds that income or GDP is generally not an accurate indicator of welfare. This suggest that the focus on GDP growth in climate-economy models and the resulting interpretation of GDP losses (or foregone GDP growth) as a measure of the cost of climate policy is misplaced. This will be discussed in more detail under Perspective 4 in Section 4. To prelude, climate policy may look much less costly if cast in terms of happiness rather than reduced GDP growth.[6]

Perhaps the most important shortcoming of current economic studies of climate policy relying on CBA is that they incompletely account for extreme and irreversible climate scenarios, such as (Easterling et al., 2000; Reilly et al., 2001; Bryden et al., 2005; Royal Society, 2005): extreme low or high temperatures; an extreme sea level rise; a reversal of the thermohaline circulation, of which the Gulf Stream is a part; a tidal wave due to large ice floes on Greenland and Antarctica breaking off into the ocean; substantial discharges of methane (with a 20 times higher warming potential than CO_2) from permafrost regions; 'runaway carbon dynamics' caused by positive feedback mechanisms in the biosphere; changes in climate subsystems such as the 'El

[4] Several authors have theoretically studied climate policy given economic (investment) irreversibilities. They conclude that there is then a risk of overinvestment in economic capital (manufactured and human) and that current emissions reduction policy should be slightly laxer than without learning (Kolstad, 1996; Ulph and Ulph, 1997). However, these findings do not suggest a move away from precaution as climate irreversibility is characterized by much more extended time scales than economic irreversibility, while for climate capital, unlike for economic capital, no substitutes are available. These studies also employ an expected utility approach.

[5] The 'maximin welfare' criterion, which focuses on the worst possible outcome for any future generation, has been motivated by Arrow (1973) and Solow (1974) through reference to the contractual theory of justice developed by the philosopher John Rawls (1972).

[6] Martinez-Alier et al. (1998) argue that different impacts of environmental change or policy, such as economic, cultural and environmental, are incommensurable.

Niño Southern Oscillation'; acidification of the oceans due to high atmospheric CO_2 concentrations, implying a deterioration of living conditions for marine organisms with yet unforeseen effects; and extreme weather events, notably an increased likelihood of hurricanes due to warmer seas. If such changes moreover are rapid, then insufficient time for adaption will contribute to higher damage costs. The omission of these extremities is incomprehensible given that the ultimate reason for studying climate change is – or in any case should be – a concern for extreme events which will fundamentally alter environmental conditions for humans and the rest of the biosphere. In fact, studies that have incompletely taken into account the extreme events should not be taken all too seriously, and the respective authors should be modest about the policy implications of their analyses (see also Azar and Lindgren, 2003, Section 3).

The differential treatment of extreme climate events offers one explanation for the wide range of damage cost estimates of GHG emissions that one can find in the literature (Tol, 2005; Fisher and Morgenstern, 2006). Tol (2008a) performs a meta-analysis of these, suggesting that the most reliable estimate cannot be the outliers, thus explicitly questioning the high damage estimates used in the Stern Review. However, a meta-analysis assumes that all studies are equally valuable, unless one weights studies, for instance, by giving a relatively high weight to more recent studies using updated information. But since Tol does not apply such a weighting scheme, the outcome of his analysis is dominated by the large share of (older) studies which neglect or incompletely address extreme climate change scenarios and events. The meta-analysis thus hides fundamental shortcomings of the primary studies, even though it gives a flavor of objective science.

Other limitations and weaknesses of CBA of climate policy have been well documented. Tol (2008b) lists the many imperfections in a refreshingly critical and honest account of climate damage cost studies.[7] In particular, he notes the neglect in existing studies of the impact of climate change on human conflict, large scale biodiversity loss, economic development and human population/demography. Most models take immediate adaptation for granted, by assuming rational behavior by economic agents. A general shortcoming is the neglect of any impacts beyond 2100 in virtually all studies, except Cline (1992) and Stern et al. (2006). An entirely different concern is that damage cost estimates for developing countries are of lower quality than those for developed countries (and many are extrapolations from earlier studies, often for the USA). This is especially problematic since developing countries not only will suffer severely from climate change but also will be less able to undertake protection or adaptation. In addition, to estimate the costs of illness, accidents and mortality of humans, which comprise a considerable share of the costs of climate change, estimated 'values of a statistical life' have been used. However, these are problematic at a global scale in view of the immense economic and cultural heterogeneity as well as a heavily skewed international income distribution. Moreover, environmental changes to be valued under extreme climate change scenarios are large, which creates the problem that monetary valuation of them is inconsistent with a necessary condition, namely that the change to be valued is small compared with income. The latter follows from monetary valuation being based on the theoretical idea of income compensation or equivalence (Johansson, 1987).

Finally, CBA over long time horizons as in climate change analysis is extremely sensitive to discounting and particularly the choice of (social) discount rate. Given that there is much disagreement about the latter, this serves as an important reason for many observers to be critical of CBA studies in general. In fact, a large part of the variation in results of studies that have undertaken a quantitative CBA of climate policy is due to this discount rate sensitivity. The debate on intergenerational discount rates was revived by The Stern Review (Stern et al., 2006).

[7] What is disappointing though, is that after listing an impressive number of uncertainties and missing elements in existing cost studies, and presenting a range of marginal carbon cost estimates as wide as 20-669 $/tC (Tol, 2008 b, Table 2), Tol suggest to use a carbon tax in the lower range 26-50 $/tC.

The social discount rate (r) interpreted as an interest rate is generally defined as the sum of two elements, namely the pure rate of time preference (usual symbol δ) and the average growth rate of per capita consumption (g) multiplied by the elasticity of marginal utility of consumption (η): $r = \delta + \eta g$. The pure time risk δ (what Quiggin (2008) calls the inherent discount rate) was set by the Stern Review team at nearly zero to reflect intergenerational equity or egalitarity.[8] The exact value chosen was 0.1 %, corresponding to a 90% probability of the human race surviving 100 years (implying a chance of extinction of about 0.1% per year). The probability of human extinction equal to 10% in 100 years is likely to be an upper bound to the real value, suggesting that the pure rate of time preference of 0.1% is also an upper bound. Clever economists can be found to support the nearly zero value of δ (Dasgupta, 2006; Cline, 2007; and Quiggin, 2008) and to criticize it (Tol, 2006; Nordhaus, 2007; Weitzman, 2007). The value of η=1 in the review has been criticized as well (Dasgupta, 2006; Nordhaus, 2007). Stern (2007, p.140) says he is prepared to raise it to 1.5 and notes this value receives support from Nordhaus; but he says that the damages then turn out to be still much bigger than the policy cost. Quiggin (2008) nevertheless argues that η=1 is not a bad compromise given the variation of estimates in the literature, and that the criticism by Weitzman, Dasgupta and Norhaus implicitly sticks to the old assumption of expected utility behavior, even though this has been refuted as an explanatory decision-under-uncertainty model by advances in behavioral economics (see above). All in all, the criticism on the discounting by the Stern Review is not convincing. Note in this respect the range of social discount rates used. The Stern Review uses 1.4 % per year (using δ = 0.1 % per year, η = 1 and g = 1.3% per year); with η=2 this would become 2 %. Nordhaus in his various models (DICE and RICE) models has used rather complicated procedures, involving endogenous and regional discount rates. Roughly, this results in implicitly assuming a social discount rate in the order of 3–5 %. Nordhaus and Boyer (2000) applied declining discount rates, which doubles the social cost of carbon dioxide emissions compared to the earlier DICE calculations. Generally, declining discount rates mean that climate policies will more easily pass a cost-benefit test (Guo et al., 2006). Most importantly, as noted by Arrow (2007), even with a much higher social discount rate than resulting from Stern's assumptions, and well above the value range accepted by most economists (3-6%), the cost-benefit argument for stringent climate policy remains valid.

Of course, a low rate of pure time preference simply reflects the severity and irreversibility of the impacts of climate change, and our moral obligation to future generations. In fact, it is not often realized that discounting means seeing a society as analogous to an individual. But as opposed to an individual, a society does not have a finite life as it always includes multiple, overlapping generations, so that one can regard it as continuous and immortal. This holds especially true when the society aims for sustainability. Therefore, applying a positive time preference to societal, intertemporal decisions can be seen as employing an erroneous analogy (van den Bergh, 2004). Nordhaus and Weitzman do not recognize this point and instead harshly judge the Stern Review as representing a "decidedly-minority paternalistic view", "lowest bound of just about any economist's best-guess range" and "nonconventional assumptions that go so strongly against mainstream economics". But these are rhetorical statements reflecting that economists are just like ordinary people prone to conformist behavior – but conformism does not in any way guarantee truth. Moreover, speaking of mainstream economics in relation to climate policy analysis does not do justice to the fierce, fundamental criticism of the suitability of CBA as a method to evaluate climate policies – as summarized above. One can indeed interpret the fierce criticism by Nordhaus and Weitzman of Stern as a "historical accident" (to use a term from the literature on path-dependence): if Cline and Stern would have been the dominant players in the

[8] Cline (2007) argues that since there is no capital market extending to future centuries (the relevant time period for evaluating impacts of climate change), it is necessary to identify the discount rate components from first principles. Following Ramsey's ethical advice, in his original analysis (Cline, 1992) he set the time preference rate component equal to zero. The Stern Review includes a slightly positive value (0.1 %) to reflect the possibility of human extinction.

field, and Nordhaus, Mendelsohn, Tol and Yohe and others would have arrived late at the scene, they would have likely been the ones receiving fierce criticism for making unorthodox assumptions.

Nordhaus, Weitzman and others particularly refer to the gap of Stern's choices with market interest rates. However, as Stern has noted in his responses (e.g., Stern, 2007), market interest rates cannot serve as a guide for "prescriptive or even a descriptive account of value judgments", as they are the arbitrary result of short-term decisions by many individual consumers and producers on investment, saving and consumption focused on personal gains. Moreover, given that market interest rates vary this would mean the ethical judgment would vary over time, creating arbitrary discrimination among individuals living in different periods, or being born at different moments, in time. As a less sensitive procedure, one might propose to take a statistical average of discount rates in the past, but arbitrariness would then shift to the period considered. In addition, failures of financial markets should be recognized, including myopic behavior, asymmetric information, externalities, etc. (witness the current worldwide financial crisis) which surely affect the market discount rate. Next, various proponents of a low discount rate have argued that if the market serves as a guideline one should not focus on risky investments in stocks but on safe or "risk-free" investments such as money market funds, typically giving a very low return (order of magnitude 1 %), and low-risk government bonds (a return of about 2 %). These figures are rather consistent with Stern's social discount rate of 1.4 – 2 % mentioned above.[9]

Finally, low discount rates are consistent with certain stated preference and theoretical findings. Based on the results of a survey among 2,160 economists, Weitzman (2001) finds that even if every individual believes in a constant discount rate, the wide spread of opinion on what is the appropriate social discount rate causes it to decline significantly over time. Extrapolation of this finding supports a zero long term or intergenerational discount rate. Other support for a low or zero discount rate comes from the observed tendency of humans to hyperbolically discount, i.e. use a decreasing discount rate as the time horizon increases. This has also been theoretically explained (Dasgupta and Maskin, 2005). It should finally be noted that the debate on discounting and the choice of discount rate are not just important for CBA but also for assessing the costs of climate policy. The reason is that these costs are not occurring in a single point in time but extend over (a long period of) time.

All in all, there are too many reasons for not having much confidence in CBA of climate policy (but to avoid any confusion, CBA certainly is a useful evaluation tool to support environmental policy or project decisions where uncertainty and time horizons are limited).[10] Regardless of where one precisely stands in the debate on using CBA for making choices about climate policy, one has to admit that there are many elements that can and will be disputed. The extensive and fierce debate on the Stern Review illustrates this (see, e.g., the special issue of *Climatic Change* vol. 89, 2008). While Stern has been able to put climate change on the retina of many economists and government officials precisely because it was seen as an economic study, his study received criticism from mainly researchers involved in earlier economic analyses of climate change. Stern (2007) has clearly stressed that he purposefully wanted to deviate from certain incorrect assumptions of earlier models, and that he regards climate change as a problem that requires a risk analysis rather than a CBA. He sees the latter as just one input to the debate. Of course, the CBA part of the Stern Review attracted most attention, as it suggested potential high costs of climate change up to almost 20% of GDP per annum (which is somewhat confusing, as it represents a balanced growth equivalent, i.e. a current value of all future damages divided by current consumption; see Nordhaus, 2007, p.695-696).

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[9] Davidson (2006) arrives at a discount rate of 1 % along another route.

[10] Notice that application of CBA to acid rain and related SO_2 and NO_x emissions reduction policies has not received so much attention, even though this problem is more limited in scope than climate change and policy. Cost-effectiveness analyses have been performed though for acid rain, with IIASA's RAINS probably being the most well-known model (Alcamo et al., 1990).

One can be positive about the Stern Review as it initiated a debate about the very young research field of climate economics. Possibly, many economists previously not working on environmental issues have become aware of the combination of economic research challenges and political relevance that climate economics offers. An entry of new ideas and expertise is very much needed, as so far the debate has been too much dominated by a small group of like-minded individuals adopting very similar assumptions. As the field of innovation studies teaches us, diversity of approaches enhances the pace of innovation, which hopefully is the fate of climate economics.[11]

3. Estimates of climate policy cost

Next we consider less but still ambitious studies that use models to assess the cost of climate policy. To begin with, it should be noted that the notion of policy cost is not very clear as both the policy scenario and the benchmark (status quo) are a matter of choice and surrounded by considerable degree of uncertainty.[12] The best starting point is undoubtedly IPCC (2007), as it synthesizes the then available primary studies on the cost of mitigation options. It aims for a stabilization in the range of 535–590 CO_2 equivalent ppm, and reports cost estimates ranging from slightly negative to 4% of global income.[13] IPCC makes a distinction between market and economic mitigation potentials, where the first type is based on private costs and discount rates given current market conditions and prevailing policies, while the second type involves social costs and discount rates under appropriate policies to remove market failure. IPCC notes that an evaluation of primary cost-effectiveness studies indicates that a global carbon prices in the range US$20-80/tCO2-eq by 2030 would be able to realize a stabilization of approximately 550 CO_2-eq by 2100. Still, it is debated how safe is the goal of stabilizing greenhouse gas concentrations in the atmosphere at 550 parts per million (ppm) of CO2-equivalent (CO2e), which would cause a 2 degrees Celsius higher temperature in a hundred years from now. While the pre-Industrial Revolution concentration was 280 ppm CO2e, the current level is about 385 ppm CO2e. We are quickly approaching the relatively safe concentration of 450 parts per million, meaning that (cheap) opportunities to stabilize at a safe level are become scarcer. An important factor of uncertainty is the residence time of CO_2 in the atmosphere. It is highly uncertain and its estimate has increased considerably during recent years. According to Montenegro et al. (2007) "about 75% of CO2 emissions have an average perturbation time of 1800 years and the remainder has a lifetime much longer than 5000 years". Matthews and Caldeira (2008) even suggest that in order

[11] One might claim that the field of climate damage cost assessment is too young (17 years, taking Nordhaus (1991) as the starting point) to deliver a robust set of insights. Tol (2008b) notes that there are only 14 estimates of total damage costs, while 9 of these have formed the basis for all 211 estimates of marginal damage cost. He concludes (p4) that "There are a dozen studies. The number of authors is lower, and can be grouped into a UCL Group and a Yale one … dominance in this field is for want of challengers.". Ironically, Tol has been the foremost critic of the most influential challenger, namely Stern and his research team (Stern, 2006). Nevertheless, Tol (2008b, p. 18) remains optimistic about CBA, despite the fundamental problems associated with its application to climate change: "… there are no more unknown unknowns, at least no sizeable ones." He concludes with suggesting considerably more research funds on the theme will solve the problems. This does, however, not recognize the fundamental nature of some of the shortcomings of CBA applied to climate, as documented here. Tol (2008b, p.8) himself in fact supports this view: "These problems are gradually solved, but progress is slow. Indeed, the above list of caveats is similar to those in Fankhauser and Tol (1996, 1997)."

[12] Jaccard et al. (2003) note that various definitions of cost are employed in the literature, and point at the difference between financial costs of technologies, (business) option value and consumer surplus.

[13] To compare, in The Nederlands the sum of private and public costs of environmental policy was about €13 billion per year in 2007, and has been about 2.5% of GDP for the last 20 years. For other countries these figures are somewhat lower (PBL, 2008).

to stabilize atmospheric concentrations, anthropogenic emissions will have to be reduced to zero for a period ranging from decades to possibly centuries.[14]

Many other economic studies allow for higher concentrations and as a result non-stabilizing temperatures or stabilizing at much higher temperatures. The Stern Review (Stern et al., 2006) assesses the mitigation costs based on the annual cost of cutting total greenhouse gas emissions to 75% of current levels by the year 2050 (stabilization level of 550 ppm CO2e). This includes declining costs of low-carbon technologies and improvements in energy efficiency. The PAGE2002 model was used giving an estimate of the mitigation costs to be on average 1% of global GDP, with a range of +/-3%. The wide range reflects the uncertainties related to technological innovation, scale of mitigation needed, flexibility of policy, and fossil fuel extraction costs. Costs estimates for mitigation over time can vary considerably based on the level of technological change expected in the model, to the extent that it is not even certain which technologies will have the most market potential and lowest social cost. In addition, the timing of mitigation has an impact on the cost estimates. Delaying the emission reductions will most likely cut the costs of mitigation. However, delaying action may imply very high damage and adaptation costs (Stern et al., 2006).

Various studies offer systematic comparisons and meta-analyses of cost estimates of climate policy (Repetto and Austin, 1997; Barker et al., 2002, 2006; Fischer and Morgenstern, 2006; Hawellek et al., 2007; Söderholm, 2007). This simultaneously involves identifying critical assumptions and weaknesses of existing economic analyses of the costs of climate policy. Söderholm (2007) distinguishes between direct, partial equilibrium, general equilibrium, non-market and policy design costs. Different studies have emphasized particular costs while ignoring or simplifying others. Systems engineering or bottom-up models stress the cost of behavioral change and changes between discrete technologies. Top-down models such as general equilibrium and neoclassical growth models describe continuous production (or cost) functions and focus on interactions between aggregate markets. The two model approaches are in this sense rather complementary, explaining the existence of hybrid models. Indicators of the cost of policy reported in different studies vary: total direct compliance costs; carbon price required to comply with a given emissions reduction; the loss in GDP (for country or world); and equivalent variation (the income change that would cause the same utility change as the climate policy).

The estimated costs of climate policy reducing greenhouse gas emissions show much variation. This is due to a number of assumptions which differ between studies: the assumed required emissions reduction (trivial, but confuses comparisons); the structural characteristics of the models, notably substitution possibilities (fuels, products), level of technological detail, assumptions regarding technological progress (and whether it is exogenous, endogenous policy-induced); the design of climate policy (e.g., market based instruments like taxes or tradable permits, or command-and-control measures); and, the inclusion of non-market costs and benefits.

Technical progress comes out as a crucial factor, and therefore the specification of the relation between policy and technical change is important. This requires models with endogenous (or induced) technological change. Models without this feature are likely to overestimate policy costs. Bottom-up models account for endogenous technological change through the use of learning curves. Neoclassical economic models see technological change as due to investment in R&D. The learning curve approach generally produces much lower policy cost estimates. Underrepresentation of knowledge spillovers across different sectors of the economy may further lead to overestimating climate policy costs. On the other hand, the existence of market failures

[14] According to Gowdy (2008), CO_2 levels have been below 300 ppm for at least the past 650,000 years, and for a business-as-usual scenario (no additional climate policy) it is projected to increase to 600 ppm by 2050. If all available fossil fuels would be burned CO_2 levels could ultimately reach 2000 ppm (Kump, 2002). Some observers think that the most likely scenario is that atmospheric CO_2 will peak at 1200 ppm in the next century (Kasting, 1998) or at 1400 in three centuries (Bala et al., 2005).

associated with R&D as well as path-dependence and technical lock-in may mean that policy costs are underestimated. Finally, differences in cost estimates can be due to different assumptions regarding the use of carbon tax revenues (if policy is a tax, charge or levy): revenue recycling in the most neutral way (lump-sum rebates) or reducing other types of taxes (notably on labor) to correct market distortions and thus improve welfare.

Despite shortcomings as identified, let us consider two recent studies in more detail, to illustrate a few more aspects of estimating the cost of climate policy. The first study was undertaken for the USA by a renowned team of energy-CGE modelers, namely Jorgenson et al. (2008). It finds that the U.S. economy can easily accommodate a stringent climate policy. By 2020, reductions in real GDP are in the range of 0.5 to 0.7%, and by 2040 1.2%. Spread over thirty-four years, this loss entails a negligible slowdown in economic growth. Evidently, energy prices are most affected, and coal the most. While the production side of the economy feels the negative effect, consumption is much less affected. By 2020, consumption foregone is in the range of 0.1 to 0.2% of baseline levels and, by 2040, the loss increases to 0.5%. In dollar terms, policy costs are $33 per household in 2010, $158 per household in 2020 and $672 per household in 2040. The analysis assumes lump-sum transfers of permit and tax revenues, which means that effects may be smaller even (double dividends). The same holds for the omission of induced technical change. The contribution of this the authors think to be considerably smaller than that of substitution and economic restructuring.

The cost of post-Kyoto climate policy has been studied for the Netherlands by Bollen et al. (2004). They assume developed countries to reach emission reduction levels of 30% below 1990 levels, which is the goal of the European Union, consistent with an increase of average world temperature of no more than 2 degrees Celsius above the pre-industrial level. An important cost factor is whether developing countries participate. If they do, the estimated costs will be 0.8% of the Real National Income (assuming a high economic growth rate). If only industrialized countries participate, many cheap options will disappear leading to a cost ratio of 4.8%. The second important cost factor is the growth rate. If moderate instead of high growth is assumed the cost falls to 0.2% of the National Income, as the economy and with it GHG emissions increase more slowly. A third factor is the policy instrument: a system of tradable emission rights will realize the minimum cost of mitigation. The results further assume inclusion of the United States and Australia, even though these countries at the time of the study had not ratified the Kyoto Protocol (in the meantime Australia did). The analysis ignores the costs of adapting the economic structure and the transaction and enforcement costs of climate policy.

The previous discussion suggests that costs estimates of climate policy in the literature are extremely rough and uncertain, and involve many debatable assumptions. A broad view going beyond single model limits can improve our understanding of the costs of climate policy.

4. Fourteen perspectives on the cost of climate policy

Perspective 1: Extrapolation of learning curves for renewable energy

The easiest way to reason about the cost of climate policy is considering a most likely definite solution to the core problem, that is, the emission of greenhouse gases, notably carbon dioxide. Renewable energy offers the only definite solution, as it can in principle support supply of electricity and other types of energy carriers in a carbon-free way. Of course, this requires that the equipment and indirect support of renewable energy are themselves produced with renewable, carbon-free energy. In order to allow the wide-spread adoption of renewable energy, it needs to produce electricity at market-competitive prices.[15]

[15] Some readers will propose to regard nuclear fission energy as a definite solution as well. But it is not so cheap as generally thought, while it excludes the cost of insurance against calamities. Moreover, it may show rising costs due to supply chain and financial (lending) bottlenecks, high construction costs (high steel prices), and very little experience with generation III reactors. Of course, the strong public resistance associated with proliferation, nuclear waste and potential accidents are sufficient reasons to not consider nuclear energy as an environmentally sustainable alternative,

Within renewable energy one can identify as the main candidates for future dominance wind turbines, water power, biomass energy (including biofuels), concentrated (solar) heat power, and solar photovoltaics (PV). However, which technology ultimately will emerge as the most attractive is uncertain. Wind is close to competitive, but limited in application because of visual and noise hinder problems. Still, it is expected to undergo a large growth before saturization. The early optimism about biofuels has been severely tempered in the last years. The net energy and decarbonization effect of (first generation) biomass and biofuels have recently been questioned. It has even been claimed that some biofuels produce more CO_2 emissions than they save, among others, because they involve clearing of natural vegetation (Fargione et al., 2008; Searchinger et al., 2008). In addition, worries have been raised over the potential impact on food production and prices as well as over the unsustainability of biofuel agriculture. Many observers plea for a second generation focusing on waste biomass and non-edible parts of plants, but this still requires a long process of R&D and learning, while it is not expected to provide a large contribution to energy supply, simply because suitable waste streams are limited. Concentrated solar heat power (CSHP) seems a neglected technology, which is surprising as it represents a fairly simple technology, which has the advantage that there are few surprises in further development and application. Moreover, one square km of desert with CSHP can generate about 100 times the amount of electricity produced from biofuel crops grown on 100 square km. Perhaps the main barriers are related to requiring international cooperation and infrastructure, such as high voltage direct current cables under the sea between Europe and North Africa, and continuing Western energy dependence on instable regions. All in all, there is much to say in favor of Solar PV: it can be easily integrated in buildings, produces directly electricity, and there are diverse sub-technologies around, which suggests much learning potential and many options in the face of uncertainty. Compare this, for instance, with nuclear fusion, of which there is only one large scale experiment worldwide, namely the ITER reactor constructed at Cadarache in South France.

Energy conservation, including increased energy efficiency improvements, is generally seen as a cheap strategy to realize GHG mitigation. However, this is not always the case if it requires costly investment in new capital and R&D. One should in deciding between investments in energy conservation and renewable energy take into account which learning curve is steeper, i.e. where investment can lead to substantial cost reductions. One should further recognize that, especially extreme, energy conservation can go along with large rebound effects (Greening et al., 2000). If new, energy-efficient technologies considerably improve productivity in energy intensive industries economy-wide rebound effects can exceed 50% (Sorrell, 2007) and in the long run energy consumption might even increase – what Polimeni et al. (2008) call the "Jevons paradox". Frondel et al. (2008) find for a panel of German household travel diary data that between 1997 and 2005 higher energy efficiency of cars caused more travel in a range from 57 to 67%. Rebound involves substitution in consumption (saving energy involves shifting expenditures, like to air travel), price effects (less market demand), coupled markets (imperfect substitutes, such as transport and telecommunication), substitution of inputs (more capital or materials) causing indirect energy use effects, and even sector restructuring with consequences for communication, transport and international trade with associated (embodied) energy uses. The policy lesson is that rather than stimulating voluntary ("costless") energy conservation, it would be more effective to focus policy on avoidance of GHG emissions using price instruments so as to prevent any leakages and thus rebound. Currently, for instance, lack of good climate regulation of air traffic offers a clear route for rebound effects.

In view of the foregoing discussion, and for illustrative purposes, the case of solar PV will be considered here in more detail as a basis for assessing the cost of climate policy (for a

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even though it can contribute to carbon free electricity supply. Another recently much discussed solution is carbon capture and storage (CCS). However, it neither can be regarded as a definite or sustainable solution. Moreover, experience with it is very limited and it is far from cost-effective right now.

similar exercise for wind see Nemet, 2008). Van der Zwaan and Rabl (2003, 2004) have analysed scenarios of the price and cost of solar PV on the basis of experience or learning curves. Such curves convey that overall production costs tend to decline with an increase in cumulative production. It is true that overall costs not only capture learning and innovation (R&D) effects but also changes in market prices of inputs (notably material inputs). The latter may sometime increase which can (temporally) reverse the normal, negative relation between cumulative production and costs. Nevertheless, generally learning curves are seen as a quite robust tool to examine long run cost behavior of technologies. For solar photovoltaic (PV) energy, a most likely or middle scenario delivers an estimate of an order of magnitude equal to US$60 billion associated with a cumulative production of about 150 GW_p (note: in 2004 cumulative production was about 1 GW_p). This amount of money represents an extra expenditure over the investment in fossil fuel electricity, which is needed to make solar PV competitive with electricity produced from fossil fuels (van der Zwaan and Rabl, 2004, Table 2, progress ratio 0.8). If learning is favorable, then US$30 billion (at 50 GW_p) is a better estimate, while if learning is slow the cost may rise to US$300 billion (at 1000 GW_p).[16]

The authors provide several arguments for why one can put trust in these figures. PV cost decreases have been following the learning curve model rather well; PV is already competitive in certain niche markets; and the PV market has expanded by 15% annually over the over the past two decades, which serves as a good basis for cost reductions. Further, the recent sharp rise of the oil price makes it easier for solar PV to become competitive, although a potential consequence is that worldwide more electricity will be produced from coal. Evidently, it is important that good choices are made in terms of diversity of solar PV sub-technologies and applications (van den Heuvel and van den Bergh, 2008; van den Bergh, 2008). Nemet (2008) and De Zwaan and Rabl (2004) warn that projected costs may be very sensitive to certain parameters. In addition, using a learning curve may overestimate the cost decrease if rapid investment in solar PV capacity is undertaken, simply because then the time for learning is shorter and the capacity to spend the R&D funds will be limited (notably too few researchers with adequate education and expertise). Finally, studies show that cost decreases are no free lunch, but require investments in private and public R&D and public policies like subsidies (Messner, 1997).

It was argued here that the cost of solar PV is not excessive. The presented cost range will be given more meaning in subsequent perspectives.

Perspective 2: Global climate policy cost normalized by OECD GDP

Here the cost of worldwide climate policy will be normalized by, or compared with, GDP of OECD countries. This can be motivated on the basis of their historical contribution to climate change (Botzen et al., 2008) as well as their currently high incomes relative to the rest of the world, i.e. historical and intragenerational fairness. We can then take the range of 1– 4 % suggested by a review of studies by IPCC (2007) (Section 3) as one basis for a climate policy cost estimate. The second estimate can be drawn from the previous section, where the cost of public support to make solar PV competitive was estimated to be in the range of US$30 billion to US$300 billion with a best, middle estimate of US$60 billion. These costs result in only 0.17 % (with an uncertainty range 0.08 – 1.65 %) of the joint GDP of the 30 OECD countries in 2007 (which was 36316 billion US$; OECD, 2008). An equal distribution would simply come down to 60/30= US$ 2 billion per country, which is not a shocking figure. If the investment would be spread over the course of 10 years, then it would amount to only US$ 200 million per country per year (during 10 years) or on average 0.017 % of GDP (with an uncertainty range of 0.008 – 0.17 %). In the worst case this would imply a cost to a family with a net income of € 25000 about € 40,

[16] Interestingly, the president-elect of the USA Barack Obama has promised to invest $150 billion over the next ten years to support renewable energy (http://www.barackobama.com/issues).

in the most likely case this would be € 4, and in the most favorable case € 2, for a period of 10 years.

An alternative is to allocate costs proportional to country GDP or country per capita GDP, which simply will mean higher absolute costs for some and lower absolute costs for other OECD countries. Of course, if other than OECD countries share in the costs, the burden will be spread over a larger basis and result in lower figures per country and individual. Anyhow, my aim here was just to show the magnitude of the cost rather than suggest any fair distribution. This is an ethical issue which evidently will involve continuing international political debate.

In 2007, OECD income was about 55 % of world GDP (about US$66 trillion). If OECD would carry all the cost of climate policy, and taking the climate policy cost range identified by IPCC (1– 4 %), this would lead to an average cost for OECD countries equal to 1.8–7 % of GDP. This is significantly higher than the estimates based on public support of solar PV. Why is that so? First, the 4 % is quite a high estimate, and it is likely that the 1 % estimate is a more reasonable order of magnitude, giving for OECD the 1.8 %. This is, however, still about 100 times larger than the yearly middle estimate and 10 times the yearly upper end estimate (assuming a period of 10 years investment to make solar PV competitive), of the cost of public support of solar PV. One important reason is that climate policy initially will indeed be more expensive as solar PV is still maturing, so that it can not make a significant contribution to GHG emissions reduction. However, according to the scenario sketched under Perspective 1, after a period of 10 years solar PV should fairly quickly take over the market and provide the major means of GHG reduction.

All in all, this would imply that for the first 10 years one should expect a relatively high cost of 1.8 % and subsequently a rapidly falling cost of climate policy to 0.017 % (again with uncertainty range 0.008-0.17 %). This pattern should not be a surprise, as it simply reflects an initial investment in R&DDD and then enjoying the returns on investment. This is consistent with the suggestion by Sandéna and Azar (2005) that we need to have a decade of experimentation with low carbon technologies.

Perspective 3: Delayed GDP growth

If it is true that climate policy will cost about 1 % of GDP per year, then given that economic growth historically in many countries has been around 2 % on average, and in some countries higher, this would mean that net growth, after discounting for the cost of climate policy, would still be positive, and that one would reach a certain level of income with a delay.

A related perspective on the cost of climate policy was proposed by Azar and Schneider (2002). They take as a starting point studies suggesting that the absolute cost of reaching what is regarded by the IPCC as “safe” concentrations of CO_2 is in the range of 1 to 20 trillion US$. Although this may seem impressive, it turns out to imply only a few, namely 1 to 3, years delay in achieving a specific level of income in the distant future. The delay evidently depends on income growth. Global income during the 21st century is expected to increase about tenfold (on average 2.35 % per annum). Azar and Schneider (2002, p. 77) calculate that “If the cost by the year 2001 is as high as 6 % of global GDP and income growth is 2 % per year, then the delay time is 3 years …”. This 3 years delay is moreover dominated by random noise given the uncertainties involved in GDP movements over a period of one century. This simply means there is little reason to worry about the long term negative effects of climate policy on the economy. In other words, seen in a long-term perspective, the costs of a stringent climate policy are marginal in economic terms. Aznar and Schneider further note that “… the global economy is expected to be an order of magnitude larger by the end of this century—the prime driver of the increasing carbon emissions — we would still be expected to be some five times richer on a per capita basis than at present, almost regardless of the stabilization target.

Perspective 4: Happiness instead of GDP

As was made clear in sections 2 and 3, the economic evaluation of climate policy is often cast in terms of lost GDP. This seems attractive, as the economic and welfare impact is captured in a simple, aggregate number. However, the implicit assumptions and judgments about the relationship between well-being, happiness and GDP have been firmly criticized (van den Bergh, 2008c). In fact, there is a very large literature on this topic, involving two approaches. From the angle of traditional microeconomic and welfare theory notions like negative externalities, inequity, non-substitutable or lexicographic needs, informal activities, and unaccounted resource use and environmental degradation are stressed (Mishan, 1967; Nordhaus and Tobin, 1972; Hueting, 1974; Sen, 1976; Daly, 1977; Dasgupta, 2001). In addition, a steadily increasing number of empirical studies in economics, sociology, and psychology on subjective well-being and happiness have also questioned the use of indicators like income and GDP as relevant to measuring social welfare and progress. There is much support that beyond a threshold that has been passed by most rich countries, average income increases do not translate in significant increases in well-being. In particular, this research indicates that somewhere in between 1950 and 1970, the increase in welfare stagnated or even reversed into a negative trend in most industrials (OECD) countries, in spite of steady GDP growth (Blanchflower and Oswald, 2004). This so-called "Easterlin Paradox" (Easterlin, 1974) is supported by the 'Eurobarometer surveys', the half-yearly opinion polls of the inhabitants of the EU Member States, as well as by aggregate indicators of sustainable income based on GDP corrections, notably the ISEW and (derived) GPI indicators (Daly and Cobb, 1989; Lawn and Clarke, 2008). The income level at which de-linking occurs between GDP and (subjective) social welfare has been estimated to approximate $15,000 (Helliwell, 2003). Of course, one should not expect a rigid threshold to apply generally for all countries, cultures and times. Nevertheless, the various empirical findings provide evidence for a stabilization of social welfare in spite of continued GDP growth. Layard (2005) also provided support, by showing that countries with high incomes show little variation in average reported happiness. At best, the country comparison clarifies that happiness is characterized by diminishing returns of increases in GDP per capita. This means, not surprisingly, that for poor, developing countries the correlation of income and well-being is higher than for rich countries.

Three stylized facts assessed by happiness research can explain the observed delinking of income and happiness (Frank, 1985, 2004; Ng, 2003; van Praag and Ferrer-i-Carbonell, 2004; and Kahneman et al., 2004). First, income and income growth contribute considerably to happiness if people are poor or countries are in a low development phase, as extra income will be used to provide for lacking fulfillment of basic needs. Second, empirical findings suggest that although people may enjoy short term or transitory increased happiness effects, ultimately they will adapt to a higher income. Third, people compare their situation with that of others in a peer group, so that their welfare has a relative component. This is associated with status seeking and rivalry in consumption. In addition, studies have consistently found that income-independent factors greatly influence individual welfare or happiness, the most important ones being: health, having a stable family (partner, children), personal freedom (political system), and being employed. Some studies reported below also point out the relevance of environmental and climate factors. Note that some of these findings from rigorous econometric studies of subjective well-being data were already hypothized in older writings (Hirsch, 1976; Scitovsky, 1976).

The implication of the three stylized facts is that individual income at best imperfectly, and beyond a certain threshold hardly, correlates with individual welfare (Easterlin, 2001; Frey and Stutzer, 2002; van Praag and Ferrer-i-Carbonell, 2004; Ferrer-i-Carbonell, 2005; Clark et al., 2008). Relative income turns out to be critical. Happiness research further suggest that there are limits to improving happiness by income since happiness is to a large extent based on unobservable or not easily observable factors which may be summarized as a pessimistic or optimistic attitude towards life in general. Indeed, the causality may be often reverse in the sense that optimistic individuals are on average found to be relatively happy and successful in life, and thus are capable of earning a relatively high average income (Ferrer-i-Carbonell and Frijters, 2004). Another important insight of this literature is that individuals adapt or get used to changed circumstances, to the extent that subjectively felt well-being may not increase (Frederick and Loewenstein, 1999). One explanation for this is that our senses can only handle a limited amount of stimuli, and ultimately satisfaction or boredom results. Since most people do not realize the phenomenon of adaptation they continue striving for 'more'. This is reflected by a range of terms used by different researchers: 'addiction', 'hedonic adaptation', 'hedonic treadmill' and 'preference drift'.

Another relevant consideration is that high incomes generally go along with many working hours. But happiness evidently depends also on leisure, which implicitly is valued negatively if one employs GDP as a progress indicator, since it has an opportunity cost as it means forgone production opportunities. OECD (2006) adjusts GDP by valuing leisure at GDP per hour worked (somewhat debatable), and finds that the result (in per capita terms) leads to a quite different ranking of countries than according to GDP per capita. In this ranking, The Netherlands scores best of all OECD countries, for two reasons: the inactive part of the working force is relatively large, and part-time working is very common (de Groot et al., 2004).

Using effects on happiness instead of GDP as a criterion for judging climate policy is likely to provide quite different conclusions. Three considerations are relevant here. First, although climate policy may lead to less rapid economic growth (a lower growth rate) of GDP or GDP per capita, this translates into a smaller or even insignificant loss in happiness terms, depending on which country or group of people is considered. Secondly, climate policy avoiding extreme events means avoidance of serious reductions in happiness, given that happiness directly depends on climate, i.e. involves direct non-market effects on individuals and households. This means that the economic and welfare effect of climate change measured in GDP terms may underestimate the real impact on happiness. In fact, especially extreme climate events are not easily captured in GDP or any cost terms, as argued in Section 2. Extreme climate events will have such profound impacts in terms of local-regional climate conditions, sea level, temperature change and extreme weather patterns. This can in turn cause extreme effects on resource availability (notably clean water), human health, human security, vulnerability of poor people in regions with low productivity (Sahel countries), migration and violent conflicts. It is virtually impossible to cost account for these, even though it is clear that human happiness and basic needs are then seriously at stake. Third, although climate change may not much affect the happiness of people in Western countries, for people in poor countries it may mean that their basic needs will come under threat, which is likely to create severe and structural losses in happiness. In addition, richer people and richer countries can more easily adapt to climate change so that they can restore or approximate their old happiness levels. This is because rich countries are characterized by high levels of wealth (financial reserves), high average education, good access to modern technologies, and a generally large capacity for collective action.[17]

Although no serious climate policy study has employed a happiness type of criterion or goal, a few studies have examined the impact of climate conditions on happiness. Rehdanz and Maddison (2005) start from the view that climate affects the daily life of humans in various ways: through heating and cooling requirements, health, clothing, nutritional needs and recreational activities. Therefore, they expect individuals to have a clear preference for particular climate conditions. Based on a panel of 67 countries and using self-reported levels of happiness in relation to climate variables like temperature and precipitation, they show with multiple regression analysis that climate variables have a highly significant effect on happiness. Climate

[17] The criticism extends to other policies than related to climate change. Frank (1985), Ireland (2001) and Layard (2005) illustrate specific findings of happiness research as applied to economic policy: (extra) taxation of working overtime, (extra) taxes on status goods, limiting commercial advertising, and restricting flexible labour contracts. Although from a traditional economic growth perspective these look like bad measures, they are positively evaluated from a real welfare or happiness perspective.

change may thus affect happiness, depending on the specific impact on the country or region where an individual lives. The authors find that high-latitude countries generally benefit from climate change raising temperatures, while countries already characterized by very high summer temperatures would most likely suffer losses. Other studies with similar findings are Frijters and van Praag (1998), who focus on well-being in Russia in 1993 and 1994. They examine how climate conditions in various parts of Russia affect the cost of living and well-being. Maddison (2003) applies the hedonic pricing method assuming that individuals can freely migrate in response to geographical conditions, including climate related ones. Using data for 88 countries, a 2.5°C increase in mean temperature is found to benefit individual well-being in high latitude countries whereas it will lead to losses in low latitude countries. Rehdanz and Maddison (2004) perform a similar type of study to assess the amenity value of climate in Germany. They find that German households are compensated for climate amenities mainly through hedonic housing prices. House prices turn out to be higher in areas with higher January temperatures, lower July temperatures and lower January precipitation. Moreover, in East Germany wages are found to be higher in areas with higher January precipitation.

Welsch (2006) examines the relation between pollution and happiness using subjective well-being panel data for ten European countries combined with air pollution data. Pollution is found to play a statistically significant role as a predictor of inter-country and inter-temporal differences in subjective well-being: $750 per capita per year for nitrogen dioxide and $1400 for lead emissions. A related study is Luechinger (2007). Other studies supporting the relevance of climate and environmental conditions on happiness are Ferrer-i-Carbonell and Gowdy (2007) and Brereton et al. (2008).

Cohen and Vandenbergh (2008) consider the lessons that can be learned from happiness research for climate policy, focusing on consumers. Taxes on pollutive consumption with a positional good character has two benefits: it reduces the status externality due to reduced consumption of such goods (Ireland, 2001); and it reduces the total pollution associated with the consumption. Layard (2005) suggests to tax income so as to stimulate leisure and temper status games in income and consumption. This may reduce status effects and pollution related to goods consumption equally, although this will depend on the shift in consumption (e.g., more holidays to distant countries will give rise to increased air traffic with associated GHG emissions). According to Cohen and Vandenbergh (2008, p.9) “Economists have never argued that money and economic wealth are all that matters. Instead, their starting point has always been ‘utility maximization’ which includes individual leisure activities, health, family situation, and other components.” Two comments are in order here. First, standard microeconomics and its application to environmental policy theory, labor economics, and many other areas of applied economics generally employ utility functions which do not take the phenomena of adaptation and relative welfare into account. Second, empirical macroeconomics and political pleas for economic growth are completely uncritical of GDP information and assume that GDP growth is equivalent with (social) welfare growth or human progress. This is inconsistent with both standard microeconomics and enlightened microeconomics incorporating insights from empirical happiness research. Applications of economics to climate change and climate policy need to start taking the lessons of happiness research into account. The general implications outlined above are that we should worry more about climate change, and that safe climate policy becomes a more attractive option than under CBA-GDP types of evaluations.

A provision to the above arguments is that people may adapt to a changed climate in the sense of being initially affected (negatively) in their happiness, while later slowly recuperating their old happiness level. However, such adaptation is difficult to imagine for extreme climate change and events.

This perspective has received relatively much attention. The reason is that it may well be the major alternative perspective on the cost of climate policy, one that is urgently needed to arrive at a correct picture of what we really gain and sacrifice if we undertake a stringent, safe climate policy worldwide.

Perspective 5: Comparison with large public investments: Irak war, financial crisis and military R&D

The cost of climate policy or more in particular of making solar PV a competitive technology might be seen as a large public project. This suggests a comparison with other public projects. Three large 'projects' will be considered, namely the Irak war, combating the financial crisis and R&D investment in the military sector.

Stiglitz and Bilmes (2008) have estimated the cost of the Irak war to the United States to be at least US$3 trillion (3000 billion). This excludes the cost to the rest of the world (notably the UK and Iraq, with an estimated 40-100,000 casualties). The Irak war comes out then as the second most expensive war in history, after the Second World War, which cost about $5 trillion (in 2007 dollars adjusted for inflation). The Irak war cost estimate above is much higher than the official number given by the Bush administration as this excludes relevant cost categories. The Stiglitz/Bilmes figure includes as broad categories budgetary costs (notably military operations, health care and disability compensation) and economic costs (notably loss of lives, welfare effects relating to oil prices and interest payments). Hartley (2006) has suggested a figure of similar magnitude, at least about US$1 trillion up to 2007, although including cost to civilians and of reconstruction in Irak. He argues that the economic costs of war receive far less attention than political, moral, legal (UN) and military (safety) considerations. In line with this he suggest that the US could have bribed Sadam Hussein by offering him and his family US$20 billion to leave Irak, giving the Iraqi people US$50 billion, and on top of this save US$30 billion given that the cost of the war was ex ante (grossly under) estimated at US$ 100 billion.

Another interesting comparison is with the current financial crisis. The USA decided overnight to reserve US$700 billion to stabilize the US banking system. Goverments in Europe are likely to reserve an amount of similar size. For example, the Netherlands has created a fund of € 20 billion to stabilize the financial sector, while it acquired Fortis Bank Nederland (Holding) N.V. for a total sum of EUR 16.8 billion. The Belgium government spent € 4.7 billion in Fortis Bank Belgium, and Luxemburg € 2.5 billion in Fortis Bank Luxemburg. The United Kingdom spent about € 44 billion to take a majority share in, so as to rescue, four large British banks, namely HBOS, Royal Bank of Scotland, Barclays and Lloyds TSB. In total, OECD countries may invest about US$2 trillion (2000 million) to stabilize the financial system. The urgency of it is clear given the threats the financial crisis imposes on the world economy. Similarly, if the threats implied by climate change would be recognized and translated into a similar investment in GHG emissions reduction and renewable energy, the problem would quickly be solved. One may argue that some of the guarantees offered by countries are in fact only creating reserves or represent investments in (shares of) banks rather than being effective spending, but nevertheless the countries or at least their governments are willing to set aside so much money in response to a threat (without any cost-benefit analysis or other type of pseudo-welfare optimization). Moreover, spending on public R&D or support of private R&D on renewable energy also should count as investments rather than fading spending. (Of course, recognizing the seriousness of climate threats and translating this in immediate public action requires less myopia of governments. Moreover, whereas we have negative experiences with financial crises in the past and are determined to avoid new ones, we lack similar experiences with extreme climate change in the past.)

So governments worldwide are investing roughly US$5 trillion in the Irak war and stabilizing the financial crisis. We can compare this with the range of climate policy cost estimates, i.e. 1 – 4 % of world GDP (US$66 trillion in 2007), i.e. 0.7 – 2.7 trillion US$, or only 14 – 54 % of the mentioned public investments. If one focuses on the cost range of making solar PV competitive, i.e. US$30 billion to US$300 billion with a middle scenario estimate of US$60 billion (see Perspective 1 above), then as a proportion of the current investments in Irak and the financial crisis this comes down to a central estimate of about 1 % and a range of 0.6 – 6 %. In other words, if these percentages of current public investments would be diverted to renewable energy, we would very likely solve the energy scarcity and climate change problems. If the cost of making solar PV competitive is compared with the cost of the Irak war only, then the assessed central estimate of US$60 billion and the higher end estimate of US$300 billion result in only 2 % and a uncertainty range of 1-10 % of the expenditures up till now on the Irak war.[18]

Finally, another relevant comparison is with current expenditures by countries worldwide on military research, which is estimated to be roughly 140 US$ billion.[19] Of this, the largest single investor, the USA, spends about US$85 billion per year (Brzoska, 2008). Earlier, between 1953 and 1970 America spent about 10% of its GDP on R&D. Later, this percentage dropped and reached a minimum of 0.45% in 1979 (Roland, 2001). Of course, the tremendous increase of GDP means that the absolute value of the R&D has increased steadily over time. These investments in military R&D are especially interesting as they suggest that governments are willing to undertake enormous investments in R&D even without a clear problem to be solved. Similarly, safeguarding us from the effects of extreme climate change might be responded to with an investment in R&D in renewable energy at a similar scale. In two years the world spends almost US$300 billion on military R&D, which is equivalent to the upper limit estimate of the range of investments needed to make solar PV competitive. Per year, the world invests more than twice the middle estimate (US$60 billion). If the solar PV investment is spread of 10 years, then it would equal 5% of world expenditures on military research in the same period.

Perspective 6: Avoided climate damage costs

Without repeating the discussion on climate damage costs in Section 2, one important argument needs to be explicitly mentioned in the current list of perspectives. If a safe climate policy means considerably less costs than the absence of such a policy, then a rational approach would be to choose in favor of climate policy, a kind of cost-effectiveness combined with precaution (given the uncertainties involved). As a guidance we can take Nordhaus and Boyer’s (2000) estimate of 10% and the Stern Review’s (Stern et al., 2006) estimate of almost 20% potential GDP damage cost of climate change as a guidance, both of which involve accounting for certain extreme climate scenarios. If we compare these figures with climate policy cost estimates in the IPCC range of 1 – 4 % of global GDP (Section 3) then safe climate policy clearly is cost-effective. The slogan used by some environmental NGOs is surprisingly appropriate: ‘the most expensive climate policy is doing nothing’.

Perspective 7: Ancillary benefits

Climate policy analysis based on CBA has typically omitted many benefit categories, as discussed already in Section 2. The euphemistic term employed for some of these is ancillary benefits or co-benefits of policy. One that has received ample attention is that the reduction of GHGs generated by fossil fuel combustion will sometimes go along with reductions in other emissions, notably acidifying substances (nitrogen oxides and sulphur dioxide). For example, HEAL (2008) estimates that if the European Union would raise its GHG emission target from the current 20% to 30% (in line with IPCC recommendations), then additional co-benefits in the range of € 6.5 to 25 billion per year would result due to health savings arising from an associated reduction in emissions of fine particles, nitrogen oxide and sulphur dioxide.

More generally, all avoided cost categories in CBA studies can be regarded as ancillary benefits. A first one is avoidance of human conflict due to climate change. Such conflict would be stimulated if climate change causes water to become scarcer and agriculture to loose productivity,

[18] And nobody has asked for or offered a cost-benefit analysis before the start of this war.
[19] Private/civilian spending on R&D is estimated to be roughly ten times this amount.

which may result in increasing land pressure and migration. Another category of ancillary benefits of climate policy is omitted large scale biodiversity loss, which can be enhanced by shifting climate zones from which certain species cannot escape. The strong connection between scarce fossil fuel resources and greenhouse gas emissions from combusting fossil fuels also creates a relevant co-benefit. Notably, solving emissions problems by creating new sources of energy (renewables) will mean reducing problems of energy resource scarcity, avoiding potential fierce oil peak shocks, enhancing energy security, and avoiding conflicts over scarce energy resources. For example, a study assessing the social cost of the OPEC oil cartel to the US identified four cost categories (wealth transfer to OPEC, cost of strategic petroleum reserve, total GNP loss due to price shocks and shortages, and military costs), and arrived at an estimated cost ranging from about US$150 to 400 billions per year (1990$) during the period 1974-1985 (Green and Leiby, 1993). Finally, a special type of ancillary benefits arises when adaptation options are being created as a result of mitigation activities. An example is that planting forests to capture CO_2 in turn will allow for protection of biodiversity, water regulation, and reduced vulnerability against flooding or storms. Finally, reducing GHG emission through taxes can result in extra tax revenues which can be used to reduce distorting taxes on capital and especially labor. The long standing debate on the double dividend of shifting taxes from labor to environment (or recycling environmental tax revenues to reduce labor taxes) suggests that one should not hope for too large effects, but it is nevertheless widely agreed that some positive effects are likely. Notably, the employment benefits due to less tax distortions in labor markets are robust, even though in welfare terms they are considerably smaller than the environmental benefits (de Mooij, 1999; Patuellia et al., 2005).

Perspective 8: Upward bias in ex ante estimates of regulation cost

Various studies indicate that there is often a gap and sometimes even a large gap between ex ante and ex post estimates of the costs of environmental regulation (including both private and public-administrative costs) (Harrington et al., 1999). MacLeod et al. (2007) find this for a wide range of environmental policies in European countries, including policies aimed at water and air pollution, health, food safety, fuel standards, directives on combustion plants, and animal welfare. There are two important reasons why ex ante cost assessments my deliver overestimates. First, information on actual costs often is provided by firms having an interest or stake. As a result, those being regulated may provide too high estimates of individual abatement costs. This can be due strategic behaviour to resist implementation of stringent regulation, or simply because of individual uncertainty about (future) abatement costs. In fact, standard environmental economics regards price regulation as having the advantage that it decentralizes the problem of environmental regulation, and does not require governments to have full information about pollution abatement technologies and associated costs (Baumol and Oates, 1988). Second, estimates may neglect or underestimate the potential for abatement cost reduction as a result of innovation and adaptation by polluters. This was already discussed in Section 3, so we will not go into any details here.

Perspective 9: International cooperation and agreements

An additional important factor of influence on cost estimates of climate policy is the presence (or absence) of international agreements or more generally international cooperation between countries on climate policy and related technology cooperation and diffusion. If international agreements are absent or weakly constraining individual countries, large differences in policy may exist between countries. As a result, the costs for industries or consumers of stringent national regulation, including safe climate policy, may be high, since it will mean a loss in the international competitive position of industries subject to it. Instead, a stringent climate policy agreed upon by all countries in the world would mean a level playing field that would reduce the policy cost. This relation between cost of policy and international cooperation or agreements has the character of a vicious circle. The reason is that as long as countries or governments think that the cost of safe climate policy is high, they will refrain from committing themselves to a stringent international climate agreement. However, as long as such an agreement is lacking, the cost of unilaterally stringent climate policy will be excessively high, which in turn supports the idea that climate policy is expensive. A way out is clever strategies in negotiation for international agreements (Barrett, 2007). Note in this respect that the Kyoto agreement does not count as a stringent agreement, and as a result is quite ineffective (McKibbin and Wilcoxen, 2002). The Kyoto limits are far removed from what is needed to stabilize the CO_2 concentration in the atmosphere (at any close to safe level), it meant no restriction at all for Germany (unification) and Russia (economic collapse), and it excludes all developing countries as well as the largest economy of the planet (USA).

Perspective 10: Behavior, learning and substitution

Economists are optimistic about prices as signals of scarcity that stimulate appropriate changes in behavior. Possibly, their model assumptions underestimate the responses that individuals in reality will show to stringent climate policy. More generally, many substitution opportunities, at the level of inputs, sectors and demand are insufficiently recognized by existing models, because of aggregation, and by the empirical data, because price changes in the past have not covered ranges that are consistent with stringent climate policy. Aggregation is relevant as shown by meta-analyses of different model studies, which indicate that particularly inclusion of more fuel types and energy technologies leads to lower cost estimates (Söderholm, 2007, Table 4.2). Generally, the more substitution opportunities exist, the easier it is for systems to adapt in a way so as to reach a similar performance level without much additional cost. Moreover, in the long run people will change fundamental choices that affect their energy use, such as commuting distance (changing job or house). For example, road pricing is often resisted on the basis that it would make life very hard for many car users. However, in practice people can respond in very many ways to a higher (variable) cost of driving a car: changing the time of driving (outside peak hours), car pooling, using other means of transport (walking, biking, public transport), travelling less, being more efficient in combining trips, and in the longer run changing job or house to reduce commuting distance. Similarly, both households and firms can reduce energy use in many different ways in response to higher prices, including over longer periods of time changing structural conditions through investments in buildings and technical equipment.

Behavior is not well treated in current climate policy analyses, as these mostly assume that agents behave rationally in the sense of perfectly maximizing utility or profits (Gowdy, 2008). However, people may act as citizens or as consumers which are better characterized by habits, imitation, social pressure (in terms of both status and conformity), cooperation and altruism while firms may be better described as showing routine-like behavior (van den Bergh et al., 2000). Moreover, one should recognize the diversity of behaviors within both consumers and producers populations. In fact, some consumers show a great deal of altruism, citizenship and solidarity with the future. Current studies are inaccurate as they insufficiently reflect the diversity and bounded rationality of behavior. In addition, empirical studies are based on substitution elasticities that do not take the full range of relevant variables into account. Based on a review of economic and psychological studies of environmental behavior by households with regard to energy, water and waste, van den Bergh (2008a) finds that existing econometric-statistical empirical studies represent mostly an incomplete assessment of the motivations and factors behind behaviors like waste collection, energy conservation and prudent use of water. In particular, integrated studies of economic and psychological factors are rare. However, at the same time the statistical findings of such studies – notably estimated price and income elasticities – often form the basis for more complex economic model analyses like in the context of climate policy studies. All in all, it is very likely that substitution opportunities are not well represented in current climate policy studies.

A particular aspect of behavior of firms and individuals is learning. Sagar and van der Zwaan (2006) examine learning-by-doing in relation to renewable energy and note various learning mechanisms: at the individual worker level (education, learning-by-operating so as to develop tacit skills), within a firm (learning-by-manufacturing), within the industry (learning by copying), across different industries, and within demand-supply interactions (learning-by-implementing, such as integrating PV systems into buildings, on roofs; this involves institutional structures such as for obtaining finance and maintenance of equipment). Feedback from users to producers, from products to processes, and systemic improvements (adjustment of all elements, such as institutions, markets, integrated building components, production chain) leads to falling overall costs of the renewable energy technology. Generally, the literature shows that adding endogeneity of growth, i.e. R&D or learning instead of exogenous technological change, reduces policy cost estimates (Söderholm, 2007).

Finally, note that some types of bounded rationality may lead to higher estimates for certain policy cost categories than rational agent assumption. The energy gap literature illustrates this. Firms do not always invest in profitable energy conservation opportunities for various reasons: one is that agents do not have full information; another is that they do not minimize overall costs but instead focus on main activities or investments of which energy conservation is not part (DeCanio, 1998). This can either lead to underestimations of the cost of climate policy, namely if agents in a model are assumed to be rational rather than behaving consistently with the energy gap (e.g., habitual behavior has been suggested as one explanation). However, information provision and other strategies to stimulate more rational responses as part of climate policy may increase energy conservation (rebound effects not considered) and thus reduce the cost of effective policy. A good translation of insights from behavioral to environmental, energy and climate economics is currently lacking and would be needed to shed more light on these issues (Gowdy, 2008).

Perspective 11: The current cost of energy is fairly low

Current fossil fuel based energy (gasoline and electricity) is cheap, and too cheap in view of associated negative externalities. The cost of CO_2 is high if extreme climate events and scenarios are taken into account: an order of magnitude 100-300 dollars per ton emitted CO_2 (see Section 3). While the cost of energy sources has fluctuated over time due to instability of the OPEC cartel and conflicts in oil-rich regions, energy efficiency improvements in electricity generation and light production have caused a structural trend of falling energy costs in production, household consumption and transport. For example, Fouquet and Pearson (2006) show for the UK that in 2000 the cost of lighting was 1/3000 of its 1800 value, while during the same period income (purchasing power) increased 15 fold. Of course, falling cost of energy services (light, manufacturing, transport, and more recently various appliances in the house) have gone along with rebound effects (see Perspective 1), and increasing demand for such services due to sustained increases in income as well as product and process innovations over time. Fouqeut and Pearson document this by noting a 25000 fold increase in lighting consumption between 1800 and 2000. If one regards the share of energy cost in total income as a useful measure of the cost of energy, then the following picture emerges from these findings: the share for only light services dropped between 1800 and 2000 with a factor 25000/(3000*15) = 5/9. For other uses of energy the story is more complicated as the energy output is not a homogeneous service. Nevertheless, energy intensity defined as energy input per monetary output has dropped by more than 30 % since the 1970.

The falling cost of energy in various areas can be observed by considering the share of energy cost in total national income. The ratio of (all) energy expenditures to GDP since the 1970s shows a pattern that starts at around 8 %, increases to about 14 % in the early 1980s and then drops again to levels below those of 1970 and recently increases again (EIA, 2008). This illustrates that – in any case until recently – the cost of energy can be judged as fairly low, especially if one realizes that energy is the fundamental input to all human-economic activity. That is, roughly 90 % of income is spent on other things than energy. In addition, further, structural GDP growth and an almost constant share of energy costs in it suggest that the disposable income after energy expenditures has increased over time. A disadvantage of the aggregate approach to measure energy expenditures as share of GDP is that it hides income inequality. Generally, low income families spend a larger part of their income on energy, and they will also see a relatively rapid increase in the cost share when energy prices increase. The shares can differ between low, middle and high incomes from 15, 5 and 2 %, respectively. Roberts (2008) regards households as "undoubtedly fuel poor" when they are spending more than 10 per cent of their income on energy just to meet basic requirements. This 10 % threshold may reflect, however, that we take for granted a very low share of energy cost in income, simply because this is a historical fact.

Another indication that (until recently) the cost of energy is (was) not very high or even low is that we are currently experiencing a price level that is roughly between 3 and 5 times the long term average oil price. If calculated from 1869 to 2007, this average (US crude oil prices adjusted for inflation in 2006 US$) equals $21.66 per barrel for world oil prices, while during the same period fifty percent of the time world prices were below the median oil price of $16.71 per barrel; for the post-1970 period equivalent indicators are $32.23 and $26.50 (http://www.wtrg.com/prices.htm).

In addition, the sharp increase of the oil price in the last years did not give rise to serious and sustained social unrest. This supports the belief that the cost of energy is not perceived as very high. It means that there is room for safe climate policy, which will undoubtedly increase the price of energy. Admittedly, further rises in the oil price weaken this argument. Note, however, that high oil prices are no substitute for climate policy as they are likely to stimulate a worldwide shift to coal, the combustion of which contributes considerably more to enhanced global warming than that of oil (per unit of useful energy generated). Furthermore, if the price of fossil fuel energy goes up due to climate policy, this will also increase the cost of renewables since the production of the latter depends on inputs of fossil fuel energy. In other words, the environmental gains of increasing fossil fuel prices should not be overestimated.

All in all, higher energy prices are feasible. It is likely that the economic system and the consumer (in developed countries) can handle higher energy costs due to climate policy without serious repercussion.

Perspective 12: Lack of insurance against climate change

Currently, private insurance with premiums that reflect risk against extreme events like those possibly caused by climate change, such as flooding and hurricanes, is largely missing in most countries (Botzen and van den Bergh, 2008a). This has two consequences for judging the cost of climate policy. First, it means that there is no efficient sharing of climate related risks which will reduce overall costs of both consequences of climate change and climate policy. Second, it means that incentives are lacking to stimulate producers, consumers and even insurance companies to efficiently respond to climate change risks and climate policies. Both insured and insurers have incentives to limit climate risk in case increases in frequency and severity of natural hazards is reflected in higher cost of offering insurance and higher premiums. Moreover, with insurance adaptation at the individual and social level will be more adequate so that climate policy possibly will need to be less stringent. In other words, with adequate insurance arrangements in the face of climate related risks, safe climate policies will turn out to be more efficient, i.e. less expensive. This is especially true since climate insurance would imply many indirect economic effects because insurance affects the direct and indirect costs of economic activities and therefore works as a price signal of risk. If climate policy is undertaken in the presence of adequate insurance arrangements for risks related to climate change, or if such policy includes incentives for insurance companies to undertake these arrangements, then the cost of climate policy will be lower than without such arrangements.

A different angle is offered by Schock et al. (1999). They regard R&D on energy technology as an insurance investment to reduce four risks, namely climate change, oil price shocks and cartel pricing, urban air pollution, and other energy disruptions. Based on these risks, they estimate the total value for the USA to be at least $12 billion/year. They note that only about half of this may be warranted as some R&D will reduce multiple risks simultaneously. They compare the finding with the total investment in R&D on energy technology by the US Department of Energy, which is about $1.5 billion per year in 1999 to argue that a larger investment would be warranted, particularly relating to climate change, oil price shocks, and urban air pollution. Although this study was undertaken about a decade ago, its conclusions seem more urgent in view of current patterns of GHG emissions, climate change and oil prices since then.

Perspective 13: Stimulating a fundamental social-technical transition

Combating climate change is not about installing a one-time solution with a fixed cost. It is better conceptualized as balanced investment and R&D for many years to come: too much R&D will mean waiting too long with effective investments in reducing emissions; too little R&D will mean too quickly investing in less than mature – environmental ineffective or overly expensive – technologies. The right balance has been cast in the literature as the exploration-versus-exploitation and optimal diversity problem (van den Bergh, 2008b). The long term dimension of investments and R&D is important, as R&D will take time before new technologies can diffuse worldwide at a significant scale. In the meantime, carbon-intensive fossil fuel technology and infrastructure will be invested in. The long-term perspective is needed also for making good choices about nuclear and carbon capture and storage: are these suitable as transition technologies or should we have the intention to really move further on their learning curves. And a long term angle will affect choices between expensive energy efficiency improvements and renewable energy. Details of all these options were already discussed under Perspective 1.

Climate change policy is further not a simple, one-dimensional policy or instrument with a clear cost, but a complex process of multilevel and multidimensional change involving unlocking of a dominant, undesirable system of fossil fuel technologies and infrastructures, changing institutions, incentives, knowledge bases, and international cooperation. Very likely, a mixture of general policy principles is needed notably regulation of externalities (environment foremost), resource policies, innovation policies (including public investments) and specific unlocking policies (giving shocks to the system, subsidy programs, etc.). A growing group of researchers is calling this approach a "social-technical transition to sustainability". It recognizes that a stringent climate policy will in due time lead to structural changes in the economy, including technological innovations, and alterations in sector structure, demand side patterns, products types and designs, and institutional arrangements. Such qualitative changes are not well captured in one-dimension monetary indicators, be it cost measures or foregone GDP growth.

Against this background, Prins and Rayner (2007) argue in favor of "placing investment in energy R&D on a wartime footing". Former US Vice-President and Peace Nobel laureate Al Gore earlier made a similar call for a "global Marshall Plan". Various others have referred to the Manhattan Project in this context. In fact, even the US Bush administration has expressed more interest in R&D than environmental (climate) regulation. Sufficient R&D on decarbonized energy technologies is indeed not guaranteed by environmental regulation alone, and neither is a transition to sustainable energy technologies, given lock-in features of fossil fuel energy and related technologies (vehicles with combustion engines).

Case studies of historical transitions show that a number of conditions need to be satisfied for a transition to occur (Geels, 2005). One of these is public investment in infrastructure and basic (fundamental) research. The history of nuclear fission shows this clearly; it received strong support through direct subsidies and military R&D (in the USA). Several other technologies have benefitted greatly from public R&D, and particularly investments in military R&D. Notably, ICT supporting technologies like solid state electronics, semi-conductors, transistors, integrated circuits, data transmission networks, and not to forget basic software codes have received massive funding from the (American) military complex. The motivation for such expenditures was usually the Cold War. Agriculture in many countries also has received much public support, both to maintain the status quo (protection) and to foster certain transitions (Green revolution). For example, the post-war transition in Dutch agriculture was extensively funded by the government, through investment subsidies or financial compensation for taking out land to public investment in land consolidation, and the creation and maintenance of drainage systems. Of course, the reasons were regarded morally and fundamentally important, notably food security and self-sufficiency. Similarly, if one recognizes stable climate as a basic condition for human life and activity one needs to seriously invest in it.[20]

Perspective 14: Climate and economic instability

Climate policy can be seen as the outcome of a trade-off between risks of natural and economic instability. But these risks are not comparable or symmetric. With a *given global environment* under a stringent climate policy, humans cannot predict economic changes with certainty, but they can guide and control them within boundaries. Economic stability can thus be maintained. However, under *extreme changes in the global environment* – due to a lax or lacking climate policy – one may be unable to avoid that the fragile world economy responds in an erratic way to a large number of changing environmental variables, notably when these – as in the climate-biosphere system – show catastrophic, irreversible and discontinuous features. Any control of economic change may then be very difficult and costly so that economic instability is likely. The upshot is that economic adaptation under stable natural conditions, enhanced by a stringent climate policy, is easier and safer than under unstable natural conditions resulting from a lax climate policy. 'Easier' can be seen as close to 'cheaper' in cost terms. This is consistent with the view of Azar and Schneider (2003, p. 331): "Thus, we do not see costs and benefits in a symmetrical cost-benefit logic, but rather as an equity problem and a risk management dilemma." Also the Stern Review reflects this standpoint, and many other observers have made similar statements.

Some have gone further, and denied the relevance of normal scientific analysis of complex issues like climate change and climate policy, on the basis of the climate system being complex and able to show catastrophic behavior (Margolis and Kammen, 1999; Rind, 1999). Add to this the other dimensions of global change that may interact in nonlinear and unknown ways with climate change, such as land use, deforestation, water use, destruction of wetlands, acid rain, and human control of a sizeable portion of primary production. Complexity implies that causal connections between a multitude of potential factors and effects cannot be identified, let alone be quantified. Against this background, a 'post-normal science' has been pleaded for, characterized by "uncertain facts, values in dispute, high stakes and urgent decisions" (Funtowicz and Ravetz, 1993). The climate problem satisfies all four characteristics. Because of its urgency, the new borne climate economics has unusually rapidly attained political influence, with all risks involved. But as discussed in Section 2, it is unlikely that a more mature climate economics will be able to capture the complexity of the climate-biosphere-economy system in a comprehensive model.

The foregoing suggests that neither decision-making based on quantitative CBA nor waiting until more information comes available are clever strategies. The implementation of the Precautionary Principle in climate policy emerges as a rational strategy for certain combinations

[20] I am grateful to Frank Geels for suggesting these examples.

(beyond thresholds) of uncertainty and potential impacts (Gollier et al., 2000).[21] An often-heard argument against the Precautionary Principle is that climate policy means that alternative public goals have to be sacrificed (Lomborg's simplified view). But whereas, for instance, less health care and education can indeed reduce growth and welfare, they are not connected to extreme and discrete changes at a global scale. For this reason, climate policy deserves to be treated as fundamentally different from other areas of public policy.

Table 1 summarizes the perspectives.

[INSERT Table 1 HERE]

5. Conclusions

It has been argued that both cost-benefit analysis and cost accounting of policy using quantitative models are overly ambitious, even though we can evidently learn much from them. The multi-perspective approach to evaluating the cost of climate policy as presented here can be regarded as a way out of the never-ending debate on the usefulness and feasibility of cost-benefit analysis of climate policy. Indeed, if climate policy is seen as a precautionary strategy to avoid unpredictable, extreme and irreversible natural and economic catastrophes rather than as a way to optimise social welfare (or GDP growth) in the face of GHG emission-climate-economic damage feedback, then a focus on risk analysis and the cost of climate policy is more sensible than a cost-benefit analysis. This is true both for methodological reasons: CBA represents possibly an overly risk-loving decision maker; and for practical reasons: accounting for extreme events with small probabilities is not feasible.

We have seen a range of arguments associated with the fourteen different perspectives, showing that a safe climate policy does not need to be very expensive. This is subject to the usual conditions and provisions: nothing is certain when talking about such a complex issue as climate change and climate policy. Moreover, since 'expensive' is a relative concept, various perspectives have aimed at putting the cost in a particular context, such as comparing with the GDP of OECD countries or with expenditures on large public projects, arguing that energy is not very expensive, and interpreting climate policy from the angle of human happiness.

The happiness or subjective well-being perspective on the cost of climate policy comes out as possibly the most important new view. We should urgently introduce it into the debate on climate policy to arrive at a correct picture of what we really gain and sacrifice if we undertake a stringent, safe climate policy worldwide. Climate policy may have a GDP cost, not in the sense of reducing GDP in the long run, but slowing down its growth rate, thus reaching a given level of GDP a few years later (Perspective 3). Happiness research (Perspective 4) indicates that this is not worrisome at all. Four considerations are important here. First, GDP is not a reliable measure of welfare or happiness, notably for rich countries. Second, climate policy avoiding extreme events means preventing serious reductions in happiness. Such reductions are not or insufficiently captured by GDP analysis as these events involve many non-market effects related to extreme impacts on resource availability (clean water), human health, vulnerability of poor people in regions with low productivity, migration and violent conflicts. Third, climate change for people in poor countries may mean that their basic needs will come under threat. Fourth, climate policy concerns a period of many decades to several hundreds of years in the future, during which the GDP of rich countries will certainly have grown far beyond any welfare or happiness maximizing level. Concluding, in happiness or real welfare terms climate policy looks much less expensive than in lost GDP terms while climate change may be evaluated as more expensive than in lost GDP terms. Finally, on the basis of various quantitative measures it was argued that energy is not

[21] Heal and Kriström (2002) state: "Most economists, if asked to think of a justification for this principle [the precautionary principle], would probably couch it in terms of learning, irreversibilities and option values …" (p.26).

very expensive (Perspective 11), so that there is room for increasing its price through climate policy.

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Table 1. An overview of the 14 perspectives on the cost of a safe climate policy

Perspective	**Main insight**	**Provision**
1. Extrapolation of learning curves for renewable energy	- Learning curve solar PV looks promising, - Extrapolation of learning curve leads to middle estimate of US$60 with an uncertainty range of US$30-300. - Concentrated solar heat power (CSHP) seems a neglected technology.	- No problem-free renewable source. Solar technologies (PV and CHP) offer many advantages. - Cost decreases are no free lunch, but require investments in private and public R&D and public policies like subsidies. - Sensitivity of extrapolated costs requires careful monitoring of cost dynamics and appropriate adjustment of incentives (e.g., subsidies).
2. Global climate policy cost normalized by OECD GDP	- If solar PV investment spread over 10 years, 0.017 % of GDP (with uncertainty range 0.008 – 0.17 %) - If policy cost range of IPCC used (1– 4 % of world GDP) then cost to OECD for first 10 years 1.8 % of GDP and then rapidly falling 0.017 %. - An alternative is to allocate costs proportional to country GDP or country per capita GDP, which simply will mean higher costs for some and lower costs for other OECD countries.	- If technological innovation slower then longer period during which high cost estimate applies.
3. Delayed GDP growth	- If GDP growth is 2 % per year, and the cost of climate policy ranges from US$1 to 20 trillion then the delay time to reach a certain GDP within about a century from now will be no more than 3 years. - The IPCC climate policy cost range of 1-4 % means a set back in time of about 2 years if GDP growth is 2 %. This is hardly noticeable in terms of spending power.	
4. Happiness instead of GDP	- Less GDP growth due to climate policy translates into a smaller loss in happiness terms, as GDP growth in rich countries does not or hardly raises happiness. - GDP effect of climate change (no climate policy) underestimates impact on happiness effect (non-market effects), especially in poor countries.	- People may adapt to a changed climate in the sense of being initially affected (negatively) in their happiness, while later slowly recuperating their old happiness level.
5. Comparison with large public investments	- Making solar PV competitive comes down a total cost with a central estimate that is 2 % and an uncertainty range of 1 – 6 % of the estimated cost of the Irak war for the USA. - One may also compare with the cost of governmental responses to the financial crisis, on the basis of the argument that these respond, like climate policy, to a severe threat. - Per year, the world invests more than twice the central estimate of the cost of making solar PV competitive (US$60 billion). If the solar PV investment is spread of 10 years, then it would cost only 5% of world expenditures on military research in that period. - In two years the world spends almost US$300 billion on military R&D, which is equivalent to the upper limit estimate of the range of investments needed in R&D to make solar PV competitive.	
6. Avoided climate damage costs	Cost of no policy is higher than cost of policy (IPCC range 1-4 %), witness the potential cost estimates of 10% of GDP by Nordhaus and almost 20% GDP damage cost of climate change. These figures are moreover based on analyses that represent an incomplete coverage of possible extreme climate events and trends.	
7. Ancillary benefits	Reduction of GHGs generated by fossil fuel combustion can go along with reductions in other emissions, notably acidifying substances (nitrogen oxides and sulphur dioxide); avoidance of human conflict due to climate change; omitted large scale biodiversity loss due to shifting climate zones; solving GHG emissions by new energy sources (renewables) will reduce energy resource scarcity and related conflicts, avoid fierce oil peak shocks, and enhance energy security; adaptation options arising due to mitigation activities; and shifting taxes from labor to environment may create modest employment benefits due to less tax distortions in labour markets.	Certain studies of climate policy cost take parts of some of these ancillary benefits into account, but most studies do not or imperfectly.
8. Upward bias in ex ante regulation cost estimates	Ex ante assessments of policy costs generally deliver overestimates, for two reasons: information on actual costs often comes from those having an interest or stake, who strategically may provide too high estimates of individual abatement costs, to avoid implementation of stringent regulation; estimates further often neglect or underestimate the potential for abatement cost reduction as a result of innovation and	Also certain downward biases, but probably relatively less important.

	adaptation by polluters.	
9. International cooperation and agreements	Without international climate agreement differences in policy cause a high cost for industries or consumers in countries with stringent regulation. Level playing field due to joint agreement reduces national policy cost.	
10. Behavior, learning and substitution	Overestimation of climate policy cost for various reasons related to behavior: aggregation in models for policy cost assessment hides substitution and adaptation opportunities for economic agents; realistic bounded rationality, including psychological factors, missing in most economic models; many ways of individual, group and system learning underrepresented in formal models.	- Some types of bounded rationality may lead to higher cost estimates than rational agent assumption. - Good translation of insights from behavioral to environmental, energy and climate economics lacking.
11. Current cost of energy is fairly low	- No problem if it becomes more expensive due to climate policy. - For the UK in 2000 the cost of lighting was 1/3000 of its 1800 value, while during the same period income (spending power) increased 15 fold. The share for only light services dropped between 1800 and 2000 with a factor 5/9. Energy intensity defined as energy input per monetary output has dropped by more than 30 % since the 1970. - The ratio of all energy expenditures to GDP since the 1970s has been on average roughly 10 % or less, which is not high if one realizes that energy is the fundamental input to all human-economic activity (i.e. 90 % is spent on other things). - The sharp recent increase in the oil price did not give rise to social unrest.` - Cost of oil was until recently quite low. Currently, oil price is roughly 3 to 5 times the long term average. If calculated from 1869 to 2007, this average (US crude oil prices adjusted for inflation in 2006 US$) equals $21.66 per barrel for world oil prices, while during the period fifty percent of the time world prices were below the median oil price of $16.71 per barrel, and for the post-1970 period equivalent indicators are $32.23 and $26.50	If the price of fossil fuel energy goes up due to climate policy renewables will become more expensive since their production depends on fossil fuel energy inputs.
12.Lack of insurance against climate change	Insurance against extreme events due to climate change is largely missing, therefore: - No efficient sharing of climate related risks which will reduce overall costs of both climate change and climate policy. - Incentives are lacking to stimulate producers, consumers and even insurance companies to efficiently respond to climate change risks and climate policies.	
13. Stimulating a fundamental social-technical transition	- Going beyond cost-benefit thinking; entirely different world that can not simply be compared with current world in terms of cost and benefits. - Climate change policy is not about a simple, one-dimensional policy or even policy instrument with a clear cost, but a complex process of multilevel and multidimensional change. Very likely a mixture of general policy principles is needed, notably regulation of externalities (environment foremost), resource policies, innovation policies (including public investments) and specific unlocking policies (giving shocks to the system, subsidy programs, etc.).	- Escaping from lock-in difficult and possibly costly. - A sustainable energy system will likely require much larger share of labor going to energy supply (exploration, production).
14. Instable climate vs. instable economy	Economic adaptation under stable natural conditions, enhanced by a stringent climate policy, is easier than under unstable natural conditions resulting from a lax climate policy.	