Climatic Change (2010) 101:339–385
DOI 10.1007/s10584-009-9719-7

Safe climate policy is affordable—12 reasons

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Received: 27 January 2009 / Accepted: 27 August 2009 / Published online: 3 November 2009

Abstract There is a widespread sense that a sufficiently stringent climate mitigation policy, that is, a considerable reduction of greenhouse gas emissions to avoid extreme climate change, will come with very high economic costs for society. This is supported by many cost–benefit analyses (CBA) and policy cost assessments of climate policy. All of these, nevertheless, are based on debatable assumptions. This paper will argue instead that safe climate policy is not excessively expensive and is indeed cheaper than suggested by most current studies. To this end, climate CBA and policy cost assessments are critically evaluated, and as a replacement twelve complementary perspectives on the cost of climate policy are offered.

1 Introduction

It is generally felt that a climate policy which stabilizes atmospheric concentrations of greenhouse gases (GHGs) at a 'safe' level will be extremely expensive, whether measured in terms of monetary costs, reduced GDP growth or forgone welfare. This

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is supported by a number of influential economic cost–benefit analyses of climate policy as reviewed in Kelly and Kolstad (1999) and Tol (2008a, b).[1] In this paper it will be argued that the application of cost–benefit analysis (CBA) to climate change and policy should 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 that a better option is to adopt a more modest and practical approach, namely examining the cost of a safe climate policy. This reflects a policy aimed at a stable and safe level of atmospheric GHG concentrations—thus focusing on mitigation, not adaptation. The combination of risk aversion, pervasive uncertainty, and extreme climate change and events motivates such a safe or precautionary approach as a rational alternative to an optimal climate policy. In fact, (avoiding) extreme climate change may be regarded as the ultimate reason for us to worry about and respond to climate change. Even two strong advocates of using CBA to analyze climate change, 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."

It will be argued here that the cost of climate policy has so far been approached from too narrow a perspective. This will involve a discussion of fundamental problems associated with applying CBA to climate change and policy. Spash (2007) concludes that cost-effectiveness studies are not much better than CBA's. Indeed, studies attempting to assess the monetary cost of climate policy make many debatable assumptions as well. Nevertheless, the shortcomings are less serious than in the case of climate CBA studies because the monetization of climate damage is avoided. Since some of the shortcomings of CBA's and cost assessments of climate policy cannot be resolved, one cannot hope for a single model analysis of climate policy to provide the definite insight about its cost let alone its optimality.

This paper will therefore offer an alternative approach consisting of assessments of the cost of climate policy from a range of complementary perspectives. Together, these aim to avoid or surpass the limits of existing CBA and policy cost studies. The alternative approach can be seen as trying to determine the economic and social costs of a safe or reasonably safe—given all sorts of uncertainties involved—climate policy by considering a range of perspectives to somehow bound the "cost space". The focus on a safe or precautionary climate mitigation policy can be regarded as the outcome of a qualitative risk analysis, as will be discussed in Section 3. Twelve perspectives on the cost of climate policy are offered. Together they deliver quite an optimistic conclusion, namely that climate policy is not excessively expensive and is certainly cheaper than suggested by most current studies. In other words, our global society can afford to invest in a safe climate policy. This should serve as relevant information for all politicians who fear severe economic consequences from stringent regulation of GHG emissions.[2]

[1] See also the Energy Modeling Forum (http://www.stanford.edu/group/EMF).

[2] B. Lomborg 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.

The remainder of this article is organized as follows. Section 2 briefly argues the failure of cost–benefit analysis of climate policy. Section 3 presents the main arguments in favor of a safe, precautionary approach to climate policy. Section 4 discusses the meaning of the cost of a safe climate policy and reviews the methods and assumptions that have been used to produce the main cost estimates. Together, Sections 2 and 4 show that the current economic approaches to assessing the (net) costs of climate policy have severe limitations. As a result, they are prone to generating inaccurate estimates of these costs, so there is a need for an alternative approach, as offered here. Section 5 contains the main thrust of the paper. It presents the new approach consisting of 12 perspectives on, and interpretations of, climate policy costs that move beyond current model assumptions and limitations. Section 6 provides conclusions.

2 The failure of cost–benefit analyses of climate policy

The history of climate CBA shows enormous variation in estimates. For example, whereas early studies (e.g., Nordhaus 1991) excluded adaptation to and benefits of climate change, later studies did take them into account and arrived at lower climate damage costs. Despite variation, most climate CBA studies share many basic assumptions. These have received considerable criticism, much of 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; Ackerman et al. 2009; and various responses to the Stern Review). Criticism has been directed, among others, at the assumed behavior of economic agents, the social welfare objective used, the treatment of small-probability-high-impact scenarios, discounting and social discount rate values, 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). Weitzman (2007, p. 703) says about this: “The basic issue here is that spending money to slow global warming should perhaps not be conceptualized primarily as being about consumption smoothing as much as being about how much insurance to buy to offset the small chance of a ruinous catastrophe that is difficult to compensate by ordinary savings.” The latter means that social welfare losses due to extreme climate change cannot be reversed or undone through adaptation. This view is the motivation for the approach adopted in this paper, namely an assessment of the cost of a (reasonably) safe climate policy. In this context, the treatment of extreme climate change and climate events characterized by a combination of small probabilities and large impacts has been argued to not go together well with an expected value

Moreover, expenditures on these various policy areas do not come out of a fixed budget, or spending on one does not necessarily diminish spending on the others. Lomborg’s policy conceptualization further fails to account for the cumulative and irreversible features of climate change as well as for the likelihood of extreme climate scenarios.

approach to cost–benefit analysis. This specific, fundamental criticism is addressed in more detail in Section 3, which will result in an extended argument in favor of a precautionary approach to climate mitigation policy.

Several other fundamental issues can be raised about CBA-style evaluations 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 an intergenerational allocation of economic endowments. Using a simple model, they show that efficiency does not guarantee environmental sustainability. Tol (2008b) mentions population as being endogenous to climate change since the latter will directly 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 an intergenerational maximin criterion[3] and maximization of a quality of life (human development) indicator. Indeed, there is an extensive 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 Section 5.4 in Section 5.

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; a slow-down or halting of the global thermohaline circulation, of which the Gulf Stream is a part; an extreme increase of the world's mean sea-level over centuries due to the collapse of the ice sheets on Greenland and West Antarctica; 'runaway dynamics' caused by positive feedback mechanisms in the biosphere, such as substantial emissions of methane (with a much higher warming potential than CO_2) from permafrost regions; changes in climate subsystems such as the 'El Niño Southern Oscillation'; acidification of the oceans due to high atmospheric CO_2 concentrations, meaning a deterioration in the living conditions for marine organisms with yet unforeseen effects; and extreme weather events, notably extreme rainfall, an increased probability of heat waves and droughts, and an increased intensity of hurricanes due to warmer seas. If, moreover, such changes take place rapidly, then insufficient time for adaptation will contribute to higher damage costs. According to Weitzman (2007), "There is little doubt that the worst-case scenarios of global-warming catastrophes are genuinely frightening." The omission of these extremities from CBAs 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 the environmental conditions for humans and the rest of the biosphere. In fact, studies that have incompletely taken into account extreme events should not be taken too seriously—they really

[3]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).

involve nothing more than toy models—and the respective authors should be modest about the policy implications of their analyses (see also Azar and Lindgren 2003). In particular, studies omitting extreme events will underestimate the cost of climate change, or the benefits of climate policy, and therefore be biased against safe climate policy. The omission of worst-case scenarios from cost–benefit analysis is not so much a fundamental argument against cost–benefit analysis but rather a serious omission by the modelers. The reason is, of course, that most worst-case climate change scenarios cannot be accurately quantified.

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 them, 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 the fundamental shortcomings of the primary studies, even though it gives the impression of being an objective aggregation.

Other limitations and weaknesses of CBAs 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.[4] 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 many studies. 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 will not only suffer severely from climate change but also be less able to undertake protection or adaptation. In addition, to estimate the costs of illness, accidents and human mortality, 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, the environmental changes to be valued under extreme climate change scenarios are large, which creates the problem that their monetary valuation is inconsistent with a necessary condition, namely that the change to be valued is small compared to income. The latter follows from monetary valuation being based on the theoretical idea of income compensation or equivalence (e.g., Johansson 1987).

Next, over long-term horizons, such as in climate change analysis, CBA is extremely sensitive to discounting and particularly the choice of (social) discount rate.

[4] 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 2008b, Table 2), Tol proposes to use a carbon tax in the lower range of \$26–50/tC.

This in combination with the fierce, long-standing debate over the "correct" social discount rate serves as an important reason for many observers to question the robustness of CBA studies of climate policy. 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). 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 (δ) and the average growth rate of per capita consumption (g) multiplied by the elasticity of marginal utility of consumption (η): this results in the "Ramsey formula" $r = \delta + \eta g$. The pure time preference δ (what Quiggin (2008) called the inherent discount rate) was set by the Stern Review team at nearly zero to reflect intergenerational equity.[5] The exact value chosen was 0.1%, corresponding to a 90% probability of the human race surviving 100 years (implying a chance of human 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. Respected even prominent economists can be found to support the nearly zero value of δ (Dasgupta 2007; Cline 2007; Quiggin 2008) and to criticize it (Tol 2006; Nordhaus 2007; Weitzman 2007). The value $\eta = 1$ adopted in the Stern Review has been criticized as well (Dasgupta 2007; Nordhaus 2007). Stern (2007, p. 140) has said he is prepared to raise it to 1.5 and notes that this value receives support from Nordhaus; since the damage costs then are still much larger than the policy cost, this change will not alter the conclusions. Quiggin (2008) nevertheless argues that $\eta = 1$ is not a bad compromise given the variation of estimates in the literature, and that the criticism by Weitzman, Dasgupta, and Nordhaus 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 also Section 3). All in all, the criticism on the social discount rate by the Stern Review is not convincing. Note in this respect the range of social discount rates used in the various climate CBA studies. The Stern Review uses 1.4% per year ($\delta = 0.1\%$ per year, $\eta = 1$, and $g = 1.3\%$ per year); with $\eta = 2$ this would become 2%. Nordhaus in his various 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 range of 3–5%. Nordhaus and Boyer (2000) apply 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 the one resulting from the Stern Review'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, there are several fundamental objections to be made against discounting as formalized in the Ramsey formula above. Three important ones are as follows

[5] Cline (2007) argues that since there is no capital market extending to future centuries (the relevant time period for evaluating impacts of climate change), the discount rate components must be identified from first principles. Following Ramsey's ethical advice, in his original analysis (Cline 1992) he set the time preference rate component equal to zero.

(for others, see Ackerman et al. 2009). A first, longstanding objection is ethical in nature and was already mentioned by Ramsey himself. It recognizes that long term discounting, even with small discount rates, effectively means giving very large weights to generations early in time and very small weights to generations distant in time. Many economists and philosophers have expressed that equal weighing of all generations, meaning the use of a zero discount rate, is the only ethically defensible approach. A second objection is that the formula does not account for the "diversity of uncertainty" in the sense that in reality one typically finds multiple interest rates associated with assets that show varying degrees of risk, rather than a single market discount rate (Ackerman et al. 2009). I want to propose a third fundamental consideration as well. Social discounting means imposing a feature of human individuals, who show time preferences or impatience, upon a society. This comes down to treating a society as analogous to an individual. But unlike 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 (environmental) sustainability, which is in fact the motivation for the evaluation of potential climate policies. A related difference is that whereas individuals discount their own future utility over their lifetime, social discounting by the current generation discounts utility of other, future generations over time periods beyond the current generation's lifetime. These differences suggest that applying a positive time preference to societal, intergenerational decisions can be seen as employing an erroneous analogy (van den Bergh 2004). Nordhaus, Weitzman, Tol, and various others do not want to give credit to such fundamental objections against social time preference discounting 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 the fact that economists, just like ordinary people, are 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 fundamental criticism of the suitability of CBA as a method to evaluate climate policies, as summarized above. One can indeed interpret the fierce attacks by Nordhaus and Weitzman on the Stern Review as a "historical accident", to use a term from the literature on path-dependence: if Cline and Stern had been the dominant players in the field, and Nordhaus, Mendelsohn, Tol, and Yohe had arrived on the scene late, they would have likely been the ones receiving fierce criticism for making unorthodox assumptions.[6]

Nordhaus, Weitzman, and others particularly refer to the gap between the Stern Review's discount rate choices and market interest rates. However, as Stern has noted in his responses (e.g., Stern 2007), market interest rates cannot serve as a guide for a "prescriptive or even a descriptive account of value judgments", as they are the result of short-term decisions by many individual consumers and producers on investment, saving, and consumption motivated by personal gains. Moreover, there

[6]Very likely, the influence of Nordhaus on "climate economics" relates to his impressive publication record and reputation within mainstream economics, notably in the areas of economic growth, technical change, and energy issues. Note also that he published on the economic implications of climate change as early as 1977 (Nordhaus 1977).

are many rates of return which vary significantly (Brekke and Johansson-Stenman (2008) mention an average range of 0.4% to 8.8% for the USA during the period 1926–2000), market interest rates vary over time, and empirically estimated implicit discount rates obtained through stated choice experiments vary considerably as well (Frederick et al. 2002). This all suggests that any ethical judgment would vary over time or between the specific markets or investment assets taken as a basis, thus implying arbitrary discrimination among individuals living in different periods or born at different moments in time. In addition, the market interest rate is affected by failures of financial markets, which are due to myopic behavior, asymmetric information, market power, environmental externalities, etc. Witness in this respect the current worldwide financial crisis, which has consequences for market interest rates. 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 and low-risk government bonds. These typically give a very low return with an order of magnitude of 1% and 2%, respectively. These numbers are surprisingly consistent with the Stern Review's social discount rate of 1.4 ($\eta = 1$) and 2% (if $\eta = 2$ would have been used), as mentioned above.[7]

Finally, low discount rates are consistent with certain stated preferences 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. to use a decreasing discount rate as the time horizon increases. Different theoretical explanations involving evolutionary history, commitment, and self-control have been offered (Frederick et al. 2002; Dasgupta and Maskin 2005; Fudenberg and Levine 2006). Given bounded rationality in intertemporal decision-making by individuals, Brekke and Johansson-Stenman (2008) think that it makes sense to use a substantially lower social discount rate than the average return on investments. To support this, they wield arguments relating to prospect theory (Kahneman and Tversky 1979), notably status quo (climate damage is a loss, not a foregone gain) and nonlinear responses to (subjective) probabilities associated with climate risk (Botzen and van den Bergh 2009). Finally, it should 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 many reasons for not having much confidence in CBAs of climate policy. 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 following the Stern Review illustrates this. While Stern has been able to put climate change

[7] Davidson (2006) arrives at a climate discount rate of 1% following another line of reasoning.

on the retina of many economists and government officials precisely because it was seen as an economic study, the CBA part received severe criticism. Stern (2007) has clearly stressed that he purposefully wanted to deviate from certain incorrect assumptions of earlier climate CBA studies, and that he regards climate change as a problem that really requires a risk analysis rather than a CBA, which he merely regards as one input into the debate. One can at least be positive about the Stern Review because it initiated a much-needed fundamental debate on the very young but already (policy-) influential 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 injection of new ideas and expertise is very much needed, as so far the debate has been too dominated by a small group of like-minded individuals adopting very similar assumptions. As the field of innovation studies teaches us, a diversity of approaches enhances the pace of innovation, which one would hope is the fate of climate economics.[8]

CBA is an attractive and reasonable evaluation method for well-bounded problems (local, sectoral) with limited time horizons, non-extreme and manageable uncertainties, reversible scenarios, and limited income inequality. But its application to global, long-term climate change and policy questions runs into severe problems.[9] Here CBA is not merely stretched to its extreme but breaks down. This does not mean that one has to reject qualitative-type of CBA thinking. Indeed, it is difficult to escape thinking in terms of trade-offs between qualitative costs or the disadvantages and benefits or advantages of any choice. Such a qualitative, conceptual approach is in fact needed to support a precautionary approach to climate policy. But unlike the quantitative CBA approach, its qualitative counterpart expresses clearly that specific, detailed statements about the social optimality of choices in the context of climate policy are overly ambitious.

[8]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 nine 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 et al. 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 by suggesting that considerably more research funds for climate economics 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) says: "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)." One is tempted to add that if the list of caveats did not alter over a decade, progress is very likely too slow.

[9]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. The economic research on acid rain has been dominated by cost-effectiveness analysis, with RAINS developed at IIASA probably being the best-known study of this type (Alcamo et al. 1990).

3 Arguments for a safe, precautionary approach to climate policy

If it can be argued that a safe climate policy means considerably lower net costs than the absence of such a policy, it is rational to be in favor of such a policy. This represents a kind of cost-effectiveness combined with precaution, given the uncertainties involved, aimed at avoiding extreme damage costs due to climate change. As a guide we can take Nordhaus and Boyer's (2000) estimate of 10% and the Stern Review's estimate of almost 20% potential GDP damage cost of extreme climate change (Stern et al. 2006). As noted in Section 2, considerably lower damage costs require the omission of relevant extreme climate events and scenarios. If we compare these figures with climate policy cost estimates in the IPCC range of 1–4% of global GDP (Section 4), then safe climate policy is clearly seen to be socially efficient. The slogan used by some environmental NGOs is surprisingly appropriate: 'the most expensive climate policy is doing nothing'.

The combination of small probabilities and large impacts associated with extreme climate change and climate events does not go together well with an expected value approach to cost–benefit analysis, and moreover does not reflect the way humans generally tend to evaluate such problems (Kahneman and Tversky 1979; Diecidue and Wakker 2001; Weitzman 2007; Botzen and van den Bergh 2009; 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 scenarios have a small expected value compared to more certain changes associated with less extreme costs, and as a consequence receive a relatively low weight in CBA analysis. This effectively means a risk-neutral or risk-loving approach. Nevertheless, one 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 services, as is the case with climate change.

In line with this view, Loulou and Kanudia (1999) and van den Bergh (2004) have proposed studying climate change using a precautionary principle formalized via a minmax regret goal. This represents more risk aversion than an expected value approach and less risk aversion than, for example, maximin net benefits.[10] 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: (1) there are no serious risks; (2) we can adapt successfully to whatever comes our way, however big the changes; (3) the future is of little importance. The first is absurd, the second reckless, and the third unethical."

Environmental economists have long thought about uncertainty, irreversibility and precaution, which has given rise to option value theory (Arrow and Fisher

[10] 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).

1974). But surprisingly they have refrained from systematically applying it to the most relevant case of irreversible environmental change, namely climate change (an exception is Schimmelpfennig 1995). In brief, this would mean 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 accept climate change at a later date or not, where the flexibility is due to investing in GHG emissions reduction to avoid the irreversible build-up of greenhouse gases in the atmosphere. Ha-Duong (1998) applies the notion of quasi-option to climate policy, which states 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 the low-probability, high-impact scenarios associated with climate change.[11]

Gollier et al. (2000) have shown the precautionary principle to result from a rational decision formalized as dynamic optimization under uncertainty and irreversibility involving Bayesian updating/learning. The conditions for precautionary action turn out to depend on risk aversion and "prudence". The latter is captured by the third derivative of the utility function and reflects the degree to which an individual increases his savings in response to an increase in uncertainty about future revenues (Kimball 1990). Other approaches than expected utility maximization and minimax regret to support a precautionary policy are maximin utility and nonlinear methods like prospect theory or rank-dependent utility theory, which one can characterize either as rational or boundedly rational (but not irrational) approaches. Although experts seem not to entirely agree on the best theoretical approach to address decisions in the face of low-probability, high-impact scenarios, a defensible approach seems to be to give relatively more attention or weight to extreme case scenarios, which comes down to a kind of minimax regret approach.

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 or by reducing uncertainty to (subjective) risk. All existing models that include 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 they insufficiently reflect the irreversibility of climate change, the extreme uncertainty (content and likelihood) associated with certain scenarios and events, and the non-insurability against extreme climate change and events due to risks being highly correlated for all regions in the world.

[11] 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, since 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 can also be criticized for employing an expected utility approach.

A somewhat different way to understand the rationale behind a precautionary approach to climate policy is based on comparing the likelihood and features of climate and economic instability. This represents a kind of risk management view, which conceptualizes climate policy as the outcome of a trade-off between the risks and costs associated with natural and economic instabilities. However, these two risks are neither on equal par nor symmetric. One may even go as far as to say they are of a different order and thus simply incomparable. This can be reasoned as follows. 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 then be maintained. For example, if a stringent climate policy turns out to create too high economic costs and too much instability, the policy may be altered or adapted. However, under extreme climate change—due to a lax or lacking climate policy—one has to reckon with macro-scale risks, with catastrophic and irreversible changes in the coupled climate-biosphere system which cannot be controlled by any public policy, even though impacts may in some cases be ameliorated by climate adaptation policies. Governments will then be unable to avoid extreme impacts on the world economy, and economic policy will have a very hard time stabilizing economic responses to extreme climate change. In fact, a severe climate crisis may very well stimulate an unprecedented economic crisis. All in all, economic adaptation and policy under stable natural, climate conditions, enhanced by a stringent climate policy, are easier and safer than responding to unstable natural conditions resulting from a lax climate policy. 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." The Stern Review also shares this standpoint, and many other observers have made similar statements.

The extensive literature on resilience and ecosystem functioning also suggests that we should be extremely careful in tinkering with the biosphere through human-induced climate change, as this may cause discrete, structural changes in all kinds of ecosystems (freshwater, marine, rangeland, wetland, forest, arctic) when certain critical thresholds of GHG concentration in the atmosphere are surpassed (Holling 1986). The risk of extreme events or disasters, as documented in Section 2, is relevant here, as many of them will considerably affect basic conditions for many ecosystems. In addition, the uncertain synergy between biodiversity loss and climate change is relevant. Biodiversity supports the stability of ecosystem functions and related services to humans, while biodiversity loss is being enhanced by climate change. Against this background, some have even denied the relevance of normal scientific analyses 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 with climate change in nonlinear and unknown ways, such as land use, deforestation, water use, destruction of wetlands, acid rain, acidification of the oceans, and human control over 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 meets all four characteristics.

The foregoing set of considerations suggests that the implementation of a precautionary principle in climate policy emerges as a rational strategy.[12] Neither decision-making based on quantitative CBA nor waiting until more information is available are convincing strategies. 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—see note 2). But whereas, for instance, less health care and education can indeed reduce growth and welfare, they are unlikely to cause extreme and discrete changes at a global scale. For this reason, climate policy needs to be treated as fundamentally different from many other areas of public policy.

4 Cost assessments of climate policy

Next we consider less 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 a considerable degree of uncertainty.[13] 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 stabilization in the range of 535–590 CO_2 equivalent ppmv and reports cost estimates ranging from slightly negative to 4% of global income.[14] 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 failures. IPCC notes that an evaluation of primary cost-effectiveness studies indicates that a global carbon price in the range of US\$20–80/tCO_2e (CO_2-equivalent) by 2030 would be able to realize a stabilization of approximately 550 CO_2e by 2100. It is, however, still debatable how safe the goal of stabilizing greenhouse gas concentrations in the atmosphere at 550 parts per million (ppmv of CO_2e) is, which might cause a 2 C higher temperature 100 years from now. While the pre-Industrial Revolution concentration was 280 ppmv CO_2e, the current level is about 385 ppmv CO_2e. We are quickly approaching the relatively safe concentration of 450 ppmv, meaning that (cheap) opportunities to stabilize at a safe level are become scarcer. It is even being debated whether anything beyond the current 380 ppmv is safe; 450 ppmv may lock us into a 3°C temperature increase (Lynas 2007). An important uncertainty factor is the residence time of CO_2 in the atmosphere: it is highly uncertain and estimate have increased considerably during recent years. According to Montenegro et al. (2007, p. 1), "About 75% of CO_2 emissions have an average perturbation lifetime

[12]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).

[13]Jaccard et al. (2003) note that the literature employs various definitions of policy cost. They point to the difference between financial costs of technologies, (business) option value and consumer surplus.

[14]To compare, in The Netherlands 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 most other countries, these figures are somewhat lower (PBL 2008).

of 1800 years and 25% have lifetimes much longer than 5000 years." Matthews and Caldeira (2008) even suggest that in order to stabilize atmospheric concentrations, anthropogenic emissions will have to be reduced to zero for a period ranging from decades to possibly centuries.[15]

Various studies offer systematic comparisons and meta-analyses of cost estimates of climate policy (Repetto and Austin 1997; Barker et al. 2002, 2006; Fisher 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. The indicators of the cost of policy reported in different studies vary: total direct compliance costs, the carbon price required to comply with a given emissions reduction, the loss in GDP (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 mitigation policy show a great deal of variation. This is due to a number of assumptions which differ between studies: the assumed required emissions reduction (trivial, but it nevertheless makes straightforward comparisons impossible); the structural characteristics of the models, notably substitution possibilities (fuels, products), level of technological detail, assumptions regarding technological progress (and whether it is exogenous or endogenous); 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 emerges as a crucial factor, and therefore the specification of the relation between policy and technical change is important. This requires models with endogenous (or policy-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 associated with R&D as well as path dependence and technical lock-in may mean that policy costs are underestimated. Finally, differences in cost

[15] According to Gowdy (2008), CO_2 levels have been below 300 ppmv 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 ppmv by 2050. If all available fossil fuels were burned CO_2 levels could ultimately reach 2,000 ppmv (Kump 2002). Some observers think that the most likely scenario is that atmospheric CO_2 will peak at 1,200 ppmv in the next century (Kasting 1998) or at 1,400 in three centuries (Bala et al. 2005). According to Anderson and Bows (2008), stabilization far below 650 ppmv CO_2e is improbable given current trends.

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 the shortcomings identified, let us consider a few recent studies in more detail to illustrate a few more aspects of estimating the cost of climate policy. A study undertaken for the USA by a renowned team of energy-CGE modelers (Jorgenson et al. 2008) finds that the US 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 they are 1.2%. Spread over 34 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, foregone consumption is in the range of 0.1% to 0.2% of baseline levels and, by 2040, the loss rises 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 permits and tax revenues, which means that the effects may be even smaller (double dividends). The same holds for the omission of induced technical change. The authors think that its contribution is considerably smaller than that of substitution and economic restructuring.

Bollen et al. (2004) have studied the cost of post-Kyoto climate policy for The Netherlands. They assume that developed countries reach emission reduction levels of 30% below 1990 levels, which is the European Union's goal, consistent with an increase in average world temperatures of no more than two degrees Celsius above the pre-industrial level. Note that the 2°C temperature rise is surrounded by uncertainty (Meinshausen 2006) and that it implicitly assumes that the emission patterns of countries not bounded by the Kyoto protocol do not rise sharply. Related to the latter, 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 rise more slowly. A third factor is the policy instrument: a system of tradable emission rights will realize the minimum cost of mitigation (although only under the assumptions of a general equilibrium system, with fully rational agents, perfect information, no strategic behavior, and clearing markets). 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 (although Australia has in the meantime). The analysis ignores the costs of adapting the economic structure and the transaction and enforcement costs of climate policy.

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, leading to an atmospheric stabilization level of 550 ppmv CO_2e. The PAGE2002 model was used giving an estimate of the associated mitigation costs, yielding an average of 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. Cost estimates for mitigation over time can vary considerably based on the level of technological change in low-carbon technologies and the improvements in energy efficiency 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). Finally, some relatively cheap strategies to reduce emissions are not considered in most economic studies, such as reducing emissions from deforestation and forest degradation (REDD; Lubowski 2008).

McKinsey and Company (2009) suggests that if immediate action is taken it will be possible to maintain global warming below 2°C at an overall cost of less than 1% of global GDP. This is based on a study that constructed a global cost curve (version 2.0), including more than 200 opportunities for reducing GHG emissions across ten sectors and 21 world regions. According to the report's most optimistic scenario, investing in a transition to a low-carbon economy is potentially as 'cheap' as 0.5% of global GDP. This, however, involves an assumption that approximately 40% of the global potential reduction of GHG emissions can be achieved by energy conservation and more energy-efficient technologies in transport, daily household activities and buildings. This may be overly optimistic as it seems to be based on a partial analysis, having overlooked the rebound effects of energy conservation. There is increasing evidence that optimism about energy conservation is unwarranted, since rebound effects are much larger than often thought. Rebound may even be higher than 100%, but this is impossible to prove due to the limited system boundaries and time horizons used in energy analyses as well as the difficulty of proving causal effects of energy conservation (Sorrell 2007, 2009). From the perspective of rebound risks, renewable energy has a major advantage over energy conservation. That is why it is given prominent attention in Section 5.1 in Section 5.

The previous discussion suggests that cost estimates of climate policy in the literature are clouded by uncertainty and debatable assumptions. A broad view going beyond single model limits can improve our understanding of the costs of climate policy.

5 Twelve reasons why a safe climate policy is affordable

The section below presents twelve new, complementary perspectives on the cost of climate policy.

5.1 Perspective 1: extrapolating learning curves for renewable energy

The easiest way to reason about the cost of climate policy is by considering a most likely definite solution to the core problem, that is, the emission of greenhouse gases, notably carbon dioxide. Renewable energy really offers the only definite solution, as it can in principle support the supply of electricity and other types of energy carriers in a carbon-free way. Of course, this requires the equipment and indirect support of renewable energy themselves to be produced with renewable, carbon-free energy. In order to allow for the wide-spread adoption of renewable energy, it needs to produce electricity at market-competitive prices.[16]

Within renewable energy, one can identify wind turbines, water power, biomass energy (including biofuels), concentrated (solar) heat power, and solar photovoltaics (PV) as the main candidates for future dominance. However, which technology will ultimately emerge as the most attractive is uncertain. Wind is close to being competitive but limited in application because of visual hindrance and noise problems. Still, it is expected to undergo a large growth before saturation. The early optimism about biofuels has been severely tempered in the last few years. The net energy and de-carbonization 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 because, among other reasons, they involve clearing natural vegetation (Fargione et al. 2008; Searchinger et al. 2008). In addition, concern has 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 major contribution to the energy supply, simply because suitable waste streams are limited. Concentrated solar (heat) power (CSP) seems to be a neglected technology, which is surprising since it is 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 CSP can generate about 100 times the amount of electricity produced from biofuel crops grown on 100 km^2. 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, along with continuing Western energy dependence on unstable regions. All in all, there is much to say in favor of Solar PV: it is characterized by decentralized, local applications, can be easily integrated into buildings, produces directly electricity, and there are diverse sub-technologies which suggest a great deal of 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 southern France.

Energy conservation, including increased energy efficiency improvements, is generally seen as a cheap strategy to achieve GHG mitigation. However, this is not always the case if it requires costly investments in new capital and R&D. In

[16]Some readers will suggest regarding 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 nuclear proliferation, waste and potential accidents are sufficient reasons to not consider nuclear energy as an environmentally sustainable alternative, even though it can contribute to a carbon-free electricity supply. Another solution that has been discussed a great deal recently is carbon capture and storage (CCS). However, it can be regarded as neither a definite nor a sustainable solution. Moreover, experience with it is very limited, and it is far from cost-effective right now.

deciding between investments in energy conservation and renewable energy, one should take into account which learning curve is steeper, i.e. where investment can lead to substantial cost reductions. One should further recognize that energy conservation can come hand in hand with large rebound effects (Greening et al. 2000; Sorrell 2007, 2009). If new, energy-efficient technologies considerably improve the productivity of 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". Based on a panel of German household travel diary data, Frondel et al. (2008) find that between 1997 and 2005 cars' higher energy efficiency caused 57% to 67% more travel. 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 energy conservation, it would be more effective to focus policy on avoiding GHG emissions with adequate price corrections for energy-related externalities. This would then prevent leakages and thus rebound in terms of both energy use and related externalities. Currently, for instance, the lack of good regulatory climate for air traffic offers a clear route for rebound effects. With adequate externality and thus energy pricing, the economic system can endogenously find the best route to energy sustainability in terms of combinations of energy conservation and renewable energy over time, something that cannot be accomplished by stimulating voluntary energy conservation.

In view of the foregoing discussion, the case of solar PV will be considered here in more detail as a basis for assessing the cost of climate policy (for a similar exercise for wind see Nemet 2008). van der Zwaan and Rabl (2003, 2004) have analyzed 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 change in market prices of inputs (notably material inputs). The latter may sometime increase which can (temporarily) reverse the normal, negative relation between cumulative production and costs. Nevertheless, generally speaking learning curves are seen as quite a robust tool to examine the long-run cost behavior of technologies. For solar photovoltaic (PV) energy, a most likely or middle scenario delivers an estimate on 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).[17]

[17] US President Obama promised to invest $150 billion over the next 10 years to support renewable energy (http://www.barackobama.com/issues).

van der Zwaan and Rabl (2004) provide several arguments for why these figures are reliable. 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. Furthermore, sharp rises of the price of oil, as witnessed in 2008, would make it easier for solar PV to become competitive, although a potential negative consequence is a worldwide rise in electricity production with 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 2009; van den Bergh 2008a, b). Nemet (2008) and van der Zwaan and Rabl (2004) warn that projected costs may be 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 takes place, simply because then the learning time is shorter and the capacity to spend the R&D funds will be limited—notably, too few researchers with adequate education and expertise will be available. Finally, studies show that cost reductions are not a free lunch but require investments in private and public R&D and public policies like subsidies (Messner 1997).

It is often argued that we cannot hope—not even in the very long run—for the energy supply to rely totally on renewable energy sources, mainly because of their volatility due to natural fluctuations in sunshine and wind. There are many ways to resolve this, including energy storage, creating over-capacity, and combining energy sources with complementary variation patterns. Once solar PV electricity has become competitive, we can resolve many of the remaining barriers. It was argued here that the expected cost of bringing the price of solar PV electricity down is not excessive.[18] The presented cost range will gain more meaning in the subsequent perspectives.

5.2 Perspective 2: global climate policy cost normalized by OECD GDP

Here the cost of worldwide climate policy will be normalized by the GDP of OECD countries. This can be justified 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 intra-generational fairness. We can then take the range of 1–4% suggested by a survey of studies by IPCC (2007) as one basis for a climate policy cost estimate (see Section 3). 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$60 billion. These costs result in only 0.17% (with an uncertainty range of 0.08–1.65%) of the joint GDP of the 30 OECD countries in 2007 (which was US$ 36,316 billion; 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 were spread over the course of ten years, then it would amount to only US$200 million per country per year (over 10 years) or on average 0.017% of GDP

[18]It is fair to say that the investment to make PV electricity competitive with fossil fuel-generated electricity would have to include a reconfiguration of the grid and new equipment (e.g., transport vehicles). Part of this can come out of the regular maintenance and replacement investment for existing infrastructure and equipment connected with fossil fuel technology.

(with an uncertainty range of 0.008–0.17%). In the worst case scenario, this would imply a cost to a family with a net income of €25,000 about €40; in the most likely case this would be €4, and in the most favorable case €2, over a 10-year period.

An alternative is to allocate costs proportional to country GDP or country per capita GDP, which would simply mean higher absolute costs for some and lower absolute costs for other OECD countries. Of course, if non-OECD countries share in the costs, the burden will be spread over a larger base and result in lower figures per country and individual. In any event, the aim here is just to show the magnitude of the cost rather than suggest any fair distribution.

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, yielding 1.8% for the OECD countries. This is, however, still about 100 times larger than the yearly middle estimate and ten times the yearly upper end estimate (assuming a 10-year investment period 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, meaning that it can not make a significant contribution to reducing GHG emissions. However, according to the scenario sketched under Section 5.1, after a 10-year period solar PV should fairly quickly take over the market and provide the major means of reducing GHG.

Therefore, during the first ten years one should expect a relatively high cost of 1.8% and subsequently a rapid drop in the cost of climate policy to 0.017% (with an uncertainty range of 0.008–0.17%). This pattern should not come as a surprise, as it simply reflects an initial investment in R&DDD and then enjoying the returns on this investment. This is consistent with the suggestion by Sandén and Azar (2005) that we need to enter a decade of experimentation with low carbon technologies.

5.3 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 in many countries has historically been around 2% on average, and in some countries higher, this would mean that net growth, after discounting 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 one to three, years' delay in achieving a specific level of income in the distant future. The delay evidently depends on income growth. Global income during the twenty-first 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-year delay is moreover easily dominated by random noise given the uncertainties involved in GDP movements over a period of one century. That is, uncertainty over such a long time horizon might translate in a variation of the final GDP level (i.e. after one century) which exceeds the 6% figure. This all 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…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."

5.4 Perspective 4: happiness instead of GDP

As was made clear in Sections 2 and 4, 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, this neglects the fact that the implicit assumptions and judgments about the relationship between well-being, happiness, and GDP have been staunchly criticized (van den Bergh 2009). In fact, there is quite extensive 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, 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 rising number of empirical studies in economics, sociology, and psychology assessing subjective well-being and happiness have questioned the use of indicators like income and GDP as proxies for social welfare and progress. There is much support for the view that beyond a certain threshold, which has been passed by most rich countries, average income increases do not translate in significant rises in well-being. In particular, this research indicates that somewhere 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 be 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 happiness and 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 on 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 de-linking of income and happiness (Frank 1985, 2004; Ng 2003; van Praag and

Ferrer-i-Carbonell 2004; 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 mainly spent on basic needs. Second, although people may enjoy short-term or transitory increased happiness effects, ultimately they will adapt or get used to a higher income and changed circumstances in various other dimensions (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 ensues. Since most people are not aware of 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'. Third, people compare their situation with that of others in a peer group, so 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. Certain 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 hypothesized in older writings (Hirsch 1976; Scitovsky 1976).

Happiness research further suggests that there are limits to improving happiness through 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 opposite in the sense that optimistic individuals are found to be relatively happy and successful in life on average and are thus capable of earning a relatively high average income (Ferrer-i-Carbonell and Frijters 2004). Another relevant consideration is that high incomes generally come with many working hours. But happiness evidently depends also on leisure, which is implicitly valued negatively if one employs GDP as a progress indicator, since it has an opportunity cost in the sense of forgone production opportunities. The 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. The Netherlands leads the OECD countries in this ranking, which can be explained by the fact that the inactive part of the working force is relatively large and part-time working is very common there (de Groot et al. 2004). Note that because being (un)employed is also an important factor in happiness, the OECD adjustment represents merely a partial correction.

The implication of the foregoing stylized facts is that absolute 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. But at the societal level, relative income changes are largely a zero-sum game: what one wins another loses. In conclusion, GDP (per capita) increases are neither a necessary nor sufficient condition for improving individual well-being and social welfare (for more detailed argumentation, see van den Bergh 2009).

Therefore, 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 a slower pace of economic growth, the foregoing discussion suggests that 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 aimed at preventing extreme events implies avoidance of serious reductions in happiness, given that happiness directly depends on climate, i.e. it involves direct non-market effects on individuals and households. This means that the economic and welfare effects of climate change measured in GDP terms may underestimate the real impact on happiness. Especially extreme climate events are not easily captured by GDP or other monetary cost terms, as argued in Section 2. Extreme climate change will have a profound impact on local and regional sea levels, temperatures, and 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 affect the happiness of people in Western countries much, 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 high capacity for collective action.

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 use multiple regression analysis to show that climate variables have a highly significant effect on happiness. 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.

Welsch (2006) examines the relationship 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 $1,400 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 (2008) and Brereton et al. (2008). The shortcoming of many of the previous studies of the link between climate and happiness is that they consider small temperature changes or differences and give no attention to large changes or even extreme climate change or events. As a result, these studies may deliver an overly optimistic and insufficiently representative general picture of how people's happiness responds to climate change.

In translating the results of such studies, one might take into account the fact that the projected temperature change is largest for higher latitudes, so that happiness effects may be larger here; at lower latitudes with already high temperatures, the change is projected to be lower.

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 taxing income to stimulate leisure and temper "status games" with respect to 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). Brekke and Howarth (2002) have studied the interaction between status and environmental externalities and even apply this to the context of climate change. They find that ignoring status signalling in the analysis of public policy, in particular consumption and income taxes, will lead to significant biases in optimal tax rules. In addition, the inclusion of status in a climate-economy model shows that traditional policy analysis overvalues consumption and undervalues a stable climate.[19]

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 employs 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 to (social) welfare growth or human progress. This is inconsistent with both standard microeconomics and enlightened microeconomics

[19] The happiness perspective also affects the evaluation of other types of policies. 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 labor contracts. Although from a traditional economic growth perspective these look like bad measures, they are positively evaluated from a real welfare or happiness perspective.

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 (negatively) affected in their happiness, while later slowly recovering their old happiness level. However, such adaptation is difficult to imagine for extreme climate change and events. Finally, note that adopting a happiness approach may also affect the discount rate debate. The reason is that one would then be less inclined to discount as this would mean that the happiness of a person in the future would be valued less than that of a person living now. When more general, abstract notions like costs and benefits are employed instead, as in CBA studies, specific people and their happiness disappear from the picture, making the case for discounting easier to defend.

The happiness perspective has been given relatively much attention here. The reason is that it may well be the major alternative perspective to CBA on the cost of climate policy, one that is urgently needed in order to arrive at an accurate picture of what we really gain and sacrifice if we undertake a stringent, safe climate policy worldwide.

5.5 Perspective 5: comparison with large public investments: Iraq war, financial crisis, military R&D and sectoral subsidies

The cost of climate policy or more particularly of making solar PV a competitive technology might be seen as a large public project. This suggests a comparison with other public projects. Four large 'projects' will be considered, namely the Iraq war, combating the financial crisis, R&D investment in the military sector, and expenditures on subsidies to economic sectors.

Stiglitz and Bilmes (2008) have estimated the cost of the Iraq war to the United States to be at least US$3 trillion (3,000 billion). This excludes the cost to the rest of the world (notably the UK and Iraq, with an estimated 40–100,000 casualties). The Iraq 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 cost estimate for the Iraq war is much higher than the official number given by the Bush administration as this excludes relevant cost categories. The broad categories in the Stiglitz/Bilmes figure includes both 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 a similar magnitude, at least about US$1 trillion up to 2007, though including the cost to civilians and of reconstruction in Iraq. 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 makes the interesting remark that the US could have bribed Saddam Hussein by offering him and his family US$20 billion to leave Iraq, giving the Iraqi people US$50 billion, and on top of that save US$30 billion given that the cost of the war was ex ante (grossly under-) estimated at US$100 billion. The main message here is not that outlays on certain wars have been too large (that would be the theme of another paper), but that democratic societies have clearly shown a willingness to spend large amounts of money to avoid low-probability, high-impact catastrophes in the social realm.

Another interesting comparison is with the financial crisis in 2008/2009. The USA decided overnight to reserve US$700 billion to stabilize the US banking system. Governments in Europe are likely to have reserved a similar amount. For example, The Netherlands created a €20 billion fund 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 on Fortis Bank Belgium, and Luxemburg €2.5 billion on Fortis Bank Luxemburg. The UK spent about €44 billion to take a majority share in four large British banks to rescue them, namely HBOS, Royal Bank of Scotland, Barclays, and Lloyds TSB. In total, OECD countries may have invested more than US$2 trillion (2,000 billion) to stabilize the financial system. The urgency of this was evident in view of the threats the financial crisis posed on the world economy. One may argue that some of the guarantees offered by countries in response to the financial crisis 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 were willing to set aside so much money in response to a threat without the support of any cost–benefit analysis or any other type of pseudo-welfare optimization. Similarly, if the threats posed by climate change were recognized and translated into a similar investment in GHG emissions reduction and renewable energy, the most serious risks associated with climate change might be avoided. An important barrier may be that whereas we have negative experiences with financial crises in the past and are determined to avoid new ones, we humans lack similar experiences with extreme climate change in the past.

So governments worldwide are investing roughly US$5 trillion in the Iraq war and countering the financial crisis jointly. We can compare this with the range of climate policy cost estimates, i.e. 1–4% of world GDP (US$66 trillion in 2007), or 0.7–2.7 trillion US$, which is only 14–54% of the aforementioned 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 (Section 5.1 in this section), then as a proportion of the current investments in Iraq 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 problems of energy scarcity and climate change. If the cost of making solar PV competitive is compared only to the cost of the Iraq war, 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 on the Iraq war.

A third relevant comparison is with current expenditures by countries worldwide on military research, which is estimated to be roughly US$140 billion.[20] 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 1% of its GDP on military 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 expenditures on R&D has increased steadily over time.

[20]Private/civilian spending on R&D is estimated to be roughly ten times this amount.

These investments in military R&D are especially interesting as they suggest that governments are willing to undertake enormous investments in R&D even when there is no 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 investment 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 were to be spread over 10 years, then it would equal 5% of world expenditures on military research in the same period.

A final comparison is with current expenditures worldwide on direct (on-budget) and indirect (off-budget) subsidies to economic, resource-based sectors like agriculture, energy, and transport. In the period 1994–1998, more than US$1 trillion was spent worldwide on subsidies to these sectors (van Beers and van den Bergh 2009). Important subsidies include market price support, output payments, and input subsidies. For OECD countries, off-budget subsidies to the agricultural sector amounted to US$318 billion in 2002, which is 1.2% of the total OECD GDP. A lower bound estimate of energy subsidies (excluding external costs) for the EU-15 countries is US$37 billion. In the transport sector, most off-budget subsidies relate to road transport infrastructure, and for the world as a whole these are estimated to range from US$225 to 300 billion. The GATT and WTO trade rounds in the last 20 years led to subsidy reform but at a very slow pace, so the absolute and relative level of subsidies is still quite high. Although economists have written critically about subsidies, noting the harm they cause to social welfare and the environment, politicians have not been eager to systematically evaluate the net benefits of subsidies. The size of subsidy flows has additional relevance here, since an effective climate policy requires removal of the most environmentally harmful subsidies.

Evidently, the comparisons made under the current perspective do not deliver a sufficient argument for safe climate policy, but they should be seen in addition to some of the other perspectives offered in this section. Nor is the intention here to argue that precedent—notably, wasting money on public projects and wars—serves as an argument. Simply, for those stating that climate policy is (too) expensive and will bring about economic disaster, it is good to see things in a broader context.

5.6 Perspective 6: the current cost of energy is fairly low

Here it is argued that current fossil fuel-based energy (gasoline and electricity) is cheap, too cheap in view of associated negative externalities. The latter is especially true if the cost of CO_2 reflects extreme climate events and scenarios. Current studies estimate this cost to have an order of magnitude equal to €200–450 per ton emitted CO_2 (Kuik et al. 2008[21]; see also Section 2). This is even likely to be an underestimation as the studies on which it is based only partially address potential catastrophic scenarios.

[21] (Kuik et al. 2008, p. 5) state: "... the spread of MAC across observations is quite large: for 2025 the minimum and maximum estimates are €0.0 and €199.9 and for 2050 the spread is €1.4 to €449.3 per tonne of CO_2."

While the cost of energy sources has fluctuated over time, in part 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. Fouquet and Pearson (2006) show for the UK that in 2000 the cost of lighting was 1/3,000 of its 1,800 value, while during the same period income (purchasing power) had increased 15-fold. Of course, the falling cost of energy services (light, manufacturing, transport, and more recently various household appliances) has come with rebound effects (see Section 5.1) and an 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 25,000-fold increase in lighting consumption between 1,800 and 2,000. 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 light services alone dropped between 1,800 and 2,000 by a factor 25,000/(3,000 × 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 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. Even though energy is the fundamental input to all human economic activity, roughly 90% of income is spent on things other than energy. Moreover, continuous 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 measuring energy expenditures as a 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 rise. The shares can differ between low, middle, and high incomes from 15%, 5% and 2%, respectively. This suggests that for some people, energy use may represent a considerable expenditure, while for many it does not. Roberts (2008) regards households as "undoubtedly fuel poor" when they are spending more than 10% of their income on energy just to meet basic requirements. This 10% threshold may reflect, however, that we take a very low share of energy cost in income for granted simply because this is a historical fact. Income inequality does suggest, though, that a serious climate policy raising energy prices might need to be complemented by an income redistribution policy (e.g., as part of shifting taxes from labor to energy).

Another indication that the cost of energy is not very high or even low is that the long-term average oil price (US crude oil prices adjusted for inflation in 2006 US$), if calculated from 1869 to 2007, equals $21.66 per barrel for world oil prices, while during the same period 50% 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 in the oil price in 2007–2008 did not give rise to serious, sustained social unrest. This supports the belief that the cost of energy is not perceived as very high, and since then it has even come down a lot. This all means that there is room for safe climate policy, which will undoubtedly increase the price of energy. Admittedly, future 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 the combustion 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 renewable energy since the production of the latter depends on inputs of fossil fuel energy. In other words, the environmental gains of (endogenous) increases in 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 a fair amount of increase in energy costs due to climate policy without serious social repercussions.

5.7 Perspective 7: 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 balancing investment and R&D for many years to come: too much R&D will mean waiting too long for effective investments in reducing emissions; too little R&D will mean investing too quickly in less than mature—environmentally ineffective or overly expensive—technologies. The right balance has been cast in the literature as the exploration-versus-exploitation (March 1991) 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 on a significant scale. In the meantime investments will go to carbon-intensive fossil fuel technology and infrastructure+. The long-term perspective is also needed for making good choices about nuclear and carbon capture and storage: are they suitable as transition technologies or should we intend to move them further on their learning curves? A long-term angle will further affect choices between costly investments in energy efficiency improvements and renewable energy. Details of all these options were already discussed under Section 5.1.

Climate change policy is not a simple, one-dimensional policy or an instrument with a clear cost, rather a complex process of multilevel and multidimensional change involving the unlocking of a dominant, undesirable system of fossil fuel technologies and infrastructures, and 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 (prices reflecting real scarcity), innovation policies (including public investments), and specific unlocking policies (e.g., subsidy programs). A growing group of researchers is calling this approach a "social-technical transition to sustainability". It recognizes that in due time a stringent climate policy will 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-dimensional 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". Earlier, former US Vice-President and Nobel Peace laureate Al Gore made a similar call for a "global Marshall Plan". Various others have referred to the Manhattan Project and New Green Deal in this context. Even the US Bush administration expressed interest in directly stimulating energy-related R&D—rather than implementing stringent environmental (climate) regulation. Sufficient R&D on de-carbonized energy technologies and a transition to sustainable energy technologies are indeed not guaranteed by environmental regulation alone. One important reason is the lock-in features of fossil fuel energy and related technologies like vehicles with combustion engines.

Case studies of historical transitions show that a number of conditions need to be met 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 benefited greatly from public R&D, particularly investments in military R&D. Notable in this respect are information and communication technologies (ICT), supporting technologies like solid state electronics, semi-conductors, transistors, integrated circuits, data transmission networks, and of course basic software codes. All these have received massive funding from the (American) military complex, usually with the motivation of the Cold War. In many countries, agriculture also has received a great deal of 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, financial compensation for taking out land, public investment in land consolidation, and the creation and maintenance of drainage systems. This was motivated by a strong urge to achieve food security and self-sufficiency. Similarly, if one recognizes a stable climate as a basic condition for human life and activity, one needs to seriously invest in it.[22] But perhaps reducing dependence on imported oil is a more effective motivation for fundamental changes in the energy sector. This is in any case illustrated by the transition to nuclear energy in France during the 1970s (after the oil crisis), and more recently by government support for bio-ethanol agriculture in the US.

5.8 Perspective 8: behavior, learning and substitution

Closely related to the previous transition perspective is a behavioral perspective. Economists are generally optimistic about prices as signals of scarcity that stimulate appropriate changes in households' and firms' behavior. Their model assumptions may well underestimate individuals' actual responses 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 limits of empirical data. Notably, stringent climate policy moves prices outside ranges historically observed, so that, for instance, the empirical price elasticities of demand may underestimate potential responses. Aggregation is relevant as shown by meta-analyses of different model studies, which indicate particularly that inclusion of more

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

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, models often do not reflect the fact that in the long run people can change fundamental choices that affect their energy use. For example, road pricing (or toll roads) 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 they drive (outside peak hours), carpooling, using other means of transport (walking, biking, public transport), traveling less, being more efficient in combining trips, and in the longer run changing jobs or houses to reduce commuting distances.

Behavior is not adequately dealt with in current climate policy analyses, since they mostly assume that agents behave rationally in the sense of perfectly maximizing utility or profits (Laitner et al. 2000; Gowdy 2008; Brekke and Johansson-Stenman 2008). However, people may act as citizens or as consumers, which are more characterized by habits, imitation, social pressure (in terms of both status and conformity), cooperation, and altruism, whereas 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 consumer and producer 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. 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 entail mostly an incomplete assessment of the motivations and factors behind behaviors like waste collection, energy conservation, and a 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 (partial or general) equilibrium-type economic analyses 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 the behavior of firms and individuals is learning and innovation. 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 supply-demand interactions (learning-by-implementing, such as integrating PV systems into buildings, on roofs, which involves institutional structures such as for financing and equipment maintenance). Feedback from users to producers and from products to processes, along with systemic improvements (adjustment of all elements, such as institutions, markets, integrated building components, production chain) lead 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, some types of bounded rationality may lead to higher estimates for certain policy cost categories than the 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 what they regard as main activities or investments, which does not include energy conservation (DeCanio 1998); and habitual behavior has also been suggested as an explanation. 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; Brekke and Johansson-Stenman 2008).

5.9 Perspective 9: ancillary benefits

As discussed in Section 2, CBA studies of climate policy have omitted many benefits or avoided cost categories. 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 sulfur dioxide). For example, HEAL (2008) estimates that if the European Union raised 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 from health savings arising from an associated reduction in emissions of fine particles, nitrogen oxide, and sulfur dioxide.

All avoided cost categories in CBA studies of climate policy can be regarded as ancillary benefits. An important one is avoidance of human conflict due to climate change. Such conflict would be stimulated, for example, if climate change causes water to become scarcer and agriculture to loose productivity, which may result in increasing land pressure and migration. Although it is difficult to definitely prove, the Darfur crisis has been attributed to less rainfall due to climate change. Population pressure in Sahel countries like Sudan may already have gone beyond the carrying capacity in view of low agricultural productivity, making these countries extremely vulnerable to even slow changes in climate conditions.

Another category of ancillary benefits of climate policy is omitted large-scale biodiversity loss. This is enhanced by shifting climate zones from which certain species cannot escape. Synergy between multiple causes of biodiversity loss—including also overexploitation, hunting, fragmentation due to land use and road infrastructure, invasion of exotic species, and environmental pollution—adds to the direct or pure impact of climate change on biodiversity loss.

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 (renewable) 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, namely wealth transfer to OPEC, cost of strategic petroleum reserve, total GNP loss due to price shocks and shortages, and military costs. This resulted in an estimated cost ranging from about US$150 to 400 billion per year (1990$) during the period 1974–1985 (Green and Leiby 1993).

Ancillary benefits further arise when adaptation options are being created as a result of mitigation activities. One example is that planting forests to capture CO_2 will in turn allow for protection of biodiversity, water regulation, and reduced vulnerability to flooding or storms.

Finally, reducing GHG emission through taxes generates tax revenues which can be used to reduce distorting taxes on capital and especially labor. Even though the debate on the double dividend of shifting taxes from labor to environment suggests that one should not hope for too large effects of this kind, some positive effects are likely. Notably, the employment benefits due to fewer tax distortions in labor markets are robust, even though in welfare terms they are considerably smaller than the associated environmental benefits (de Mooij 1999; Patuellia et al. 2005).

An argument against considering certain ancillary benefits in climate policy evaluation is that they might have been achieved more directly and cheaply by specific, appropriate policies (e.g., acid rain policy). However, whenever the side effects are an inevitable consequence of the climate policy under consideration, one can regard them as efficient and relevant to the evaluation of this policy.

5.10 Perspective 10: 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. (2009) 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 may deliver overestimates. First, information on actual costs is often provided by firms having an interest or stake. As a result, those being regulated may provide overly high estimates of individual abatement costs. This can be due to strategic behavior to resist implementation of stringent regulations, or simply to individual uncertainty about (future) abatement costs. Standard environmental economics somehow recognizes these problems, regarding price regulation as having the advantage that it decentralizes the problem of environmental regulation, and not requiring governments to have full information about pollution abatement technologies and associated costs (Baumol and Oates 1988). A second reason for ex ante overestimates is that they may neglect or underrate the potential for reduction of abatement costs through polluters' innovation, learning, and adaptation. As this was already discussed in Sections 4 and 5.8, we will not enter into further details here.

5.11 Perspective 11: international cooperation and agreements

An additional important factor influencing 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 technological diffusion.

If international agreements are absent or weakly constrain individual countries, vast differences in policy may exist between countries. As a result, the costs of stringent climate policy for industries or consumers may be high since it will mean a loss in the international competitive position of industries as well as leakage of emissions from countries with stringent to those with less stringent policies. Instead, a stringent climate policy agreed upon by all countries in the world would mean a level playing field that reduces the policy cost, as competitive disadvantages and emission spill-over is avoided (Neuhoff 2006).

The relationship between policy cost and international cooperation is like a vicious circle. As long as 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 because of the loss of competitive position. One way out is to design clever strategies in negotiations 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 a safe level); they entailed no restrictions whatsoever for Germany (unification) and Russia (economic collapse); and they do not bind all developing countries or the largest economy on the planet (USA).

Brekke and Johansson-Stenman (2008) argue that taking into account social preferences (a form of bounded rationality) implies that successful international agreements are estimated as being more likely than when assuming purely selfish motives. This may involve altruistic rewards and punishment, reciprocity, the greater altruistic capacity of teams than of individuals (think of climate negotiating teams), shame, and citizen (voting) rather than consumer behavior. Unfortunately, bounded rationality may also involve opposite effects. Brekke and Johansson-Stenman mention as an example ‘cognitive dissonance’, i.e. inconsistency between beliefs and behaviors causing an uncomfortable psychological tension which can sometimes lead to a change in beliefs rather than behavior, so the two match up. With regard to climate change, some people who (indirectly) cause many GHG emissions may show such ‘cognitive dissonance’ by denying or playing down the facts and risks of climate change.

5.12 Perspective 12: lack of insurance against climate change

Currently, private insurance with premiums that reflect the risk of extreme events like those possibly caused by climate change, such as flooding and hurricanes, is largely lacking in most countries (Botzen and van den Bergh 2008). This has three consequences for judging the cost of climate policy. First, it means that there is no efficient sharing of climate-related risks which would reduce the overall costs of the consequences of both climate change and climate policy. Second, the absence of insurance means that appropriate incentives for adequate adaptation to climate risks and changes is lacking. Third, it also means disoptimal incentives for stimulating producers, consumers, (re)insurance companies, and even governments to efficiently reduce greenhouse gas emissions. At present, insurers are already actively involved in promoting reductions in greenhouse gas emissions (Botzen et al. 2009). Such efforts are likely to become stronger if more climate change risks were covered through private insurance. Both insured and insurers have incentives to limit climate risk in case increases in the frequency and severity of natural hazards are reflected in a 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 mitigation policy may need to be less stringent and thus less expensive. In other words, with adequate insurance arrangements in the face of climate-related risks, safe climate mitigation 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 a policy includes incentives for insurance companies to undertake these arrangements, then the cost of climate policy will be lower than without such arrangements. This is likely not a large effect, but for completeness one should take it into consideration.[23]

Table 1 summarizes the perspectives.

6 Conclusions

This paper has argued that both cost–benefit analysis and cost assessment or accounting of climate policy using quantitative models are overly ambitious, despite the fact that we can evidently learn much from them. The multi-perspective approach to evaluating the cost of a safe, precautionary 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 analyses of climate policy. Indeed, if climate policy is seen as a precautionary strategy to avoid unpredictable and irreversible natural as well as economic catastrophes rather than as a way to optimize social welfare (or GDP growth) in the face of GHG emission–climate–economic damage feedback, then a focus on qualitative risk analysis and cost assessment of climate policy makes more sense than a quantitative cost–benefit analysis. This is true both for methodological reasons—CBA possibly represents an overly risk-loving decision-maker—and for practical reasons—quantification of extreme events with small probabilities simply is not feasible.

The paper has tried to credibly defend, using various arguments, that a safe or precautionary approach to climate policy is indeed rational. The twelve perspectives trying to assess the cost of a safe climate policy together provide a strong case for

[23] 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 by the US Department of Energy on energy technology, which was about $1.5 billion per year in 1999, to argue that a higher 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 developments in GHG emissions, climate change, and oil prices since then.

Table 1 An overview of the 12 perspectives on the cost of a safe climate policy

Perspective	Main insight	Proviso
Extrapolating learning curves for renewable energy	Learning curve of solar PV looks promising.	No problem-free renewable source. Solar technologies (PV and CHP) offer many advantages.
	Extrapolation of learning curve leads to middle estimate of US$60 with an uncertainty range of US$30–300.	Cost decreases are no free lunch but require investments in private and public R&D and public policies like subsidies.
	Concentrated solar (heat) power (CSP) seems a neglected technology.	Sensitivity of extrapolated costs requires careful monitoring of cost dynamics and appropriate adjustment of incentives (e.g., subsidies).
Global climate policy cost normalized by OECD GDP	If solar PV investment spread over ten years, cost is 0.017% of GDP (with uncertainty range 0.008–0.17%).	If technological innovation is slower then high cost estimate applies for a longer period.
	If policy cost range of IPCC used (1–4% of world GDP) then cost to OECD for first 10 years is 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.	
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 3 years if GDP growth is 2%. This is hardly noticeable in terms of spending power.	
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 raise or hardly raises happiness.	People may adapt to a changed climate in the sense of being initially affected (negatively) in their happiness, while later slowly recovering their former level of happiness.
	GDP effect of climate change (no climate policy) underestimates impact on happiness effect (non-market effects), especially in poor countries.	

Comparison with large public investments: Iraq war, financial crisis, military R&D and sectoral subsidies	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 Iraq war for the USA. One can also compare with the cost of government responses to the financial crisis, since just like climate policy it responds 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 over 10 years, then it would cost only 5% of world expenditures on military research in that period. In 2 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. In the period 1994–1998, more than US$1 trillion was spent worldwide on sectoral subsidies.	
The 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 light services alone 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 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.	If the price of fossil fuel energy goes up due to climate policy, renewable energy will become more expensive since its production depends on fossil fuel energy inputs.

Table 1 (continued)

Perspective	Main insight	Proviso
	The cost of oil has been quite low during the last decade, except during a a short period in 2007–2008. If calculated from 1869 to 2007, the average (US crude oil prices adjusted for inflation in 2006 US$) equals $21.66 per barrel for world oil prices, while during the period 50% of the time world prices were below the median oil price of $16.71 per barrel, and for the post-1970 period the equivalent indicators are $32.23 and $26.50	
Stimulating a fundamental social–technical transition	Going beyond cost–benefit thinking; the aim is an entirely different world that cannot be compared with the current world in terms of mere cost and benefits.	Escaping from lock-in is difficult and costly.
	Climate change policy is not about a simple policy instrument with a clear cost but a complex process of multilevel and multidimensional institutional 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 (subsidy programs).	A sustainable energy system will likely require a much larger share of labor going to energy supply (exploration, production) than now.
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, is missing in most economic models; many ways of individual, group, and system learning are 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 is lacking.
Ancillary benefits	Reduction of GHG emissions can go along with reductions in other emissions, notably acidifying substances (nitrogen oxides and sulfur dioxide); avoidance of human conflict due to climate change; omitted large-scale biodiversity loss due to shifting climate zones; combating GHG emissions by new (renewable) energy sources 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 fewer tax distortions in labor markets.	Certain studies assessing climate policy costs take some of these ancillary benefits (partly) into account.

Upward bias in ex ante regulation cost estimates	Ex ante assessments of policy costs may deliver overestimates for two reasons: information on actual costs often comes from those having an interest or stake, who strategically may provide overly 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 unforeseen learning, innovation, and adaptation by polluters.	Also certain downward biases, but probably less important.
International cooperation and agreements	Without an international climate agreement, policy differences have a high cost for industries and consumers in countries with stringent regulation. Level playing field due to joint agreement reduces national policy cost.	
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.	

the view that such a policy is affordable and cheaper than most previous studies have suggested. This is subject to the usual conditions and provisos: 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 precisely aimed at putting the cost in a particular context, such as comparing it with the GDP of OECD countries or with expenditures on other large public projects, arguing that (national) expenditures on energy are not very high, and interpreting climate policy from the angle of human happiness rather than economic (GDP) growth.

The happiness or subjective well-being perspective on the cost of climate policy emerges as possibly the most important new view. It is pertinent to 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. The discussion of this perspective showed that the implications may be quite different for rich and poor countries. Climate policy may have a cost in the sense of slowing down the rate of GDP growth, thus reaching a given level of GDP just a few years later in the distant future (Section 5.3). Happiness research (Section 5.4) 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 to avoid extreme events means preventing serious reductions in happiness. Such reductions are not captured or are insufficiently captured by GDP analyses as these events involve many non-market effects related to extreme and highly uncertain 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 be threatened. 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. Therefore, in terms of happiness or real welfare, climate policy looks much less expensive than in terms of lost GDP, while climate change causing catastrophes may be evaluated as much more expensive in terms of happiness than in terms of GDP.

Finally, on the basis of various quantitative indicators it was argued that energy is currently not very expensive (Section 5.6), so there is considerable leeway for increasing its price through climate policy. Indeed, an effective and safe climate policy cannot avoid raising energy prices considerably, certainly if one wants to reduce the rebound effects of energy conservation and efficiency improvements and stimulate a transition to renewable energy sources.

Of course, while the costs of a safe climate policy may be manageable at global and national levels, as argued here, such a policy will pose serious challenges for particular economic sectors. But this is entirely logical and acceptable, since higher energy costs will regulate and restructure the economy and affect energy-intensive products, processes, firms, and industries relatively severely. Higher energy prices and costs will thus set into motion a process of creative destruction, which is an inevitable component in the transition to a low-carbon economy. Postponing such a transition will only make it more expensive, while safe levels of atmospheric GHG concentration will get out of reach. In other words, the optimal timing of a safe climate policy is right now.

Acknowledgements Wouter Botzen, Laurens Bouwer, Frank Geels, John Gowdy, Stijn van den Heuvel, Richard Tol and two anonymous reviewers provided useful suggestions.

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