WORKING PAPER
2009-07

REPA

Resource Economics
& Policy Analysis
Research Group

Department of Economics
University of Victoria

The Economics and Policy of Global Warming

G. Cornelis van Kooten, E. Calvin Beisner and Pete Geddes

December 2009

REPA Working Papers:

2003-01 – Compensation for Wildlife Damage: Habitat Conversion, Species Preservation and Local Welfare (Rondeau and Bulte)
2003-02 – Demand for Wildlife Hunting in British Columbia (Sun, van Kooten and Voss)
2003-03 – Does Inclusion of Landowners' Non-Market Values Lower Costs of Creating Carbon Forest Sinks? (Shaikh, Suchánek, Sun and van Kooten)
2003-04 – Smoke and Mirrors: The Kyoto Protocol and Beyond (van Kooten)
2003-05 – Creating Carbon Offsets in Agriculture through No-Till Cultivation: A Meta-Analysis of Costs and Carbon Benefits (Manley, van Kooten, Moeltne, and Johnson)
2003-06 – Climate Change and Forest Ecosystem Sinks: Economic Analysis (van Kooten and Eagle)
2003-07 – Resolving Range Conflict in Nevada? The Potential for Compensation via Monetary Payouts and Grazing Alternatives (Hobby and van Kooten)
2003-08 – Social Dilemmas and Public Range Management: Results from the Nevada Ranch Survey (van Kooten, Thomsen, Hobby and Eagle)
2004-01 – How Costly are Carbon Offsets? A Meta-Analysis of Forest Carbon Sinks (van Kooten, Eagle, Manley and Smolak)
2004-02 – Managing Forests for Multiple Tradeoffs: Compromising on Timber, Carbon and Biodiversity Objectives (Krcmar, van Kooten and Vertinsky)
2004-03 – Tests of the EKC Hypothesis using CO2 Panel Data (Shi)
2004-04 – Are Log Markets Competitive? Empirical Evidence and Implications for Canada-U.S. Trade in Softwood Lumber (Niquidet and van Kooten)
2004-05 – Conservation Payments under Risk: A Stochastic Dominance Approach (Benítez, Kuosmanen, Olschewski and van Kooten)
2004-06 – Modeling Alternative Zoning Strategies in Forest Management (Krcmar, Vertinsky and van Kooten)
2004-07 – Another Look at the Income Elasticity of Non-Point Source Air Pollutants: A Semiparametric Approach (Roy and van Kooten)
2004-08 – Anthropogenic and Natural Determinants of the Population of a Sensitive Species: Sage Grouse in Nevada (van Kooten, Eagle and Eiswerth)
2004-09 – Demand for Wildlife Hunting in British Columbia (Sun, van Kooten and Voss)
2004-10 – Viability of Carbon Offset Generating Projects in Boreal Ontario (Biggs and Laaksonen-Craig)
2004-11 – Economics of Forest and Agricultural Carbon Sinks (van Kooten)
2004-12 – Economic Dynamics of Tree Planting for Carbon Uptake on Marginal Agricultural Lands (van Kooten) (Copy of paper published in the Canadian Journal of Agricultural Economics 48(March): 51-65.)
2004-13 – Decoupling Farm Payments: Experience in the US, Canada, and Europe (Ogg and van Kooten)
2004–14– Afforestation Generated Kyoto Compliant Carbon Offsets: A Case Study in Northeastern Ontario (Biggs)
2005–01– Utility-scale Wind Power: Impacts of Increased Penetration (Pitt, van Kooten, Love and Djilali)
2005–02 –Integrating Wind Power in Electricity Grids: An Economic Analysis (Liu, van Kooten and Pitt)
2005–03 –Resolving Canada-U.S. Trade Disputes in Agriculture and Forestry: Lessons from Lumber (Biggs, Laaksonen-Craig, Niquidet and van Kooten)

2005–04–Can Forest Management Strategies Sustain the Development Needs of the Little Red River Cree First Nation? (Krcmar, Nelson, van Kooten, Vertinsky and Webb)
2005–05–Economics of Forest and Agricultural Carbon Sinks (van Kooten)
2005–06– Divergence Between WTA & WTP Revisited: Livestock Grazing on Public Range (Sun, van Kooten and Voss)
2005–07 –Dynamic Programming and Learning Models for Management of a Nonnative Species (Eiswerth, van Kooten, Lines and Eagle)
2005–08 –Canada-US Softwood Lumber Trade Revisited: Examining the Role of Substitution Bias in the Context of a Spatial Price Equilibrium Framework (Mogus, Stennes and van Kooten)
2005–09 –Are Agricultural Values a Reliable Guide in Determining Landowners' Decisions to Create Carbon Forest Sinks?* (Shaikh, Sun and van Kooten) *Updated version of Working Paper 2003-03
2005–10 –Carbon Sinks and Reservoirs: The Value of Permanence and Role of Discounting (Benitez and van Kooten)
2005–11 –Fuzzy Logic and Preference Uncertainty in Non-Market Valuation (Sun and van Kooten)
2005–12 –Forest Management Zone Design with a Tabu Search Algorithm (Krcmar, Mitrovic-Minic, van Kooten and Vertinsky)
2005–13 –Resolving Range Conflict in Nevada? Buyouts and Other Compensation Alternatives (van Kooten, Thomsen and Hobby) *Updated version of Working Paper 2003-07
2005–14 –Conservation Payments Under Risk: A Stochastic Dominance Approach (Benítez, Kuosmanen, Olschewski and van Kooten) *Updated version of Working Paper 2004-05
2005–15 –The Effect of Uncertainty on Contingent Valuation Estimates: A Comparison (Shaikh, Sun and van Kooten**)**
2005–16 –Land Degradation in Ethiopia: What do Stoves Have to do with it? (Gebreegziabher, van Kooten and.van Soest)
2005–17 –The Optimal Length of an Agricultural Carbon Contract (Gulati and Vercammen)
2006–01 –Economic Impacts of Yellow Starthistle on California (Eagle, Eiswerth, Johnson, Schoenig and van Kooten)
2006–02 -The Economics of Wind Power with Energy Storage (Benitez, Dragulescu and van Kooten)
2006–03 –A Dynamic Bioeconomic Model of Ivory Trade: Details and Extended Results (van Kooten)
2006–04 –The Potential for Wind Energy Meeting Electricity Needs on Vancouver Island (Prescott, van Kooten and Zhu)
2006–05 –Network Constrained Wind Integration: An Optimal Cost Approach (Maddaloni, Rowe and van Kooten)
2006–06 –Deforestation (Folmer and van Kooten)
2007–01 –Linking Forests and Economic Well-being: A Four-Quadrant Approach (Wang, DesRoches, Sun, Stennes, Wilson and van Kooten)
2007–02 –Economics of Forest Ecosystem Forest Sinks: A Review (van Kooten and Sohngen)
2007–03 –Costs of Creating Carbon Offset Credits via Forestry Activities: A Meta-Regression Analysis (van Kooten, Laaksonen-Craig and Wang)
2007–04 –The Economics of Wind Power: Destabilizing an Electricity Grid with Renewable Power (Prescott and van Kooten)
2007–05 –Wind Integration into Various Generation Mixtures (Maddaloni, Rowe and van Kooten)
2007–06 –Farmland Conservation in The Netherlands and British Columbia, Canada: A Comparative Analysis Using GIS-based Hedonic Pricing Models (Cotteleer, Stobbe and van Kooten)

2007–07 –Bayesian Model Averaging in the Context of Spatial Hedonic Pricing: An Application to Farmland Values (Cotteleer, Stobbe and van Kooten)
2007–08 –Challenges for Less Developed Countries: Agricultural Policies in the EU and the US (Schure, van Kooten and Wang)
2008–01 –Hobby Farms and Protection of Farmland in British Columbia (Stobbe, Eagle and van Kooten)
2008-01A-Hobby Farm's and British Columbia's Agricultural Land Reserve (Stobbe, Eagle, Cotteleer and van Kooten)
2008–02 –An Economic Analysis of Mountain Pine Beetle Impacts in a Global Context (Abbott, Stennes and van Kooten)
2008–03 –Regional Log Market Integration in New Zealand (Niquidet and Manley)
2008–04 –Biological Carbon Sequestration and Carbon Trading Re-Visited (van Kooten)
2008–05 –On Optimal British Columbia Log Export Policy: An Application of Trade theory (Abbott)
2008–06 –Expert Opinion versus Transaction Evidence: Using the Reilly Index to Measure Open Space premiums in the Urban-Rural Fringe (Cotteleer, Stobbe and van Kooten)
2008–07 –Forest-mill Integration: a Transaction Costs Perspective (Niquidet and O'Kelly)
2008–08 –The Economics of Endangered Species Poaching (Abbott)
2008–09 –The Ghost of Extinction: Preservation Values and Minimum Viable Population in Wildlife Models (van Kooten and Eiswerth)
2008–10 –Corruption, Development and the Curse of Natural Resources (Pendergast, Clarke and van Kooten)
2008–11 –Bio-energy from Mountain Pine Beetle Timber and Forest Residuals: The Economics Story (Niquidet, Stennes and van Kooten)
2008-12 –Biological Carbon Sinks: Transaction Costs and Governance (van Kooten)
2008-13 –Wind Power Development: Opportunities and Challenges (van Kooten and Timilsina)
2009-01 –Can Domestication of Wildlife Lead to Conservation? The Economics of Tiger Farming in China (Abbott and van Kooten)
2009-02 – Implications of Expanding Bioenergy Production from Wood in British Columbia: An Application of a Regional Wood Fibre Allocation Model (Stennes, Niquidet and van Kooten)
2009-03 – Linking Matlab and GAMS: A Supplement (Wong)
2009-04 – Wind Power: The Economic Impact of Intermittency (van Kooten)
2009-05 – Economic Aspects of Wind Power Generation in Developing Countries (van Kooten and Wong)
2009-06 – Niche and Direct Marketing in the Rural-Urban Fringe: A Study of the Agricultural Economy in the Shadow of a Large City (Stobbe, Eagle and van Kooten)
2009-07 – The Economics and Policy of Global Warming (van Kooten, Beisner and Geddes)

For copies of this or other REPA working papers contact:
REPA Research Group
Department of Economics
University of Victoria PO Box 1700 STN CSC Victoria, BC V8W 2Y2 CANADA
Ph: 250.472.4415
Fax: 250.721.6214
www.vkooten.net/repa

The Economics and Policy of Global Warming

G. Cornelis van Kooten, E. Calvin Beisner and Pete Geddes[1]

1. INTRODUCTION

All interesting and important policy questions involve choosing among competing values. Does climate change demand drastic and immediate action? If so, at what cost? How willing are we to give up inexpensive fossil fuel energy and accept the consequences? However well intended, it is naïve and irresponsible to ignore the unavoidable tradeoffs.

Along with the tradeoffs come opportunity costs. The best measure of cost is the opportunities forgone, i.e., the value of alternatives sacrificed. Money spent to combat climate change cannot be spent to eradicate malaria (which kills 2 million people per year, mostly children under 5), to improve female literacy (perhaps the key investment for social progress), to fight hunger, malnutrition and communicable diseases, or to build roads, electric power plants and grids, and water and sewage treatment plants.

The world is discovering that combating climate change will be extremely difficult and expensive. It is especially vexing because:

- The atmosphere is a commons with unrestricted access. The benefits of burning fossil fuels accrue to individuals, but the costs of emissions are borne by all. This makes climate change the mother of all collective action problems. It requires the cooperation of others who often have different interests and incentives.
- The costs and benefits of climate change and of its mitigation will be unequally distributed. This means different countries will bargain strategically to advance their perceived interests.
- Carbon dioxide is a persistent atmospheric resident. If overnight we eliminated every source of manmade CO_2, the atmosphere could continue warming for 100 years or more.
- If current trends continue, developing countries will quite soon become the largest emitters. (China has already become number one.) Their leaders understand that increasing energy consumption is a prerequisite for continued economic development—and, because of cost and availability, the fuels of choice will likely be carbon based.
- Reducing emissions fast enough and far enough to avoid allegedly dangerous human interference with the climate system requires an unprecedented transformation of energy systems. For example, to cut global emissions in half by 2050 requires that, on average, the world economy will then have the same carbon intensity as Switzerland had in 2004—an immense and unprecedented challenge to national and international institutions.

It's clear: Whether anthropogenic or natural, whether dangerous or benign, climate

[1] The authors wish to thank Adel Abadeer, P. J. Hill, Tracy Miller, Shawn Ritenour, Timothy Terrell and Charles van Eaton for helpful comments on earlier drafts to this paper, although any remaining errors should not be attributed to them.

change is inevitable. Our challenge is to deal with it responsibly. This section offers suggestions on how we might begin.

2. CLIMATE CHANGE POLICY

Some scientists, like Sir John Houghton, a former co-chair of the Scientific Assessment Working Group of the United Nations' Intergovernmental Panel on Climate Change (IPCC), and influential public figures, like former American Vice President Al Gore, assert that dangerous anthropogenic global warming (DAGW) is the greatest threat to civilization. Former President Bill Clinton has said, "I worry about climate change. It's the only thing that I believe has the power to fundamentally end the march of civilization as we know it, and make a lot of the other efforts that we're making irrelevant and impossible."[2]

With some exceptions, economists take the view that, because meteorological, atmospheric and oceanic sciences are outside their realm of expertise, they should accept such warnings without qualification. While their humility is admirable, it is not economists' only justified response. As economist and Czech President Vaclav Klaus points out (Klaus 2008), though economists are not climate scientists, they are trained in the use of mathematical models and know what is necessary for models to be useful in predicting the future. They can recognize when models misuse data or statistical methodology and fail the basic test of falsifiability. Models that predict DAGW do just that by assuming the results of climate models that are plagued by literally hundreds of 'parameters' (variables whose values are unknown and must be supplied by little better than guesswork) and unverified, sometimes falsified assumptions about how climate works.

Nonetheless, as noted, few economists challenge the scientists' claims. Instead, they assume DAGW and then attempt to analyze its costs and benefits, searching for an optimal economic response. William Nordhaus of Yale University summarizes this approach as follows:

> "Global warming is a serious, perhaps even a grave, societal issue [and] there can be little scientific doubt that the world has embarked on a major series of geophysical changes that are unprecedented in the past few thousand years. … A careful look at the issues reveals that there is at present no obvious answer as to how fast nations should move to slow climate change. Neither extreme—either do nothing or stop global warming in its tracks—is a sensible course of action. Any well-designed policy must balance the economic costs of actions today with their corresponding future economic and ecological benefits" (Nordhaus 2008, pp.1-2).

In a series of books and articles (e.g., Nordhaus 1991, 1994, 2008), Nordhaus concludes that the effort spent on mitigation should attempt to slow DAGW relative to what it would otherwise be but not stop it, and that controls on emissions should ramp up (become more stringent) over time. Consequently, he concludes that an optimal carbon tax should rise from $9.50 per ton of CO_2 in 2005 to about $25 in 2050 and $56 in 2100—or 12¢ per gallon of

---

[2] All quotes here and elsewhere in this paper that are not otherwise cited can be found at (as viewed July 20, 2009): http://www.c3headlines.com/global-warming-quotes-climate-change-quotes.html and/or http://www.laurentian.ca/Laurentian/Home/Research/Special+Projects/Climate+Change+Case+Study/Quotes/Quotes.htm?Laurentian_Lang=en-CA

gasoline in 2005 to nearly 70¢ by 2100 (Nordhaus 2007a, 2008).[3,4] This optimal path for a carbon tax is predicated on unmitigated damages from climate change that amount to nearly 3% of global output in 2100 and 8% by 2200. Three scenarios of projected damages from different assumed variables that Nordhaus inserted into his model appear in Table 1. It is important to note that these are calibrations, not statistical evidence, so they really amount to nothing more than an assumed relation between temperature increase and economic damages based on projections of possible damages in specific sectors (such as agriculture), and each of these sectoral analyses has its own sometimes dubious assumptions regarding the relationship between projected climate change and damages. Also, Nordhaus fails to take adequately into account a fundamental truth of economics: People respond to incentives, so adaptations are likely to reduce or eliminate much of the damage even if the warming occurs as projected.

Table 1: Modeled relation between temperature rise and damages

Temperature rise	Damages as proportion of global output		
	Worst case	Mid case	Best case
0 ^{o}C	0.00%	0.00%	0.00%
1 ^{o}C	0.32%	0.28%	0.10%
2 ^{o}C	1.27%	1.14%	0.58%
2.5 ^{o}C	1.98%	1.77%	1.01%
3 ^{o}C	2.85%	2.55%	1.60%
4 ^{o}C	5.07%	4.54%	3.28%
5 ^{o}C	7.93%	7.10%	5.74%
6 ^{o}C	11.41%	10.22%	9.05%

Source: Nordhaus (2007b)

A recent critique by Murphy (2009) of Nordhaus's model found that it probably overstated future greenhouse gas concentrations, climate sensitivity (the temperature increase to be expected from doubled CO_2 concentration after feedbacks), and the expected damages from any given temperature increase. It also argued that Nordhaus's model incorporated an unjustifiable 'catastrophic impact' component that unrealistically raised risk projections. Eliminating that component and reducing climate sensitivity from Nordhaus's (and the IPCC's) 3.0° C to a more defensible 2.5° C (a 17% reduction) resulted in reducing the optimal carbon tax in any given year by 77 percent (e.g., from $41.90 to $9.46 per ton in 2015, and from $137.82 to $30.62 per ton in 2075). If the studies cited in the science section of this document pointing toward climate sensitivity of about 0.5° C (83% reduction from Nordhaus and the IPCC) are

[3] Values are in real 2005 purchasing power US dollars.

[4] CO_2 is considered the most important greenhouse gas and other GHGs are generally measured in terms of their CO_2 equivalence, denoted $CO_{2\text{-}e}$. For convenience, we will simply use CO_2 to refer to carbon dioxide plus other greenhouse gases measured in terms of their CO_2 equivalence.

correct, the justification for a carbon tax effectively disappears.

In contrast to the approaches used by Nordhaus (1994, 2008) and Tol (2002), which rely on integrated assessment models, Goklany (2009) measures the impacts of projected global warming on human risks, mortality and ecosystems using a bottom-up approach. Surprisingly, he is one of the few who begin with the IPCC's (2000) emission scenarios, which are the principal driver of fears of DAGW (see also Tol 2005a). Goklany provides a brief description of four key scenarios in the first eleven rows of Table 2. The scenarios indicate the range of possible greenhouse gas emissions for different economic development trajectories if nothing is done to mitigate climate change and include assumptions about technological change, land use changes, and the energy mix. The final three rows summarize Goklany's (2009) estimates of the associated changes in mortality, changes in populations at risk due to water stress, and losses of coastal wetlands.

The crucial thing to note about Goklany's scenarios is the projected increase in per capita GDP (measured in 2005 US dollar equivalents). *All scenarios foresee substantial increases in wealth*. Even the scenario leading to the lowest increase in income (scenario A2) and highest increase in population would have those living in developing countries producing more than $16,000 per person, equivalent to standards existing in some eastern European countries today. Two scenarios (A1F1 and B1) see those in developing countries with incomes equivalent to those in rich countries today, while those in rich countries will see a doubling of their real incomes. The negative impacts of climate change are offset by rising incomes, so much so that the overall climate impact is essentially negligible. Among the scenarios, *the greatest damages occur for the situation where people are poorest—no matter what the climate*.

Goklany (2009) also reports that net biome productivity will increase as a result of climate change and less wildlife habitat will be converted to cropland as a result of global warming, a finding similar to that of Sohngen, Mendelsohn and Sedjo (1999). Finally, compared to mitigation through emissions reductions, Goklany finds that targeted adaptation can yield large benefits. This implies that adaptation, not mitigation, is the optimal policy response. Nonetheless, the demand continues for mitigation.

In addition to the idea of a policy ramp, economists who (like Goklany) accept IPCC projections of DAGW and (unlike Goklany) favor mitigation over adaptation almost unanimously prefer market incentives, particularly a carbon tax that uses proceeds to reduce other taxes (thus making it revenue neutral), as the means of reducing greenhouse gas emissions. A carbon tax would theoretically lead to higher well-being as the economic distortions caused by other taxes would be reduced—the so-called double dividend of a green tax. It could also increase employment (see Bovenberg and Goulder 1996). As Nordhaus's work indicated, the optimal mitigation policy would be to impose a carbon tax set low to begin with and then slowly increased over time. One compelling reason for a tax is to avoid getting locked into an emission-reduction technology that might prove inferior to another option yet to be developed. For example, one would not want to lock into the hydrogen economy with its network of transmission lines and fueling stations in case a much better option, such as a competitive electric vehicle capable of going 200 km or more on a single charge, should come along. Doing so might be prohibitively expensive and militate against the development of such an electric vehicle.

Table 2: Selected emission scenarios used to drive projections of global warming and the projected impact on population and ecosystem health

	IPCC Scenarios			
Item	A1F1	A2	B2	B1
Population ($\times 10^9$) in 2085	7.9	14.2	10.2	7.9
Average global per capita GDP in 2085 ($)[a]	78,600	19,400	29,900	54,700
Average per capita GDP in 2100, Industrialized countries ($)[a]	160,300	69,000	81,300	108,800
Average per capita GDP in 2100, Developing countries ($)[a]	99,300	16,400	26,900	60,000
Technological change	Rapid	Slow	Medium	Medium
Energy use	Very high	High	Medium	Low
Energy technologies	Fossil fuel intensive	Regionally diverse	"Dynamics as usual"	High efficiency
Land-use change	Low-medium	Medium-high	Medium	High
Atmospheric CO_2 concentration (ppm) in 2085	810	709	561	527
Global temperature change (^oC) in 2085	4.0	3.3	2.4	2.1
Sea level rise (cm) in 2085	34	28	25	22
Change in total mortality in 2085 compared to baseline[b,c]	–2,064,000	+1,927,000	–1,177,000	–2,266,000
Total population at risk due to water stress compared to baseline[c]	299,000	5,648,000	2,746,000	857,000
Average net global loss in coastal wetlands by 2085 compared to baseline[c]	13%	9%	9%	10%

[a] GDP per capita is given in 2005 US $, converted from 1990 $ using the US CPI.

[b] Mortality due to hunger, malaria and flooding; deaths directly due to climate change increase slightly, but are offset in the A1F1, B2 and B1 scenarios by reduced mortality resulting from improved living standards.

[c] The baseline assumes incomes are kept at the 1990 level and there is no climate change.

Source: Adapted from Goklany (2009)

Thinking a carbon tax would not guarantee adequate emissions reductions, some economists prefer quantitative controls and emissions trading, arguing that if the price of a permit to emit CO_2 becomes too high the authority can always issue more permits. If carbon trading is the instrument of choice, the majority of economists and environmentalists prefer that the government auction off permits, using the revenues to reduce income taxes and other taxes. But economists are not wedded to the idea of auctions because, other than the revenue benefits to government and the potential for a double dividend, the emissions outcomes are the same whether permits are auctioned, given freely to existing emitters on the basis of past emissions, or allocated in some other fashion. Large industrial emitters prefer a scheme that grandfathers permits instead of either a carbon tax or a scheme that requires them to pay for permits. Environmentalists, however, are against grandfathering because they see it as rewarding polluters for polluting. We return to market incentives below because they have a great deal of impact on efficiency and the poor.

3. THE ECONOMIC DEBATE

Two unrelated events changed the foregoing consensus among economists who accept the claims of DAGW. First was the publication of the Stern Review (Stern 2007). Contrary to all previous economic analyses (e.g., Nordhaus 1991, 1994; van Kooten 2004; Tol 2005b), the Stern Review asserts that the benefits of severely restricting CO_2 emissions today exceed the costs, and it offers no ramping up policy, only the conclusion that immediate severe restrictions on CO_2 emissions are warranted.

The reasons, and their weaknesses, soon became apparent: to convert future values into present values, Stern relied on a very low (1.4%) rate of discount (a concept to be explained below) (Mendelsohn 2006). This implied that distant damages (costs) of global warming were much more highly valued today than had been assumed before (Nordhaus 2007a), thereby raising the discounted benefits of acting now. This bias was compounded by another. By cherry picking the most pessimistic estimates of warming's effects on agriculture, health, insurance and economic development, and ignoring contrary studies, the Stern Review assumed damages from global warming three or more times higher than were previously assumed, and much lower costs of mitigating CO_2 emissions (Tol 2006; Mendelsohn 2006; Nordhaus 2007a; Goklany 2009; Byatt et al. 2006). But it is only when non-market environmental damages are taken to be extremely large that an argument can be made for immediate drastic action to reduce CO_2 output (Weitzman 2007).[5] These first two errors—applying an unrealistically low discount rate and exaggerating future damages from warming (especially ecological damages)—compounded each other. Finally, on the grounds that we cannot rule out the possibility of a future climate disaster caused by anthropogenic emissions, Stern argued that it would be folly not to take action immediately to avert disaster.

---

[5] Much controversy surrounds attempts to demonstrate high values of such things as forest ecosystems, wildlife species, etc. In addition to the problem of budget constraints in the estimation of values (some people are willing to pay more than their entire income to protect nature, others very little), there is much confusion about average versus marginal values. For example, an old-growth forest might have tremendous worth, but a single hectare might have little non-market value at the margin, much as the hundredth pair of shoes has little value to a single owner.

The Stern Review did not change the view of economists that society should wait before taking costly action on global warming. Rather, economists widely condemned it as "the greatest application of subjective uncertainty the world has ever seen" (Weitzman 2007, p. 718), an analysis not based on "solid science and economics" (Mendelsohn 2006, p. 46), and one that "can therefore be dismissed as alarmist and incompetent" (Tol 2006, p. 980).

The second event was the global financial crisis that began in 2008, one effect of which was to rivet attention on the costs of climate policy. In some circles, however, the crisis became an excuse to circumvent markets, with economist Jeffery Sachs commenting, "Free-market ideology is an anachronism in an era of climate change."

The difficulty of discount rates

Because costs are incurred and benefits accrue at different points in time, cost-benefit analysis relies on discounting to a common date so that financial inflows and outflows occurring at different times are comparable. Compared to low interest rates, high rates encourage saving and investment that lead to higher future incomes, but they also cause one to focus more on the short run because gains and losses that occur farther in the future are valued less today (as they are discounted more highly). There is no ready consensus about what discount rate to use when analyzing public policies and projects.

On debatable moral grounds, some advocate a zero discount rate in comparing one generation's costs and benefits with another's. Discounting implicitly values future generations' costs and benefits less than the present generation's. The higher the discount rate, the lower is the *current* value of a *future* gain or loss.

The long-run rate of growth in per capita consumption is often used as a starting point for calculating the discount rate. To this is added a rate of time preference of one or two percent (not the 0.1% used by Stern). Thus, if the rate of growth in consumption is 1.3%, then the actual rate of discount might be 2.3% or 3.3%. As noted above, the Stern Review employed a discount rate of 1.4%, with the result that future damages (which were also overstated) appeared 10 to 20 times larger in current terms than under a more realistic discount rate, as did future benefits from mitigation.

There is a more puzzling aspect of discounting when time frames are on the order of many decades or even centuries, as is the case with climate change. As the controversy surrounding the Stern Review indicates, small differences in the discount rate used in cost-benefit analysis can lead to significantly different policy conclusions. However, the world changes greatly over the course of a half century or more. One hundred years ago, the automobile was only slightly more than a curiosity; today the economies of most industrial and developing nations depend on it. Electricity, refrigeration, airplanes, radio, television and computers were largely unknown, but today we cannot envision doing without them. How can we predict the potential damages (or benefits) from climate change in 2050 or 2100, much less 2200, without knowing what technologies and social constructs will have arisen, and what will have fallen into disuse?

Some think discounting costs borne and benefits enjoyed by future generations is morally objectionable, violating the command to "Love your neighbor as yourself." Yet in the parable of the talents (Matthew 25:14-30) Jesus has the ruler (who represents God) condemn the servant who buried his talent in the ground for not at least putting it into a bank, where it would have earned interest. Interest is the discount rate for future money. People discount the future because they quite properly prefer something today (because it's sure and can be used productively immediately) over something tomorrow (because it's unsure and cannot be used productively until the future). They exhibit an implicit rate of time preference. Thus a dollar of future benefits or costs should be valued less than a dollar of benefits or costs today. The moral objection disappears when we distinguish between the intrinsic value of *people* (all of whom bear the image of God) and the subjective value of money, time, labor and other things. Discounting applies to the latter, not to people *qua* people.

Lomborg's view: We adapted before, we can adapt again

By far the best and most rational cost-benefit analysis of future climate change has been conducted by Bjørn Lomborg (2007a). It is the only one of which we are aware that takes into account technical progress in assessing climate change. Lomborg's approach is simple, but sensible and powerful. He indicates that the climate change that has occurred in the past 100 years is about what models predict, both in terms of global temperature rise and sea level rise, for the next. He then compares life a hundred years ago with life today, showing how well people have adapted, and considers it rational to expect the continuation of similar adaptive abilities and technological changes in the future. The result is the expectation that people will be better off in any case.

Weitzman's case: drastic response to low-probability catastrophe

A very different approach to that of Stern (2007) is taken by Martin Weitzman, who first criticized the Stern Review for its highly speculative nature but then set about to provide an alternative defense for taking drastic action on DAGW, one not based on low discount rates and optimistic estimates of mitigation costs. Weitzman (2009a, 2009b, 2009c) bases his case on what he calls 'fat-tailed' probability density functions that, based on his derivations (discussed below), provide a reasonable probability that average global temperatures might rise by more than 10^{o} C or possibly even 20^{o} C. "At a minimum such temperatures would trigger mass species extinctions and biosphere ecosystem disintegration matching or exceeding the immense planetary die-offs associated in Earth's history with a handful of previous geoenvironmental mega-catastrophes" (Weitzman 2009a, p. 5). The cause of the catastrophe, according to Weitzman, is unprecedented anthropogenic greenhouse gas emissions coupled with a critical climate sensitivity parameter that converts changes in atmospheric CO_2 into temperature increases. "It is universally accepted that in the absence of any feedback gain, *s* [warming from doubled CO_2 before feedbacks] = 1.2° C" (Weitzman 2009, p. 4). But it is *climate sensitivity* (warming *after* feedbacks) that is uncertain, so much so that its probability distribution is necessarily characterized by 'fat tails' that bring about the high probabilities of large increases in temperature.

How does Weitzman come to the conclusion that there is a high probability of high temperature increase? He bases this on four points (Weitzman 2009b, 2009c):

1. According to Antarctic ice core data reported by Dieter et al. (2008), current atmospheric concentrations of CO_2 are the highest ever recorded in perhaps the past 850,000 years, and the current rate of increase in atmospheric CO_2 is historically unprecedented. This unprecedented increase can only be attributed to human causes.
2. Weitzman applies what he calls a "meta-analysis based on Bayesian model averaging" to

22 studies reported in IPCC's Fourth Assessment Report (IPCC-AR4) (IPCC 2007, pp. 721-722, 798-799) to determine the scientific consensus about expected future temperatures if emissions of CO_2 continue unabated. On the basis of this analysis, he suggests that there is a 5% probability that the expected temperature will increase by more than 7^o C and a 1% probability that it will exceed 10^o C.

3. Next, he assumes that higher atmospheric concentrations of CO_2 lead to higher temperatures, which will cause permafrost and boggy soils to release methane, thereby amplifying global warming (Sheffer et al. 2006, Matthews and Keith 2007, and *The Economist* 2009). The possibility of such a feedback effect leads Weitzman to increase the value of climate sensitivity so that, based on information from Torn and Harte (2006), the probability that temperatures could rise above 11.5^o C is 5% and that they could rise above 22.6^o C is 1%! However, recognizing the crude and speculative nature of his calculations, Weitzman rounds these levels down to 10^o C and 20^o C.
4. Finally, given the potential for huge increases in temperature, Weitzman argues that economic damage (utility) functions parameterized on the basis of current fluctuations in temperature make no sense. While the damages reported by other economists might make sense for low temperature rise, they will be much, much higher for the larger increases in temperature.

Based on these values, Weitzman concludes that there is a real possibility that, regardless of the discount rate, the damages from climate change could be infinite—that humans cease to exist as a species.

Weitzman makes a creative case for a massive R&D program to find a technological solution to DAGW (an argument in which Weitzman depends on Barrett 2008, 2009). But Weitzman's economics rests on three faulty premises: (1) humans are solely responsible for the vast majority of the observed increase in atmospheric CO_2; (2) increased atmospheric CO_2 leads to increased global temperatures via strong net positive feedbacks, resulting in high climate sensitivity (warming anticipated from doubled CO_2 *after feedbacks*); and (3) there is a rational basis for assigning probabilities to the catastrophically high temperature increases. If any of these suppositions is false, or even if one of them is only partially true, the economic conclusions disappear.

The first premise is doubtful, since even slight warming of the oceans, which we know has happened before in the absence of anthropogenic greenhouse gases, could explain recent increases in CO_2 (Spencer 2009a).

The second premise is almost certainly false. Weitzman's bias on the matter is clear: "It is universally accepted that in the absence of any feedback *gain* [emphasis added], *s*=1.2° C". He does not even consider that there could be feedback *loss*. The Earth's surface temperature with no greenhouse effect would be about 18° C; with it, but with no feedbacks, it would be about 60° C; with feedbacks, it is actually about 15° C. In the natural system, then, feedbacks eliminate about 58% of GHG warming—that is, *feedbacks are strongly net negative*. But to get climate sensitivity above 1.2° C one must assume that positive feedbacks are strongly net positive—precisely the opposite of what is found in nature. Research published since the May 2005 cutoff date for consideration in the IPCC 2007 Scientific Assessment Report (Schwartz 2007, Spencer et al. 2007, Spencer and Braswell 2008, Spencer 2008, and Lindzen and Choi 2009) confirms that the feedbacks are net negative, with climate sensitivity probably around 0.5° C instead of the

IPCC's midrange of 3.0° C. This virtually eliminates the possibility of 10° to 20° C warming from doubled CO_2.

The third premise is false. The so-called probabilities provided by the 22 studies reported by the IPCC (2007), and on which Weitzman based his calculations, are determined solely from computer models, beginning with models used to develop the emission scenarios and then the global circulation models (GCMs) that provide projections of associated future climate scenarios. These are not probabilities in the classical sense—based on repeated observations, as in the case of a fair coin toss yielding a 50% probability that the coin comes up tails. The future level of warming is not a matter of chance but of physics. It *will* turn out only one way, and it will be the feedbacks that largely determine that. As climatologist Roy Spencer explains, the use of statistical probabilities implies that the climate system's response to any change is a roll of the dice. It is not. Unlike rolling dice, outcomes in the climate system are not random events. There is instead a real climate sensitivity in the real climate system. Worse, Weitzman's ad hoc meta-analysis both confuses peer-reviewed scientific publications with climate-system processes and treats them, too, as random events. But even if 99 papers claim the climate system is very sensitive and only one says it is not, that does not mean there is a 99% chance that the climate system is very sensitive. Often a single research paper overturns what most scientists thought they knew. Even assuming (wrongly) that scientific publications were random events would only imply a 99% chance that the next paper would espouse high sensitivity. Since in climate research those 99 papers typically all make the same assumptions, they are nearly guaranteed to reach the same conclusions. Hence, they are not independent pieces of evidence. They are evidence of group think in the climate-science community (Spencer 2009b).

Properly speaking, probability theory cannot be applied meaningfully to climate projections. Weitzman's exercise is nothing more than a scientific-sounding way to express his level of faith.

Finally, the 'fat tails' argument (low probably of infinitely disastrous consequences) fails to acknowledge fat tails at the other end. If a temperature increase of 10^{o} C or more is a disaster, what about a fall in average global temperature of 10° C or more? Geologic history tells us that this is possible, and if enhanced atmospheric CO_2 could mitigate a possible new ice age, that would surely be good. It seems convoluted to be concerned about one side of the probability distribution but not the other.

In short, Weitzman's case for massive spending to fight global warming on the basis of 'fat tail' probability analysis fails.

4. IMPLEMENTING POLICY

The U.S. House of Representatives in July 2009 narrowly passed the American Clean Energy and Security Act (also known as Waxman-Markey), which is intended to reduce American CO_2 emissions by 17% from the 2005 level by 2020 and by 83% by 2050. As we write, Senate committees are considering similar legislation proposed by John Kerry and Barbara Boxer that would reduce emissions by even more by 2020..

One aspect of the Waxman-Markey bill is a cap-and-trade scheme that would require firms to purchase permits to emit CO_2 (and other GHGs). Covered firms (about 7,400) would receive 4.627 billion allowances in 2012 and as few as 1.035 billion in 2050, with each allowance permitting one metric ton of CO_2 emissions. Interestingly, 29.6% of allowances will be auctioned off in the first two years, 2012-2013, thereby raising $846 billion in federal revenue—a cost that firms will pass on to consumers. The proportion of allowances auctioned off falls to less than 18% in 2020, rises to 18.4% by 2022, and then gradually rises to about 70% by 2031, where it would remain.[6] In the first few decades, therefore, significant allowances would be grandfathered.

Grandfathering allowances ensures the support of industry, although there is the notion that, by freely giving allowances to large emitters such as power companies, there will be little immediate impact on output prices. This is misleading. Because allowances have a market value (as they are traded), a company will consider its 'freely-allocated' allowances to be an asset whose cost must be covered by revenues. Large industrial emitters could take the 'free' asset, sell it, and invest the proceeds in reducing CO_2 emissions. The cost of reducing CO_2 emissions will certainly need to be covered. Consequently, whether they are auctioned or given away (grandfathered), allowances' cost will be reflected in final output prices. Thus, all citizens will face higher costs for energy and everything produced by energy.

Economists do not care in principle whether emission permits are auctioned or given away—the goal is to meet the desired outcome at least cost. But the different methods do result in different distributions of income—different sets of winners and losers. From a theoretical perspective, income inequalities can be adjusted by lump sum transfers, although the potential double dividend is lost under tradable permits instead of a carbon tax, and where such transfers do occur they are somewhat suspect. However, large industrial firms love climate mitigation schemes that give them free emission allowances. The financial gains can be enormous, with taxpayers and consumers footing the bill. Financial institutions such as Morgan Stanley, Goldman Sachs, and JP Morgan-Chase, and well-placed individuals like Al Gore (Solomon 2009), eagerly savor the opportunities afforded by carbon trading; after all, carbon is forecast to become the largest commodity traded in the world, with a trading value estimated to reach $3 trillion by 2020.[7] No wonder large financial institutions lobby governments to employ permit trading instead of carbon taxes—this has the makings to be the next crisis with huge amounts of money to be made before the bubble bursts.

Unfortunately, in addition to enabling large companies to gain at everyone's expense, politicians also introduce subsidies, regulations and provisions that lead to inefficiency—that actually increase the costs of meeting emission targets. Waxman-Markey, for example, comes laden with regulations and provisions that make achieving targets much more expensive than would be the case with a carbon tax or even emissions trading; lock the economy into potentially inefficient investments; and make it much less likely that targets will be met. For example, there are mandated biofuel targets, with subsidies to farmers for ethanol production. Agricultural

---

[6] This information is based on a report by the Congressional Budget Office and Congressional Joint Committee on Taxation, as reported by Amanda DeBard (CBO: House climate bill to raise $973B, Washington Post Monday, June 8, 2009) and available at <viewed June 11, 2009>: http://washingtontimes.com/news/2009/jun/08/cbo-house-climate-bill-raise-973b/ . See also Congressional Budget Office (2009a).

[7] See Matthew Carr, China, Greenpeace Challenge Kyoto Carbon Trading (Update1). 19 June. Available at <viewed 31 August 2009>: www.bloomberg.com/apps/news?pid=20601080&sid=aLM4otYnvXHQ

economists have long opposed ethanol subsidies because they raise food prices (which harm the least well off in society), intensify crop production (increasing chemical use and machinery operations), distort land use by converting grassland into crop production and forestland into agriculture, reduce the performance of automobiles consuming gasoline with ethanol, provide only questionable climate mitigation benefits, and lock society into facilities that will produce ethanol for many years to come (Morriss et al. 2009, pp.79-89; Crutzen et al. 2008; Searchinger et al. 2008; Klein and LeRoy 2007).

Potential Costs of Reducing CO_2 Emissions: Evidence from Waxman-Markey

What will be the cost of Waxman-Markey or something quite similar? Low-end estimates come from two government agencies. Based on estimates that allowances for greenhouse gas emissions would start around \$13 to \$15 per ton of CO_2 in 2010 and increase to \$26 in 2019, the Congressional Budget Office (CBO) and Environmental Protection Agency (EPA) estimate that each household will have to pay upwards of \$140 (EPA) or \$175 (CBO) per year so that firms can purchase emission allowances (CBO 2009b; EPA 2009). The estimated costs of allowances are low if the European Union's Emissions Trading System (ETS) can be used as a guide, since permits have already traded in the ETS for more than \$30 (Ellerman and Joskow 2009). The CBO expects the annual budgetary cost to U.S. taxpayers of Waxman-Markey to rise from \$52 billion in 2012 to over \$800 billion by 2020 (CBO 2009a). The EPA projects an increase in consumption expenditures of 18% to 19% between 2010 and 2020.

The optimistic cost estimates provided by the CBO and EPA are misleading, however, because they fail to take into account costs to the economy as a whole. These are difficult to calculate, especially because true economic costs are opportunity costs. But several studies provide some rough calculations. The more realistic forecasts come from two private sources.

First, McKibbin, Wilcoxen and Morris (2009) of the Brookings Institution estimate the costs to consumers of a cap-and-trade scheme that seeks to reduce CO_2 emissions by upwards of 49%, not the more costly 83% of the 2050 Waxman-Markey target. They estimate that cap and trade would lead to a loss in personal consumption of \$1 to \$2 trillion (about \$3,225 to \$6,450 per person) in present-value terms. The authors suggest that even an additional 8% cut in CO_2 emissions would increase costs by 45%. U.S. GDP would be lower by 2.5% in 2050 with cap and trade, and there would be 1.7 million fewer jobs in the average year in the first decade compared to the without-cap-and-trade baseline.

Second, the Heritage Foundation (Beach et al. 2009a) estimates an average annual GDP loss of \$393 billion, reaching a high of \$662 billion in 2035.[8] Over the period 2012-2035, the accumulated GDP loss is estimated to be \$9.4 trillion (in 2009 dollars)—about \$1,260 per person per year. It also finds that in the average year there will be 1.1 million fewer jobs compared with the baseline assumptions, and that, by 2035, there could be 2.5 million fewer. Electricity rates are projected to rise by 90%, gasoline prices by 74%, and residential natural gas prices by 55%. The average household's direct energy costs are expected to rise by over \$1,200 per year, to which undetermined indirect costs must be added (Beach et al. 2009b).

None of the studies cited above provides a full economic accounting of costs and

---

[8] As a reference point, U.S. GDP was \$13,312.2 million in 2008 (measured in 2005 dollars).

benefits. No study attempts to determine the true costs to the U.S. economy using a general equilibrium model that would take into account changes in prices and the economic effects of an increased government role in the economy and subsidies for biofuels, wind energy and so on. Subsidies and regulations could increase costs significantly. However, one would not expect joblessness to continue for long as, in a well-functioning economy where wages can adjust, wages would fall and more people would be employed. Studies also ignore environmental costs and benefits—costs would increase if lands are converted from forest to cropland, for example, while there might be benefits from reduced consumption of certain automotive fuels. Again, calculating all of these costs and benefits is no easy task.

Job Creation and Citizens' Willingness to Pay to Mitigate Global Warming

Employment is a controversial element of any government program as politicians are wont to promote job creation as the most essential component of any legislation. So-called green (or environmentally friendly) jobs have been touted by proponents of action to reduce reliance on fossil fuels. However, an in-depth study by Morriss et al. (2009) carefully explores what is meant by green jobs, indicates that special interest groups have overstated the number of jobs various clean-energy (and other positive environmental) initiatives have created, and questions whether environmental expenditures (such as subsidies to ethanol producers, wind and solar energy) increase jobs overall. In this regard, a recent Spanish study by Álvarez et al. (2009) found that, for every green job created (in producing renewable energy), 2.2 jobs were lost elsewhere in the economy. Similarly, the claim that electricity from renewable energy creates more jobs per kWh than traditional power generation simply implies "that renewable energy is more costly in labor terms than alternatives—hardly a virtue to anyone asked to pay for the energy produced" (Morriss et al. 2009, p. 44). We could, of course, create millions more jobs by paying people to produce electricity by riding stationary bicycles attached to generators, but the electricity produced would not be worth the time and caloric energy consumed. Creating jobs is not an end to be pursued; it is a means to an end—one that should be minimized, not maximized.

It is also helpful to consider (i) the benefits of spending money on emissions reduction and (ii) whether citizens are prepared to pay for climate mitigation efforts. The benefits of climate change mitigation brought about by U.S. action are minuscule. They amount to a reduction of perhaps 0.20^{o} C in the projected temperature increase in 2100 if Waxman-Markey is fully implemented and only slightly more if all rich nations follow suit—and this assumes climate sensitivity at the midrange estimate of the IPCC, though more recent studies point to an increase of only one-sixth that amount (Schwartz 2007; Spencer et al. 2007; Spencer and Braswell 2008; Spencer 2008; Lindzen and Choi 2009), which would entail an insignificant temperature reduction of 0.03º C instead. The problem is that developing countries, particularly China and India, are not about to restrain their development simply because rich countries are concerned about an environmental problem that ranks at the bottom of their list of priorities (see Lomborg 2004, 2007b).[9] With AIDS killing more than 2 million people annually in Africa, and worldwide more than 4 million children dying of respiratory infections, diarrhea and malaria

[9] From U.S. Senate hearings on 7 July 2009, it is clear that Waxman-Markey will have no effect on climate unless both China and India reduce their CO_2 emissions. See http://epw.senate.gov/public/index.cfm?FuseAction=Minority.PressReleases&ContentRecord_id=564ed42f-802a-23ad-4570-3399477b1393 (viewed July 9, 2009).

each year, global warming is mainly a concern of the rich (e.g., Lomborg 2004).

Next consider citizen willingness to pay and a poll conducted by YouGuvPolimetrix for *The Economist*.[10] Forty-one percent of those polled called climate change a "very serious" problem with 28% calling it "somewhat serious." For comparison, 57% of respondents thought it was a "very serious" problem that many Americans do not have health insurance, while a further 27% rated this "somewhat serious." When asked to choose between passing health care legislation or legislation to address global warming, 61% chose health care reform ahead of global warming, with only 16% considering global warming more important; the remaining 23% were "not sure." Finally, Americans tended to favor legislation to reduce CO_2 emissions only as long as it did not cost much. When costs reached even the low Congressional Budget Office (2009b) estimate of $175 per household per year, the majority was opposed (see Figure 1). Needless to say, costs of mitigating climate change are very likely going to be vastly greater than this.

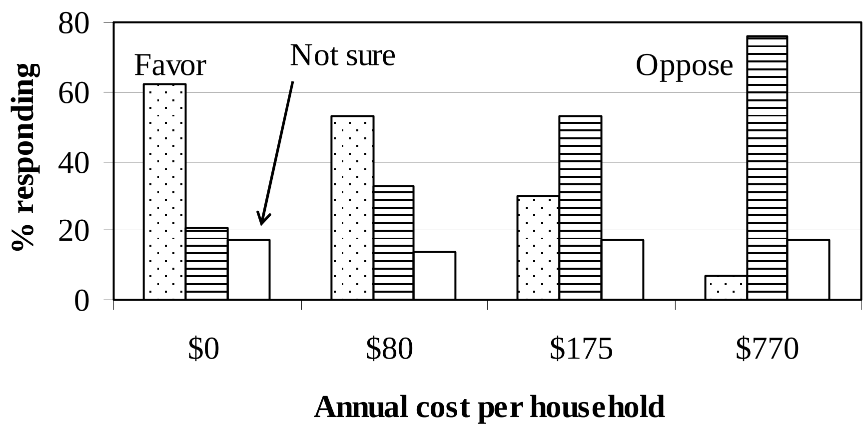

Figure 1: Respondents' willingness to pay to mitigate climate change

Carbon Taxes vs. Emissions Trading

From an economist's perspective, it is disconcerting, though from a politician's perspective it is unsurprising, that governments have eschewed a carbon tax in favor of emissions trading. A carbon tax is a straightforward instrument that can be adjusted to the severity of climate change damages, with revenues used to improve economic performance elsewhere in the economy (resulting in a double dividend) and to fund R&D for addressing climate and other challenges. In this regard, McKitrick (2007) proposes a tax based on actual temperatures in the tropical troposphere, which is where an early and strong signal of anthropogenic warming not affected by solar activity is predicted to occur (CCSP 2006, ch. 5). The tax would be based on temperature data from satellites. According to McKitrick, if the tax were set at twenty times the three-year moving average of mean tropical troposphere temperature anomalies, it would amount in 2005 to about $4.70 per ton of CO_2. If IPCC projections of global

[10] Reported in The Economist, July 4, 2009 (pp.24-25) with the full results available at http://media.economist.com/media/pdf/Toplines20090701.pdf (as viewed July 21, 2009).

warming are correct, the tax would rise aggressively to some $200 per ton by the end of this century. If global warming is truly a dire threat, the rising tax will bring about the desired changes in anthropogenic emissions or the R&D needed to remove CO_2 from the atmosphere, or both. McKitrick's tax plan is unambiguous, not dependent on controversies surrounding temperature increases projected from climate models and economic analyses mired in similar assumptions, and can easily be adopted globally.

In contrast, emissions trading is fraught with political maneuvering, corruption, questionable offset credits, high monitoring costs because of the variety of offsets already appearing in carbon markets, lack of revenue recycling (no double dividend), and difficulties in bringing all countries into the scheme. Political maneuvering is already evident in Waxman-Markey, for example, because much of the pain has been delayed to 2020 and later, well beyond the next round of elections, and large emitters have been granted an enormous windfall in the form of free credits. Yet, the emission credits have value that constitutes an expense to be charged to consumers, much like a tax. In essence, therefore, large industrial emitters, instead of government, tax energy consumers, while large financial firms reap huge benefits as intermediaries in carbon trading. Again, it is little wonder that large firms not only favor cap-and-trade schemes, but actually lobby for them. No wonder large industrial emitters and oil companies have backed away from funding climate research that contradicts the mainstream consensus—with emissions trading there is no financial incentive to contradict claims of DAGW. Whether DAGW is occurring or not, large companies are better served by emissions trading that would be hard to stop even if the temperatures in the tropical troposphere were to indicate that a more prudent approach would be wiser.

5. DEVELOPMENT, ENERGY GROWTH, AND CLIMATE CHANGE

While good governance (low corruption, effective rule of law, etc.) is crucial to economic growth, economic development cannot occur without expanding energy use (Smil 2003). All modern societies depend on massive and uninterrupted flows of energy. In the developing world, increased energy production is an absolute prerequisite for reducing poverty. In this section, we briefly consider the alternatives to fossil fuels and increased emissions of CO_2.

The tremendous strides in human progress since the Industrial Revolution have been made possible by our ability to harness fossil fuel energy. By replacing animal and human muscle power and low-density, high-pollution fuels like wood, peat and dung, we have liberated billions from crushing poverty and short lives characterized by toil.

Over the next fifty years, the world's developing nations will seek to emulate the West's material success, and acknowledged in the IPCC's emissions scenarios. Their leaders know that improving their citizens' quality of life (including the most basic measures: health and life expectancy) requires more, not less, energy consumption. Fossil fuels are currently the choice to meet this growing demand, because they are easily storable, have high energy densities, provide reliable generation, and are cheap. Coal-fired generating stations operate with high load factors of 75% or more over a year, and nuclear plants above 90%. In contrast, wind and solar are intermittent and hence cannot deliver power consistently. Annual load factors of wind generation in Denmark, Germany and Spain are 20% to 25% (or often lower), meaning the wind turbines sit idle for the equivalent of 270 to 290 days per year.

Some people presume that affordable renewable energy sources will soon displace fossil fuels. But absent subsidies, low-carbon energy technologies advance only when they are cheaper than fossil fuels. With the exception of natural gas (the proven reserves of which have risen significantly in the past several years due to new technologies),[11] the popular alternatives (e.g., wind and solar) are too expensive and limited by geography.

The U.S. consumes about 100 quadrillion BTUs of thermal energy per year. Electricity generation accounts for about 40% of this. Currently we meet this demand with coal (49%), natural gas (21%), and uranium (20%). Hydro provides 5% and all other renewables (mainly biomass) together account for only 2.5%.

In all modern economies, electricity does the vast majority of the heavy lifting. Because of their low cost and ability to generate power without interruption, fossil and nuclear fuels dominate generation. Displacing them requires that any alternative energy source must be storable and reliable. As Richard Feynman said, “For a successful technology, reality must take precedence over public relations, for nature cannot be fooled” (Feynman 1986).

Electricity has met almost all of the growth in U.S. energy demand since the 1980s. This is not surprising, since about 60% of our GDP comes from industries and services that rely primarily on electricity to produce or power their products. (In 1950, the figure was only 20%.) Demand for electricity is projected to continue to grow and will do so especially rapidly if plug-in hybrid or electric-only vehicles become more common.

By 2030, global energy use is expected to increase by some 150% of that in 2005. This will require the equivalent of one new 1,000 megawatt (MW) power generating plant coming on stream every day for the next twenty years just to satisfy growth in electricity demand (Duderstadt et al. 2009, p. 9). The majority of growth in energy use will come in developing countries, especially China and India, which together account for about one-third of the world’s population. Developing countries will strongly resist attempts by rich countries to reign in economic growth for the purpose of mitigating climate change, although they will welcome rich-country subsidies for clean and renewable energy. Energy policies that reduce rates of economic growth in developing countries will simply perpetuate the misery of millions of people who live in poverty. While clean and renewable energy sources can contribute to the energy needs of developing nations, economic growth will depend primarily on traditional sources of energy, such as coal, oil and increasingly natural gas, because they are relatively cheap and ubiquitous.

Alternative Fuels

So what role will renewable energy sources play? Are solar and wind viable alternatives? Both have the potential to generate vast amounts of carbon-free, clean energy, but currently they contribute less than 0.1% of total U.S. energy consumption. What is their future?

Renewable sources of energy include large-scale hydro, small-scale run-of-river hydro (a modern version of the water wheel), wind, tidal, solar, wave, municipal solid wastes, biomass for the generation of electricity and space heating, and biofuels (ethanol and biodiesel) for

[11] Natural gas reserves are now sufficient to provide energy for 60 years or more, but CO_2 is often released during extraction.

transportation.[12] Some of these sources are severely constrained.

Biomass

While there has been a great deal of emphasis on the use of terrestrial carbon sinks for reducing atmospheric concentrations of CO_2, and even offsetting fossil fuel emissions, the costs of sequestering carbon in agricultural and forest ecosystems are generally quite a bit higher than emission-reduction options (Manley et al. 2005; van Kooten et al. 2004, 2009). There are some fundamental problems with the use of terrestrial sinks that make them a very dubious means of mitigating climate change; these include their ephemeral nature, high monitoring and transaction costs in establishing CO_2 baselines and flux, and potential for corruption (van Kooten 2009a, 2009b).[13]

Current policies to mitigate climate change have focused on the potential of using biomass to generate electricity or as a liquid fuel instead of gasoline. Increasing electrical power production from waste biomass is constrained by high transportation costs, competition by other potential uses for biomass, and in some cases toxic wastes (Stennes et al. 2009; Niquidet et al. 2009). Ethanol is made from corn, biodiesel is made from other grains, and cellulosic ethanol is produced from crop residues, switchgrass, willow or hybrid poplar.

One problem with biofuels is that they are not neutral with respect to GHG emissions; CO_2 is released whenever biofuels are burned, and often more CO_2 is released to generate the same amount of energy compared with fossil fuels. The biomass needs to be harvested, transported and processed, which contributes to CO_2 emissions. Only the growth of plants and trees removes CO_2 from the atmosphere, and such growth takes time—a lot in some regions—or inputs of chemical fertilizers (whose production, transport and application also release GHGs). While ethanol can be burned in place of gasoline, its energy content is only about two-thirds that of gasoline. Further, compared to fossil fuels, the growth and processing of energy crops requires enormous amounts of land and water, some of the latter coming from non-renewable aquifers (Bryce 2008, pp. 183, 191). Finally, increased demand for energy crops (especially for production of biofuels) reduces cultivated area devoted to food production and so raises food prices (Searchinger et al. 2008), and may convert natural habitat to cropland, which can jeopardize biodiversity.

From a policy perspective, therefore, biological methods are not an efficient means of addressing climate change, although research into various biological organisms that make this

---

[12] Unless otherwise indicated, much of the material for this section comes from graduate student research, seminars and discussions at the University of Victoria's Institute for Integrated Energy Systems (http://www.iesvic.uvic.ca/).

[13] Carbon capture and storage is ignored here because it is extremely expensive, is still a long way from being technically feasible on a large scale, and has one crucial safety problem. There is always a risk that captured CO_2 is released, which could potentially lead to large loss of life, as when an underwater landslide in 1986 naturally "burped" a large mass of CO_2 from Lake Nyos in Cameroon, forming a low-lying cloud that suffocated over 1,700 people, thousands of livestock, and all other air breathing animals it covered before it dispersed (Stager 1987). Unless carbon storage occurs in remote regions, which increases its costs, people would need to be compensated to have a storage facility nearby. Research pertaining to the transportation and storage of nuclear wastes (by comparison minute by volume and much less transient) indicates that this could be an enormous cost (see Riddell and Shaw 2003).

process more efficient is ongoing. In essence, the only real options are to conserve energy or turn to alternative renewable or nuclear fuels. Landfill gas generated from solid waste is a potential source of electricity, but even if it is employed on a large scale, its contribution to the globe's electricity needs would be extremely small. The same holds for the incineration of municipal wastes.

Hydro, tidal and wave

Large-scale hydro remains one of the best options for generating electricity, but its main drawbacks relate to inadequate runoff for power generation (especially in regions where water availability is inadequate, intermittent or unreliable) and negative environmental externalities (changes in the aquatic ecosystem, impediments to fish migration, land inundation by reservoirs, etc.). Environmentalists oppose large-scale hydro development, particularly in developing countries, because of the ecological damage it causes, while even small-scale, run-of-river projects have been opposed in rich countries on environmental grounds, and their overall generating capacity will inevitably remain limited in scope.

Tidal and wave energy are also promising. Tidal energy is considered particularly desirable because of its regularity and predictability. While some tidal barrage systems are in place and experiments are underway with tidal turbines (which function much like wind turbines), huge technological and cost obstacles still need to be overcome. This is even more the case for wave energy conversion systems, which simultaneously suffer from unpredictability and intermittency. For both wave and tidal systems, costs of transmission lines can be prohibitive.

Solar

There are two types of solar energy: (i) solar photovoltaic (PV) converts the sun's energy directly into electricity and (ii) solar heaters warm water (swimming pools, water tanks, etc.). Solar heaters convert up to 60% of the sun's energy into heat, while PV cells convert only 12% to 15% of the energy into electricity, although PV laboratory prototypes are reaching 30% efficiency.

One problem with solar electricity is its prohibitive capital costs, which amount to some \$13,000 to \$15,000 per kilowatt (kW) of installed capacity (van Kooten and Timilsina 2009).[14] This would amount to roughly \$14 billion for each 1,000 megawatt generating plant, or, assuming that one plant of such capacity is added to world production each day, about \$5 trillion ($\$5\times10^{12}$)—about one-twelfth of gross world product—per year. In addition, solar power is intermittent (e.g., output is greatly reduced on cloudy days), unavailable at night, and, in high latitudes, less available in winter when demand is high than in summer (due to shorter days). Nonetheless, for remote locations that receive plenty of sunshine and are not connected to an electrical grid, avoiding the costs of constructing transmission lines to bring in outside power might make solar PV and solar heaters a viable option, but likely only on a small scale.

Wind

Given the drawbacks of many other renewable sources of energy, wind appears to be the renewable alternative of choice when it comes to generating electricity. As a result, global wind

---

[14] Kilo is abbreviated with k and equals 10^3; Mega (M, 10^6); Giga (G, 10^9); Tera (T, 10^{12}).

generating capacity has expanded rapidly from only 10 megawatts (MW) of installed capacity in 1980 to more than 100,000 MW by the end of 2008.

However, the euphoria about wind energy needs to be accompanied by a realistic view of its potential contribution to a future energy economy. First, it is unlikely that, even under the most optimistic estimates, wind will account for more than 5% of total global electricity production (van Kooten and Timilsina 2009). Second, wind energy requires storage, is unreliable, costly to install, a noise nuisance, harmful to wildlife, visually unattractive, and, above all, destabilizing to electrical grids. Wind turbines only produce about one-fifth of their rated output because of vagaries in wind, while attempts to reduce intermittency by scattering wind farms across a large geographic area and integrating wind power into a 'super grid' have not overcome the grid instability that occurs when wind provides about 30% of the electricity fed into a grid.[15,16] Even adding a more stable renewable source, such as tidal power, does little to address the problem of intermittency (Monahan et al. 2008).

Nuclear

It is clear to us that the greenhouse gas emission reduction targets proposed by the developing countries and by the U.S. Congress cannot be achieved without nuclear energy, which is why many other scientists favor it (see Scott 2007). It is also why the prominent environmentalist responsible for the Gaia Hypothesis, James Lovelock, initially came out in support of nuclear energy, though he subsequently backed away from it (and any renewable solution to global warming), arguing instead that the human population needs to be drastically curtailed (Lovelock 2009).

There are now 439 nuclear reactors in operation worldwide, meeting the power needs of more than a billion people. Thirty-four are under construction in 14 countries (none in the U.S.). In 2007, France got 77% of its power from nuclear; Lithuania 64%; Belgium 54%; Sweden 46%; Switzerland 40%; Japan 35%; Germany 26%; the U.S. 20%; the United Kingdom 19%; and Spain 17%. However, any attempt to increase reliance on nuclear energy and other non-carbon sources of energy, or to increase conservation of energy, will require huge investments in R&D. Yet, in the United States, for example, energy output is $1.27 trillion annually, but R&D spending is only $3.8 billion, of which the U.S. government supplies $1.4 billion. Government spending on energy R&D is only one-fifth of what it was in the 1970s and 1980s and well below the $20 to $30 billion annually recommended by the Brookings Institution (Duderstadt et al. 2009).

Many people fear that nuclear energy is unsafe. The fears are generally rooted in misunderstanding and misinformation. A nuclear explosion at a power plant is physically impossible—the fuel never approaches the necessary purity, and the extremely complex firing mechanism necessary to trigger a nuclear explosion is absent. Radiation exposure is well below

---

[15] Most of these results are based on various modeling exercises (see, e.g., van Kooten 2009c; Prescott and van Kooten 2009; Maddaloni et al. 2008; Lund 2005).

[16] Unless wind power is readily storable behind large hydro dams, wind requires fast-responding, open-cycle (as opposed to base load closed-cycle) gas plants as backup. However, since any wind energy will first displace electricity produced by fast-responding gas (as gas is most expensive), it cannibalizes existing peak load gas capacity and makes investments in such plants less attractive.

minimum danger levels. Spent fuel can be reprocessed for reuse, and nuclear waste, tiny in volume compared with waste from coal and other energy sources, can be stored safely or used in many industrial and medical applications. Bernard L. Cohen (2005), one of the world's leading experts on nuclear energy, estimates that, even after accounting for all the challenges of waste disposal, the number of deaths per 1,000 MW plant year over the next 500 years from nuclear wastes is about -0.06. That's right, it's a negative number because of the health-enhancing effect of low-level radon exposure from nuclear wastes. In other words, nuclear waste saves lives. By comparison, wastes from the same capacity coal plant would lead to about 25.6 deaths and from solar 1.6 (cadmium sulphide is used in a solar apparatus) For Americans living near a nuclear plant, the risk of lost life expectancy is about 1/10 of a day; that compares admirably with the risk from eating half a pound of charbroiled steak per week (about 1/3 day), riding a bicycle (6 days), drinking water (about 25 days), motor vehicle accidents (about 200 days), being 20% overweight (about 1,000 days), smoking (about 2,300 days), or being an alcoholic (about 4,000 days) (Cohen 1995). "While one can easily count scores of workers who have been killed in refinery, petrochemical plant, and coal mining operations over the decades," write Alan Herbst and George Hopley, "not a single U.S. nuclear worker has been killed in the workplace or in incidents related to workplace conditions. This is truly an enviable record, a record that the rest of the energy community would like to own" (Herbst and Hopley 2007; on nuclear safety see also Tucker 2008; Cravens 2008).

Cost comparisons

It is difficult to compare costs of producing electricity from renewable sources with those from traditional sources, but it can be done. Using data from a survey conducted by the International Energy Agency (IEA 2005), it is possible to provide some comparison of costs on a per megawatt hour (MWh) basis. Estimates are provided in Table 3. They indicate that electricity generated from renewable energy sources, including wind, is significantly more expensive than that from traditional sources.

Waste incineration is only the lowest cost means of generating electricity if there is a payment to dispose of municipal and industrial waste (which explains the negative value in the third column, indicating a benefit). Further, because of their relatively small supply, the contribution of wastes to total electricity generation will be small, which is also true of combined heat and power (CHP). Coal and nuclear are the lowest cost realistic alternatives. Gas is more expensive because of high fuel costs, but gas plants are cheap to build and are needed for fast response to shifts in load. At low, mid and high costs, solar PV and solar thermal run 6 to 27 times the cost of nuclear and coal and multiples of all other options (except run of river/small hydro compared with solar thermal in the high-cost scenario). Wind runs about 1.5 to 2.5 times the cost of nuclear. These cost differences do not count the problem of intermittency.

The argument made by proponents of renewable energy generation is that the costs in Table 3 do not reflect externality costs, in particular the costs associated with CO_2 emissions in the case of fossil fuel plants (as other pollutants, such as SO_2, are now dealt with in the construction of new plants) and the risks to health and safety associated with nuclear power plants. What happens when we account for externalities? Assuming that coal emits 0.9 to 1.0 ton of CO_2 per MWh of electricity (van Kooten 2009c)—an emission level that is dropping as more efficient plants come on line—it would take a carbon tax well above what the EPA envisions (as discussed above) before even wind energy, let alone solar, is competitive with coal, and especially so if the externality costs of wind are taken into account. But there remains another problem: With the exception of biomass and large-scale hydro, only nuclear and CCGT plants can replace coal because, without storage, intermittent sources of power cannot serve base-load needs (van Kooten 2009c).

Table 3: Index of lifetime generation costs by generating type[a]

Generating Type[b]	Midpoint	Low	High
Waste incineration	1.00	-0.41	5.37
Nuclear	2.70	2.14	7.05
Coal (high quality)	2.80	2.66	7.10
CHP (using coal)	3.43	2.57	4.82
Coal (lignite)	3.45	3.02	6.62
CHP (using other fuel)	3.51	3.02	10.22
Coal (integrated coal gas)	3.93	2.80	6.07
Biomass	4.28	3.83	10.32
Large-scale hydro	4.66	4.66	8.72
Gas (CCGT)	4.80	3.92	6.43
Gas (open)	4.80	4.80	5.03
CHP (using CCGT)	4.84	2.91	8.31
Wind onshore	5.98	3.19	14.81
Wind offshore	6.90	5.19	12.68
Run of river/small hydro	9.51	4.08	24.85
Solar PV	16.88	12.39	192.75
Solar thermal	17.00	17.00	27.67

[a] The costs include capital costs, operating and maintenance costs, and fuel costs over the lifetime of a power generating plant, discounted to the present and 'levelized' over the expected output of the generating source over its lifetime. Values are in 2008 US dollars. The midpoint value is based on a 5% discount rate, as is the low value (except in the case of high quality coal); the high value is derived using a 10% discount rate.

[b] Open-cycle gas turbines lose exhaust heat but are therefore able to respond quickly to changes in demand; closed-cycle gas turbines (CCGT) recycle exhaust heat, but this makes such plants suitable for base-load power and more difficult to ramp up and down. Combined heat and power (CHP) occurs when exhaust heat from space heating is used to generate power; such power is usually available at night and in colder climates.

Source: adapted from van Kooten and Timilsina (2009)

Concluding Comments

It appears that there is a lot of rhetoric associated with climate change and GHG emission reduction targets. While some reduction in CO_2 might be attainable, the targets being proposed in the post-Kyoto world are simply not rooted in reality. The reality is that

- Developed countries have been unable to achieve the much easier Kyoto targets, which amounted to a reduction in CO_2 output of less than 6% from 1990 levels.

- Unless energy production is drastically curtailed or there is a huge immediate investment in nuclear energy, or both, the tougher targets cannot possibly be met. Meanwhile, subsidies and legislation under consideration will lock several generations into energy systems that are detrimental to their interests and harmful to the least well off.
- If access to cheap energy is curtailed, economic development in places such as Africa and India will be set back; however, if access to cheap energy is curtailed only in rich countries, developing countries will benefit as the prices they face fall, but CO_2 emissions will increase all the more. Without curtailment of CO2 emissions in developing countries, any efforts to do so in developed countries will have very little impact on the climate change expected by IPCC predictions..
- People are not willing to pay the high price needed to reduce greenhouse gas emissions to the degree advocated by believers in DAGW, which is why democratically elected politicians have tended to postpone the pain until after the next cycle of elections or even farther into the future.

In light of this discussion and that in the science and theology sections of this document, we conclude, in agreement with the Copenhagen Consensus (Lomborg 2004, 2007b) that:

(a) Policies requiring drastic reductions in carbon dioxide emissions are unrealistic and threaten human well-being, especially in developing countries, where, by curtailing use of the most abundant, reliable and affordable energy sources, they would prolong abject poverty and the miseries of toil, disease and premature death that accompany it.

(b) The worst sort of emissions reduction policy is cap and trade; the least bad (but still not good) is a carbon tax indexed to tropical tropospheric temperatures.

(c) The most scientifically, economically and ethically defensible policy response to alleged dangerous anthropogenic global warming is to promote economic development, especially for the world's poor, through policies that ensure abundant and affordable energy, on the one hand, and, on the other, reduce specific risks from which the poor suffer regardless of climate change (e.g., under-nutrition and malnutrition; waterborne, pest-borne and communicable diseases; depressed income because of tariffs, trade restrictions and corrupt governments; high rates of accidental injury and death because of poor transport and industry infrastructure).

6. REFERENCES

Álvarez, Gabriel Calzada, Raquel Merino Jara, Juan Ramón Rallo Julián and José Ignacio García Bielsa, 2009. Study of the Effects on Employment of Public Aid to Renewable Energy Sources. Lessons from the Spanish Renewables Bubble. Borrador Draft. March. Madrid: Universidad Rey Juan Carlos. Available at <viewed 11 August 2009>: http://www.juandemariana.org/pdf/090327-employment-public-aid-renewable.pdf

Barret, Scott, 2009. The Coming Global Climate-Technology Revolution, *Journal of Economic Perspectives* 23(2): 53-75.

Barret, Scott, 2008. The Incredible Economics of Geoengineering, *Environmental and Resource Economics* 39(1): 45-54.

Beach, William W., David W. Kreutzer, Karen A. Campbell and Ben Lieberman, 2009a. The Economic Impact of Waxman–Markey. Heritage Foundation WebMemo No. 2438. May 13. 6pp.

Beach, William W., David W. Kreutzer, Karen A. Campbell and Ben Lieberman, 2009b. Son of Waxman-Markey: More Politics Makes for a More Costly Bill. Heritage Foundation WebMemo No. 2450. May 18.

Brander, James A. and M. Scott Taylor, 1998. The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use, *American Economic Review* 88(1): 119-138.

Bryce, Robert, 2008. *Gusher of Lies: The Dangerous Delusions of 'Energy Independence'*. New York: Public Affairs.

Bovenberg, A.Lans and Lawrence .H. Goulder, 1996. Optimal Environmental Taxation in the Presence of other Taxes: General-Equilibrium Analysis, *American Economic Review* 86(4): 985–1000.

Byatt, Ian, Ian Castles, Indur M. Goklany, David Henderson, Nigel Lawson, Ross McKitrick, Julian Morris, Alan Peacock, Colin Robinson, and Robert Skidelsky, 2006. "The Stern Review: A Dual Critique, Part II: Economic Aspects," *World Economics* 7 (4): 199-224. Online at http://www.katewerk.com/temp/sda_WE.pdf, accessed October 20, 2009.

CCSP, 2006: *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Thomas R. Karl, Susan J. Hassol, Christopher D. Miller, and William L. Murray, (eds.)]. Washington, DC.

Cline, William R., 2007. *Global Warming and Agriculture. Impact Estimates by Country*. Washington, DC: Center for Global Development and Peterson Institute for International Economics.

Cohen, Bernard L., 1995. "The Hazards of Nuclear Power," in *The State of Humanity*, edited by Julian L. Simon et al. Cambridge, MA: Blackwell Publishers.

Congressional Budget Office, 2009a. Cost Estimate: H.R. 2454 American Clean Energy and Security Act of 2009. June 5. 40pp.

Congressional Budget Office, 2009b. The Estimated Costs to Households from H.R. 2454 American Clean Energy and Security Act of 2009. June 19. 16pp. Viewed 6 August 2009 at http://www.cbo.gov/ftpdocs/103xx/doc10327/06-19-CapAndTradeCosts.pdf.

Cravens, Gwyneth, 2008. *Power to Save the World: The Truth About Nuclear Energy*. Reprint edition. New York: Vintage.

Crutzen, P.J., A.R. Mosier, K.A. Smith and W. Winiwarter, 2008. N_2O Release from Agro-biofuel Production Negates Global Warming Reduction by Replacing Fossil Fuels, *Atmospheric Chemistry and Physics* 8: 389-395.

Darwin, R., M. Tsigas, J. Lewandrowski and A. Raneses, 1995. *World Agriculture and Climate Change. Economic Adaptations*. AE Report No. 703, US Department of Agriculture, Economic Research Service, Washington DC. June. 86pp.

Diamond, J., 2005. *Collapse*. New York: Viking.

Diamond, J., 1997. *Guns, Germs, and Steel*. New York: W.W. Norton.

Dieter, Lüthi, Martine Le Floch, Bernhard Bereiter, Thomas Blunier, Jean-Marc Barnola, Urs Siegenthaler, Dominique Raynaud, Jean Jouzel, Hubertus Fischer, Kenji Kawamura and Thomas F. Stocker, 2008. High-resolution carbon Dioxide Concentration Record 650,000-800,000 Years before Present, *Nature* 453(15 May): 379-382.

Duderstadt, James, Gary Was, Robert McGrath, Mark Muro, Michael Corradini, Linda Katehi, Rick Shangraw, and Andrea Sarzynski, 2009. Energy Discovery-Innovation Institutes: A Step toward America's Energy Sustainability. Washington: Brookings. February. http://www.brookings.edu/~/media/Files/rc/reports/2009/0209_energy_innovation_muro/0209_energy_innovation_muro_full.pdf

Ellerman, A. Denny and Paul L. Joskow, 2009. The European Union's Emissions Trading System in Perspective. Arlington, VA: PEW Center on Global Climate Change. May 10. 54pp. Available at <viewed 10 August 2009>: http://www.pewclimate.org/eu-ets.

Fagan, Brian M., 2008. *The Great Warming. Climate Change and the Rise and Fall of Civilizations*. New York: Bloomsbury Press.

Fagan, Brian M., 2000. *The Little Ice Age. How Climate Made History 1300-1850*. New York: Basic Books.

Feynman, Richard, 1986. "Personal Observations on Reliability of Shuttle," vol. 2, appendix F of *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, accessed October 20, 2009, online at http://history.nasa.gov/rogersrep/v2appf.htm.

Goklany, Indur M., 2009. Is Climate Change the 'Defining Challenge of Our Age', *Energy & Environment* 20(3): 279-302.

Gould, Stephen J., 1999. *Rocks of Ages. Science and Religion in the Fullness of Life*. New York: Ballantine.

IEA, 2005. *Projected Costs of Generating Electricity. 2005 Update*. Nuclear Energy Agency, International Energy Agency, OECD, Paris.

IPCC, 2007. *Climate Change 2007. The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

IPCC, 2000. *Special Report on Emissions Scenarios*. Cambridge, UK: Cambridge University Press.

Klaus, Vaclav, 2008. *Blue Planet in Green Shackles: What Is Endangered: Climate or Freedom?* Translated from Czech. Washington: Competitive Enterprise Institute.

Klein, Kurt and Danny G. LeRoy, 2007. The Biofuels Frenzy: What's in it for Canadian Agriculture? Lethbridge, AB: Alberta Institute of Agrologists. Available at <viewed 8 May 2008>: http://www.aic.ca/whatsnew_docs/Klein%20Final%20%234.pdf.

Lindzen, Richard S., and Yong-Sang Choi, 2009 (forthcoming). On the determination of climate feedbacks from ERBE data, *Geophysical Research Letters*, <accessed August 13, 2009> online at http://www.leif.org/EOS/2009GL039628-pip.pdf.

Lomborg, Bjørn, 2007a. *Cool It. The Skeptical Environmentalist's Guide to Global Warming*. New York, NY: Alfred A. Knopf.

Lomborg, Bjørn (ed), 2007b. *Solutions for the World's Biggest Problems: Costs and Benefits*. Cambridge: Cambridge University Press. (Report of the Second Copenhagen Consensus)

Lomborg, Bjørn (ed), 2004. *Global Crises, Global Solutions*. Cambridge: Cambridge University Press. (Report of the Copenhagen Consensus)

Lovelock, James R., 2009. *The Vanishing Face of Gaia*.

Lund, Henrick, 2005. Large-Scale Integration of Wind Power into Different Energy Systems, *Energy* 30(13): 2402-2412.

Maddaloni, Jesse D., Andrew M. Rowe and G. Cornelis van Kooten, 2008. Wind Integration into Various Generation Mixtures, *Renewable Energy* 34(3): 807-814. doi:10.1016/j.renene.2008.04.019.

Manley, James, G. Cornelis van Kooten, Klaus Moeltner and Dale W. Johnson, 2005. Creating Carbon Offsets in Agriculture through Zero Tillage: A Meta-Analysis of Costs and Carbon Benefits, *Climatic Change* 68(January): 41-65.

Mann, Charles C., 2005. *1491 New Revelations of the Americas before Columbus*. New York: Random House.

Matthews, H. Damon and David W. Keith, 2007. Carbon-Cycle Feedbacks Increase the Likelihood of a Warmer Future, *Geophysical Research Letters* 34: L09702. doi:10.1029/2006GL028685

McKibbin, Warwick, Pete Wilcoxen and Adele Morris, 2009. Consequences of Cap and Trade Brookings June 8, 2009. Available at <viewed July 24, 2009)> http://www.brookings.edu/~/media/Files/events/2009/0608_climate_change_economy/20090608_climate_change_economy.pdf

McKitrick, Ross, 2007. Why not tie Carbon Taxes to Actual Levels of Warming? Both Skeptics and Alarmists Should expect their Wishes to be Answered, *Financial Post*, 12 June.

Mendelsohn, Robert O., 2006. A Critique of the Stern Report, *Regulation* 29(4): 42-46.

Mendelsohn, Robert, Wendy Morrison, Michael E. Schlesinger, and Natalia G. Andronova, 2000. Country-Specific Market Impacts of Climate Change, *Climatic Change* 45: 553–69.

Mendelsohn, Robert, William D. Nordhaus and D Shaw, 1994. The Impact of Global Warming on Agriculture: A Ricardian Approach, *American Economic Review* 84: 753–71.

Monahan, Katherine, Susan Boronowski and G. Cornelis van Kooten, 2008. The Economics of Tidal Stream Power. Selected paper presented at the Canadian Economics Association Annual meeting in Vancouver (May) and at the XIIth Congress of the European Association of Agricultural Economists in Ghent, Belgium (September).

Morriss, Andrew P., William T. Bogart, Andrew Dorchak and Roger E. Meiners, 2000. Green Jobs Myth. University of Illinois Law and Economics Research Paper Series No. LE09-001. 97pp. Available at <viewed 11 August 2009>: http://ssrn.com/abstract=1358423

Murphy, Robert P., 2009. Rolling the DICE: William Nordhaus's Dubious Case for a Carbon Tax. *Independent Review*, vol. 14, no. 2 (Fall 2009), 197—217. Available online at viewed http://www.independent.org/pdf/tir/tir_14_02_03_murphy.pdf (viewed October 19, 2009).

Niquidet, K., B. Stennes and G.C. van Kooten, 2009. Bio-energy from Mountain Pine Beetle Timber and Forest Residuals: The Economics Story. CFS Working Paper. Victoria, BC: Canadian Forest Service. Under review at *Biomass & Bioenergy*.

Nordhaus, William, 2009. An Analysis of the Dismal Theorem. Cowles Foundation Discussion Paper 1686. Yale University, New Haven, CT. 16 January 26pp. Available at <viewed 20 August 2009>: http://cowles.econ.yale.edu/P/cd/d16b/d1686.pdf

Nordhaus, William, 2008. *A Question of Balance. Weighing the Options on Global Warming Policies*. New Haven, NJ and London, UK: Yale University Press.

Nordhaus, William D., 2007a. A Review of the *Stern Review on the Economics of Climate Change*, *Journal of Economic Literature* 45: 686-702.

Nordhaus, William, 2007b. Accompanying Notes and Documentation on Development of DICE-2007 Model: Notes on DICE-2007.delta.v8 as of September 21, 2007.

Nordhaus, William D., 1994. *Managing the Global Commons: The Economics of Climate Change*. Cambridge, MA: MIT Press.

Nordhaus, William D., 1991. To Slow or Not to Slow: The Economics of the Greenhouse Effect, *Economic Journal* 101: 920-937.

Prescott, R. and G.C. van Kooten, 2009. Economic Costs of Managing of an Electricity Grid with Increasing Wind Power Penetration, *Climate Policy* 9(2): 155-168.

Riddel, Mary and W. Douglass Shaw, 2003. Option Wealth and Bequest Values: The Value of Protecting Future Generations from the Health Risks of Nuclear Waste Storage, *Land Economics* 79(4): 537-548.

Scheffer, Martin, Victor Brovkin and Peter M. Cox, 2006. Positive Feedback between Global Warming and Atmospheric CO_2 Concentration Inferred from Past Climate Change, *Geophysical Research Letters* 33: L10702. doi:10.1029/2005GL025044

Scott, D.S. 2007. *Smelling Land. The Hydrogen Defense against Climate Catastrophe*. Canadian Hydrogen Association and Natural Resources Canada, Ottawa, ON.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes and T. Yu, 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-use Change, *Science* 319(29 February): 1238-1240.

Schwartz, S. E., 2007, Heat capacity, time constant, and sensitivity of the Earth's climate system. *Journal of Geophysical Research*, 112, doi:10.1029/2007JD008746.

Smil, V. 2003. *Energy at the Crossroads. Global Perspectives and Uncertainties*. MIT Press, Cambridge, MA.

Sohngen, Brent, Robert Mendelsohn and Roger Sedjo, 1999. Forest management, conservation, and global timber markets, *American Journal of Agricultural Economics* 81(1): 1-13.

Solomon, Lawrence, 2009. Carbon baron Al Gore, *Financial Post*, August 26. Accessed online September 1, 2009, at http://network.nationalpost.com/np/blogs/fpcomment/archive/2009/08/25/lawrence-solomon-carbon-baron-gore.aspx.

Spencer, Roy W., 2008. Global Warming as a Natural Response to Cloud Changes Associated with the Pacific Decadal Oscillation (PDO), <accessed August 13, 2009> online at http://www.drroyspencer.com/research-articles/global-warming-as-a-natural-response/.

Spencer, Roy W., 2009a. Global Warming Causing Carbon Dioxide Increases: A Simple Model. Available online at http://www.drroyspencer.com/2009/05/global-warming-causing-carbon-dioxide-increases-a-simple-model; accessed September 2, 2009.

Spencer, Roy W., 2009b. The MIT Global Warming Gamble. Available online at http://www.drroyspencer.com/2009/05/the-mit-global-warming-gamble/; accessed October 19, 2009.

Spencer, Roy W., and William D. Braswell, 2008. Potential Biases in Feedback Diagnosis from Observational Data: A Simple Model Demonstration, *Journal of Climate*, February, 5624—5628.

Spencer, Roy W., William D. Braswell, John R. Christy, and Justin Hnilo, 2007. Cloud and radiation budget changes associated with tropical intraseasonal oscillations, *Geophysical Research Letters*, vol. 34, L15707.

Stager, Curt, 1987. "Silent Death at Cameroon's Killer Lake," *National Geographic*, 172 (3) (September): 404-420.

Stennes, B., K. Niquidet and G.C. van Kooten, 2009. Implications of Expanding Bioenergy Production from Wood in British Columbia: An Application of a Regional Wood Fibre Allocation Model. CFS Working Paper. Victoria, BC: Canadian Forest Service. Under review at *Forest Science*.

Stern, Nicholas, 2007. The Economics of Climate Change: The Stern Review. Cambridge, UK: Cambridge Univ. Press.

Stott, John, 1972 (2006). *Your Mind Matters*. Leicester, UK: Intervarsity Press.

The Economist, 2009. Thaw Point: Global Warming and the Permafrost, *The Economist*, August 1, p.70.

Tol, Richard S.J., 2006. The Stern Review of the Economics of Climate Change: A Comment, *Energy & Environment* 17(6): 977-981.

Tol, Richard S.J., 2005a. Adaptation and Mitigation: Trade-offs in Substance and Methods, *Environmental Science & Technology* 8: 572-578.

Tol, Richard S.J., 2005b. The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties, *Energy Policy* 33(16): 2064-2074.

Tol, Richard S. J. 2002. Estimates of Damage Costs of Climate Change, *Environmental and Resource Economics* 21: 47–73.

Torn, Margaret S. and John Harte, 2006. Missing Feedbacks, Asymmetric Uncertainties, and the Underestimation of Future Warming, *Geophysical Research Letters* 33: L10703. doi:10.1029/2005GL025540.

Tucker, William, 2008. *Terrestrial Energy: How Nuclear Energy Will Lead the Green Revolution and End America's Energy Odyssey*. Savage, MD: Bartleby Press.

U.S. Environmental Protection Agency, 2009. EPA Preliminary Analysis of the Waxman-Markey Discussion Draft. April 20. Office of Atmospheric Programs. Viewed 10 August 2009 at: http://www.epa.gov/climatechange/economics/pdfs/WM-Analysis.pdf

van Kooten, G. Cornelis, 2009a. Biological Carbon Sequestration and Carbon Trading Re-Visited, *Climatic Change* doi: 10.1007/s10584-009-9572-8. In press.

van Kooten, G. Cornelis, 2009b. Biological Carbon Sinks: Transaction Costs and Governance, *The Forestry Chronicle* 85(3): 372-376.

van Kooten, G. Cornelis, 2009c. Wind Power: The Economic Impacts of Intermittency. Under review at *Letters in Spatial and Resource Science*. 23pp.

van Kooten, G. Cornelis, 2004. *Climate Change Economics*. Cheltenham, UK: Edward Elgar.

van Kooten, G. Cornelis and Govinda R. Timilsina, 2009. Wind Power Development: Economics and Policies. Policy Research Working Paper 4868. Washington, DC: The World Bank, Development Research Group, Environment and Energy Team. March. 32pp.

van Kooten, G. Cornelis, Susanna Laaksonen-Craig and Yichuan Wang, 2009. A Meta-Regression Analysis of Forest Carbon Offset Costs. *Canadian J of Forest Research*, In press.

van Kooten, G. Cornelis, Alison J. Eagle, James Manley and Tara Smolak, 2004. How Costly are Carbon Offsets? A Meta-analysis of Carbon Forest Sinks, *Environmental Science & Policy* 7(4 August): 239-51.

Weitzman, Martin L., 2009a. On Modeling and Interpreting the Economics of Catastrophic Climate Change, *Review of Economics and Statistics* 91(February): 1-19.

Weitzman, Martin L., 2009b. Some Basic Economics of Extreme Climate Change. February 19. 29pp. Available at <as viewed July 24, 2009> http://www.economics.harvard.edu/faculty/weitzman/papers_weitzman

Weitzman, Martin L., 2009c.Reactions to the Nordhaus Critique. May 17. 18pp. Available at <as viewed July 24, 2009> http://www.economics.harvard.edu/faculty/weitzman/papers_weitzman

Weitzman, Martin L., 2009d. Additive Damages, Fat-tailed Climate Dynamics, and Uncertain Discounting. April 27. 23pp. Available at <as viewed July 24, 2009> http://www.economics.harvard.edu/faculty/weitzman/papers_weitzman

Weitzman, Martin L., 1998. Why the Far-Distant Future Should be Discounted at its Lowest Possible Rate, *Journal of Environmental Economics and Management* 36(3): 201-208.

Weitzman, Martin L., 2007. A Review of the *Stern Review on the Economics of Climate Change*, *Journal of Economic Literature* 45: 703-724.