The Costs of Inaction: The Economic and Budgetary Consequences of Climate Change

Tuesday, July 29 2014, 10:00am, Room SD-608, in Dirksen Senate Office Building

The Senate Budget Committee

Testimony by Bjorn Lomborg, Copenhagen Consensus Center

Summary:

Global warming is real, but a problem, not the end of the world

Climate is not the only cost – climate policy also adds costs

Even the smartest climate policy will likely have almost as high total costs as inaction this century

A more politically plausible climate policy will have *much* higher cost than inaction this century

To answer the committee's question on the US cost of inaction and action for climate change:

- The total, discounted cost of inaction on climate change over the next five centuries is about 1.2% of total discounted GDP.
- The cumulative cost of inaction towards the end of the century is about 1.8% of GDP
- While this is not trivial, it by no means supports the often apocalyptic conversation on climate change.
- The cost of inaction by the end of the century is equivalent to losing one year's growth, or a moderate, one-year recession.
- The cost of inaction by the end of the century is equivalent to an annual loss of GDP growth on the order of 0.02%.
- However, policy action as opposed to inaction, also has costs, and will still incur a significant part of the climate damage. Thus, with extremely unrealistically optimistic assumptions, it is possible that the total cost of climate action will be reduced *slightly* to 1.5% of GDP by the end of the century.
- It is more likely that the cost of climate action will end up costing upwards of twice as much as climate inaction in this century – a reasonable estimate could be 2.8% of GDP towards the end of the century.
- Thus, for the first half century, it is absolutely certain that any climate action will have greater total costs than inaction. For the second half of the century it is very likely that any realistic climate action will have greater costs than climate inaction.
- While it is possible to design clever, well-coordinated, moderate climate policies that will do more good than they will cost, it is much more plausible that total costs of climate action will be more expensive than climate inaction.
- To tackle global warming, it is much more important to dramatically increase funding for R&D of green energy to make future green energy much cheaper. This will make *everyone* switch when green is cheap enough, instead of focusing on inefficient subsidies and second-best policies that easily end up costing much more.
- It is likely that the percentage cost to the US budget is in the same order of magnitude as that of the percentage costs to the US economy.

The Costs of Inaction: The Economic and Budgetary Consequences of Climate Change

What is the cost of inaction and action?

Is global warming happening? Yes. Man-made global warming is a reality and will in the long run have overall, negative impact.

It is important to realize that many economic models show that the overall impact of a moderate warming (1-2°C) will be beneficial whereas higher temperatures expected towards the end of the century will have a negative net impact.[1] Thus, as indicated in Figure 1, global warming is a *net benefit* now and will likely stay so till about 2070, after which it will turn into a net cost.

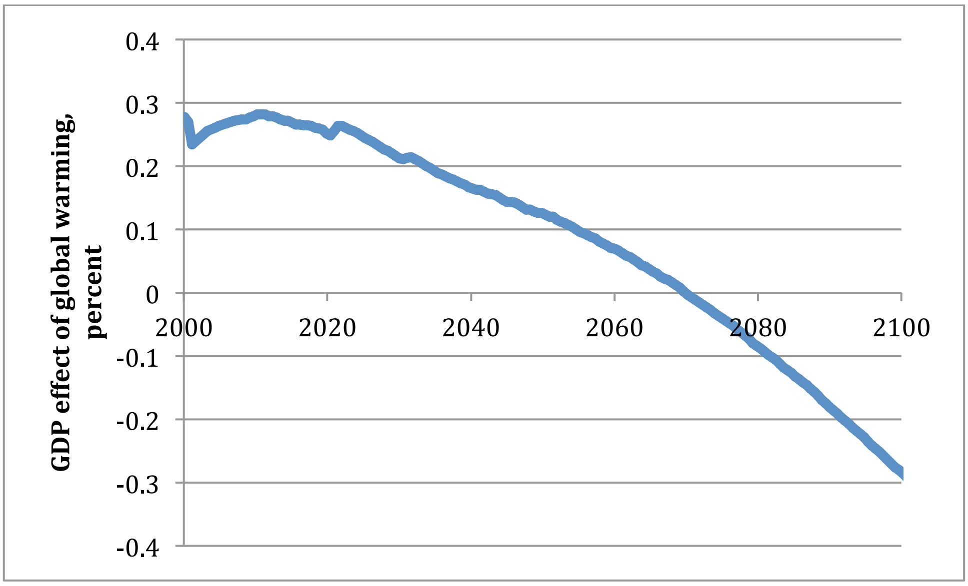

Figure 1 Net benefit or cost of global warming. Benefit is positive, cost is negative.[2]

How important is global warming? To get a sense of the importance of global warming, take a look at the total impact of damage compared to the cumulated consumption using the discount rates from Nordhaus' 2010 DICE model. The total, discounted GDP through the year 2200 (almost the next two centuries) is about $2,212 trillion dollars. The total damage is estimated at about $33 trillion or about 1.5% of the total, global GDP, as indicated in Figure 2. This means that while the global warming impact is *not* zero but *negative*, it does *not* signify the end of the world, either. It is a problem that needs to be solved.

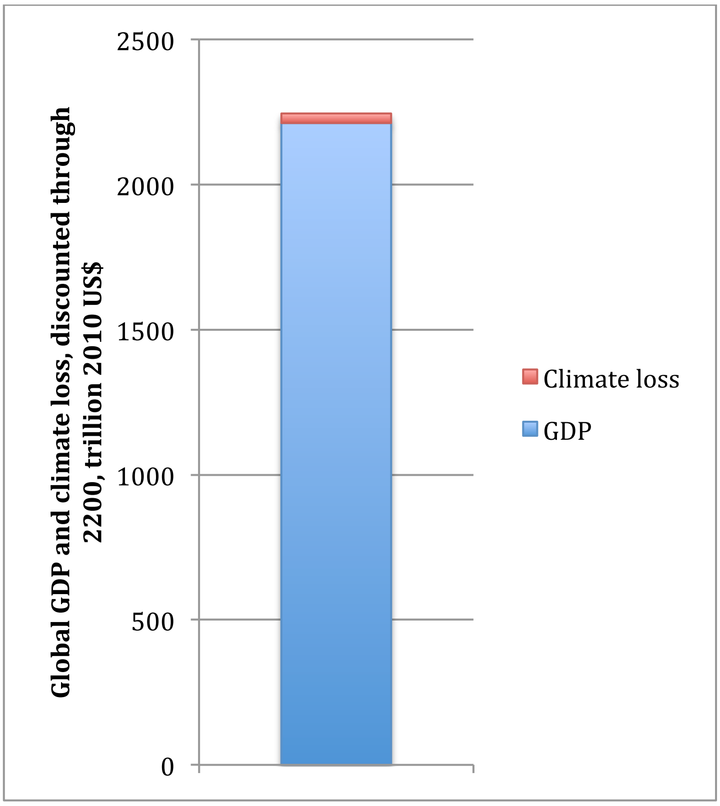

Figure 2 Global, total, discounted GDP through 2200, and climate loss.[3]

What is the impact of global warming on the US economy? There are a number of integrated climate models. I'll here use Nordhaus' RICE model[4] The model contains 12 regions, including the US, China and the EU, an economic sector and geophysical sectors, linking the economy and climate impacts like sea level rise. It has a equilibrium climate sensitivity of 3.2°C, a bit above average, expecting 3.4°C temperature rise by 2100 in the base scenario. Remember also, that the costs of the risks of abrupt and catastrophic climate change are included in the damage estimates in the RICE model.

The RICE model shows instant damages from temperature, making it more pessimistic than most estimates, as referenced above. Moreover, the model shows a 1.95% GDP loss in 2075 from unrestricted global warming at 1.95°C. The IPCC found that the cost of 2°C higher temperatures would be 0.2-2% of income.[5] This means that the RICE model, if anything, is at the high end cost estimates of the integrated models.

The RICE model show the total, discounted GDP for the US across the next 5 centuries is about $842 trillion (2005$), but this will be reduced by about $10 trillion from cumulative impacts from global warming, as indicated in Figure 3. This means that the total damages from unmitigated global warming for the US is on the order of 1.2%.

This indicates, as has often been pointed out, that the US is *less* vulnerable to climate change, compared to many other regions (especially the poorer countries). Moreover, it emphasizes that while the global warming impact is *a net negative* for the US, it is in no way a catastrophe, either.

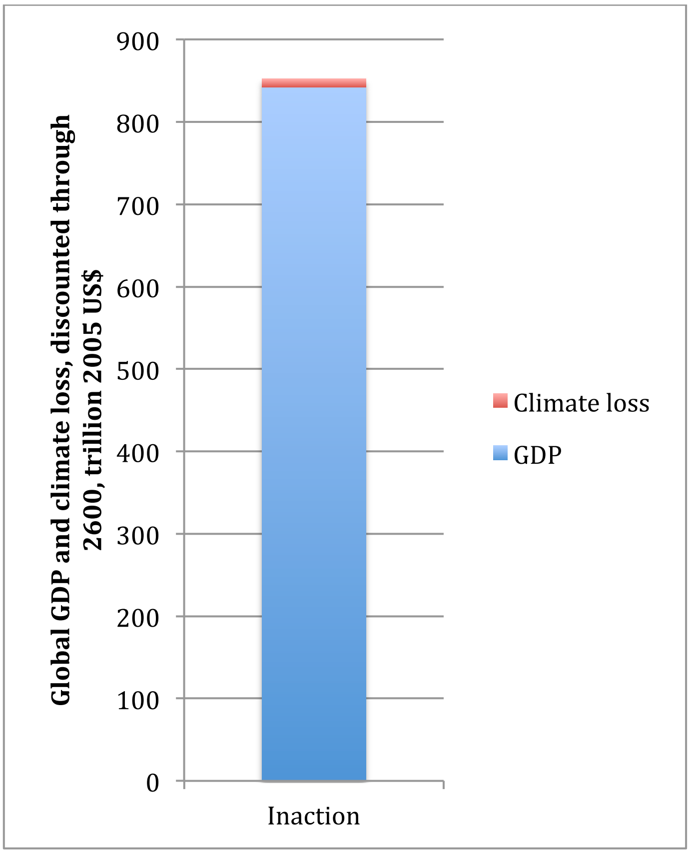

Figure 3 Total US, discounted GDP through 2500, and climate loss.[6]

How much will global warming directly impact the federal budget? I know of no direct estimate of the total impact of global warming on the federal budget. Consequently, I will here assume that the main impact of global warming on the federal budget will be a reduction in total revenue, in line with the reduction in US GDP due to global warming (expecting unchanged taxes). On the one hand, because not all damages included in the RICE model will be translated into actual GDP losses, this may be an over-estimate. On the other hand, it is likely that parts of the costs of global warming will be borne disproportionately by the federal government. Thus, in total, it is likely that the loss estimate from GDP from the RICE model translates directly into the negative impact on the federal budget. In the following discussions I'll treat the impact to the US economy and the federal budget as similar percentages (although of course, of a different base, since the US GDP is about $16 trillion, and the federal budget is about $3 trillion).

That means that the total direct impact on the US federal budget is likely to be a reduction of about 1.2% across the next centuries.

However, this is not actually the avoidable impact from climate, since some climate impact will happen no matter what we do. The internationally most ambitious target (which is probably almost out of reach) is the 2°C goal. Figure 4 shows the cost of unmitigated global warming in the upper line, reaching a US cost of 1.8% of GDP by 2100. The lower, 2°C line shows a cost that is almost indistinguishable for the first decades, leveling off just below 0.6% of GDP by 2100. Thus, the avoidable global warming is the area between the two lines, or about 1.2% GDP by 2100.

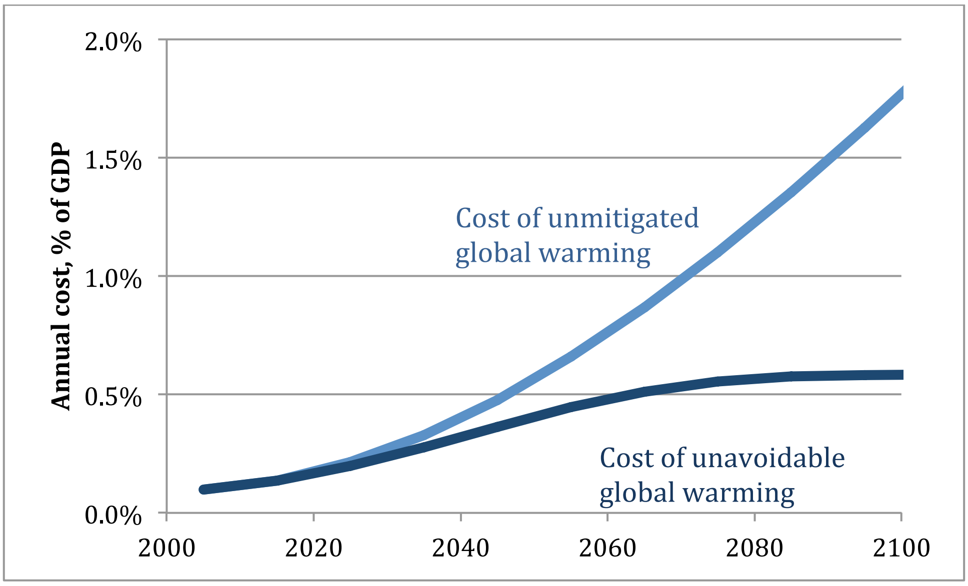

Figure 4 US cost for each year, in % of US GDP that year. Upper line shows the cost of unmitigated global warming. Lower line shows the unavoidable cost of global warming, if all nations achieve the most efficient policies to reach the 2ºC target. All calculations from RICE.

The RICE model show the total, discounted GDP impact of global warming for the US across the next 5 centuries is $10 trillion, as mentioned above, while the cost of the unavoidable global warming is about $3 trillion. This means that the total avoidable damages from global warming for the US is on the order of 0.8%.

With similar reasoning as above, it seems likely that the total avoidable impact on the US federal budget will be in the order of 0.8% of GDP.

How much will global warming indirectly impact the US economy? It is important to remember that the cost of global warming is not the only impact on the US economy or the federal budget. Any climate policy enacted to (partially) counter global warming will also carry both costs and benefits. These will indirectly, through policy, impact both the US economy and the federal budget.

The 2ºC policy. Consider the world implementing the widely promised (but fairly unlikely) 2ºC implemented in the most efficient way possible. This would entail a single, global, uniformly imposed carbon tax, which would increase rapidly through the century. In the RICE model, the indication is that the global carbon tax would have had to be $19/ton CO_2 in 2010, and would have to be $26 in 2015 and $16 in 2020, about $170 in 2055 and $296 in 2105.[7]

To give an indication, this would add ¢22 to a gallon of gasoline about now and $3.40 to a gallon of gasoline in 2085, across the world, including the poorest places on earth.

This is already politically very unlikely to happen. Moreover, the cost is likely a low estimate. Another survey of a 8 global energy models showed the 2ºC target might cost in the order of 12.9% of GDP by the end of the century, leading to carbon taxes of four times the RICE model at $4004 per ton CO_2.[8]

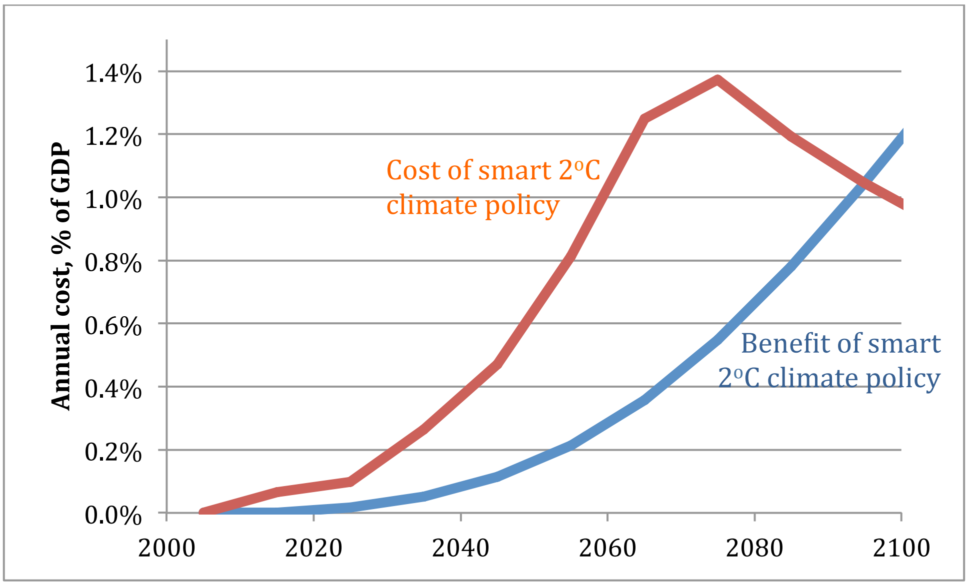

Figure 5 US cost and benefit for each year, in % of US GDP that year of 2°C efficient climate policy. Blue line shows net benefit (avoided costs) from less global warming. Red line shows extra cost. All calculations from RICE.

The important point to realize here is that the costs to the US fall heavily in the early part of the period whereas the benefits tend to come later. This is a standard finding for all climate models and all climate policies.

Here, the cost to the US economy will run upwards of 1.4% of GDP in the second half of the century or about $600 billion in annual costs vs. $250 billion in avoided damages.

Despite everyone else including China and India also implementing similarly expensive climate policies, the US costs will outweigh the benefits for the US from this global policy until the early 2090s, although the benefits will clearly outweigh the costs in the 22nd century and beyond.

With Nordhaus' discounting this climate policy is actually still seen as socially beneficial, because the benefits from future centuries sufficiently outweigh the net cost in this century. The avoided damages run to almost $7 trillion, whereas the policy costs a bit more than $4 trillion. The numbers are almost similar with a traditional 3% discount rate, but with a 5% discount rate, the total policy costs are more than twice the benefits.

Moreover, it seems unlikely that other countries would enact this sort of policy. The annual costs for China would in 2065 be $863 billion annually, with benefits of just $170 billion.

The 'optimal' climate policy. The optimal policy in the RICE model is estimated as the climate policies coordinated and enacted by all nations starting in 2010 that maximize global economic welfare across the next six centuries.

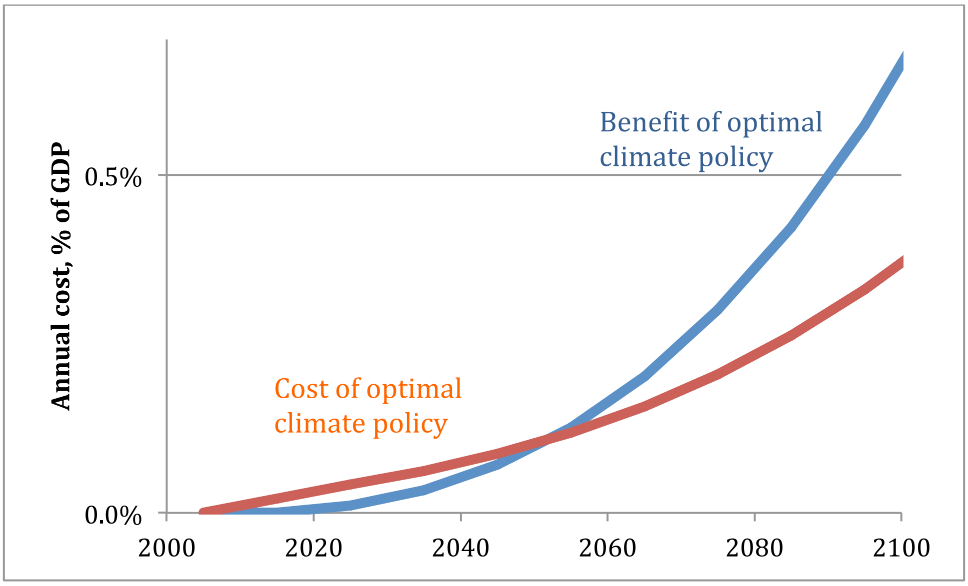

Figure 6 US cost for each year, in % of US GDP that year of optimal climate policy. Blue line shows net benefit (avoided costs) from less global warming. Red line shows extra cost. All calculations from RICE.

The costs and benefits for the US can be seen in Figure 6. Again, the costs outweigh the benefits for the first half-century, but the benefits significantly outweigh the costs for the coming centuries.

This policy is less politically prohibitive, since it requires a lower carbon tax. In the RICE model, the indication is that the global carbon tax would have had to be \$9/ton CO_2 in 2010, \$12 in 2015 and \$16 in 2020, about \$50 in 2050 and \$130 in 2100.[9] In terms of gasoline, this would have added about ¢8 on a gallon in 2010 globally, ¢18 in 2020, about ¢40 in 2050 and \$1.14 in 2100.

This policy is a net benefit, and quite substantial. With Nordhaus' discounting, it costs the world \$1.5 trillion, but avoids climate damages worth \$5 trillion. With 5% discount rate, it is still a slight net benefit.

Yet, actually seeing this policy enacted is wholly unrealistic, as Nordhaus acknowledges.[10] It requires policies that would be coordinated across the entire world, with carbon taxes imposed even on the poorest nations. For instance, the costs for China would remain higher than the Chinese benefits until after 2080, making this a very hard political sell.

As Nordhaus points out, the costs up till mid-century are five times higher than the benefits:

> Abatement costs are more than five times the averted damages. For the period after 2055… however, the ratio is reversed: Damages averted are more than four times abatement costs. Asking present generations—which are, in most projections, less well off than future generations—to shoulder large abatement costs would be asking for a level of political maturity that is rarely observed.

Importantly, the optimal policy will avoid very little of global warming impacts in the 21st century. Figure 7 shows the total damages for both action and inaction.

The damages for inaction (business-as-usual) is just the climate damage from Figure 4, with a cost of about 0.14% of GDP now, and a cost of 1.8% of GDP in 2100. The cost of the optimal, globally coordinated climate policy is the cost of climate policies and the residual negative climate impact. It starts out slightly higher at a cost of 0.16% of GDP now and with a cost of 1.4% of GDP in 2100.

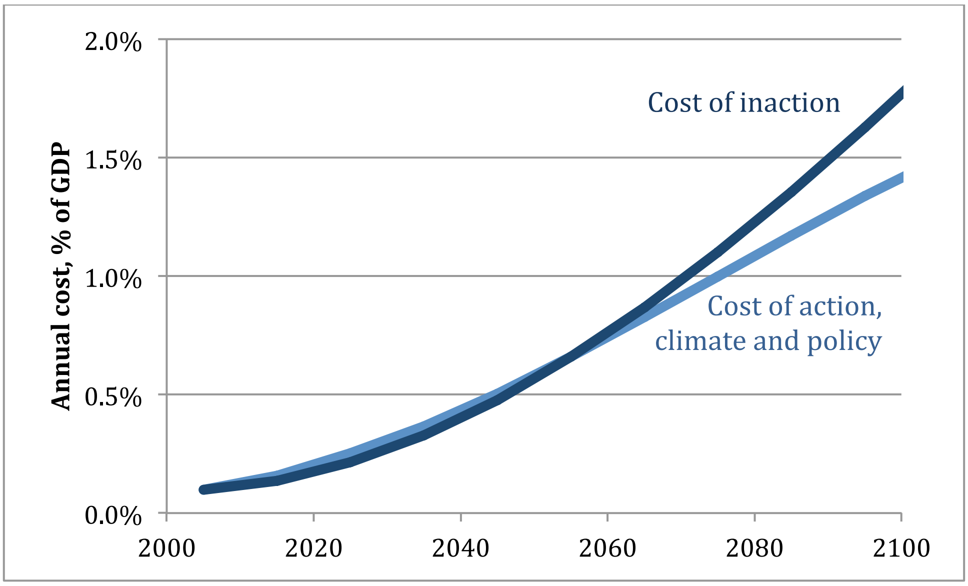

Figure 7 Total cost of climate impact and climate policy for the US. Dark blue line shows the total cost of inaction. Light blue line shows the total cost of smartest, globally coordinated action, both from policy and residual climate damage. All calculations from RICE.

Remembering this is a wholly unrealistic policy to be implemented and be implemented well, the most optimistic statement that can be made on the cost of action and inaction on climate change for the US in the 21st century is that there is little difference. Starting out more expensively, even the optimal climate policy will incur nearly as much cost as no action at all, at 1.4% instead of 1.8% of GDP by the end of the century. As will be apparent below, this is an extremely and unrealistically rosy assessment.

Mostly rich world, ambitious reductions. Both India and China have defended their right to keep their emissions increasing. It is unlikely that they or the rest of the developing, mostly very poor countries will substantially reduce their emissions anytime soon. Nordhaus develops a scenario with rich countries (US, EU, Japan, Russia and the the rest of the rich countries) engage in strong emissions reductions but where the developing countries only participate in the 22nd century.[11] On the current set of policies from both rich and poor countries, this scenario seems a lot more realistic.

In this scenario, the costs are greater than the optimal policy for the rich countries, because they have offered to cut much, much more. This is evident in the EUs professed approach to cut emissions at least 80% below 1990 levels by 2050, and in similar statements from the current US administration.

The benefits, however, are smaller, because many of the biggest emitters are not included. This is readily evident in Figure 8, where China now emits almost twice what the second-largest emitter, the US, does. Of course, China, India and the other poor country emitters will still experience a net benefit in lower climate damages due to the generous reductions from the rich countries.

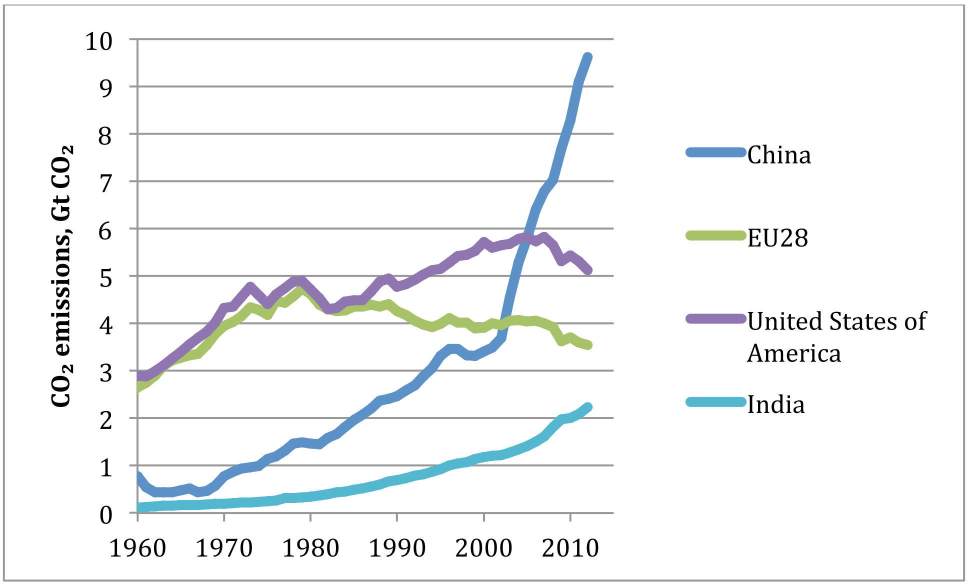

Figure 8 CO_2 emissions from the leading four emitters, China, US, EU and India, 1960-2012.[12]

Nordhaus estimate the future US reductions from the 2009 US climate bill that was passed by the House but not the Senate. In this scenario, the US will by mid-century have reduced its emissions some 75% below what they would otherwise have been.

The climate policy costs for the US will not be trivial. Assuming a full trading zone between all participants, the annual policy costs will run to $145 billion by mid-century and some $250 billion by the end of the century, or about 0.4% of GDP. The full trading assumption is rather unrealistic, as trading has generally been only weakly implemented and often only for small parts of the emissions spectrum. The more realistic cost with a no-trade assumption shows the US costs at about twice the annual cost at $280 billion by mid-century and $400 billion by the end of the century.

We can check the reasonableness of these costs by looking at the well-modeled costs of the EU climate policy to 2020.[13] The average cost by 2020 from 6 models runs to €209 billion or about $280 billion per year (1.3% of GDP). The Nordhaus model (admittedly doing a much more simplified analysis) finds the cost at less than $5 billion, even without trade, suggesting that the RICE estimates are certainly not exaggerated.

However, a consistent result from the studies of the EU climate policy is that real climate policies are often poor, second-best policies, with a mish-mash of regulation of different sectors and regions. The most pertinent summary of the Stanford Energy Modeling Forum's assessment of the EU policies finds:

> Second-best policies increase costs. A policy with two carbon prices (one for the ETS, one for the non-ETS) could increase costs by up to 50%. A policy with 28 carbon prices (one for the ETS, one each for each Member State) could increase costs by another 40%. The renewables standard

could raise the costs of emissions reduction by 90%. Overall, the inef!ciencies in policy lead to a cost that is 100–125% too high.[14]

Thus, it is very likely that a more realistic estimate of costs will be a bit above twice the optimal estimate. For the RICE model, that means that the US costs of an ambitious climate policy will more likely incur annual costs of about half a trillion by mid-century and some $800 billion by the end of the century.

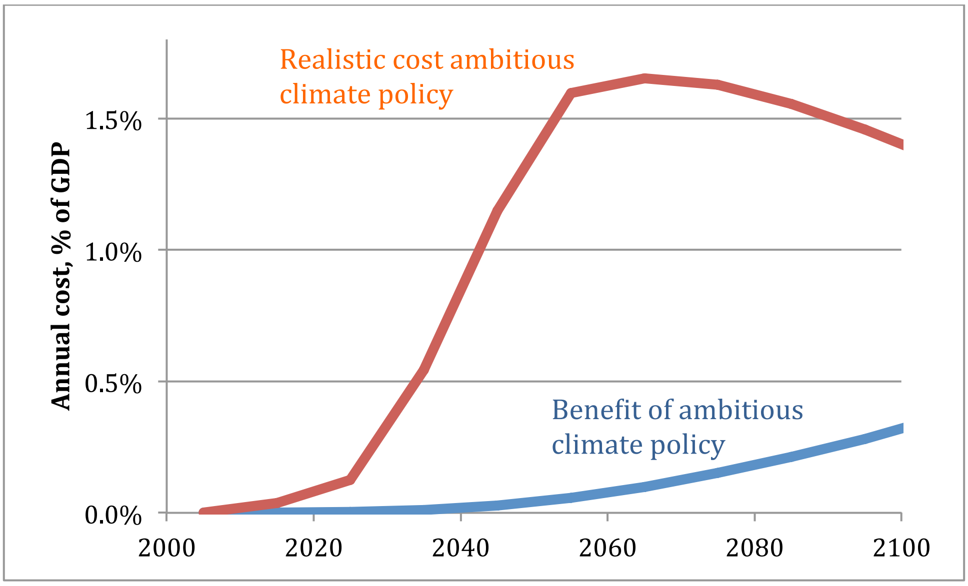

Figure 9 US cost and benefits for each year, in % of US GDP that year of realistic, ambitious climate policy ("Copenhagen Accord with only rich countries," no trade and 2x policy costs). Blue line shows net benefit (avoided costs) from less global warming. Red line shows policy costs. All calculations from RICE.

The overview of the 21st century is available in Figure 9. The policy cost is vastly greater than the avoided climate damages, with costs running above 1.5% of GDP (about similar to what the moderate EU climate efforts will cost the EU by 2020), while benefits run between 0.1% and 0.3% in the second half of the century.

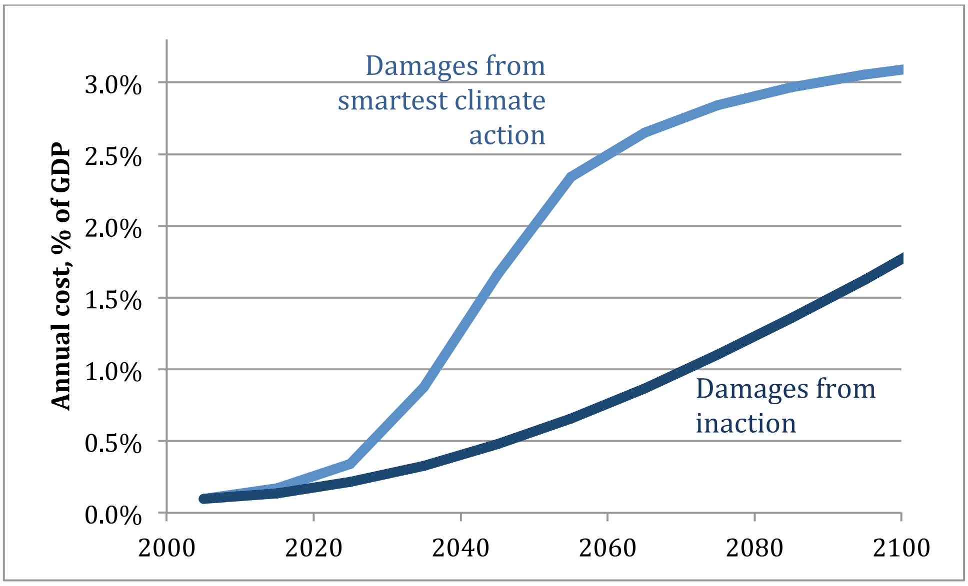

Figure 10 Total damages from climate impact and climate policy costs for the US, in % of US GDP that year. Dark blue line shows the total cost of inaction. Light blue line shows the total cost of realistic, ambitious climate action. All calculations from RICE.

Again, it is important to emphasize that such an ambitious climate policy does not reduce total impacts to the US economy or the federal budget, but actually dramatically increase the total cost, as is evident in Figure 10. In such a situation the US would have to both suffer significant costs from only slightly reduced climate change while incurring even higher policy costs.

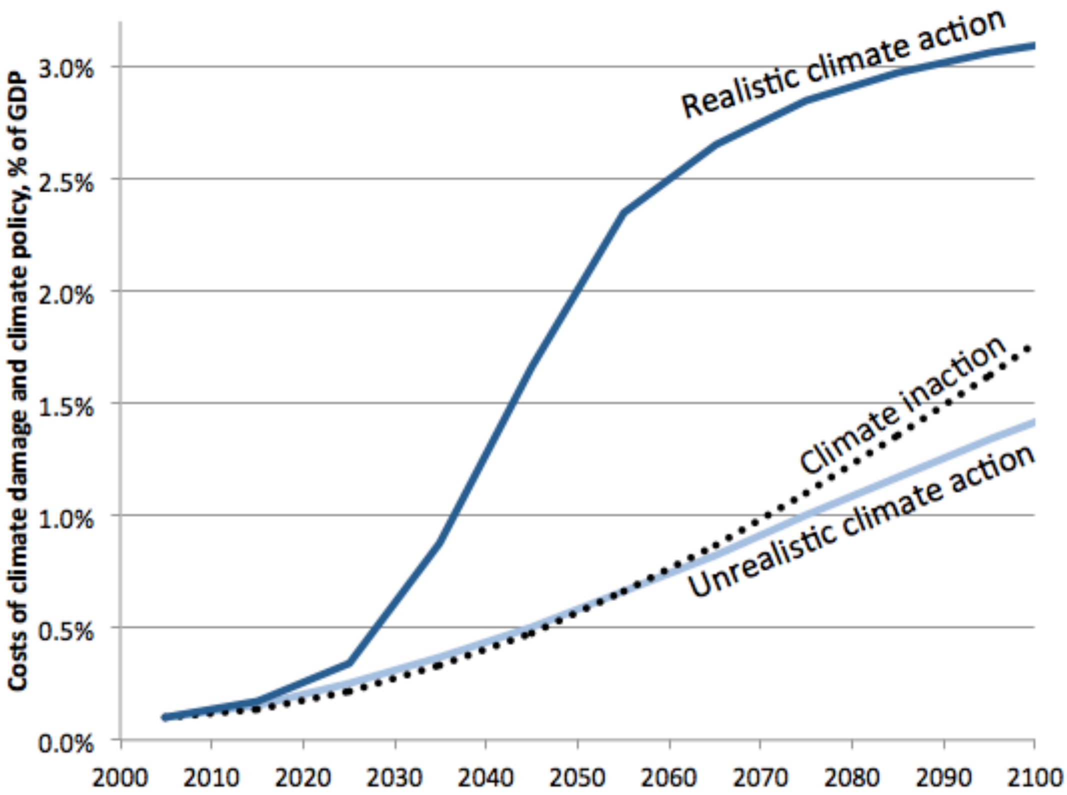

Figure 11 Total costs and benefits from inaction and action for the US. Black dotted line shows the cost of inaction. The light blue line shows the absolutely best-case cost of optimal, globally coordinated policies, with the cost of policy and the cost of residual climate damage. Dark blue line shows the more realistic cost of a mostly rich-country-led, ambitious, second-best climate policy along with residual climate damage. All calculations from RICE.

Figure 11 answers the committee's question on the costs of climate inaction and climate action. The costs of inaction rise through the century to about 1.8% of GDP in 2100. With extremely unrealistically optimistic assumptions, it is possible that the total cost of climate policy action will be reduced *slightly* to 1.5% of GDP by the end of the century. With more likely assumptions, the cost of climate action will end up costing upwards of twice as much as climate inaction in this century, or about 3.1% of GDP towards the end of the century. No matter what, the cost of action is higher than the cost of inaction in the first half of the century.

Another way to see look at the cost of action and inaction is to look at the total, discounted cost of global warming and global warming policy on the 21st century in Figure 12. The cost for the unrealistic action, the optimal policy, is 0.49% of the period's total GDP. The cost for inaction is 0.52%, while the cost for the optimal 2°C policy is 0.78% and the realistic, ambitious climate policy is 1.17%. For following centuries, the relative cost of inaction will increase.

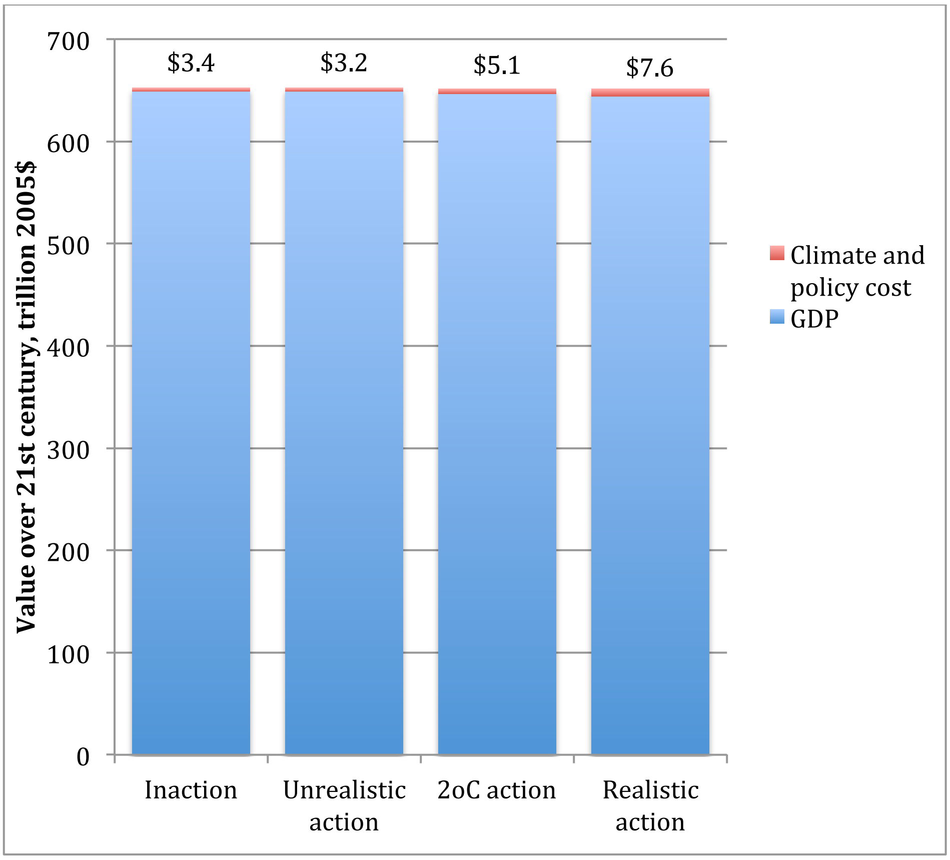

Figure 12 Costs of climate impacts and climate policy, and remaining GDP, for four different scenarios, over 21st century. The unrealistic action is the optimal action, generating a climate and policy cost of $3.2 trillion, and with a remaining GDP of $649.1 trillion. Realistic action is the mostly-rich-world scenario All calculations from RICE.

Two points are clear. First, global warming is by no means the most important part of the 21st century. Second, there is much greater scope for climate policies to make the total climate cost *greater* thought the 21st century.

Failed policies to tackle global warming

This underscores the central question of how else to approach global warming.

The first realization needs to be that the current, old-fashioned approach to tackling global warming has failed. The current approach, which has been attempted for almost 20 years since the 1992 Earth Summit in Rio, is to agree on large carbon cuts in the immediate future. Only one real agreement, the Kyoto Protocol, has resulted from 20 years of attempts, with the 2009 Copenhagen meeting turning into a spectacular failure.

The **Kyoto approach is not working** for three reasons. **First**, cutting CO_2 is **costly**. We burn fossil fuels because they power almost everything we like about modern civilization. Cutting emissions in the absence of affordable, effective fossil fuel replacements means costlier power and lower growth rates. The only current, comprehensive global warming policy, the EU 20-20-20, will cost about $280bn/year.[15]

Second, the approach **won't solve the problem**. Even if everyone had implemented Kyoto, temperatures would have dropped by the end of the century by a miniscule 0.004°C (0.007°F). The EU policy will, across the century, cost about $20 trillion, yet will reduce temperatures by just 0.05°C (0.1°F).[16]

Third, **green energy is not ready** to take over from fossil fuels.[17] It is generally much costlier, its deployment does not in general create new jobs (because its higher, subsidized costs destroy jobs in the rest of the economy)[18], and because it typically produces electricity, which is not generated with oil, it doesn't reduce oil dependence[19]. Today, wind supplies 0.7% of global energy and solar about 0.1%, and even with very optimistic assumptions from the International Energy Agency, wind will supply only 2.4% in 2035 and solar 0.8%.[20]

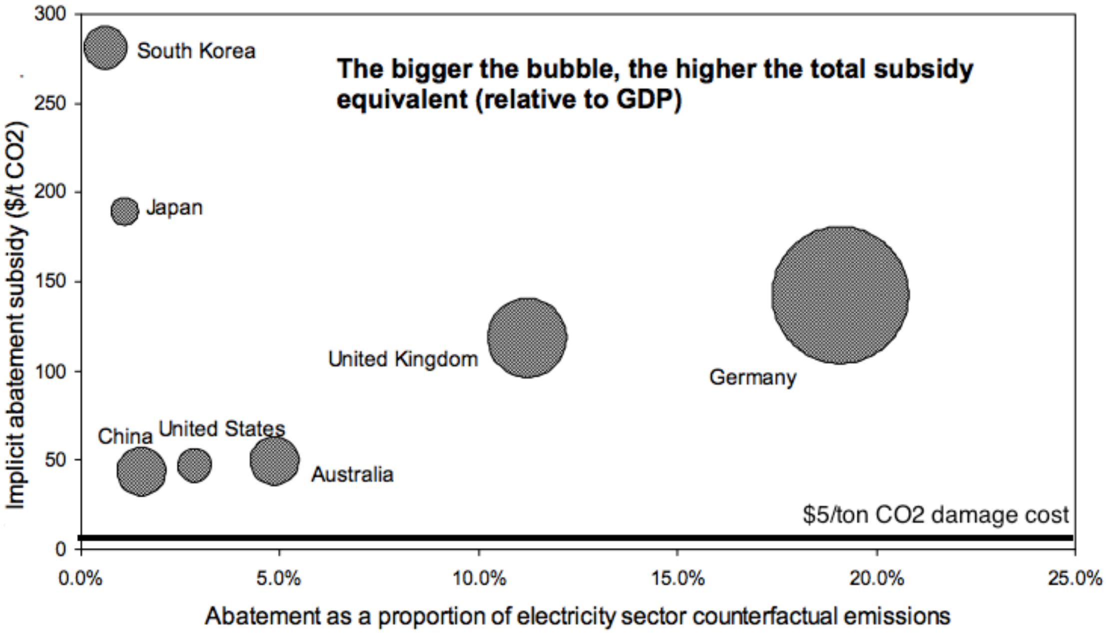

Figure 13 Abatement and implicit CO2 reduction cost for electricity, various nations. $5/ton CO2 damage insert for referece. In AUS$, which is almost equivalent to US$.[21]

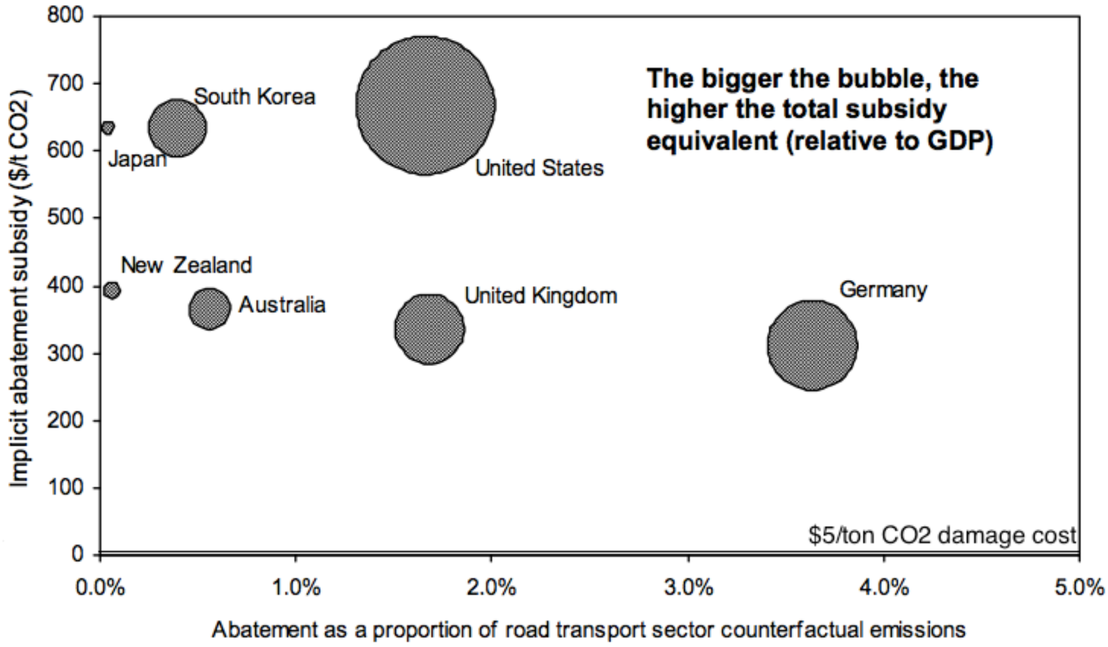

Figure 14 Abatement and implicit CO2 reduction cost for biofuels, various nations. $5/ton CO2 damage insert for referece. In AUS$, which is almost equivalent to US$.[22]

Because there is no good, cheap green energy, the almost universal political choices have been expensive policies that do very little. In Figure 13 we see how all major nations have managed to enact policies for electricity that cost a lot, yet do very little (Germany is leading the pack and still only reducing emissions from the power sector of 19% or 7% of the economy).

The cost per ton of CO2 avoided is universally far above the most likely $5/ton CO2 damage,[23] with China at the cheapest at 8 times the damage of at about $40, and South Korea at a phenomenal $280/ton CO2, 56 times higher than the damage cost. Germany pays each year about 0.3% of its GDP in electricity subsidies.

On biofuels, the excess cost is even more pronounced, and yet the emission reductions even smaller, as can be seen in Figure 14. Germany is paying 62 times too much or $310/ton CO2, reducing just 0.6% of its total emissions at a cost of $1.7bn. The US is paying a phenomenal 133 times too much, at $666/ton CO2, costing $17.5bn/year and reducing just 0.5% of its total emissions.

Yet, the cost is not just in economic terms. There is also increasing dissatisfaction with high energy costs in countries like the UK and Germany. In Germany the cost of electricity has risen 80% in real terms since 2000, as is evident in Figure 15. A fourth of all consumer energy costs are now direct subsidies to renewables.

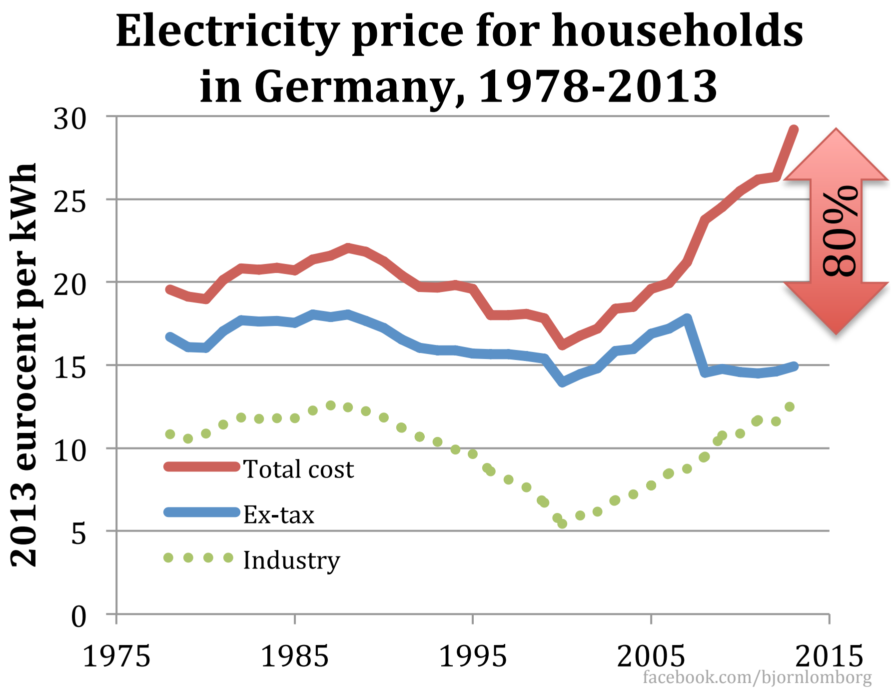

Figure 15 Electricity price for households in Germany, 1978-2013.[24]

A better policy approach to tackling global warming

It is important to realize that the old-fashioned policies have failed. Current green technologies just won't make it[25]. The only way to move towards a long-term reduction in emissions is if green energy becomes much cheaper. If green energy was cheaper than fossil fuels, everyone would switch.

This requires breakthroughs in the current green technologies, which means focusing much more on innovating smarter, cheaper, more effective green energy.

Of course, pursuing an approach of R&D holds no guarantees—we might spend dramatic amounts on R&D and still come up empty in 40 years — but it has much higher likelihood of succeeding than our twenty-year futile attempts to cut carbon so far.

This was the recommendation of the Copenhagen Consensus on Climate, where a panel of economists including three Nobel laureates found that **the best long-term strategy** is to dramatically increase investment in green R&D.[26] They suggested to 10-fold increase the current investment of $10bn to $100bn/year globally. This would be 0.2% of global GDP, and would entail a commitment of about $40bn from the US.

This approach would be significantly cheaper than the current policies (like the EU 20-20) and 500 times more effective. It is also much more likely to be acceptable to the developing countries.

The **metaphor** here is the **computer** in the 1950s. We did not obtain better computers by mass-producing them to get cheaper vacuum tubes. We did not provide heavy subsidies so that every Westerner could have one in their home in

1960. Nor did we tax alternatives like typewriters. The breakthroughs were achieved by a dramatic ramping up of R&D, leading to multiple innovations, which enabled companies like IBM and Apple to eventually produce computers that consumers wanted to buy.

This is what the US has done with fracking. The US has spent about $10bn in subsidies over the past three decades to get fracking innovation, which has opened up large new resources of previously inaccessible shale gas. Despite some legitimate concerns about safety, it is hard to overstate the overwhelming benefits. Fracking has caused gas prices to drop dramatically and changed the US electricity generation from 50% coal and 20% gas to about 40% coal and 30% gas.

This means that the US has reduced its annual CO_2 emissions by about 300Mt CO_2 in 2012.[27] This is about twice the *total* reduction over the past twenty years of the Kyoto Protocol from the rest of the world, including the European Union. At the same time, the EU climate policy will cost about $280 billion per year, whereas the US fracking is estimated to *increase* US GDP by $283 billion per year.

Conclusion

To answer the committee's question on the US cost of inaction and action for climate change, the short summary is this:

- The total, discounted cost of inaction on climate change over the next five centuries is about 1.2% of total discounted GDP.
- The cumulative cost of inaction towards the end of the century is about 1.8% of GDP
- While this is not trivial, it by no means supports the often apocalyptic conversation on climate change.
- The cost by the end of the century is equivalent to losing one year's growth, or a moderate, one-year recession.
- The cost of inaction by the end of the century is equivalent to an annual loss of GDP growth on the order of 0.02%.
- However, policy action as opposed to inaction, also has costs, and will still incur a significant part of the climate damage. Thus, with extremely unrealistically optimistic assumptions, it is possible that the total cost of climate policy action will be reduced *slightly* to 1.5% of GDP by the end of the century.
- It is more likely that the cost of climate action will end up costing upwards of twice as much as climate inaction in this century – a reasonable estimate would be 2.8% of GDP towards the end of the century.
- Thus, for the first half century, it is absolutely certain that any climate action will have greater total costs than inaction. For the second half of the century it is very likely that any climate action will have greater costs than climate inaction.
- While it is possible to design clever, well-coordinated, moderate climate policies that will do more good than they will cost, it is much more likely that the total costs of climate action will be much more expensive than climate inaction.

- To tackle global warming, it is much more important to dramatically increase funding for R&D of green energy to make future green energy much cheaper. This will make *everyone* switch when green is cheap enough, instead of focusing on inefficient subsidies and second-best policies that easily end up costing much more.
- It is likely that the percentage cost to the US budget is in the same order of magnitude as that of the percentage costs to the US economy.

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[1] Figure 1, p912, Richard S.J. Tol 2013: "Targets for global climate policy: An overview" in *Journal of Economic Dynamics & Control* 37 (2013) 911–928.

[2] Figure 4.1 in Gary W. Yohe, Richard S.J. Tol,, Richard G. Richels, Geoffrey J. Blanford 2009: The Challenge of Global Warming, in Lomborg, B 2009: *Global Crises, Global Solutions*, 2nd edition, Cambridge University Press.
http://www.copenhagenconsensus.com/Files/Filer/CC08/Papers/0%20Challenge%20Papers/CP_GlobalWarmingCC08vol2.pdf

[3] Calculated from Nordhaus DICE model 2010, http://nordhaus.econ.yale.edu/RICEmodels.htm

[4] William D. Nordhaus 2010: "Economic aspects of global warming in a post- Copenhagen environment" in *Proceedings of the National Academy of Sciences*, 107:26, p11721–11726, doi: 10.1073/pnas.1005985107

[5] p19, http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf

[6] Calculated from Nordhaus RICE model 2010, http://nordhaus.econ.yale.edu/RICEmodels.htm

[7] Nordhaus 2010, p4, recalculated to per ton CO_2 and CPI corrected to 2013.

[8] Richard Tol 2010, Carbon Dioxide Mitigation, in Lomborg 2010 *Smart Solutions to Climate Change*, Cambridge UK, Cambridge University Press.

[9] Nordhaus 2010, p4, recalculated to per ton CO_2 and CPI corrected to 2013.

[10] "Although unrealistic, this scenario provides an efficiency benchmark against which other policies can be measured."

[11] The so-called "Copenhagen Accord with only rich countries." I will here assume no trading between the blocks.

[12] http://cdiac.esd.ornl.gov/GCP/carbonbudget/2013/

[13] Christoph Böhringer et al. 2009: "EU climate policy up to 2020: An economic impact assessment" *Energy Economics* 31 (2009) S295–S305; Christoph Böhringer et al. 2009: "The EU 20/20/2020 targets: An overview of the EMF22 assessment" *Energy Economics* 31 (2009) S268–S273; Richard S.J. Tol 2012: "A cost–benefit analysis of the EU 20/20/2020 package." *Energy Policy* 49 (2012) 288–295,

[14] Christoph Böhringer et al. 2009: "The EU 20/20/2020 targets: An overview of the EMF22 assessment" *Energy Economics* 31 (2009) S268–S273.

[15] Richard S. J. Tol (2010) *The Costs and Benefits of EU Climate Policy for 2020*, Copenhagen Consensus Center.

[16] Tol (2010).

[17] Isabel Galiana and Christopher Green (2010) *Technology-Led Climate Policy*, in Smart Solutions to Climate Change; Comparing Costs and Benefits, Cambridge University Press.

[18] Gürcan Gülen (2011) *Defining, Measuring and Predicting Green Jobs*, Copenhagen Consensus Center.

[19] Research by climate economist Böhringer even shows that, fully implemented, the EU 20-20-20 plan does not boost energy security. See: Christoph Böhringer and Andreas Keller (2011) *Energy Security: An Impact Assessment of the EU Climate and Energy Package*, Copenhagen Consensus Center.

[20] International Energy Agency (2010) *World Energy Outlook 2000*, IEA/OECD.

[21] Pxxxvii, Australian Government Productivity Commission 2011: Carbon Emission Policies in Key Economies, http://www.pc.gov.au/projects/study/carbon-prices/report

[22] Pxxxix, Australian Government Productivity Commission 2011: Carbon Emission Policies in Key Economies, http://www.pc.gov.au/projects/study/carbon-prices/report

[23] Richard S. J. Tol (2011). The Social Cost of Carbon, Annu. Rev. Resour. Econ. 2011. 3:419–43, doi: 10.1146/annurev-resource-083110-120028.

[24] Data from OECD (prices http://bit.ly/10IXX5J.

[25] For a sobering examination of the scale of the technological challenge, see: Isabel Galiana, Christopher Green (2009) *A Technology-led Climate Policy*, in Advice for Policymakers, Copenhagen Consensus Center. http://fixtheclimate.com/fileadmin/templates/page/scripts/downloadpdf.php?file=/uploads/tx_templavoila/COP15_Policy_Advice.pdf

[26] Other influential research papers arguing for this approach include:
Prins, Gwyn and Galiana, Isabel and Green, Christopher and Grundmann, Reiner and Korhola, Atte and Laird, Frank and Nordhaus, Ted and Pielke Jnr, Roger and Rayner, Steve and Sarewitz, Daniel and Shellenberger, Michael and Stehr, Nico and Tezuko, Hiroyuki (2010) *The Hartwell Paper: a new direction for climate policy after the crash of 2009*. Institute for Science, Innovation & Society, University of Oxford; LSE Mackinder Programme, London School of Economics and Political Science; and also
Steven F. Hayward, Mark Muro, Ted Nordhaus and Michael Shellenberger (2010) *Post-Partisan Power: How a limited and direct approach to energy innovation can deliver clean, cheap energy, economic productivity and national prosperity.* American Enterprise Institute, Brookings Institution, Breakthrough Institute.

[27] Zeke Hausfater 2013: Explaining and understanding declines in US CO_2 emissions.