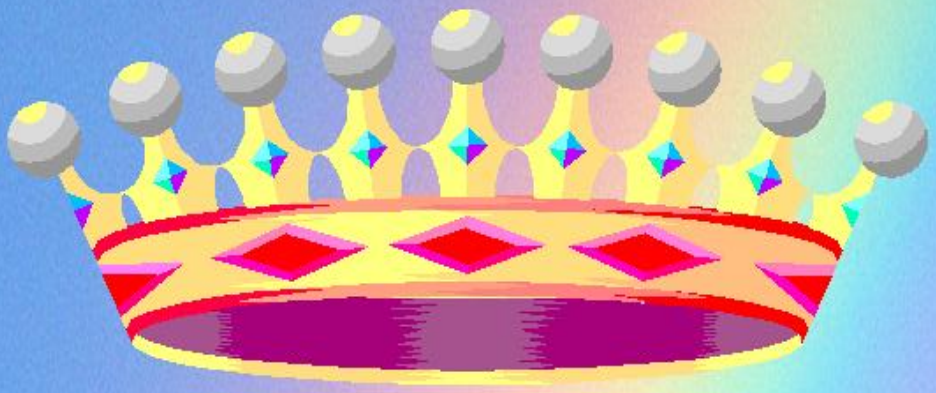
Regulation
without reason



The Canadian Government's proposed

Reduction of Carbon Dioxide Emissions From Coal-Fired Generation of Electricity Regulations

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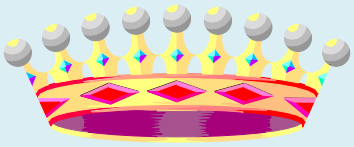
Contents

Why the regulations would not work	4
Summary	5
The questions Environment Canada should have asked	6
How much global warming would the proposed regulations abate?	7
How cost-effective would the regulations be in mitigating global warming?	8
How much would it cost to abate all global warming from 2015-2030?	9
What is the cost of taking no action to mitigate global warming?	10
Would it be more cost-effective to do nothing to mitigate CO2 emissions?	11
Are the IPCC's global-warming projections proving accurate?	12
Is Environment Canada's scientific and economic analysis fit for its purpose?	13
Should these or any CO2-mitigation regulations be implemented?	14
Conclusions	15
Recommendations	16
Technical Annex	17
References	28



Why the regulations would not work

TABLE 0 Parameter	Value
Total cost of the regulations at present value	$6.4 bn
Fraction of global CO2 emissions abated	0.03%
Business-as-usual CO2 concentration in 2030 *... and after the full effect of the regulations*	437.676 ppmv *437.665 ppmv*
CO2 radiative forcing abated, 2015-2030	0.00013 W m^{-2}
Global warming prevented, 2015-2030	0.00007 C°
Mitigation cost-effectiveness	$84 tr/C°
Global abatement cost: Cash Per capita As % GDP	$29.4 tr $4000/head 3.89% GDP
Cost of damage arising from climate inaction	0.22% GDP
Action-inaction ratio: the multiple by which the cost of action exceeds the cost of inaction	(3% disc.) 7.6 (5% disc.) 17.6

Table 0. The reasons why abandonment of the regulations is recommended. At the minimum market discount rate of 5%, it would be almost 18 times costlier to implement the regulations than it is to meet the cost of climate-related damage that may arise from taking no action to control CO2 emissions at all.

Summary

- **The cost of abating global warming as cost-ineffectively as the regulations would be 8 to 18 times the cost of damage from inaction.**
- The present value of the global cost of climate-related damage arising from failure to act on CO2 emissions is little more than **0.2% of global GDP.**
- If the proposed regulations were brought into full effect, only **0.03%** of global CO2 emissions would be abated over the 16-year term of the regulations.
- CO2 concentration, projected at 389.2 ppmv in 2014, would rise to **437.676** ppmv by 2030 without the regulations, and to **437.664** ppmv with them.
- 16 years of regulation would abate only **0.012 ppmv** of CO2 concentration, representing just **0.002%** of the projected CO2 concentration in 2030.
- The regulations would abate **0.00015** W m^{-2} of CO2 forcing & **0.00007 C°** of global warming – a little above **1/14,000 C°,** or less than **1/700** of the threshold below which no change in global temperature can be detected.
- Warming abated would be **0.03%** of the projected **0.25 C°** warming to 2030.
- The CO2-mitigation cost-effectiveness of the regulations, expressed in dollars per C° of global warming abated, would be **$92 trillion/C°.**
- The global cost of abating all of the 0.25 C° warming projected from 2015-2030 by methods of equivalent cost-effectiveness would be **$29.4 trillion.**
- This global abatement cost would represent **$4200** per capita of global population, or **3.9% of global GDP** over the 16-year regulatory period.
- For many reasons, it is very likely that the above figures make the proposed regulations seem very much more cost-effective than they are.
- The regulatory impact statement is silent on the CO2 concentration, CO2 radiative forcing and global warming the regulations are expected to abate.
- Environment Canada's use of "the social cost of carbon [dioxide]" rather than of a scientific measure of the cost of climate inaction is inappropriate.
- The "social cost of CO2" is an inappropriate metric, in that its fixed price fails to represent the logarithmic decline in CO2 forcing as concentration rises.
- Environment Canada uses a 3% pure rate-of-time-preference discount rate for costing the regulations, but the minimum market discount rate is **5%.**
- The low discount rate unduly favours action over inaction, yet it would still be many times as costly to implement the regulations as to do nothing.
- Environment Canada has not made explicit its discount rate for the cost of inaction, which appears to be different from its rate for the cost of action.
- The cash "benefits" of the regulations are wrongly calculated and exaggerated.
- **Since the cost of taking action under the regulations exceeds that of inaction 8 to 18 times over, the regulations should be abandoned.**

The questions Environment Canada should have asked

The regulatory impact statement that prefaces the Canadian Government's proposed regulations on *Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity* (Environment Canada, 2011) suggests cutting Canada's coal-generation industry by more than half.

Before so grave an assault on one of Canada's major industries could be justified, many serious questions should have been asked and answered. Environment Canada did not ask them, still less answer them.

1. **How much global warming would the proposed regulations abate?**
2. **How cost-effective would the regulations be in abating CO2-driven global warming?**
3. **How would the cost-effectiveness of the regulations compare with that of other CO2-mitigation schemes worldwide?**
4. **What would be the worldwide cost of abating all global warming projected to occur over the lifetime of the regulations?**
5. **What is the cost of the climate-related damage that might arise if no mitigation were attempted?**
6. **Would it be more cost-effective to take no mitigation action at all?**
7. **Are the IPCC's global-warming projections proving accurate?**
8. **Is the scientific and economic analysis in Environment Canada's regulatory impact statement fit for its purpose?**
9. **Should these or any CO2-mitigation regulations be implemented?**

It is striking that Environment Canada did not ask these questions. They must now be asked. It is the purpose of this paper to ask them, and to answer them as objectively and as accurately as possible.

To many, the conclusions in this paper may seem startling, even incredible. Accordingly, a full Technical Annex explains the derivation of every result in enough detail to allow independent verification, and refers to the sources.

Though the methodology deployed here is simple, it is not *simpliste*. It is certainly more sophisticated than that of Environment Canada. It is designed to allow non-specialist policy-makers rapidly but reliably to appraise this or other existing or proposed strategies to mitigate carbon dioxide emissions worldwide.

Question 1

How much global warming would the proposed regulations abate?

The regulatory impact statement published as a preface to the draft regulations (Environment Canada, 2011) states that the objective of the regulations is to reduce CO2 *emissions*. Yet it is CO2 *concentration* remaining in the atmosphere that determines the extent to which the Earth may warm. The statement makes no mention of the quantum of CO2 concentration that the full implementation of the proposed regulations is expected or intended to achieve. This is a serious omission.

To establish the CO2 concentration that may be abated by regulations such as those now proposed, it is first essential to establish the fraction of global CO2 emissions that the proposed regulations would abate. The statement makes no attempt to identify this value – another significant and puzzling omission. The Friends of Science have estimate that the abatement fraction is **0.037%.** We find this estimate too large by almost a quarter. The true abatement fraction is **0.03%.** The derivation of all values in this paper is given in the Technical Annex.

Nowhere in Environment Canada's statement is there any estimate of the atmospheric CO2 concentration before and after the 16-year regulatory period from 2015-2030 inclusive on a business-as-usual scenario. This is an essential benchmark, without which the fall in CO2 concentration and consequently the abatement of global temperature brought about by the regulations cannot be assessed at all.

On the A2 emissions scenario, close to today's global CO2 emissions, in 2014 the concentration will be **398.2 ppmv,** and in 2030 **437.676 ppmv**. If the regulations were implemented in full, and were every bit as successful in reducing CO2 emissions as Environment Canada predicts, CO2 concentration in 2030 would fall **from 437.676 to 437.664 ppmv,** a decline of just **0.012 ppmv,** which represents only **0.002%** of the projected CO2 concentration in 2030. Even if all nations adopted Canada's regulations, only **0.1%** of CO2 concentration in 2030 would be abated.

From these values, adopting the IPCC's methodology as normative, it is possible to determine that the CO2 forcing abated after 16 years of regulation would be **0.00015 Watts per square metre,** from which it follows that the global warming abated by the proposed regulations, if they succeeded fully, would be **0.000067 C°.**

That is **1/15,000 C°,** or **1/750** of the minimum threshold below which no modern instrument or method can detect a change in global temperature. Therefore, even if it were possible to distinguish between the effects of various governments' efforts to curb CO2 emissions, and even if the regulations had the intended effect, there would be no way to verify that they had succeeded.

Questions 2-3

How cost-effective would the regulations be in abating global warming?

Mitigation cost-effectiveness is a familiar concept in environmental economics but is too seldom applied to appraisals of CO2-mitigation policies. Environment Canada's stated objective is to "balance environmental and economic considerations". Yet another omission in the regulatory impact statement is that it does not balance these two considerations by determining whether the proposed regulations are cost-effective in mitigating global warming caused by anthropogenic CO2 emissions.

CO2-mitigation cost-effectiveness is here defined as the cost of abating 1 C° of global warming on the assumption that the cost-effectiveness of all other CO2-mitigation policies is equivalent to that of the proposals. Establishing this value for competing policies permits them to be ranked in order of cost-effectiveness: the higher the cost of abating 1 C° of warming, the less cost-effective the policy.

To determine CO2-mitigation cost-effectiveness, it is necessary to know only the discounted gross cost of the regulations, given by Environment Canada as **$8.2 billion** at present value assuming a **3%** discount rate, and the fraction of all worldwide emissions over the term that the policy is expected to abate (**0.03%**). The CO2-mitigation cost-effectiveness of the regulations is the ratio of the policy's cost to its emission-abatement fraction, divided by the global warming projected to occur in the absence of any mitigation over the term (here **0.25 C°** over the 16 years 2015-2030). The CO2-mitigation cost-effectiveness follows. At Environment Canada's **3% discount rate,** it is **$117 trillion per C° abated.** However, a discount rate of only **3%** is below the minimum market rate of **5%.** At this less unrealistic rate, the policy's gross discounted cost falls from $8.2 bn to **$6.4 bn,** and the mitigation cost-effectiveness improves to **$92 trillion per C° abated.** At a **5% discount rate,** the mitigation cost-effectiveness of various competing policies is shown in Table 1:

TABLE 1 CO2-mitigation policy	Term (years)	CO2-mitigation cost-effectiveness
US cap-&-trade Bill	40 years: 2011-2050	$57 trillion / C°
Canada coal regulations	**16 years: 2015-2030**	**$84 trillion / C°**
UK Climate Change Act	40 years: 2011-2050	$113 trillion / C°
EU carbon trading scheme	20 years: 2011-2030	$558 trillion / C°
Thanet (largest windfarm)	20 years: 2011-2030	$666 trillion / C°
Australia's CO2-tax Bill	10 years: 2012-2021	$1.5 quadrillion / C°

Note how much less cost-effective real-world policies (EU cap-&-trade and the world's largest wind-farm) are than the official projections of the UK, Canadian and US governments. In Australia, where a debate that has been near-absent elsewhere took place, the government was compelled to produce less unrealistic figures.

Question 4

How much would it cost to abate all global warming from 2015-2030?

If all policies to abate global warming over the term of the regulations were of identical CO2-mitigation cost-effectiveness, how much would it cost, worldwide, to abate all global warming projected to occur over the term? This is yet another question that the regulatory impact statement does not even address.

The global all-forcings abatement cost is defined as the cost of abating all of the **0.25 C°** projected anthropogenic global warming from CO2 and all other sources in the 16 years 2015-2030, on the assumption that the mitigation cost-effectiveness of all mitigation policies is equivalent to that of the regulations.

Thus, the global abatement cost, using the **5%** market discount rate from here on, is the **£6.4 billion** discounted cost of the regulations, divided by the emissions-abatement fraction **0.03%,** and also divided by the fraction of anthropogenic global warming caused by CO2, which is **70%.** Accordingly, the global abatement cost, in cash, is **$29 trillion.** The equivalent per-capita global abatement cost is **$4200 per head** of world population, and represents **3.89% of global GDP** discounted over the term – almost **300% above** the **1%-of-GDP** climate action cost that Stern (2006) estimates is achievable, but within the **3.2-to-4%-of-GDP** range estimated by Garnaut (2008). However, the global abatement costs (GAC) of real-world policies are proving greater than these and other optimistic government estimates:

TABLE 2 CO2-mitigation policy	Cash global abatement cost	Per-capita global abatement cost	GAC as % GDP
Stern (2006) benchmark	-	-	1%
US cap-and-trade Bill	$50 trillion	$7000	3%
Canada coal regulations	**$29 trillion**	**$4,000**	**4%**
UK Climate Change Act	$99 trillion	$14,000	6%
EU carbon trading scheme	$114 trillion	$16,000	21%
Thanet (largest windfarm)	$279 trillion	$40,000	28%
Australia's CO2 tax Bill	$310 trillion	$44.000	57%

Table 2. Global abatement cost of the projected **0.253 C°** global warming over the term of the regulations, expressed as a percentage of total global GDP. Canada's proposed regulations again seem in line with the US and UK Governments' estimates, but appear up to an order of magnitude less costly than real-world policies (the EU carbon trading scheme, the world's largest wind array, and the Australian carbon trading scheme, all shown in green). The question arises whether the Canadian government has underestimated the costs of its scheme and overestimated how much CO2 emission the regulations will abate.

Question 5

What is the cost of taking no action to mitigate global warming?

The most detailed study of the relative costs of action and inaction was that by Sir Nicholas (now Lord) Stern for the UK Government in 2006. Stern concluded that warming in the 21st century could be abated at a cost of **1%** of global GDP, whereas, based on estimated **3 C°** warming by 2100, the cost of climate-driven damage arising from failure to cap atmospheric concentrations of the five principal greenhouse gases would be **3% of global 21st-century GDP**. However, Stern also estimated that global warming might be **5 to 6 C°, or even 11 C°.** Margaret Thatcher had given a similar estimate in 1988, saying warming might occur at **1 C°/decade** (Thatcher, 2009). In that event, Stern concluded that the inaction cost would rise to **5-20% of global GDP,** and that the "social cost of carbon [dioxide]" was **$100/ton.**

Garnaut (2008), for the Australian Government, concluded that the costs of action and inaction respectively were **3.2-4%** and **6%** of global GDP. Yet the literature, reviewed by Lomborg (2007) and Tol (2009ab), suggests Stern and Garnaut have it the wrong way about: the cost of action matches or even exceeds the cost of inaction. Indeed, it has become clear from the EU carbon-dioxide trading scheme and from the cost outturns of individual CO2-mitigation projects such as the world's largest wind-farm (at Thanet off the Kent coast in England) that the cost of taking any form of action in an attempt to abate global warming greatly exceeds that of inaction.

Why? First, far fewer emissions are prevented per dollar spent than governments predict. The failure of the Kyoto Protocol makes the point. Secondly, Stern's inaction costs of **3-20%** of global 21st-century GDP are based on an untenably low discount rate of only **0.1%,** which he equates with the annual probability of climate-related apocalypse. He also exaggerates not only the warming expected this century but also the consequent climate-related damage that might arise.

Inaction cost (Stern)	At 3% discount	At 4% discount	At 5% discount	At 6% discount	At 7% discount
3% GDP	0.514% gdp	0.324% gdp	**0.222% gdp**	0.163% gdp	0.126% gdp
5% GDP	0.857% gdp	0.540% gdp	0.369% gdp	0.271% gdp	0.210% gdp
20% GDP	3.429% gdp	2.161% gdp	1.478% gdp	1.083% gdp	0.840% gdp

Table 3. From Stern's estimate that at a 0.1% discount rate the cost of 3 C° 21st-century warming would be 3% of global GDP, at the market discount rate of 5% his inaction cost would fall from 3% to 0.222% of GDP. Stern's 5% and 20% inaction costs are also shown.

Adjusting Stern's 3%-of-GDP inaction-cost estimate for the minimum 5% market discount rate, and assuming IPCC's central estimate of manmade warming is right, **the cost of climate inaction this century falls to just 0.22% of GDP.**

Question 6

Would it be more cost-effective to do nothing to mitigate CO2 emissions?

Environment Canada does not ask what is surely the central question that a responsible government would ask before subjecting an entire industry to complex and restrictive regulation. Is it more cost-effective to try to make "global warming" go away than to adapt in a focused way to any consequences of such warming as may occur, only if, when, where and to the extent that it may occur? Without a mature consideration of this central question of inter-temporal choice, there can be no rational basis for proceeding with regulation. Environment Canada has not explicitly asked the question, and its attempt at an answer is insubstantial.

The Canadian government's case for action is based on a simplistic assumption, drawn from now-outdated papers in the economic journals, that the "social cost of carbon [dioxide]" – i.e., the cost of damage caused by global warming if emissions are not capped – has a fixed value of **$25/tonne.** The calculation is crude: the aim is to abate **175 Mt** of CO2 emission from **2015-2030,** so the "benefit" from this abatement is said to be **25 times** this tonnage: i.e. **$4.4 billion.** Stern's estimate of **$100/tonne** is also cited, and it is said that the "benefit" on this basis would be more than **$17 billion.** This approach is untenable, for a number of reasons.

First, it is now clear that the cost of capping CO2 emissions is very much higher than economists had foreseen. Secondly, the relationship between CO2 concentration and the radiative forcing that causes warming is not linear: it is logarithmic. Adopting a flat-rate "social cost" per tonne is thus unworkable. Thirdly, the **$100/tonne** "social cost of carbon [dioxide]" is based on Stern's **0.1%** discount rate. At the **3%** discount rate adopted by Environment Canada, **$100/tonne** would become just **$17/tonne,** dragging the supposed net "benefit" from the regulations towards mere breakeven. At the **5%** market rate this "social cost" falls to **$7.40/tonne,** a net cost as large as the apparent "benefit" imagined by Environment Canada.

The more sophisticated modelling used here starts with the IPCC's climatology, adopted here as normative *ad argumentum*. Due allowance is made for everything from the IPCC's 21st-century transient-sensitivity parameter via the logarithmic dependence of warming on CO2 concentration to various discount rates.

The all-warming global abatement cost of the regulations would be **3.9% of global GDP** over the term; the Stern-based cost of inaction, adjusted for Environment Canada's unduly low **3%** discount rate and assuming the IPCC's central estimate of **3.4 C°** global warming this century, is **7.6 times greater** than the **0.51%** cost of inaction. At the minimum acceptable market discount rate of **5%** the cost of the regulations is **17.6 times greater** than the **0.22%** cost of inaction.

Question 7

Are the IPCC's global-warming projections proving accurate?

IPCC (2007, scenario A2) expects **3.4 C°** manmade global warming to 2100. The calculations so far in this paper have assumed that the IPCC is right. Environment Canada does not ask any questions about the IPCC's global-warming projections. Officials should have made some allowance for IPCC overshoot.

Since 1750, whence IPCC dates our influence on climate, a recent study (Blasing, 2011) shows **3 W m^{-2}** of forcing from our greenhouse-gas emissions, less **–1 W m^{-2}** from non-GHG influences (IPCC, 2007). Global temperature had risen by **0.5 C°** from 1750-1983 (Hansen, 1984), with a further **0.3 C°** since (HadCRUt3, 2011). Of this **0.8 C°** warming, **50 to 100%** may be manmade. Thus, the 261-year transient climate sensitivity parameter is **(0.4 to 0.8)/(3 – 1) = 0.2 to 0.4 C° W^{-1} m².** Multiplying by the forcing at CO2 doubling, i.e. **5.35 ln 2** (Myhre *et al.,* 2001, cited by IPCC, 2001, 2007), gives transient sensitivity of **0.75 to 1.5 C°** by 2100, when CO2 concentration will have doubled. Dividing this value by **0.7,** the fraction of all forcings attributable to CO2, allows for non-CO2 forcings. Expected warming would thus be **1.1 to 2.1 C°** to 2100, **32 to 62%** of IPCC's central estimate.

Since 1850, the year when the first global-temperature record was kept, the most rapid rate of warming sustained for more than a decade was **0.17 C°/decade** (HadCRUt3, 2011). Assume that, after no warming in the 2000s, this maximum supra-decadal warming rate were to become the average rate for the next nine decades. Warming would be **1.5 C°** by 2100, **44%** of IPCC's central estimate.

Since 1950, when Man first began emitting enough CO2 to influence the climate, **0.72 C°** of warming has occurred (HadCRUt3, 2011). This rate, extrapolated from the past 61 years to the next 90, gives **1.1 C°** of warming by 2100. Assuming 20 **to 40% acceleration** in the warming rate to allow for rising CO2 concentrations net of the logarithmic diminution in the CO2 forcing gives **1.3 to 1.5 C°** warming to 2100.

Averaging the results obtained from data over three recent periods by distinct methods gives **1.3 to 1.7 C°** warming by 2100 – **40 to 50%** of the IPCC's estimate.

A theoretical checksum: In Kiehl & Trenberth (1997), total forcing from H2O, CO2, CH4, O3, and N2O is given as **125 W m^{-2}** in clear skies and **86** in cloud, or **~101 W m^{-2}** overall. Holding insolation and albedo constant, the difference between surface temperatures with and without these GHGs is **288 – 255 = 33 C°.** Ignoring minor forcings, climate sensitivity of the whole atmosphere is **(5.35 ln 2)(33/101) = 1.2 C°,** which, divided by **0.7** to allow for non-CO2 forcings, gives total warming at CO2 doubling by 2100 of **1.7 C°,** or **50%** of IPCC's central estimate, **more than halving the cost-effectiveness** of the regulations.

Question 8

Is Environment Canada's scientific and economic analysis fit for its purpose?

Environment Canada's regulatory impact statement omits at least the following considerations that are essential to any mature appraisal of regulatory impacts –

- The fraction of global CO2 emissions that the regulations may abate;
- The fraction of CO2 concentration that the regulations may abate;
- The fraction of anthropogenic CO2 forcing that the regulations may abate;
- The quantum of global warming the regulations are expected to abate;
- The CO2-mitigation cost-effectiveness against other mitigation policies;
- The CO2-mitigation cost-effectiveness against the cost of climate inaction;
- The global abatement cost of the regulations, as a percentage of global GDP;
- The action/inaction ratio, as a percentage of global GDP;
- A discussion of whether the IPCC's warming projections are soundly based;
- A discussion of the appropriate inter-temporal discount rate for the appraisal;

The following considerations in the regulatory impact statement are defective –

- The analysis is non-existent; or, where it exists, it is crude and *simpliste*;
- An unduly low inter-temporal discount rate of just 3% has been adopted;
- The low discount rate unduly favours climate action over inaction;
- The cost of inaction, or "social cost of carbon [dioxide]", is mere guesswork;
- A physically-impossible fixed "social cost" per tonne has been assumed;
- An outdated and excessive value for the "social cost" has been assumed;
- Discount rates applied to the costs of action and of inaction appear different;
- The cost of replacing coal with natural gas has been underestimated;
- The CO2 emissions abated by replacing coal with gas have been overstated;
- The "benefits" of the regulations have been wrongly calculated & exaggerated;
- The health "benefits" external to the central purpose are largely speculative.

The sheer length of the regulatory impact statement gives it an air of diligence and comprehensiveness that is in truth absent. This is not a serious economic or scientific analysis at all. It is an unjustified declaration of war against the coal industry. The statement does not take a correct or economically-recognizable approach to the question of inter-temporal choice.

True, the difficulty that any government department faces in analysing climate-related questions is that a working knowledge of both the relevant climatology and the relevant economics is a minimum requirement. On both counts, Environment Canada's regulatory impact statement fails. The methodology set out in detail in the Technical Annex is designed to assist future policy-makers in addressing the inter-temporal aspects of the climate question accurately.

Question 9

Should these or any CO2-mitigation regulations be implemented?

The cost of climate action always exceeds that of inaction. We have not yet come across a policy where, at a GDP growth rate of 3%, a market discount rate of 5%, and a 21st-century global warming of 3.4 C° (IPCC's central estimate), the action/inaction ratio is below 1. It is only when action is sufficiently less costly than inaction, so that the action/inaction ratio is well below 1, that any CO2 mitigation is worthwhile.

TABLE 4 Action-inaction ratios	Warming forestalled	Mitigation cost-effect.	Stern 20%	Stern 5%	Stern 3%
US cap-&-trade	0.08 K: 2050	$57 tr K^{-1}	2	8	**14**
Canada coal regs	**0.0001 K: 2030**	**$84 tr** K^{-1}	**3**	**11**	**18**
UK Climate Act	0.007 K: 2050	$113 tr K^{-1}	4	16	**27**
EU CO_2 trading	0.004 K: 2020	$558 tr K^{-1}	14	57	**95**
Thanet windfarm	0.000+ K: 2030	$666 tr K^{-1}	19	77	**127**
Australia CO_2 tax	0.000+ K: 2020	$1.5 qd K^{-1}	39	156	**259**
School windmill	0.000+ K: 2030	$11 qd K^{-1}	321	1289	**2142**
London bike hire	0.000+ K: 2030	$91 qd K^{-1}	2607	10441	**17354**

Table 4. Action-inaction ratios for several climate-mitigation strategies, including Environment Canada's proposed regulations. The ratios of the GDP cost of following the listed policies to the cost of inaction are those of GDP growth at **3% pa,** and on Stern's **5-to-20%-of-GDP** 21st-century inaction cost if there is **5-11 C°** global warming by 2100, and on his **3%-of-GDP** inaction cost if there is **3 C°** global warming by 2100. The minimum market discount rate of **5%** is assumed throughout the table.

Though predictions by the governments of the US, Canada, and the UK of the cost-effectiveness of CO2 mitigation (red in Table 4) are optimistic compared with now-established real-world costs such as those of EU's CO2-emission trading scheme and the world's largest wind-farm (green), even if the predictions were right action would be an order of magnitude costlier than inaction.

Real-world mitigation policies are **2 orders of magnitude costlier** than inaction. Gesture policies – small windmills or the London bicycle-hire scheme (purple) – are **3-4 orders of magnitude costlier** than doing nothing. Co-benefits external to CO2 mitigation are excluded here.

For these reasons, it is unlikely that any CO2-mitigation policy will be cost-effective unless mitigation is incidental to very substantial co-benefits. **Mitigation strategies cheap enough to be affordable will be ineffective: strategies costly enough to be effective will be unaffordable.** Focused adaptation is the prudent option.

Conclusions

If the world were to adopt mitigation measures as cost-ineffective as those that the regulations propose, the cost (assuming a 5% market discount rate) would be almost 18 times greater than the cost of the do-nothing option.

Any properly-conducted inter-generational investment appraisal of the costs and benefits to us today from preventing imagined (and perhaps imaginary) climatic Apocalypse tomorrow will be likely to demonstrate that measures to mitigate CO2-driven global warming, however, piously intended, would cost more than the most extreme estimate (the 20% of GDP in Stern, 2006, here adjusted for the 5% market discount rate) of the cost of climate-related damage caused by our failure to act now. **All CO2-mitigation policies are likely to prove at least ten times costlier than any reasonable estimate (e.g. Stern's 3% of GDP) of the cost of future climatic damage from inaction.**

For the reasons set forth in more detail in the Technical Annex, the cost-effectiveness calculations given here will tend greatly to overstate the cost-effectiveness of such little CO2 mitigation as the regulations (even if implemented in full) might achieve. **The regulations' cost-ineffectiveness will be even worse than shown here.**

Accordingly, the allocation of public funds for attempted mitigation of CO2 emissions in general, and for implementation of the regulations in particular, may prove to be **the least cost-effective deployment of taxpayers' money in world history.** A more mature economic consideration, in Canada and worldwide, is now urgent.

Recommendations

In the light of the foregoing economic analysis, I recommend:

1. **That the regulations should neither be enacted nor implemented.**

2. That, since Environment Canada's regulatory impact statement contains so many lacunae and errors of method that it appears to provide no rational basis for taking any legislative or fiscal decision, **Ministers should insist that officials reply in detail to this report.**

3. **That any official reply to this report should be published.**

4. That no further action should be taken to legislate for these or any proposed regulations, still less to implement them, until the reply by Environment Canada to this report has been published and debated.

Technical Annex

- *The purpose of this Technical Annex is to provide the derivation of every value given, together with the physical-science or economic-science justification for it, with references to all relevant sources, in such a way that anyone wishing to verify or to replicate the methodology, or to apply it to other existing or proposed CO2-mitigation measures, will have all necessary information to hand.*

The regulatory impact statement

The regulatory impact statement that I examined was published as a preface to the proposed Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulations (Environment Canada, 2011).

Main points of the statement

The purpose is to cut greenhouse-gas emissions, "balancing environmental and economic considerations".

Only CO2 emissions from coal-fired electricity generation are regulated, because they account for **98%** of greenhouse-gas emissions from coal.

Coal-fired generation will fall by **55%;** gas-fired generation will rise by 46%.

Electricity accounted for 16% of Canada's CO2 emissions in 2008, of which coal-fired emissions accounted for 78% (or 93 Mte CO2e).

From 2015, over 16 years, regulation will cut total coal emissions by **175 Mte CO2.**

Emissions will rise to **850 MTe/yr** by 2020, of which 135 Mt/yr, or 16% above 2008, is from electricity.

The cost of the scheme will be **$8.2 billion** after discounting to present value at **3%.** More than half of this cost, or **$4.3 bn,** is for expansion of gas-powered generation.

The savings are put at **$9.7 bn** at present value, of which **$3.8 bn** is in closing down coal-fired capacity; **$4.3 bn** is the "social cost of carbon [dioxide]", and **$1.4 bn** is in health benefits from smog reduction.

Thus the benefit, at net present value, is said to be $9.7 – 8.2 = **$1.5 bn,** based on a "social cost of carbon [dioxide]" of **$25/tonne.**

It is asserted that the **$4.3 bn** saving on the "social cost" would rise to **$14.5 bn** at Stern's "social cost" of **$100/tonne.**

Assumptions

Climatological assumptions

Except where specifically mentioned in the text, the IPCC's climatology is accepted here as normative *ad argumentum*. In particular –

- **The CO2 radiative forcing** is 5.35 times the logarithm of the proportionate increase in concentration (Myhre *et al.*, 1998, cited in IPCC, 2001, 2007);
- **CO2 is 70% of all manmade forcings** (IPCC, 2007; and Table A1);
- **The transient-sensitivity parameter** for 1900-2100 is taken as 0.5 Kelvin per Watt per square meter (IPCC, 2007; and Table A1);
- **The CO2 concentration growth rate in the absence of mitigation** is the exponential rate which IPCC projects in its A2 scenario (Table A2).

Climatological assumptions inconsistent with the IPCC's analysis are as follows –

- **100%** of global warming since 1750 is here taken as anthropogenic;
- Abatement of forcing and consequently of global warming will occur immediately upon any reduction in CO2 emissions.

Reasons for these assumptions are as follows –

CO2 radiative forcing: The IPCC's function for the CO2 radiative forcing is taken as correct. However, the coefficient, and hence the magnitude of the forcing, was reduced by **15%,** from 6.3 to **5.35,** in the IPCC's *Third Assessment Report,* 2001.

The CO2 forcing fraction and the transient-sensitivity parameter are derived from each of IPCC's six emission's scenarios (Table A1):

$C_{1900} = 300$	ΔT_{tra}	ΔF_{tra}	C_{2100}	λ_{tra}	$\Delta F_{tra,CO2}$	q
A1B	3.0 K	6.2 W m^{-2}	700 ppmv	**0.5 K W^{-1} m^2**	4.5 W m^{-2}	**0.7**
A1F1	4.5 K	9.1 W m^{-2}	960 ppmv	**0.5 K W^{-1} m^2**	6.2 W m^{-2}	**0.7**
A1T	2.5 K	5.1 W m^{-2}	570 ppmv	**0.5 K W^{-1} m^2**	3.4 W m^{-2}	**0.7**
A2	3.8 K	8.0 W m^{-2}	840 ppmv	**0.5 K W^{-1} m^2**	5.5 W m^{-2}	**0.7**
B1	2.0 K	4.1 W m^{-2}	520 ppmv	**0.5 K W^{-1} m^2**	2.9 W m^{-2}	**0.7**
B2	2.7 K	5.6 W m^{-2}	610 ppmv	**0.5 K W^{-1} m^2**	3.8 W m^{-2}	**0.7**

Table A1. The climate-sensitivity parameter λ_{tra}, the transient CO2 radiative forcing $\Delta F_{tra,CO2}$ for 1900-2100, and the fraction q of total forcing attributable to CO2 over the two centuries, derived from the projected transient warming ΔT_{tra} and transient forcing ΔF_{tra} from all sources over the period, and from the projected CO2 concentration C_{2100} in 2100, on each of the six SRES CO2-emission scenarios. Values in green are from IPCC (2007, p. 803, Fig. 10.26). Values in dark blue are derived from these: $\lambda_{tra} = \Delta T_{tra} / \Delta F_{tra}$; $\Delta F_{tra,CO2} = 5.35 \ln(C_{2100} / C_{1900})$, where $C_{1900} = 300$ ppmv; and $q = \Delta F_{tra,CO2} / \Delta F_{tra}$.

Business-as-usual CO2 concentrations: Table A2 gives values for annual CO2 concentrations on the A2 emissions scenario in the years 2014-2030, capturing 16 full years of CO2 concentration growth.

The A2 scenario is adopted here because it comes close to actual CO2 emissions, and because it is one of the two most extreme scenarios. Any CO2-mitigation proposal that is cost-ineffective on this scenario will be cost-ineffective on all but one – the most extreme – of the other five scenarios. The A2 scenario assumes that the anthropogenic fraction of CO2 concentration will rise exponentially throughout the 21st century, reaching a central estimate of **836 ppmv** at the end of the century. On this basis, CO2 concentrations are projected to be as follows –

Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
ppmv	398.2	400.4	402.5	404.8	407.0	409.3	411.7	414.1
2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
416.5	419.0	412.5	424.1	426.7	429.4	432.1	434.9	437.7

Table A2. Business-as-usual CO2 concentrations, **2014-2030,** on IPCC's A2 emissions scenario, on the assumption that CO2 concentration was **280 ppmv in 1750** and rose by **110 ppmv** to **390 ppmv in 2010,** and that over the **90 years to 2100** the anthropogenic fraction (i.e. the fraction >280 ppmv) will rise exponentially, so that total concentration will rise by **556 ppmv** to **836 ppmv in 2100.** Eq. (A1) determines the CO2 concentration in each year y:

$$C_y = 280 + 110e^{\left(\frac{y-2010}{90}\ln\frac{556}{110}\right)}. \quad \text{(A1)}$$

Notwithstanding the answer to question 7 above, it is assumed that all global warming since 1750 has been manmade, so that, for prudential reasons, any future increase in CO2 concentrations will be assumed anthropogenic rather than natural.

It is also assumed, *per impossibile,* that abatement of the CO2 forcing, and consequently of the global warming that the forcing abated would otherwise have caused, will occur immediately upon any reduction of CO2 emissions.

Otherwise it would be necessary to assume that little or no abatement of warming will occur this century, since the IPCC's central estimate is that the residence time of CO2 in the atmosphere is 125[50, 200] years.

On that alternative assumption, no mitigation measures could ever be justified unless it became far less improbable than it is at present that our actions now could precipitate a global catastrophe at some time after 2100.

The effect of these two assumptions that are not in conformity with the IPCC's current climatology is to maximize – perhaps beyond prudence – the apparent cost-effectiveness of the regulations. The outturn will be worse than that calculated here.

In essence, therefore, the IPCC's climatology is used as the basis for this analysis. If I had not departed slightly from the IPCC's analysis, the regulations would appear still less cost-effective than they do already.

Economic assumptions

The following economic assumptions are made –

- **The pure-rate-of-time-preference annual discount rate** for inter-temporal appraisal that is adopted here is the minimum market rate of **5%.** Environment Canada itself acknowledges in the regulatory impact statement that a discount rate of as much as **7%** might be justified.
- **Real global GDP** is assumed to grow uniformly at a compound annual rate of **3%** throughout the term, and is discounted at the 5% discount rate, also throughout the term.
- **Real welfare losses from climate inaction** are assumed to arise at a uniform rate throughout the term of the regulations;
- **The basis for determining the cost of inaction** is the 3%, 5% and 20%-of-GDP inaction costs described in Stern (2006), adjusted to replace his 0.1% discount rate with the minimum market discount rate of **5%** (Table 3).
- **Costs external to that of the policy** are excluded from this analysis;
- **Opportunity losses** from the diversion of wealth to CO2 mitigation are not taken into account;
- **Co-benefits external to mitigation of CO2** forcing are also excluded from this analysis.

The reasons for these assumptions are as follows –

The discount rate of 5% is that which Klaus (2011) recommends –

> "To make a rational choice means to pay attention to inter-temporal relationships and to look at the opportunity costs. It is evident that by assuming a very low (near-zero) discount rate the proponents of the global-warming doctrine neglect the issue of time and of alternative opportunities. Using a low discount rate in global-warming models means harming current generations vis-à-vis future generations. Undermining current economic development also harms future generations.
>
> "Economists representing very different schools of thought, from Nordhaus (2008) to Murphy (2008), tell us convincingly that the discount rate – indispensable for any inter-temporal calculations – should be around the market rate of 5%, and that it should be close to the real rate of return on capital, because only that rate represents the opportunity cost of climate mitigation."

Other discount rates used in climate economics are –

- HM Treasury's standard rate of **3.5%** (Grice, 2011);
- HM Treasury's "global-warming" rates, equivalent over the 21st century to **2.75% & 3.25%** (Lowe, 2008);
- Environment Canada's **3%** rate;
- The Australian Government's "global warming" rates of **1.35% & 2.65%** (Garnaut, 2008); and, as an outlier,
- Stern (2006) for HM Government, with a widely-criticized rate of just **0.1%.**

Stern (2006, p. 263) justifies his low discount rate as follows:

> "… δ *is* the utility discount rate. The value of δ is taken to be **0.1% per annum,** so that the probability of surviving beyond time T is described by a Poisson process
>
> $$e^{-\delta T},$$
>
> "where δ is the annual risk of catastrophe eliminating society, here **0.1%.** So the probability of surviving 100 years is
>
> $$e^{-0.001(100)},$$
>
> "which is **90.5%.**"

HM Treasury's website now links to a document that repudiates Stern's discount rate as having been based on a misreading of the economic literature, and it has adopted "global warming" discount rates (Lowe, 2008) that bracket that of Environment Canada but are still well below the minimum market rate.

[Note in passing that the conditions precedent to the applicability of the Poisson theorem do not allow the replacement of Stern's **0.1%** discount rate with a market discount rate in the Poisson process, for otherwise, at **5%**, the probability of surviving climate apocalypse over the next 100 years would be less than **0.7%.**]

The annual real GDP growth rate of 3% that is adopted here is commonly used in inter-generational analyses of this kind. A lower growth rate would somewhat increase the cost-effectiveness of CO2 mitigation measures, and a higher growth rate would somewhat diminish it, as Table 3 illustrates.

A uniform rate of GDP growth is a simplifying assumption. Taking non-uniform growth profiles – unless they were extreme – would not greatly affect this assessment of the regulations' cost-effectiveness.

A uniform rate of welfare loss arising from global warming caused by failure to act now to reduce anthropogenic greenhouse-gas emissions may arise is a similar simplifying assumption. In practice, little or no welfare loss would occur (and, indeed, there might be a benefit) if global temperatures were to rise by **1-2 C° above today's values.** Beyond that, the IPCC expects net welfare losses to occur. The effect of assuming that welfare losses will occur *pari passu* with global warming is to increase (and, in the short term, to increase very greatly) the apparent cost-effectiveness of measures, such as the regulations, that are intended to mitigate CO2-driven global warming.

The welfare loss arising from climate inaction (the "inaction cost", which Environment Canada calls "the social cost of carbon [dioxide]") is based on the very detailed analysis in Stern (2006). Stern considered that if the IPCC's central estimate of **3 to 4 C°** warming this century were correct the cost of climate-related damage caused by failing to prevent that warming would amount to **3% of GDP.** However,

he also considered the possibility that global warming might rise by **5-6 C°** and even, at the extreme, by as much as **11 C°.** In that event, he considered that the inaction cost could be **5 to 20% of GDP.** Our approach has been to take Stern's three inaction-cost values – **3%, 5%, & 20% of GDP,** respectively – and to adjust them by replacing his **0.1%** discount rate with **5%.** At a uniform annual real percentage growth-rate g, Stern's 21st-century inaction costs Z_1 = **3%,** Z_2 = **5%,** Z_3 = **20% of GDP,** adjusted to allow for replacement of his **0.1%** discount rate d_s by a comparison percentage discount rate d_m, are given by Eq. (A2):

$$Z_{n,\text{adj}} = Z_n \frac{\sum_{y=1}^{100}\left(1+\frac{|g-d_m|}{100}\right)^{y\,\text{sgn}(g-d_m)}}{\sum_{y=1}^{100}\left(1+\frac{|g-d_s|}{100}\right)^{y\,\text{sgn}(g-d_s)}}. \qquad \text{(A2)}$$

Table A3 converts Stern's three inaction costs to the lower percentages of GDP that apply at discount rates higher (and thus more realistic) than his **0.1%.**

GDP growth rate	Inaction cost (Stern)	3% discount rate	4% discount rate	5% discount rate	6% discount rate	7% discount rate
	3% GDP	0.796	0.583	**0.452**	0.366	0.307
1%	5% GDP	1.326	0.972	**0.754**	0.611	0.511
	20% GDP	5.303	3.888	**3.015**	2.442	2.045
	3% GDP	0.633	0.433	**0.317**	0.246	0.199
2%	5% GDP	1.055	0.722	**0.529**	0.410	0.332
	20% GDP	4.222	2.887	**2.116**	1.641	1.329
	3% GDP	**0.514**	**0.324**	**0.222**	**0.163**	**0.126**
3%	**5% GDP**	**0.857**	**0.540**	**0.369**	**0.271**	**0.210**
	20% GDP	**3.429**	**2.161**	**1.478**	**1.083**	**0.840**
	3% GDP	0.432	0.251	**0.158**	0.108	0.079
4%	5% GDP	0.720	0.418	**0.264**	0.180	0.132
	20% GDP	2.881	1.673	**1.054**	0.721	0.529
	3% GDP	0.376	0.204	**0.118**	0.075	0.051
5%	5% GDP	0.627	0.339	**0.197**	0.124	0.085
	20% GDP	2.510	1.357	**0.788**	0.497	0.340

Table A3. Stern-based values for inaction costs $Z_{1,\text{adj}}$, $Z_{2,\text{adj}}$, $Z_{3,\text{adj}}$ as percentages of global 21st-century GDP at discount rates of **2-7%** and annual GDP growth rates of **1-5%.**

This method provides a practicable and yet cautious approach to determining the welfare losses from climate inaction over the 21st century because the inaction-cost estimates in Stern (2006) are well above others in the economic literature.

The exclusion of co-benefits external to mitigation of CO2-driven global warming is justified by the requirement for clarity about whether, *in itself,* CO2 mitigation is a public good. On the analysis here, it is not.

Key parameters used in this assessment

Based on the above assumptions, key parameters are summarized in Table A4:

A4	Description	Value
y_0, y	The first and last years of the term of the regulations	**2015, 2030**
C_{y0-1}	CO2 concentration the year before the regulations begin	**398.2 ppmv**
C_y	Projected CO2 concent. with no mitigation by the last year	**437.767 ppmv**
λ	Transient climate-sensitivity parameter, 1900-2100	**0.5**
q	Percentage of global forcings represented by CO2	**70%**
ΔF	Forcing from a proportionate change in CO2 concent.	**5.35 ln (C_b/C_a)**
d	Inter-temporal annual discount rate	**5%**
g	Annual real GDP growth-rate over the term	**3%**
o	Global population	**7 billion**
p	**Fraction of global emissions halted by 2030**	**0.000277**
r	Real global GDP over the term (3% & 5% discount)	**$960 tr & $752.6 tr**
x	**Total real policy cost to year y (3% & 5% discount):**	**$8.2 bn & $6.4 bn**
$Z_{n,adj}$	Adjusted real inaction cost as % GDP (3% & 5% discount):	**0.514% & 0.222%**

Table A4. Parameters for appraisal of the cost-effectiveness of the proposed regulations.

Term: The starting and ending years of the regulations are stated in the regulatory impact assessment as **2015 & 2030** respectively, a term of **16 years.**

CO2 concentrations in the year before the policy commences and at the end of the term are determined by Eq. (A1) above.

The **transient-sensitivity parameter,** the **CO2 radiative forcing**, and **the fraction of global emissions represented by CO2** were determined from IPCC data as shown in Table A1.

The **inter-temporal discount rate** and **annual real GDP growth rate** are discussed in the Assumptions section above.

Global population is taken as **7 billion,** based on the conclusion in UN (2011) in that by **October 31, 2011,** world population would reach that value.

The global CO2-emissions abatement fraction, i.e. the fraction of global emissions over the term of the regulations that Environment Canada expects the regulations to abate is one of the two key case-specific parameters that fall to be determined before any appraisal can begin. The other is the cost of the proposal. The regulatory impact statement does not provide a value for the regulations' global emission abatement fraction. The regulatory impact statement says the objective is to abate **175 Mt** of greenhouse gases in the **16 years 2015-2030.** Of this, **98%** (in the coal-generating sector only) is attributable to CO2. Also, according to Environment Canada's annual greenhouse-gas inventory for 2008, Canada emitted **732 Mt CO2-**

equivalent of greenhouse gases that year, which the regulatory impact statement says will rise to **850 Mt CO2e** in **2020.**

Therefore, it is a reasonable assumption that in the absence of mitigation Canada's greenhouse-gas emissions from (all sectors this time) will continue to rise at this rate – a little over **1.125%/year compound** – to **2030.** Since **577 Mt** of Canada's greenhouse-gas emissions in 2008 was CO2, it follows that **577 / 732** (i.e. **79%**) of those emissions are attributable to CO2. From this, annual projected CO2 emissions from **2015-2030** can be determined, thus –

Year	2015	2016	2017	2018	2019	2020	2021	2022
GHG	798.7	808.7	818.8	829.1	839.5	850.0	060.7	871.4
CO2	**629.6**	**637.5**	**645.4**	**653.5**	**661.7**	**670.0**	**678.4**	**686.9**

Year	2023	2024	2025	2026	2027	2028	2029	2030
GHG	882.4	893.4	904.6	916.0	927.4	939.1	950.8	962.7
CO2	**695.5**	**704.2**	**713.1**	**722.0**	**731.0**	**740.2**	**749.5**	**758.9**

Table A5. Projected total greenhouse-gas emissions and CO2 emissions (million metric tons) in Canada, **2015-2030** inclusive. Business-as-usual greenhouse-gas emissions, which were **732 Mt CO2e** in 2008, grow at **1.25%/year compound** to **2020** (when they reach **850 Mt CO2e**), and continue at that rate to **2030.** CO2 emissions are **79%** of total GHG emissions in Canada. Thus, total projected CO2 emissions over the term of the regulations are **11.077 Gt.**

Thus, Canada's business-as-usual CO2 emissions over the 16-year term are the sum of the projected annual values over the term, shown in Table A5 – i.e. **11.077 Gt.**

Thus, Canada's national CO2-emissions abatement fraction is simply the quantum of CO2 emissions projected to be abated over the term, **175 Mt,** multiplied by the fraction of all Canada's emissions from coal-fired generation that is CO2 emission, **98%,** and divided by the total projected CO2 emissions over the term, **11.077 Gt.** Accordingly, the national CO2-emissions abatement fraction is 0.0155 (i.e. **1.55%**).

The global CO2-emissions abatement fraction is the national fraction, 0.0155, multiplied by Canada's fraction of global CO2 emissions, 0.0179 (**1.79%**). Then Canada's global CO2-emissions abatement fraction is **0.000277** (0.0277%).

GDP: Taking global GDP of **$60 trillion** in **2010,** global cumulative real GDP over the **16-year** term at **3%** annual real GDP growth and **3%** discount is **$960 trillion.** The Environment Canada discount rate cancels the GDP growth-rate exactly, so cumulative GDP growth is simply **16 x $60 trillion.** Keeping growth at **3%** but discounting at **5%,** a net discount of **2%,** this value falls to **$752.6 trillion.**

The cumulative real discounted cost of the regulations is given as **$8.2 billion** in the regulatory impact statement. Adjusted for a **5% discount rate** rather than the 3% rate assumed in the statement, the cost falls to **$6.4 billion.**

Inaction costs are explained in detail in the Assumptions section above.

Determination of principal model outputs

Preliminary results

Before the principal outputs of the cost-effectiveness model can be determined, it is necessary to determine a few preliminary results.

Abated CO2 concentration in 2030: What will the CO2 concentration be in 2030, at the end of the term, if the regulations are fully and successfully implemented, and how much less is this reduced concentration than the business-as-usual concentration C_{2030} **437.676 ppmv?** Eq. (A3) gives the reduced concentration in 2030:

$$C_{\text{reg}} = C_{2030} - p(C_{2030} - C_{2014}), \quad \text{(A3)}$$

where $C2014$ = **398.214 ppmv,** and the emissions-abatement fraction p = **0.000277.** Thus, C_{reg} = **437.665 ppmv,** a reduction against B.A.U. of **0.011 ppmv.**

Note that no allowance is made for any reduction in the CO2 concentration as it will be in 2014, the year before the regulations first take effect, because the IPCC estimates that the atmospheric lifetime of CO2 is **50-200 years,** in which event there will be no reduction in CO2 concentration at all throughout the lifetime of the policy, regardless of any mitigation measures taken in Canada or worldwide.

Nonetheless, for comparison with other CO2-mitigation strategies, it is assumed that the CO2 concentration increase during the term will decrease immediately and in proportion to the fraction p by which the emissions that cause it are abated.

A substantial reduction in global CO2 emissions, maintained over centuries, might offset some of the warming caused by the pre-existing increase in atmospheric CO2 concentration from 278 ppmv in 1750 to 390 ppmv in 2010. The present value of any such distant benefit is near nil and is left out of account here.

CO2 radiative forcing abated by the regulations: Eq. (A4) gives the CO2 radiative forcing that the regulations will abate over the 16-year term:

$$\Delta F_{\text{nix}} = 5.35 \ln \frac{C_{2030}}{C_{\text{reg}}} = \frac{437.676}{437.665} = 0.00013 \text{ W m}^{-2}. \quad \text{(A4)}$$

Business-as-usual CO2-driven warming, 2014-2030: With no regulations, what will the projected business-as-usual global warming ΔT from 2014-2030 be? Eq. (5) gives the benchmark against which the effectiveness of the regulations in abating global warming should be considered:

$$\Delta T = \lambda_{\text{tra}} 5.35 \ln \frac{C_{2030}}{C_{2014}} = 0.5 \left[5.35 \ln \left(\frac{437.676}{398.214} \right) \right] = 0.253 \text{ C°}. \quad \text{(A5)}$$

Global warming abated by the regulations

Eq. (A6) gives the global warming abated by the regulations over the term:

$$\Delta T_{\text{nix}} = \lambda_{\text{tra}} \Delta F_{\text{nix}} = 0.5(0.00013) = 0.00007 \text{ C°}. \quad \text{(A6)}$$

cO2-mitigation cost-effectiveness

Eq. (A7) gives the CO2-mitigation cost-effectiveness *M* of the regulations, expressed in dollars per Celsius degree of warming, on the assumption that the cost-effectiveness of all CO2-mitigation measures worldwide is equivalent to that of the regulations:

$$M = \left(\frac{x}{p}\right)\left(\frac{1}{\Delta T}\right) = \left(\frac{6.4 \text{ x } 10^9}{0.000277}\right)\left(\frac{1}{0.253}\right) = \$92 \text{ tr/C°}. \quad \text{(A7)}$$

Note that Eq. (A7) depends not upon any warming actually forestalled but solely upon Environment Canada's estimate that for the stated cost *x* the implicit CO2-abatement fraction *p* of global CO2 emissions over the term will in fact be abated by the regulations. Nothing in the present analysis warrants that this fraction will indeed be abated at this cost: however, the equation establishes that if at this cost this fraction is abated the cost of abating 1 C° of global warming by measures of equivalent cost-effectiveness worldwide would be $92 trillion.

Global abatement cost of all warming over the term

Where ***x*** = **$6.4 bn** is the discounted cumulative cost of the policy, ***o*** = **7 bn** is global population, ***p*** = **0.000277** is the CO2-emissions abatement fraction, ***q*** = **0.7** is the fraction of global forcing represented by CO2, and ***r*** = **$752.6 tr** is the discounted global GDP over the term, and where it is assumed that the cost-effectiveness of all mitigation measures worldwide is equivalent to that of the policy, Eq. (A8) gives the global cash cost ***G,*** per-capita cash cost ***H*** and cost ***J*** as a percentage of GDP, of abating the **0.253 C°** of global warming that the IPCC's A2 scenario would lead us to expect over the term of the regulations:

Cash global abatement cost

$$G = \frac{x}{pq} = \frac{6.4 \text{ x } 10^9}{0.000277 \text{ x } 0.7} = \$29.4 \text{ tr}; \quad \text{(A8a)}$$

Per-capita global abatement cost

$$H = \frac{x}{opq} = 29.4 \text{ x} \frac{10^{12}}{7 \text{ x } 10^9} = \$4200; \quad \text{(A8b)}$$

Global abatement cost as % GDP

$$J = \frac{100x}{pqr} = 3.9\% \text{ GDP}. \quad \text{(A8c)}$$

The action/inaction ratio

The action/inaction ratio is the ratio of the **3.9%-of-GDP** global abatement cost of the regulations over the term and the **0.222%%-of-GDP** 21st-century cost of inaction based on Stern (2006), adjusted for the minimum market discount rate of **5%,** assuming a **3%** annual GDP growth rate. It is assumed that the inaction cost would be incurred at a uniformly-growing rate throughout the term, though in practice little or no cost would arise till very much later in the 21st century, and even then only if warming at the rate predicted by the IPCC were to occur, and only if it did damage on the perhaps excessive scale predicted by Stern.

Accordingly, where the cost of action is J and the cost of inaction is Z, the action-inaction ratio R of the regulations is given by Eq. (A9):

$$R = \frac{J}{Z} = \frac{3.9}{0.222} = 17.6. \quad \text{(A9)}$$

For any CO2-mitigation measure to be worthwhile, the action-inaction ratio must of course be **considerably less than 1**. However, the action-inaction ratio of the regulations is **17.6,** meaning that it would be **almost 18 times more costly** to abate all global warming projected by the IPCC over the term, if CO2-mitigation measures of equivalent cost-effectiveness to the regulations were used, than it would be to endure the climate-related damage arising from inaction.

A caveat

The results shown here are the logical conclusion of the various claims made in the regulatory impact statement as to the quantum of Canada's CO2 emissions that would be abated over the term, and as to the cost of achieving that abatement. None of Environment Canada's estimates are in any way warranted here: as Table 4 above shows, there is some reason to suspect that, like other governmental projections, they are perhaps an order of magnitude more optimistic than real-world mitigation strategies have proven to be. Nevertheless, those claims, together with those of the IPCC, are in most respects adopted as normative *ad argumentum*

Even if Environment Canada's estimates were not as optimistic as they appear to be, the method of appraisal described in detail in this Technical Annex is liable very considerably to overstate the already severe cost-effectiveness of any mitigation policy, for the following reasons:

- The IPCC takes CO2's mean atmospheric residence time as 50 to 200 years: if so, little reduction in CO2 concentration can occur before 2100.
- It is here assumed that any policy-driven reduction in CO2 concentration occurs at once, when it would be likely to occur stepwise throughout the term, halving the warming otherwise abated by that year.

- If the IPCC's central projections exaggerate the warming that may arise from a given increase in atmospheric CO2 concentration, the warming abated may be less than shown.
- The IPCC's estimates seem to be twice the true climate sensitivity: if so, the cost-effectiveness of mitigation is more than halved.
- Though emissions are rising in accordance with the IPCC's A2 emissions scenario, concentration growth has been sub-exponential for a decade, so that outturn by 2100 may be considerably below the IPCC's A2-scenario low-end estimate of 730 ppmv, and very considerably below the central estimate of 836 ppmv on which the calculations here are based.
- The A2 scenario, though close to today's emissions, is one of the more extreme emissions scenarios: use of any of the four less extreme scenarios would lead to lesser warming and hence to lesser mitigation cost-effectiveness.
- The climate-sensitivity parameter used in the case studies is bicentennial-scale: accordingly, over the far shorter period of the regulations a somewhat lesser coefficient (allowing for the fact that longer-term temperature feedbacks may not yet have acted) and consequently less warming forestalled would reduce mitigation cost-effectiveness.
- Opportunity losses from diverting resources to CO2 mitigation are ignored.

The bottom line

TABLE 0 Parameter	Value
Total cost of the regulations at present value	$6.4 bn
Fraction of global CO2 emissions abated	0.000277
Business-as-usual CO2 concentration in 2030 *... and after the full effect of the regulations*	437.676 ppmv *437.665 ppmv*
CO2 radiative forcing abated, 2015-2030	0.00013 W m^{-2}
Global warming prevented, 2015-2030	0.00007 C°
Mitigation cost-effectiveness	$84 tr/C°
Global abatement cost: Cash Per capita As % GDP	$29.4 tr $4000/head 3.89% GDP
Cost of damage arising from climate inaction	0.22% GDP
Action-inaction ratio: the multiple by which the cost of action exceeds the cost of inaction	(3% disc.) 7.6 (5% disc.) 17.6

Table 0. The reasons why abandonment of the regulations is recommended.

References

Blasing, T.J., 2011, Recent greenhouse-gas concentrations (updated August 2011), doi: 10.3334/CDIAC/atg.032, http://cdiac.ornl.gov/pns/current_ghg.html.

Environment Canada, 2011, Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulations, *Canada Gazette* 145:35, August 27: http://www.gazette.gc.ca/rp-pr/p1/2011/2011-08-27/html/reg1-eng.html#contact.

Garnaut, 2008. The Garnaut Climate Change Review: Final Report. Cambridge University Press, Port Melbourne, Australia, 680 pp, ISBN 9780521744447.

Grice, 2011. The Green Book: Appraisal and Evaluation in Central Government: Treasury Guidance. Her Majesty's Stationery Office, London, UK. http://www.hm-treasury.gov.uk/d/green_book_complete.pdf.

HadCRUt3, 2011, Monthly global mean surface temperature anomalies, 1850-2011, http://www.cru.uea.ac.uk/cru/data/temperature/hadcrut3gl.txt.

Hansen, J., A., Lacis, D. Rind, G. Russell, P. Stone, I. Fung, R. Ruedy, and J. Lerner, 1984, Climate sensitivity: analysis of feedback mechanisms, *Meteorological Monographs* 29, 130-163.

IPCC, 2001, *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 881 pp.

IPCC, 2007, *Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor and H.L. Miller (eds.)], Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

Kiehl, J.T., & K.E. Trenberth, 1997, The Earth's Radiation Budget, *Bull. Am. Meteorol. Soc.* 78, 197.

Klaus, V., 2011, *The Global Warming Doctrine Is Not a Science,* Conference on The Science and Economics of Climate Change, Downing College, Cambridge, UK, May 10.

Lomborg, B., 2007. Perspective on Climate Change, Testimony before the Committee on Science and Technology of the US House of Representatives, March 21.

Lowe, 2008. Intergenerational wealth transfers and social discounting: supplementary Green Book guidance. HM Treasury, London, ISBN 978-1-84532-419-3.

Murphy, 2008. Some Simple Economics of Climate Changes. Paper presented to the MPS General Meeting, Tokyo, September 8.

Myhre, G., E. J. Highwood, K. P. Shine, and F. Stordal, 1998, New estimates of radiative forcing due to well mixed greenhouse gases, *Geophys. Res. Lett.* 25:14, 2715–2718, doi:10.1029/98GL01908.

Nordhaus, W., 2008. A Question of Balance: Weighing the Options on Global Warming Policies, Yale University Press.

Stern, N., 2006, The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge, England, and New York, NY, USA.

Thatcher, M., 2002, *Statecraft,* HarperCollins, London, England, p. 439.

Tol, R., 2009a. The Economic Effects of Climate Change. Journal of Economic Perspectives 23:2, 29-51.

Tol, R., 2009b. An analysis of mitigation as a response to climate change. Copenhagen Consensus Center, Copenhagen Business School, Frederiksberg, Denmark.

UN, 2011, *The 2010 Revision of World Population Prospects,* United Nations, New York, USA, May 10.