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Climate Change and Economics: Update

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CLIMATE CHANGE AND ECONOMICS: UPDATE

by

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ABSTRACT

The Intergovernmental Panel on Climate Change (IPCC) is calling on countries to reduce their use of fossil fuels and thereby their emissions of greenhouse gases, primarily carbon dioxide (CO_2). The IPCC process is driven by a variety of computer models, some of which focus on energy use and accompanying CO_2 emissions, others on the effects that emissions have on temperatures around the globe, and, finally, models that focus on the economics of climate change mitigation. The process begins, however, with assumptions about future population and economic growth, the availability and technologies of energy options, the extent to which nations adopt available technologies, convergence of incomes between rich and poor countries, and so on. These aspects are examined, with particular focus on the assumptions underlying the projections of emissions pathways and the impact this has on the social cost of carbon, which, in turn, is the basis of policy related to the appropriate carbon price/tax.

Key words: integrated assessment models; costs of mitigating climate change; international climate policy

1. INTRODUCTION

Climate change is considered to be the most existential threat facing the planet today. Whether this is true or not depends on whom you talk to and where you live—it appears that concern about a future climate 'crisis' is essentially a rich-country phenomenon. The world's poor are more concerned about the impact that climate policy rather than climate change might have on economic growth. As a result, developing countries are willing to go along with the western world's climate mitigation efforts as long as they are paid handsomely for doing so. That is, developing nations are on board with the developed nations' agenda as long as it enhances or, at least, does not inhibit their ability to grow. Yet, the climate policies to be enacted under international agreements, such as the 2015 Paris Agreement, will harm the poor more than any policies ever conceived. Why? Because the policies aim to eliminate global use of ubiquitous coal, oil and natural gas, fuels that are desperately needed to drive economic growth in developing countries.

The number of people worldwide living in extreme absolute poverty, defined as those living on less than international $1.90 per day, has declined in 25 years from more than 1.9 billion (36% of the world population) in 1990 to 0.7 billion (9%) in 2015 [Roser and Ortiz-Ospina 2013]. Economic growth in China and to a lesser extent India and elsewhere has accounted for the major advance in the wellbeing of the world's poor. This improvement in economic prospects is directly attributable to increased access to energy, especially abundant coal. This, in turn, led to large increases in carbon dioxide (CO_2) emissions as indicated in Figure 1.

Looking at this figure, notice two trends: First, CO_2 emissions in developed countries have levelled off or even declined slightly. Second, emissions of the most populous developing countries, particularly China but increasingly India, are rising and overwhelming those of the developed countries. Even if the rich countries could curtail their CO_2 emissions, global emissions would rise regardless. Unless the developing countries were to stop growing and fall back into abject poverty, it would be nigh impossible to prevent global warming from taking place.

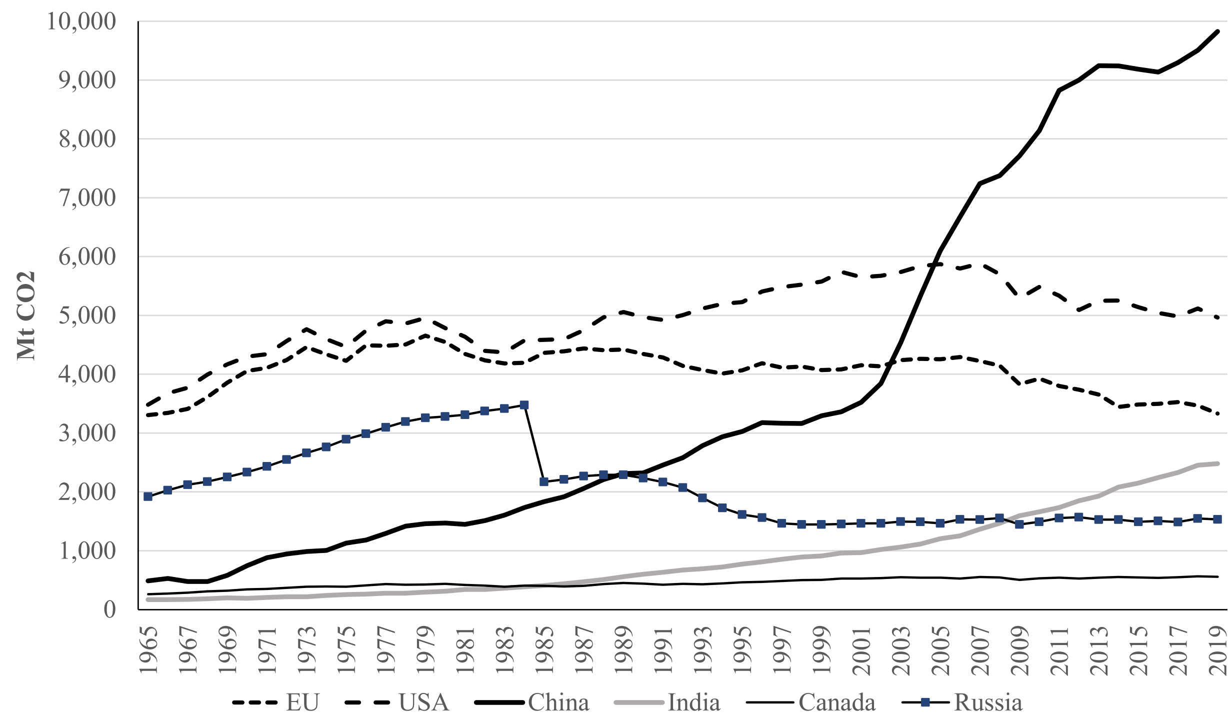

Figure 1: Global emissions of carbon dioxide (megatons per year) by selected regions/countries, 1965-2019
Source: Author's construct based on data from the BP Statistical Review of World Energy June 2020 at http://www.bp.com/statisticalreview

In thinking about the need to reduce greenhouse gas emissions (hereafter referred to as CO_2 as it is the most important greenhouse gas emitted by human activities), the principal (moral or religious) issue pertains to the impact that mitigation policies might have on the poorest in global society. Any climate policies that result in a reduction in the prospects of the poorest should be avoided, even if that means the rest of the world needs to adapt to climate change. Indeed, from that perspective, the ultimate question is whether mitigation or adaptation is the better option. Here is where economics has a role to play.

It is important to realize that climate change is a crisis built upon a computer modeling scaffold that ignores or downplays actual data, and that economic models drive the climate policy process [e.g., see Brouwer and Bergkamp 2021]. These models are referred to as integrated assessment models (IAMs) because they integrate biophysical, climate, economic and other aspects. The first type of economic models are used by the United Nations' Intergovernmental Panel on Climate Change (IPCC) to provide inputs into (2^{nd}-stage) climate models (which are not IAMs). The 1^{st}-stage economic models develop potential paths of future CO_2 emissions based on storylines concerning future economic developments, technological changes, and implementation of assumed mitigation strategies. For the third stage, economists have developed growth models that determine the optimal path of investment in climate-change mitigation—spending on mitigation is a choice variable in these models as opposed to an assumption in the stage 1 models. It is these 3^{rd}-stage IAMs that provide estimates of the social cost of carbon that informs policy makers regarding an appropriate carbon price or tax. Because the 3^{rd}-stage IAMs include a climate component (or climate emulator) that translates the path of CO_2 emissions into temperatures, the models are independent of the 1^{st}-stage IAMs and 2^{nd}-stage climate models.

2. Modeling Climate Change: Physical and Economic Aspects

The IPCC relies on outputs from 1^{st}-stage IAMs that have been developed by approved organizations. Examples include the 'Model for Energy Supply Strategy Alternatives and their General Environmental Impact' (MESSAGE) developed by the International Institute of Applied Systems Analysis (IIASA) in Austria; the Integrated Model to Assess the Greenhouse Effect (IMAGE) by the Institute for the Environment (RIVM) in the Netherlands and the Dutch government's Central Planning Bureau; and the Mini Climate Assessment Model (MiniCAM) from the Pacific Northwest National Laboratory (PNNL) in the United States. These models are complicated and may include other models as components. For example, MiniCam includes Manne et al.'s [1995] Model for Evaluating Regional and Global Effects (MERGE) of greenhouse gas reduction policies, even though MERGE was originally designed to stand alone.

The 1st-stage models are used to create Shared Socioeconomic Pathways (SSPs), which provide information on future growth in global and regional gross domestic product (GDP), per capita GDP, the rate at which per capita incomes in poor countries converge to those in rich countries, expected technological changes, the carbon intensity of future energy, and so on. The storylines underpinning the SSPs are important as indicated in Table 1, although they are often neglected in policy discussions.

Notice that, in Table 1, average global per capita GDP in constant 2005 dollars is projected to increase from $8791 to $18,000 (about double) by 2050 and to $22,000 (a factor of 2.5) by 2100 in the worst case scenario, SSP3. The SSP3 storyline forecasts world population to rise to 10.0 billion by 2050 and to 12.8 billion by 2100, while coal continues to be a dominant major source of fuel; while energy requirements will be high, coal is expected to account for 9.7% of total energy use in 2050 rising to 12.5% in 2100. The drivers in this scenario are a rapidly expanding population and failure to adopt low-carbon energy technologies.

Under SSP5, population is assumed to increase to 8.6 billion in 2050 but fall to 7.4 billion by the end of the century. The average global per capita income rises to nearly $44,000 in 2050 and $139,000 in 2100, increases of nearly 500% and more than 1500%, respectively—absurdly large increases in real income per person that are necessarily accompanied by high energy requirements and CO_2 emissions.

Clearly, SSP5 and SSP3 will result in the highest concentrations of atmospheric CO_2. In contrast, SPP1 has the lowest projected population in both 2050 and 2100 and the least emissions compared to the other SSP scenarios. SSP1 assumes a high rate of technical improvements in the provision of clean energy, while real per capita incomes are projected to increase by 388% by 2050 and by more than 900% by 2100.

Table 1: Population, income, CO_2 emissions and energy projections for base SSPS

Year	Population (10^6)	PPP GDP per person (US$2005)	Emissions from fossil fuels & industry (Mt CO_2)	Total energy (EJ)	Energy from coal (EJ)
			Baseline		
2005	6,530.5	8,791	29,394.2	340.8	31.6
			SSP1		
2050	8,530.5	34,148	42,668.6	547.6	22.3
2100	6,958.0	81,258	27,049.0	528.3	6.3
			SSP2		
2050	9,242.5	25,341	50,944.3	602.0	40.3
2100	9,103.2	59,127	73,019.3	831.8	64.9
			SSP3		
2050	10,038.4	17,991	53,999.0	591.9	57.6
2100	12,793.2	21,849	75,119.4	797.6	99.5
			SSP4		
2050	9,213.0	24,886	44,829.1	587.4	30.6
2100	9,456.3	38,121	45,152.0	652.4	29.4
			SSP5		
2050	8,629.5	43,855	80,325.7	856.4	56.8
2100	7,447.2	138,868	114,164.6	1,056.2	60.7

Source: This table is based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

Each SSP scenario assumes a convergence between the per capita incomes of rich and poor countries. For example, in the worst case scenario (SSP3), the average real incomes of Middle East and African countries are assumed to increase from $3677 in 2005 to $14,270 in 2100; under SSP5, the average income of residents in this region are assumed to increase to $120,883 per person. Annual per capita incomes in the low-income countries are projected to increase by 3.1%, 2.7%, 1.4%, 1.5% and 3.7%, respectively, across the five SSP scenarios. Given these projections, it would appear that it would be better to let economic development proceed as this would provide all countries with sufficient incomes to adapt to climate change.

To continue the story, SSPs are then used by IAMs to create Representative Concentration

Pathways (RCP)—the trajectory of future greenhouse gas emissions [Riahi et al. 2017; van Vuuren et al. 2011].[1] Along with other data, the future path of atmospheric CO_2 (Figure 2) is then used in climate models to project future global temperatures.

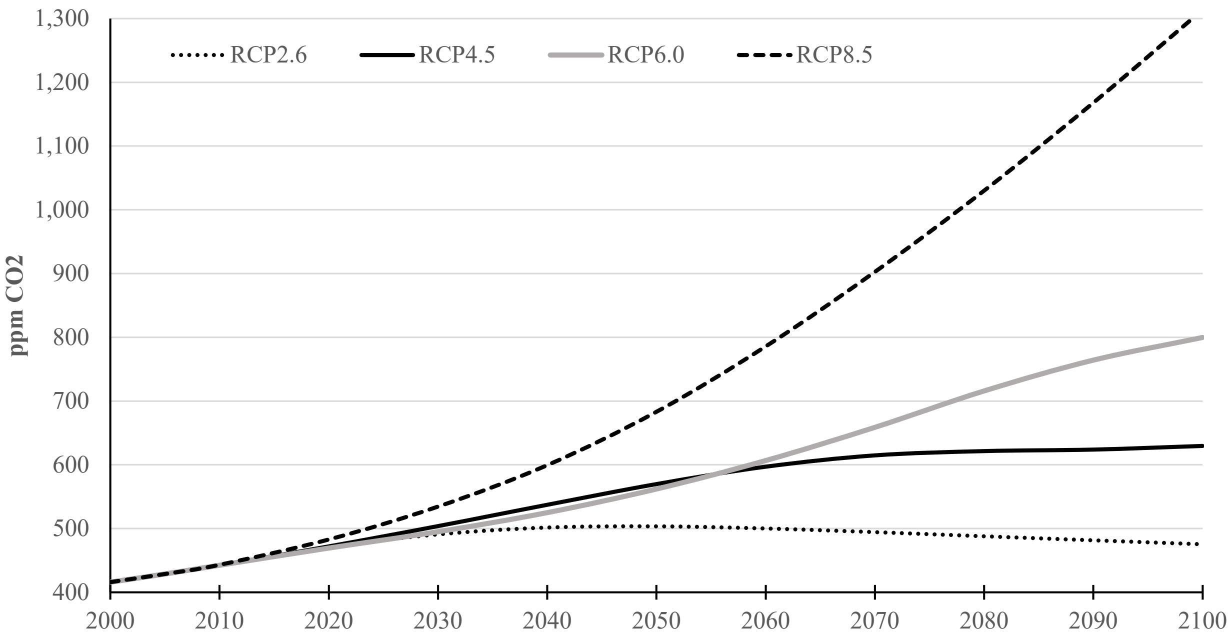

Figure 2: Four Representative Concentration Pathways (RCPs) of CO_2 used by climate models to derive IPCC projections of future temperatures

The RCP scenarios are designated with a number that represents the forcing (heating) due to CO_2 and equivalent greenhouse gases in the year 2100. As of 2019, the CO_2 forcing was estimated to be 2.08 watts per square meter (W/m^2), with the total forcing from greenhouse gases equal to 3.14 W/m^2. In 1979, the CO_2 forcing was 1.03 W/m^2 and the total forcing was 1.70 W/m^2, implying an annual rate of increase in overall CO_2 (including other gases) forcing of 1.5%. If this exponential trend continues, the overall forcing in 2100 would be 7.88 W/m^2. However, most

[1] The RCPs provide emission pathways not only for CO_2, but also for the other greenhouse gases, volatile organic compounds and black carbon (soot), as well as the source of these emissions (forestry activities, combustion of coal, oil and gas, etc.). Also provided are the resulting concentration of gases in the atmosphere and the forcing (heating) that each of the emissions causes.

scientists believe that the trend would slowly decline over time [e.g., Schildknecht 2020; van Wijngaarden and Happer 2019, 2020]. Nonetheless, the RCP8.5 (forcing of 8.5 W/m^2 in 2100) scenario is often considered the business-as-usual scenario despite criticism that it exaggerates the actual warming experienced since 1979 [Hausfather and Peters 2020; Zhu et al. 2020].

Other scenarios are considered just as valid by the IPCC, but ignored by many researchers and the media, are RCP6.0, RCP4.5 and RCP2.6. If the latter two scenarios were to occur, the best strategy for dealing with climate change would be to rely on adaptation when and if the warmer temperatures are realized [Russell et al. 2022].

3. Economic Modeling and the Social Cost of Carbon

Policymakers need estimates of marginal damages—also referred to as the social cost of carbon (SCC)—to guide decisions about carbon taxes and for determining the benefits (damages avoided) of mitigation strategies. Estimates of SCC are currently available from three integrated assessment models, two of which are open source—William Nordhaus' Dynamic Integrated Climate and Economics (DICE) model [Nordhaus 2013, 2018] and Richard Tol's Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model [Tol 2014].[2] Such IAMs have been criticized by both economists and climate scientists. For example, Robert Pindyck [2013, 2017] finds the models are too ad hoc, with outcomes highly sensitive to assumed parameter values, while Nicholas Lewis [2018] finds the parameterization of the carbon-climate component in DICE to be faulty. Despite such criticism, IAMs offer one of the only ways that economists can provide policy advice that is supposedly informed by the findings of the climate models.

The 3rd-stage models provide estimates of the social cost of carbon. However, the models do not use any of the outputs from the climate models or the 1st-stage IAMs. They maximize the

[2] The third is the Policy Analysis of the Greenhouse Effect (PAGE), which is not open source [Hope 2006].

discounted utility of a representative individual as a function of their consumption, which is a proportion of income (per capita GDP). They are a traditional neoclassical growth model that allows for investment in climate change mitigation, but only if such investment leads to an increase in future income—a reduction in future damages (where damage represents lost income).

Damages are a function of temperature and investments that reduce CO_2. The damages in question are the result of sea level rise, increased chance of malaria and other tropical diseases, lost biodiversity, increased damage from adverse weather events, et cetera [van Kooten 2021a, pp.250-252; van Kooten 2013, pp.221-252]. Given that little is known about how damages are affected by changes in the mean global temperature, the damage function is ad hoc—a guess at best [Russell et al. 2021].

But there are other issues with the models. There is disagreement among economists concerning the social rate of discount used to make comparisons across generations, which is important when models project incomes fifty to one hundred or more years into the future. Assumptions need to be made about the 'shape' of the utility function used in the objective function to measure the intrinsic value of per capita consumption—as determined by the elasticity of the marginal utility of consumption. Further, as noted, the models include a climate component that is unrelated to any 2nd-stage climate model, except that these 3rd-stage models are informed by the underlying physics and temperatures predicted by the climate models [van Kooten et al. 2021]. For example, the economic models rely on the equilibrium climate sensitivity (ECS) used in the IPCC's climate models; the ECS is the change in temperature that results from a doubling of CO_2—a contentious value. Empirical studies have estimated the ECS to be around 2.0ºC, while computer models provide estimates over 3.0ºC, even exceeding 4.5ºC [van Kooten et al. 2021, pp.16-18].

An indication of how sensitive the social cost of carbon is to these assumptions is provided in Table 2. Based on the table, different assumptions concerning the three parameters discussed in the previous paragraph result in values of the SCC in 2020 that vary from about \$15/tCO_2 to nearly \$300/tCO_2; by 2050, the price of carbon can vary from \$45/tCO_2 to \$555/tCO_2. While policymakers likely assume that a carbon tax should be set to the marginal damages or SCC, economists recognize that the SCC would need to be divided by the marginal cost of public funds, which varies across jurisdictions and by tax instrument [Sandmo 1975, 1998; Dahlby 2008]. A good rule of thumb might be to divide it by 2.0, which implies that, based on Table 2, the current carbon tax should be set between \$8/tCO_2 and \$150/tCO_2. Since the base case scenario in the DICE model assumes an ECS close to 3.0ºC, an elasticity of marginal utility of consumption of 1.45, and a social rate of time preference of 1.5%, the appropriate tax would be about \$18/tCO_2 in 2020.

Table 2: Estimated Optimal Social Cost of Carbon (\$/tCO_2), Various Scenarios and Selected Years, 2015-2100[a]

	ECS = 3.0ºC				ECS = 2.0ºC	
	Elasticity of the marginal utility of consumption					
	1.45	3.0	1.45	1.0	1.0	1.45
	Social rate of time preference (intergenerational rate of discount)					
Year	1.50%	0.10%	0.10%	0.10%	0.10%	1.50%
2015	29.48	12.99	113.48	252.62	144.33	17.14
2020	35.25	15.35	136.66	295.15	170.67	20.41
2030	49.10	22.03	187.36	376.15	220.71	28.19
2040	66.32	31.76	245.65	460.25	271.95	37.75
2050	87.25	45.14	312.98	554.77	326.91	49.27
2060	112.25	62.84	390.75	659.72	386.64	62.90
2070	141.66	85.56	481.92	772.46	452.37	78.80
2080	175.79	114.03	587.60	890.71	524.19	97.14
2090	214.94	148.92	706.04	1,012.09	600.09	118.08
2100	259.38	190.85	835.73	1,134.03	678.50	141.76

[a] Source: van Kooten et al. [2021, p.44].

Economic analyses based on 3rd-stage IAMs are problematic. First, given the wide range of potentially optimal social costs of carbon, and marginal costs of public funds, it is impossible to settle on any path of optimal carbon taxes—a policymaker could justify almost any level of a carbon tax. Second, based on recent results from the DICE model, the optimal tax is a lot lower than that being implemented by some jurisdictions. For example, British Columbia's current tax of $45/tCO_2$ (about US$36/tCO_2) will increase to $50/tCO_2 (US$40/tCO_2) in 2022, while the federal tax is set to rise from $30/tCO_2 (US$24/tCO_2) to $170/tCO_2 (US$135/tCO_2) by 2030. Third, the optimal tax cannot be applied equally across all jurisdictions because the marginal cost of public funds varies greatly across jurisdictions.

In contrast, McKitrick [2011] provides a simple pricing rule for addressing global warming, namely, a carbon tax that is contingent on the global mean temperature (GMT) and its rate of change. The tax would rise with increases in GMT and would be modified more or less frequently depending on how fast GMT changes. Unfortunately, few climate lobbyists and policymakers appear willing to adopt such a rule, perhaps because their main and perhaps only interest is to eliminate the use of fossil fuels.

4. Methodological Issues concerning Climate Modeling

First-stage IAMs are used to create the SSPs and RCPs used by the IPCC to inform the 2nd-stage climate models. The RCPs are linked to the SSPs, with the former essentially providing the storylines that are used to create the RCPs (as noted above). The 1st-stage IAMs are either of a simulation variety or, in many cases, optimize over some variables that relate to the economy. The 2nd-stage climate models then take the RCPs and determine the future path of global temperatures. Subsequently, the 3rd-stage IAMs are used by economists to provide estimates of the social cost of carbon (SCC), which interests policy makers. However, the 3rd-stage models do not use any of the outputs from the IAMs that underlie the SSPs and RCPs. Rather, they maximize discounted utility as a function of (per capita) consumption. They are a traditional neoclassical growth model that allows for investment in mitigation of climate change if such mitigation leads to an increase in income—that is, the investment in mitigation leads to a reduction in future damages (lost income). Damages are a function of temperature while the choice variable, investment in reducing CO_2, is optimized so that a current period cost of investing in mitigation is subsequently more than recovered by the increase in discounted future income that results from a reduction in damages brought about by the investment. The types of investments in mitigation are left unspecified and are assumed to appear as a result of economic incentives, such as a carbon tax or emissions-trading scheme. As noted, these IAMs include a climate component that is unrelated to any climate model except that it is informed by the temperatures predicted by the climate models. The damage function is ad hoc—a guess at best.

This description poses several questions.

1. Is this three-stage modeling effort to get SCC not methodologically flawed? Should we ignore the first two layers of modeling and simply focus solely on the 3^{rd} layer? After all, DICE, FUND and PAGE are all that are needed for policy analysis, rightly or wrongly. Why bother spending money on the other exercises?
2. Related to point 1, if the 1^{st}- and 3^{rd}-stage IAMs are indeed linked, is there not a methodological issue that needs to be considered? How does one optimize over an already optimized model? How does one optimize over an optimal path of per capita GDP (using DICE, say) when MESSAGE, say, has already provided an optimal path of per capita GDP to be used in the 2^{nd} stage?

5. INTERNATIONAL POLICY FORMATION[3]

Aside from addressing the Covid-19 pandemic, the Biden administration has made climate mitigation its central policy objective. Because climate change is impacted by global emissions of CO_2, mitigation would require an unprecedented level of international cooperation that would be extremely difficult and unlikely achievable. At the very least, the major emitters need to fall in line, or else anything the U.S. and Europe do to reduce emissions is undone within a few years by increases in China, India, and other developing countries (as evident in Figure 1).

President Biden convened a climate summit in April, 2021, that included some 30 heads of state. The purpose was to lobby them ahead of the November COP26 in Glasgow to increase their climate mitigation efforts as required under the 2015 Paris Agreement. The President committed the U.S. to reduce CO_2 emissions by 50 to 52 percent by 2030 from the base year 2005, and to make the electricity grid carbon neutral by 2035 [White House Briefing Room 2021]. Several other nations also pledged to reduce their domestic CO_2 emissions by more than originally indicated in their Nationally Determined Contribution (NDC), including Canada and Japan. Canada pledged to reduce its domestic CO_2 emissions by 40 to 45 percent by 2030 compared to 2005, while Japan committed to reduce its CO_2 emissions by 46% by 2030 compared to 2013 emissions.

The EU had already committed to reduce emissions by 55% by 2030, while the UK would reduce them by 78% by 2035 [BBC 2021; European Commission 2021]. However, India, China, Russia, Brazil and many other developing nations would not commit to reduce their emissions beyond what they had declared in their original NDCs. Although both China and India are leaders in adopting renewable energy, they are also expanding their coal fleets—China by 104 gigawatts

[3] This section is based on van Kooten [2021b].

(GW) of capacity and India by perhaps more [see Reuters 2021; Doshi and Krishnadev 2021]. Developing countries are demanding billions of dollars from rich countries to help them protect tropical forests and develop wind and solar facilities [e.g., Newburger 2021].

An indication of the problem is provided in Table 3. As evident from Figure 1, China is the largest emitter of greenhouse gases, followed by the USA, EU, India, Russia and Japan. The EU, the UK and Russia were the only entities that had lower emissions in 2019 than in the 1990 baseline—that is, they were the only jurisdictions that met their 1997 Kyoto Protocol targets. Only the EU, the USA and the UK were able to reduce their emissions relative to 2005. Reasons for meeting targets varied. Rich countries have shifted much of their manufacturing sectors to Asia, primarily China, thereby reducing CO_2 emissions attributable to goods they now import. The EU also experienced a reduction in emissions with the re-unification of Germany, which led to the mothballing of many inefficient manufacturing facilities and power plants in the former communist part of the country. The collapse of the Soviet Union led to a large reduction in GDP and accompanying greenhouse gas emissions. As a direct result of fracking in the USA, prices of natural gas fell causing a shift in power production from coal plants to gas plants, which significantly reduced emissions. However, when the Biden administration re-instated Obama-era regulations on fracking, gas prices rose resulting in some shifting back to coal-fired power.

Table 3: Current (2019) CO_2 emissions in major jurisdictions and changes in emissions from base years 1990 and 2005

Item	EU	USA	UK	China	India	Japan	Russia	World
2019 emissions (Mt CO_2)	3,330.4	4,964.7	387.1	9,825.8	2,480.4	1,123.1	1,532.6	34,169.0
% of global emissions	9.7%	14.5%	1.1%	28.8%	7.3%	3.3%	4.5%	100.0%
Change in 2019 emissions compared to those in:								
1990	–23%	0%	–35%	+323%	+312%	+3%	–31%	+60%
2005	–22%	–16%	–33%	+61%	+106%	–14%	+5%	+21%

Source: BP Statistical Review of World Energy (June 2020)

It is clear that international agreements to reduce CO_2 emissions are fickle to say the least. Unless countries adhering to the rule of law pass legislation to achieve emission-reduction targets, politicians have no incentive to take the measures required to adhere to targets—targets are not mandatory and there is no supra authority to enforce them [van Kooten 2004]. Current Canadian climate policy will be determined by the *Canadian Net-Zero Emissions Accountability Act*, which was passed on June 29, 2021.[4] The Act commits Canada to achieving net-zero emissions by 2050, which implies that any CO_2 emissions at that time would need to be offset through forestry activities (e.g., tree planting) or carbon capture and storage (CCS), which is an unproven and expensive technology.[5] While forestry activities do sequester carbon, they cannot be relied upon to soak up leftover emissions, mainly due to the potential degradation of forests and an accompanying release of CO_2. Recognizing this, Canada's NDC under the Paris Agreement excludes any emissions related to wildfire or other natural disturbance (e.g., insect infestations). Meanwhile, a CCS unit can capture no more than 85% to 95% of the CO_2 that is produced by a thermoelectric plant, and will require some 10 to 40 per cent parasitic energy (required to 'scrub out' the carbon and move it to a disposal site) along with large amounts of additional fresh water [see Eldardiry and Habib 2018].

While, according to a government report, the oil and gas industry faces a precarious future, the electricity sector will also need to be overhauled [Canadian Institute for Climate Choices, 2021, pp.62-68]. Indeed, much discussion and most policies are directed at the electricity generation

[4] See https://www.parl.ca/LegisInfo/BillDetails.aspx?Mode=1&billId=10959361&Language=E [accessed November 29, 2021].

[5] During parliamentary debate, defenders of what was then Bill C-12 indicated Canada could meet non-zero emissions as a 'moon shot', reflecting the U.S. effort to put a man on the moon. The moon shot was more realistic than 'net zero', because most of the required technology was already in place, whereas many net zero technologies do not currently exist and may never be brought to realization because of inherent physical limitations and potentially exorbitant costs.

sector even though it accounts for only one-quarter of global emissions.[6] Policymakers believe that the least-cost emission reductions—the 'low-hanging fruits'—are found in this sector, because electricity can be generated from any energy source, especially wind, solar, tidal, geothermal and other non-carbon emitting sources; the latter includes nuclear power because it emits no CO_2 and hydroelectric generation. Further, because electricity systems are much more centralized from an industrial organization perspective as compared with other energy systems, governments can more easily target the electricity sector. However, government policies to increase CSS, reduce reliance on oil and natural gas for heating, and promote electric vehicles will lead to large increases in load.[7]

Fossil fuel generation of electricity will almost need to be eliminated, with any remaining such generation offset through forestry activities and CCS. Assuming there is no appetite for nuclear energy or the construction of hydroelectric dams on major rivers (viz., objections to BC's construction of Site C), the electricity sector will need to rely almost exclusively on non-hydro renewable sources of generation, meaning intermittent wind and solar power with limited biomass.[8] Intermittent sources of electricity generation require backup from fast-responding generating assets, such as gas turbines or diesel assets, and/or from storage. Storage can take several forms—hydroelectric reservoirs (passive storage) and utility-scale batteries are the only realistic sources of storage as compressed air and flywheels are not truly up to this task. Pumped

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[6] See https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data [accessed November 29, 2021]. Forestry and land use account for 24% of global emissions, industry 21%, transportation 14%, buildings 6%, and other sources for the remainder.

[7] Electric vehicles (EVs) come with their own problems: they weigh about double that of a same-model vehicle with an internal combustion engine, need a long time to recharge the battery, production requires many rare earth and other minerals that are environmentally-costly to access, and their manufacture relies excessively on China which has cornered the market for cobalt, an essential input [Hume 2021; IEA 2021].

[8] Activists in the U.S. are lobbying to remove CCS and nuclear energy from Biden's arsenal for achieving zero-emissions for the electricity sector by 2035 [Smith 2021].

hydro (active storage) has the potential to enhance storage, but it too is expensive in parasitic energy while suitable sites are not readily found. One study concluded that: "The round trip efficiencies for [electric energy storage] systems have been calculated as between 83% and 86%, falling to between 41% and 69% where parasitic loads are included" [Baker et al. 2014, p.41; see also Lazard 2020]. Alternatively, electricity produced by intermittent sources when it is not needed can perhaps be used to produce hydrogen for use as a liquid fuel.[9]

6. Discussion

It has been evident for years that huge and growing energy demands by China, India and other emerging nations and the Net Zero agenda being pursued by the USA, UK, EU and other western countries are incompatible when it comes to mitigation of climate change. It also appears that an agreement to resolve this incompatibility may be insurmountable.

However, if the price for a COP26 compromise is the abandonment of the 1.5°C goal, the West's 2050 Net Zero agenda itself would become futile and self-destructive in face of China's unrestrained expansion of cheap energy and its rise to global dominance. Clearly, all signs point to adaptation as opposed to mitigation as the best and perhaps only means for tackling climate change.

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[9] Hydrogen production is referred to as 'grey' if electricity is used to separate the H_2 molecule from natural gas (CH_4), 'blue' if the process is accompanied by CCS, and 'green' if the hydrogen is derived from water (H_2O). Again these procedures require large amounts of energy. Further, where gas is the source of H_2, CO_2 is released unless accompanied by CCS; where water is the source, the water quality must be similar to that of distilled water.

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