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CARBON PRICING LEADERSHIP COALITION

The Economic Potential of Article 6 of the Paris Agreement and Implementation Challenges

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DISCLAIMER

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ABSTRACT

This technical paper investigates the potential economic and environmental outcomes associated with the use of Article 6 of the Paris Agreement by participating countries. The extent to which countries use Article 6, and how they use it, will be informed by design choices agreed upon by negotiators in forthcoming Conference of the Parties (COP) meetings, particularly the next one to be held at COP 25 in Chile and by the agreements made between participating parties. We use the Global Change Assessment Model (GCAM), an integrated assessment model, to quantify the economic potential of Article 6. We go on to discuss real world considerations and potential implications of design choices currently under consideration by negotiators.

We find that Article 6 has the potential to reduce the total cost of implementing nationally determined contributions (NDCs) by more than half (~$250 billion/year in 2030), or alternatively facilitate the removal of 50 percent more emissions (~5 gigatonnes of carbon dioxide per year [$GtCO_2$/year] in 2030), at no additional cost.

We note, however, that careful framing in both the design and implementation of Article 6 is essential. A poorly designed and implemented framework could frustrate the achievement of Paris goals, while a well-designed and implemented framework could further them. We conclude by identifying gaps in the research that would be useful to address before COP 25 in Chile.

Key messages

- The potential benefits to cooperation in achieving the NDCs under Article 6 are large and all parties could benefit. Potential cost reductions over independent implementation of countries' NDCs total about $250 billion per year in 2030. Cost reductions from cooperative implementation are achieved through improved economic efficiency.
- If countries are inspired to invest these cost savings in enhanced ambition, then Article 6 could facilitate additional abatement under the Paris Agreement by 50 percent or ~5 $GtCO_2$/year in 2030.
- The rules are critical. If written poorly, then rather than facilitate additional emissions reductions they could frustrate meeting current contributions and undercut progress.

INTRODUCTION

We begin by providing background on the Paris Agreement and Article 6 to contextualize the current state of negotiations and characterize the main design choices being contemplated by negotiators. The Paris Agreement established a new international framework to addressing climate change rooted in a bottom-up process that relies on national action. Parties establish short-term domestic goals (i.e., through 2030) in NDCs and report their progress through a transparency framework. Current pledges are insufficient to limit average surface temperature increase to 1.5°C (IPCCC, 2018) despite the overarching goal of the Paris Agreement, which pursues efforts to limit the temperature increase to 1.5°C (United Nations, 2015). This gap highlights the importance of enhancing ambition quickly over time.

Article 6 of the Paris Agreement allows parties to lower the costs of abatement by working together in "cooperative approaches" that create internationally transferred mitigation outcomes (ITMOs). These outcomes enable countries to achieve efficiency gains by taking advantage of their differing marginal costs of abatement and thereby potentially facilitate enhanced ambition (Aldy *et al.*, 2016; Mani *et al.*, 2018).

Article 6 allows for many cooperative systems, including linkages among homogeneous policies (e.g., multiple market-based policies); linkages among heterogeneous policies (e.g., carbon tax and performance standards) (Bodansky *et al.*, 2016); and, potentially, other innovative approaches (e.g., regional carbon clubs) (Nordhaus, 2015). The hope is that lower abatement costs realized through cooperation may increase political appetite for more ambitious targets when NDCs are reviewed (Keohane and Oppenheimer, 2016). About half of the NDCs signal interest in using forms of international cooperation through Article 6 (World Bank and Ecofys, 2018).

The most recent negotiations at COP 24 in Katowice completed the Paris Agreement Work Programme and yielded The Rulebook, which provided valuable elaboration and guidance for several Articles of the Paris Agreement, but not including Article 6. Ministers worked hard to find agreement on Article 6, but compromise could not be reached.

The Rulebook does refer to Article 6 in certain places, including in Article 13, which includes a section on basic market accounting of transfer and use of ITMOs. Ultimately, the majority of work on Article 6 must continue throughout 2019, with an objective to adopt guidance at COP 25 in Chile, where Article 6 will presumably take the mainstage. It will be crucial to successfully negotiate Article 6 in Chile, but it will also be challenging since the few detractors in Katowice brought legitimate concerns.

Despite intense focus by diplomats and analysts on how to implement Article 6, little work has focused on quantifying the potential economic and environmental opportunities offered by Article 6. We analyze both aspects by addressing two questions: What are the potential cost savings from full cooperation in implementing NDCs? If those savings were applied to enhanced mitigation goals, how much additional ambition could countries achieve? We then discuss the real-world challenges associated with realizing this potential enhanced ambition. We finally discuss considerations for negotiators as they develop rules to implement Article 6 for COP 25.

METHODOLOGY

We use the Global Change Assessment Model (GCAM) to estimate the potential value of Article 6. GCAM is an open-source, global integrated assessment model (Joint Global Change Research Institute [JGCRI], 2017 and 2018). It links energy, economy, agriculture, and land-use systems and has 32 geopolitical regions. The full documentation of GCAM is available on Github *(http://jgcri.github.io/gcam-doc/)*. The version of the model used in our study is the same as the one used in Fawcett *et al.* (2015), which is fully documented and available online *(http://www.globalchange.umd.edu/gcam/indc/)*. This section describes how we use the model to construct different scenarios, how we ensure the model is well calibrated relative to the literature, and how we calculate potential enhanced ambition facilitated by Article 6.

CONSTRUCTION OF SCENARIOS

We simulate four alternative scenarios using GCAM: a reference scenario, independent implementation of NDCs (I-NDC), cooperative implementation (C-NDC), and enhanced ambition (E-NDC). The reference scenario assumes no new policies or actions to reduce greenhouse gas (GHG) emissions after 2010 (i.e., the calibration year of GCAM). Therefore, it does not include any implementation of NDCs. The reference scenario serves as a counterfactual scenario to compare with the mitigation scenarios described in this report. This approach has been widely used in the literature.

The I-NDC and C-NDC scenarios assume that countries meet their NDC commitments through 2030 and continue at the same level of decarbonization effort required to achieve their NDCs beyond 2030.

Instead of assessing whether countries are on track to achieve their NDC goals, we assume that these goals are met and explore how different mechanisms (i.e. independent vs. cooperative implementation) affect emissions and abatement costs of countries.
In addition, we assume that countries achieve their NDCs and post-2030 mitigations through a uniform price on carbon across sectors, whereas, in reality, countries would reduce their emissions through a variety of policies and programs. To the extent that economically inefficient policies are utilized, our cost estimates and the potential gains from idealized implementation of Article 6 will be underestimated.

The I-NDC scenario assumes that countries implement their NDC goals independently and continue to decarbonize their economies on their own after 2030. In this scenario, we translate each country's NDC into an emission limit following the method of Fawcett *et al.* (2015).[1] Each country is assumed to achieve its NDC emissions limit through economically efficient policies (i.e., carbon tax on fossil and industrial emissions). From 2030 to 2100 we assume "continued ambition" as in Fawcett *et al.* (2015).

The C-NDC scenario assumes that countries cooperatively implement their NDC goals and reduce emissions beyond 2030 under Article 6 of the Paris Agreement. In this scenario, countries can purchase and sell ITMOs, which are assumed to accurately represent actual emissions mitigation implied by NDCs, to achieve their decarbonization goals. (The translation step between NDC and ITMOs is a non-trivial step that we will discuss later in this paper.) Because the marginal abatement costs vary widely, for some countries it is more cost effective to trade with other countries with lower abatement costs than to reduce emissions on their own. The actual emissions

[1] This includes the U.S. 2015 NDC, though the U.S. has signaled its intention to withdraw from the Paris Agreement. We explore how the assumption that the U.S. does not participate affects our results in supplemental materials.

of countries are different between I-NDC and C-NDC scenarios, although each country keeps the same level of ambition in these two scenarios. Note that double-counting, a key issue in COP 24 negotiations, does not occur in our modeling framework.

To explore the degree to which Article 6 could be used to enhance ambition without increasing the economic burden on Paris Agreement participants, we create an E-NDC scenario that assumes that the cost each country would have incurred had it implemented its NDC independently reflects its willingness to pay to mitigate carbon emissions. We use each country's I-NDC costs to recalculate additional ambition that could be achieved if economic efficiency gains are harnessed through cooperative mechanisms. Compared with the independent implementation of NDCs, cooperative implementation would be more efficient, reduce costs, and allow countries to achieve more with the same costs. The E-NDC scenario explores how much additional ambition could be enabled through cooperative implementation of mitigation commitments, while maintaining the same global mitigation cost as that in the I-NDC scenario. Because cooperative implementation is more efficient, with the same mitigation costs, cooperative implementation could achieve more mitigation and enhance ambition (Figure 1). Meanwhile, the shadow price of carbon would also increase, compared with C-NDC, to reach higher ambition (Figure 2).

FIGURE 1 Global fossil fuel and industrial CO_2 emissions in the reference, I-NDC, C-NDC, and E-NDC scenarios

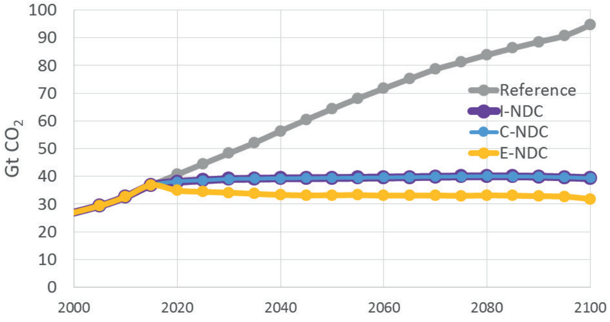
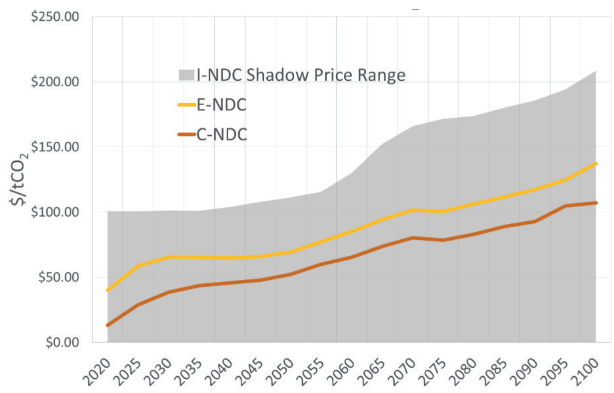


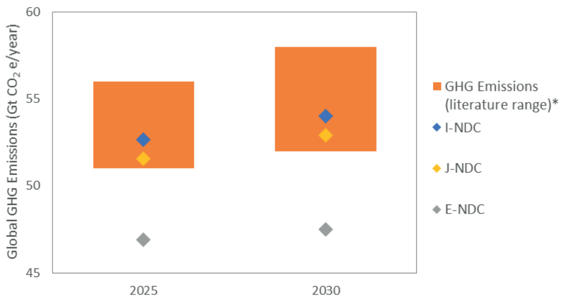
FIGURE 2 Shadow prices of CO_2 in the I-NDC, C-NDC, and E-NDC scenarios



CALIBRATION WITH OTHER MODELS

Targets established in NDCs come in a variety of forms and modeling them requires a translation of each NDC into an absolute target. Our specific translation of NDC obligations is largely consistent with other translations performed in the literature. In Figure 3, we compare our estimates of GHG emissions resulting from NDC obligations for the period 2025 to 2030 with those reported by Rogelj *et al.* (2016). Since we only constrain global CO_2 emissions from energy and industry in the I-NDC and C-NDC scenarios, the total GHG emissions are different under these two scenarios due to the underlying differences in the energy and land-use systems and non-CO_2 emissions. The efficient allocation of resources in the C-NDC scenario leads to less GHG emissions than in the I-NDC scenario. The E-NDC scenario, because of its higher ambition, has low levels of GHG emissions; in 2025 GHG emissions in the E-NDC scenario fall within the range of achieving 2°C (46–50 $GtCO_2e$ in 2025 in Rogelj *et al.*, 2016).

FIGURE 3 Global total GHG emissions in 2025 and 2030 under different scenarios



*The global GHG emissions in the literature were obtained from Rogelj *et al.* (2016)

CALCULATION OF POTENTIAL ENHANCED AMBITION

Showcasing the potential enhanced ambition that could result from efficiency gains achieved by Article 6 represents a key conceptual and empirical contribution of this paper. It is therefore important to be specific regarding how we calculate this potential. The calculation of enhanced ambition by each of the world's regions, r, in each period, t, A(r,t)ENDC, is a multi-step process that underpins our E-NDC scenario. We begin by defining several variables.

$E(r,t)_{INDC}$ = *emissions in region r associated with that region's NDC in period t.*

$E(r,t)_{ENDC}$ = *emissions in region r when that region faces a carbon price P(t) in period t.*

$P(t)_{ENDC}$ = *the global carbon price in period t.*

$C(r,t)_{INDC}$ = *cost of implementing region r's NDC in period t.*

$C(r,t)_{ENDC}$ = *cost of emissions mitigation in region r when that regions faces a carbon price P(t) in period t.*

$ET(r,t)_{ENDC}$ = *emissions sales by region r at a carbon price P(t) in period t.*

$$CT(r,t)_{ENDC} = P(t)*ET(r,t)_{ENDC}$$

We begin by calculating total global cost of emissions mitigation for the I-NDC scenario, GC(t).

We then find P(t) such that:

$$GC(t) = \sum_r C(r,t)_{INDC} = \sum_r C(r,t)_{ENDC}.$$

We then calculate the transfer payment needed in order to make the cost of independent implementation of the original NDC equivalent to the net cost of emissions mitigation with the global carbon price, P(t), including revenue (or payments) from net sales (or purchases) of emissions from the global carbon market.

The value of net sales of ITMOs to the market are $CT(r,t)_{E\text{-}NDC}$.

$$CT(r,t)_{ENDC} = C(r,t)_{INDC} - C(r,t)_{ENDC}$$

The net transfer of ITMOs to other parties (or purchases if negative) is $ET(r,t)_{E\text{-}NDC}$

$$ET(r,t)_{ENDC} = CT(r,t)_{ENDC}/P(t)$$

Finally, the increase in ambition is calculated as the sum:

$$A(r,t)_{ENDC} = E(r,t)_{ENDC} - E(r,t)_{INDC} - ET(r,t)_{ENDC}$$

ASPECTS OUTSIDE OF SCOPE

There are some design choices that we do not explicitly model. For example, we do not allow double counting, something that is prohibited by the Paris Agreement. We assume environmental integrity in all transactions. Some proposed rules could result in double counting. Such transactions can be modeled, but are counter to both the letter and the spirit of the Paris Agreement. Some parties have proposed that units issued from 6.4 would not require a corresponding adjustment. In discussions with analysts and modelers, such unaccounted sales would simply weaken the targets from seller countries by the amounts transferred –presuming that buyers would be willing to purchase and use such units. Such a practice would conflict with many references in the Paris Agreement that aim to avoid double counting. In addition, we do not model transfers "inside or outside" of NDCs. The models assume that countries transfer only from sectors that are quantified and correspondingly adjusted in their emissions accounts. Finally, we do not contemplate the use of pre-2020 Kyoto units. If these were allowed for use without corresponding adjustments, it would have the same effect of weakening the contributions of the parties involved in the transfers. Conversely, if these were allowed with corresponding adjustments, then it would offer more integrity. Each of these design elements could make for useful topics addressed in future research.

RESULTS

In this section, we first estimate economic savings that Article 6 could potentially provide in meeting NDCs as currently registered. We then investigate three alternative modeling assumptions. First, we investigate the effect of an alternative land-use policy assumption to understand the impact of this sector on overall cost-effectiveness. In our base scenario, we assume that non-agricultural lands are protected against deforestation, however, we make no attempt to expand forest areas for the purpose of increasing carbon storage. In our land-use sensitivity scenario, we allow for policies to expand forest areas to increase carbon storage in land systems. Second, we investigate the impact of the withdrawal of the United States (U.S.) from the Paris Agreement. Third, we explore continued and increased abatement efforts post-2030.

ECONOMIC SAVINGS AND POTENTIAL ENHANCED AMBITION

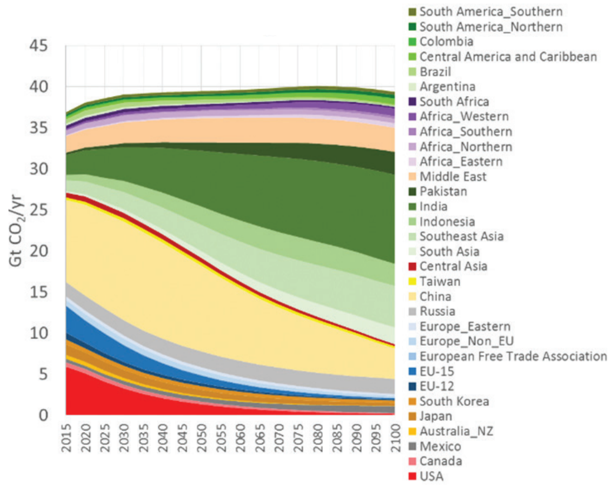
I-NDC CO_2 emissions for each of the 32 GCAM regions from 2015 to 2100 are displayed in Panel A of Figure 4. For several regions (e.g., China, Europe, and the U.S.), continued ambition implies steadily declining emissions. Shadow prices for the I-NDC are shown in Panel C of Figure 4. In 2030 the shadow prices range from zero for minimal ambition to \$101/tCO_2 (\$0 to \$111/tCO_2 in 2050; \$16 to \$209/tCO_2 in 2100). The large variation in shadow prices implies large potential gains from collaborative actions.

The common shadow price of carbon from the C-NDC scenario is shown in solid red in Panel C of Figure 4 with values of \$38/tCO_2 in 2030, \$52/tCO_2 in 2050, and \$107/tCO_2 in 2100. Regional emissions consistent with the common carbon shadow price are shown in Panel B of Figure 4.

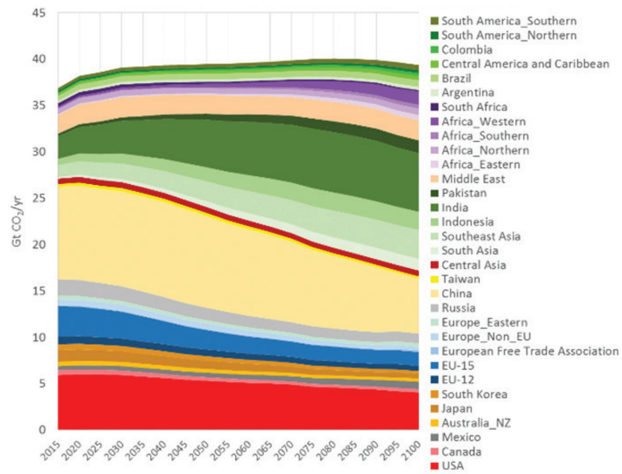
The regional differences between C-NDC and I-NDC are shown in Panel D of Figure 4. The sum of positive values (regions with increases in mitigation) represents the size of the virtual physical (as opposed to financial) carbon market, about 4.3 GtCO_2/year in 2030, roughly half of total global mitigation. A cooperatively implemented, efficient emissions mitigation effort would redistribute roughly 10 percent of emissions in 2030, growing to about 30 percent in 2100.

FIGURE 4 Energy and industry CO_2 emissions (2015–2050) and emissions mitigation by region 2030, 2050 and 2100

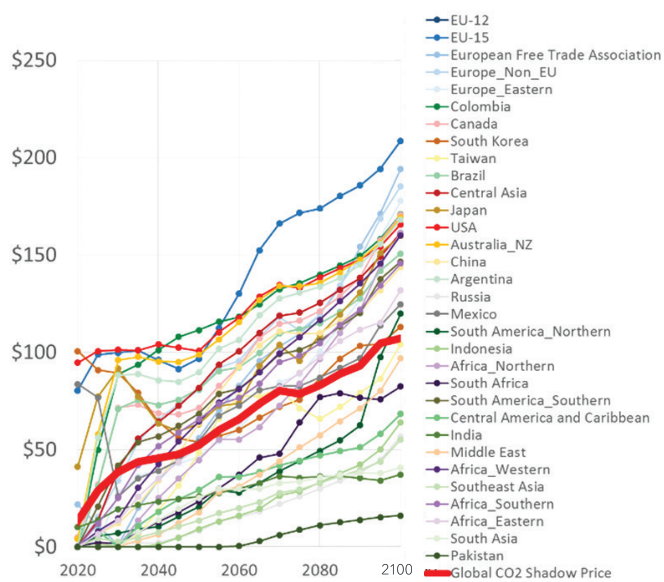
Panel A: Global I-NDC scenario CO_2 emissions



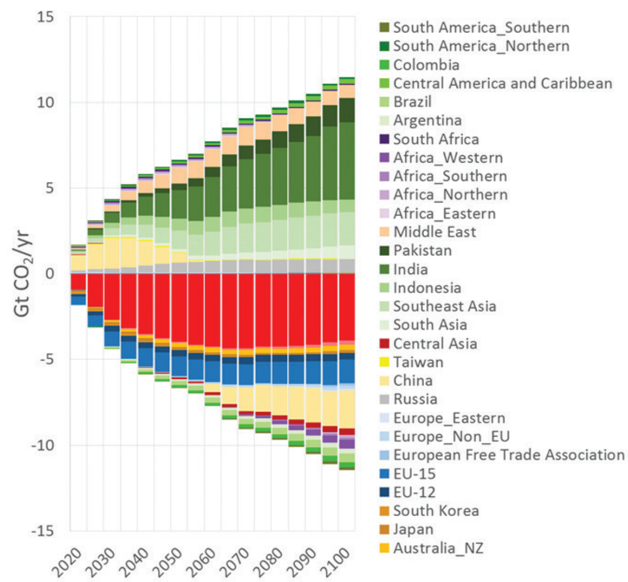
Panel B: Global C-NDC scenario CO_2 emissions



Panel C: Shadow prices of CO_2 I-NDC and C-NDC



Panel D: Change in CO_2 emissions C-NDC less I-NDC

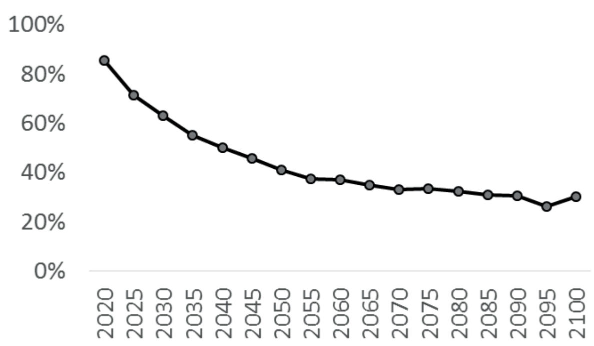


Compared with I-NDC, in the C-NDC scenario there are 11 regions that would increase their emissions mitigation in every period through 2100, four would consistently mitigate less, and 17 regions are at different times on either side of the transaction. Since I-NDC and C-NDC scenarios have identical global emissions, the sum of differences is zero.

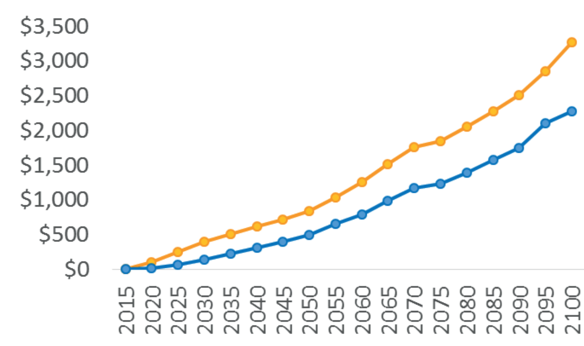
The financial size of the virtual carbon market is about $167 billion/year in 2030, increasing to $347 billion/year in 2050 and reaching $1.2 trillion/year in 2100. Our estimate falls within the range of the World Bank's estimate of $100 billion to $400 billion in 2030 (World Bank and Ecofys, 2018) but is significantly greater than the Fujimori *et al.* (2016) estimate of $58 billion (2015 $) in 2030, though aggregate physical carbon transfers are roughly equal. The lower price likely traces to alternative assumptions regarding land-use change mitigation under Article 6. We explore the implications of alternative land-use emissions mitigation policies similar to those of Fujimori *et al.* (2016) in the next section.

FIGURE 5 Reduction in economic cost (global and regional)

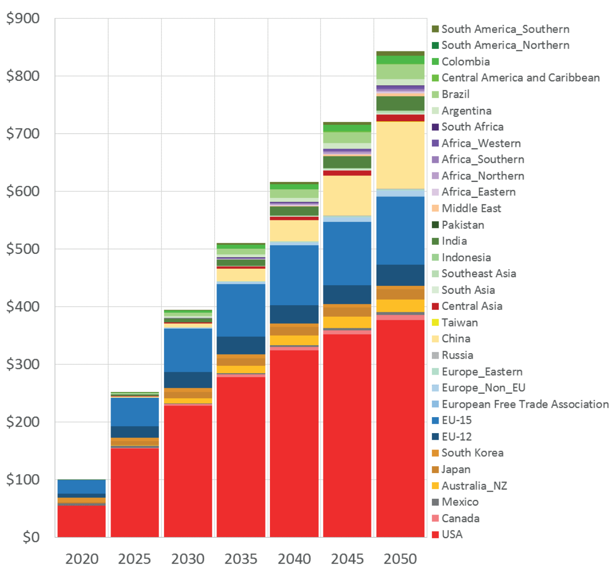
Panel A: Reduction policy cost ($)



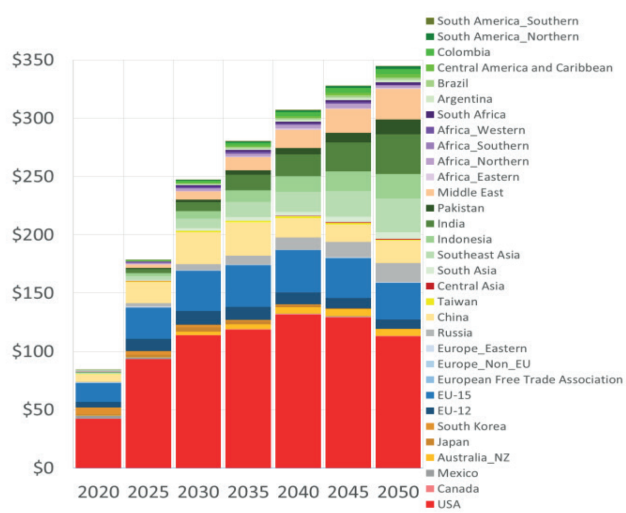
Panel B: Climate policy cost (billion 2015 $/year)



Panel C: Global I-NDC mitigation costs (billion 2015 $/year)



Panel D: Net annual GDP change (I-NDC less C-NDC; billion 2015 $)



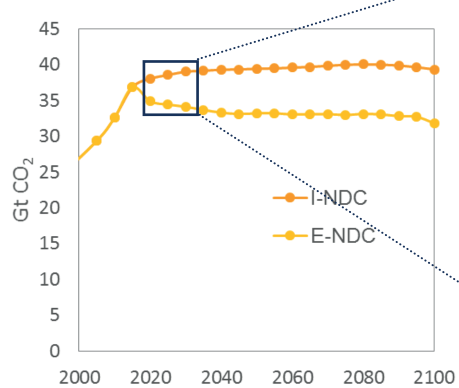
Panel A of Figure 5 shows the global emissions mitigation costs under I-NDC and C-NDC, where economic cost is measured as the integral under the marginal abatement supply schedule (JGCRI, 2018). Compared with I-NDC, C-NDC reduces costs by $249 billion (2015 $) per year (63 percent), $345 billion per year (41 percent), and $988 billion per year (30 percent), in 2030, 2050, and 2100 respectively (Panel B of Figure 5). Annual undiscounted I-NDC mitigation costs are shown in Panel C of Figure 5 and net reductions in cost are shown by region in Panel D of Figure 5. Benefits accrue to all parties.

One of the goals of Article 6 is to facilitate increased ambition through cooperative implementation. We estimate the potential enhanced ambition through Article 6 by comparing E-NDC and I-NDC. Panel A of Figure 6 shows total global emissions under the I-NDC and E-NDC scenarios and the additional ambition for each region in the first commitment period. In 2030 annual global carbon emissions mitigation is roughly 5 $GtCO_2$/year greater under E-NDC than under I-NDC. The cumulative additional mitigation enabled by perfect implementation of Article 6, with continued ambition as per Fawcett *et al*. (2015), over the course of the century exceeds 520 $GtCO_2$. The enhanced emissions mitigation scenario enables 50 percent more mitigation compared to I-NDC.

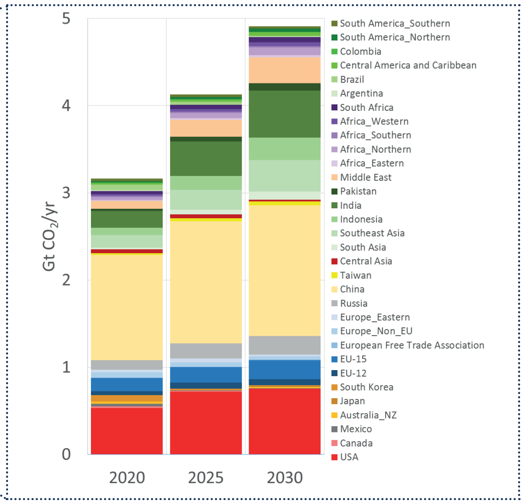
While all regions increase ambition under the E-NDC scenario, those enhanced ambitions are unavailable absent Article 6 mechanisms. The common carbon price that enables enhanced ambition is shown in Panel B of Figure 6. Enhanced ambition under the E-NDC scenario roughly doubles the marginal cost of carbon in 2030 compared to the C-NDC scenario, but keeps net annual mitigation costs by region constant at I-NDC levels. The requisite financial transfers to leave each region with identical total cost as in the I-NDC scenario are shown in Panel C of Figure 6. These are equivalent to the value of ITMOs that would be created to implement Article 6 transactions in the E-NDC scenario. The implied physical emissions trades between regions under the E-NDC scenario would be about 4.4 $GtCO_2$/year in 2030, similar to emissions redistributed under C-NDC.

FIGURE 6 Enhanced ambition enabled by Article 6

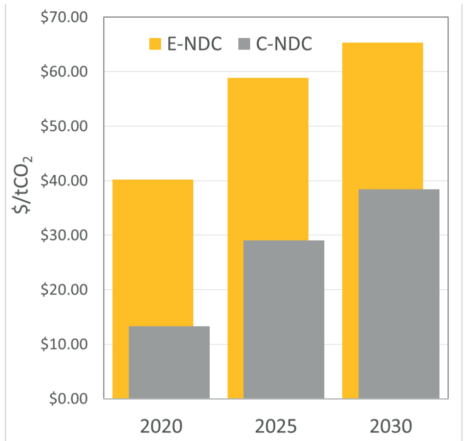
Panel A: Global CO_2 emissions from energy and industry



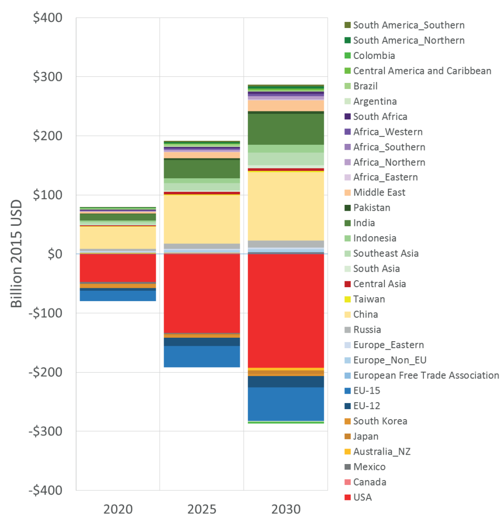
Potential first commitment period enhanced ambition



Panel B: Shadow Price of CO_2 for the C-NDC and E-NDC scenarios



Panel C: Financial transfers necessary to equate mitigation cost in each region in the E-NDC and I-NDC scenarios, valued at the E-NDC shadow price of carbon in the E-NDC scenario



IMPACT OF RESTRICTING LAND-USE SECTOR

Land-use policies are important for the cost-effectiveness of climate change mitigation. We develop an alternative scenario that constrains CO_2 emissions with policies in both land-use change and energy and industry. In the universal carbon tax (UCT) scenario, CO_2 emissions from the terrestrial system are valued equally with CO_2 emissions from fossil fuel and industrial sources. The total CO_2 emissions from land and energy systems in the UCT scenario is the same as those in the I-NDC scenario, but the I-NDC scenario assumes "protected lands" whereas the UCT scenario assumes a universal carbon tax applied equally to all emissions regardless of their origin.

The comprehensive approach of integrating terrestrial and energy systems could lower the cost of meeting the same mitigation target, consistent with findings of other studies (Tavoni *et al*., 2007; Wise *et al*., 2009). The shadow price of carbon in 2030 is as low as \$8/tCO_2 in the UCT scenario (Figure 7), similar to the estimate of Fujimori *et al*. (2016). The physical amount of carbon traded in the virtual market is roughly 5.4 GtCO_2 in 2030, 25 percent bigger than that in the I-NDC scenario. However, because of the lower shadow price, the financial size of carbon market is much smaller in 2030, about \$43 billion (Figure 8). Meanwhile, the potential sellers and buyers in the virtual carbon market also change. Brazil and Africa become the largest sellers before 2050, as shown in other studies (EDF, 2016), and China, one of the major sellers in the first half of the century under the I-NDC scenario, becomes a buyer in the UCT scenario.

FIGURE 7 Shadow prices of CO_2 in the I-NDC-UCT scenario

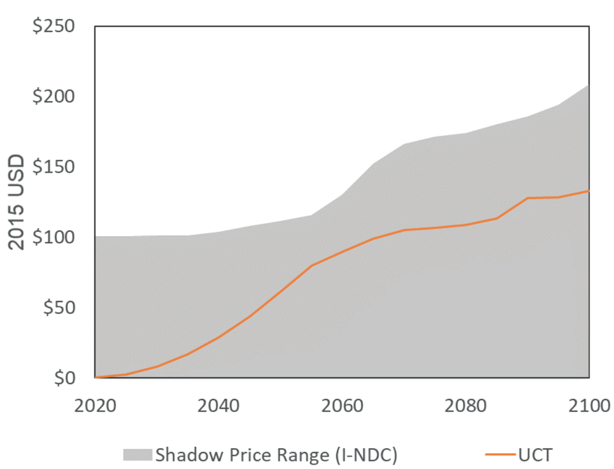
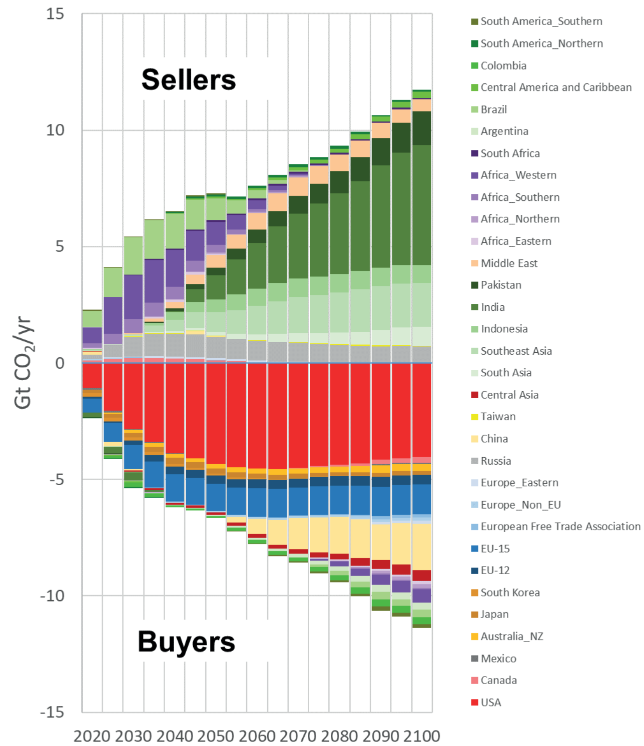
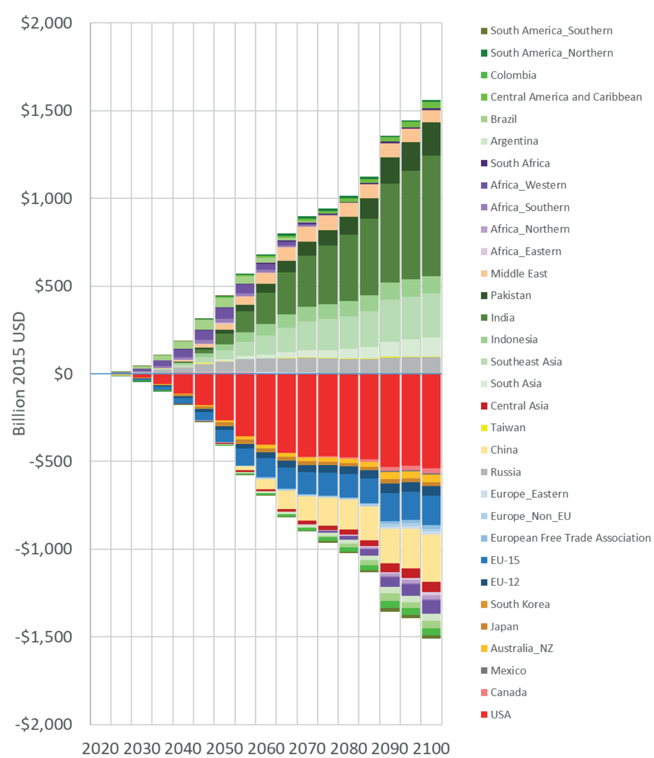


FIGURE 8 CO_2 emissions traded and the size of carbon market

Panel A: Buyers and sellers under Article 6 (UCT)



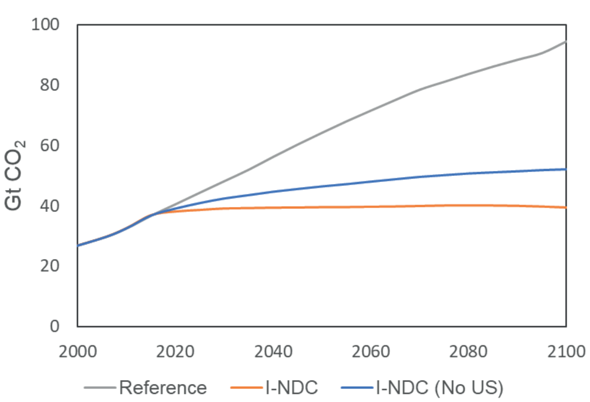
Panel B: Emissions trading market size



IMPACT OF U.S. WITHDRAWAL

The U.S. announced its intention to withdraw from the Paris Agreement in 2017. We have developed two alternative scenarios to assess the potential implications of this action for the implementation of Article 6. The I-NDC (No U.S.) scenario assumes that countries except the U.S. meet their NDC commitments through 2030 and continue at the same level of decarbonization effort required to achieve their NDCs beyond 2030. In this scenario, the U.S. takes no mitigation effort to reduce GHG emissions after 2010, while other countries are held to the same level of mitigation as in the I-NDC scenario. It is worth noting that this scenario design is a bounding scenario. It assumes that the U.S. remains on its reference trajectory, moderately only by interactions with other countries through international energy and commodity markets. It does not include the effects of measures undertaken to reduce emissions by states and local governments and non-government actors, which could have a significant impact on U.S. emissions (America's Pledge, 2018). The No U.S. scenario shown in Figure 9 is an upper bound on U.S. and global I-NDC emissions.

FIGURE 9 Global fossil fuel and industrial CO_2 emissions in the I-NDC and I-NDC (No U.S.) scenarios



The C-NDC (No U.S.) scenario assumes that countries except the U.S. collaboratively implement their NDCs and reduce emissions beyond 2030. Following Article 6 of the Paris Agreement, they can purchase and sell ITMOs to achieve decarbonization goals collaboratively. The aggregate of energy and industrial CO_2 emissions from these countries throughout the 21st century are the same in the I-NDC (No U.S.) and C-NDC (No U.S.) scenarios.

The U.S. does not take any mitigation actions after 2010 in the C-NDC (No U.S.) scenario and does not participate in the emissions trading under Article 6.

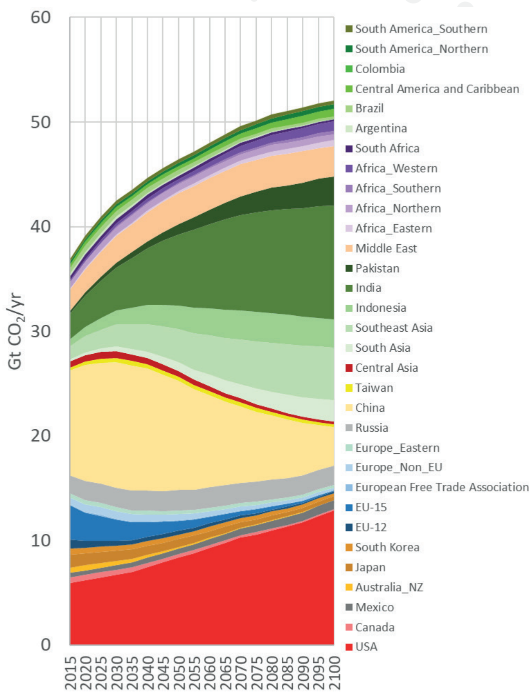
CO_2 emissions for each of the 32 GCAM regions under the No U.S. scenarios are shown in Figure 10, panels A and B. The other 31 regions keep the same level of ambition as the I-NDC scenarios, whereas U.S. emissions continue to rise. With no mitigation effort in the U.S., the global CO_2 emissions from energy and industry increase by 9 percent in 2030 (18 percent in 2050 and 32 percent in 2100), compared with the I-NDC scenario.

The changes in emissions for each region between independent and cooperative implementation scenarios without U.S. participation differ from changes between the I-NDC and C-NDC scenarios, as the size of the virtual physical carbon market is different and smaller without U.S. participation. The shadow prices of carbon are also lower, ranging from \$0 to \$94/tCO_2 in 2030, \$0 to \$100/tCO_2 in 2050, and \$13 to \$185/tCO_2 in 2100 in the independent implementation case. The variation in shadow prices across regions implies potential collaboration in mitigation. Cooperative implementation would reduce the shadow price due to its economic efficiency –\$7/tCO_2 in 2030, \$40/tCO_2 in 2050, and \$88/tCO_2 in 2100 (Figure 10, Panel C).

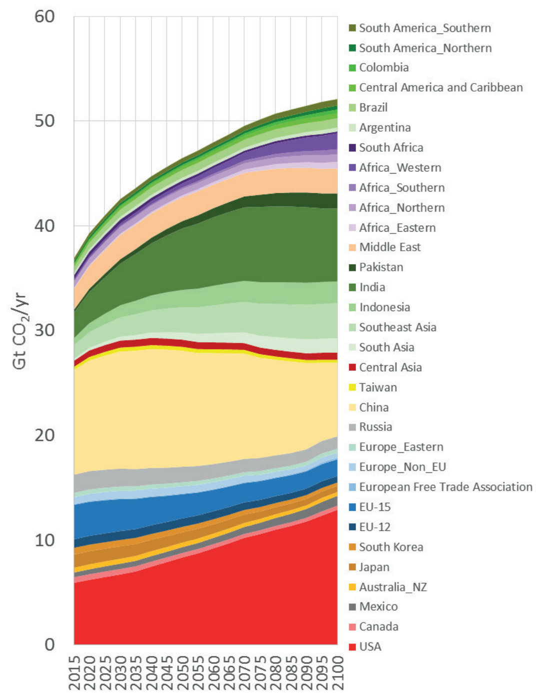
The size of the virtual physical carbon market is much smaller without the U.S. participation—only 2.1 GtCO_2/year in 2030 (4.3 GtCO_2/year in 2030 with U.S. participation). The financial size of the virtual carbon market is also much smaller, about \$15 billion in 2030, \$164 billion in 2050, and \$855 billion in 2100. The potential sellers and buyers are similar with and without U.S. participation, but the impact on China is substantial. The U.S. is the second largest GHG emitter globally. Without its participation, both China's role and the amount of carbon it purchases change significantly. China changes in 2045 from a potential seller to a potential buyer, whereas this change happens in 2060 with U.S. participation. The amount of carbon China purchased from the virtual market also increases, from 2.2 GtCO_2/year in 2100 with U.S. participation to 3.3 GtCO_2/year in 2100 without U.S. participation.

FIGURE 10 CO_2 emissions and carbon market without U.S. participation

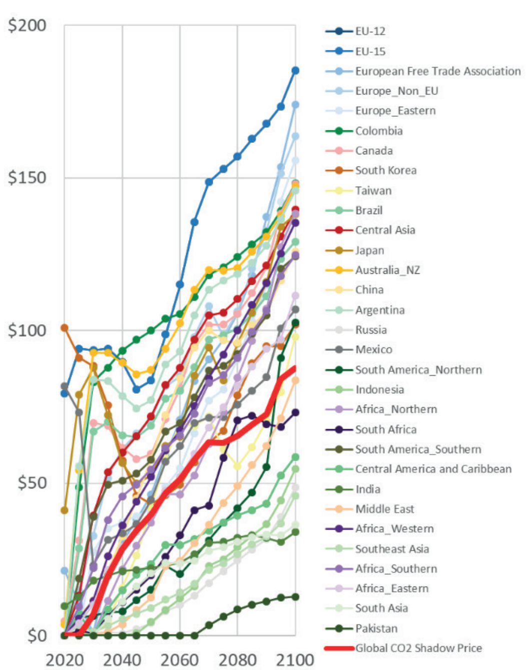
Panel A: I-NDC (No U.S.) scenario CO_2 emissions



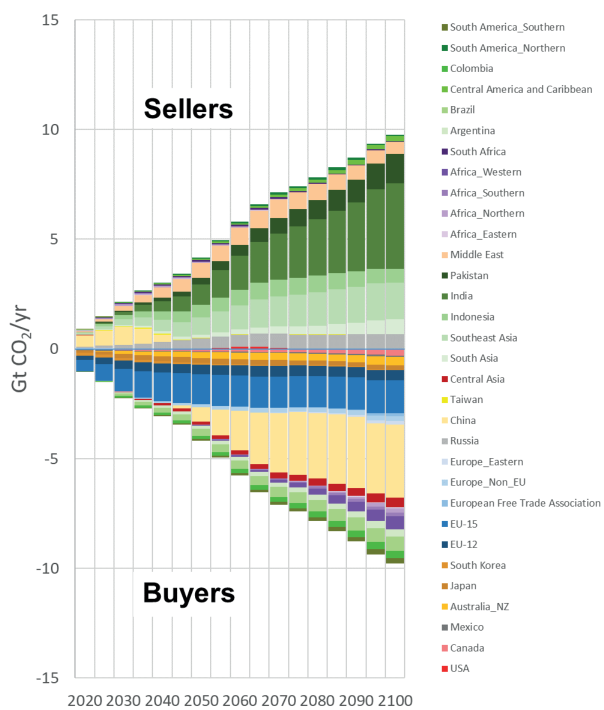
Panel B: C-NDC (No U.S.) scenario CO_2 emissions



Panel C: Shadow prices of CO_2 (No U.S.)



Panel D: Buyers and sellers under Article 6 (No U.S.)



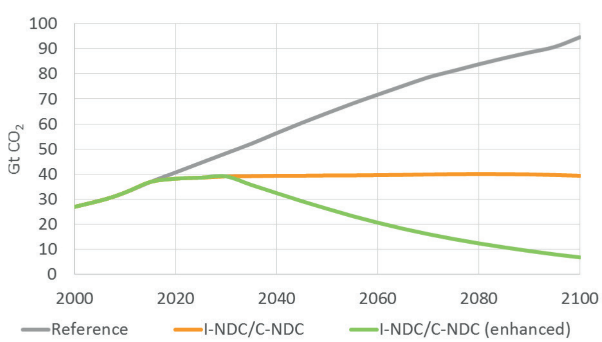
INCREASED AMBITION POST-2030

Current commitments in NDCs are not sufficient to limit global temperature rise well below 2°C (Fawcett *et al.*, 2015; Rogelj *et al.*, 2016; IPCC, 2018). To meet the long-term temperature goal set by the Paris Agreement, countries need to increase their ambitions over time. Here we develop alternative scenarios to assess the value of Article 6 when countries increase their ambitions after 2030.

We examine two scenarios with increased ambition —I-NDC-Increased and C-NDC-Increased, which indicate independent and cooperative implementation of NDCs and commitments afterwards. Both scenarios assume that countries meet their NDC commitments through 2030, which are the same as our main I-NDC and C-NDC scenarios, and then increase the level of decarbonization effort beyond 2030. In the increased ambition scenarios, we assume that countries decarbonize their economies at an accelerating rate—a higher minimum decarbonization rate of 5 percent per year, which is consistent with the Paris-Increased Ambition scenario in Fawcett *et al.* (2015).

Compared with the main scenarios with continued ambition, the increased ambition scenarios reduce global CO_2 emissions by 34 percent in 2050 and 83 percent in 2100 (Figure 11) and decrease the probability of temperature change exceeding 2°C in 2100 by 26 percent (see Fawcett *et al.* for the probabilities of temperature rise).

FIGURE 11 Global fossil fuel and industrial CO_2 emissions in the I-NDC-Increased and C-NDC-Increased scenarios

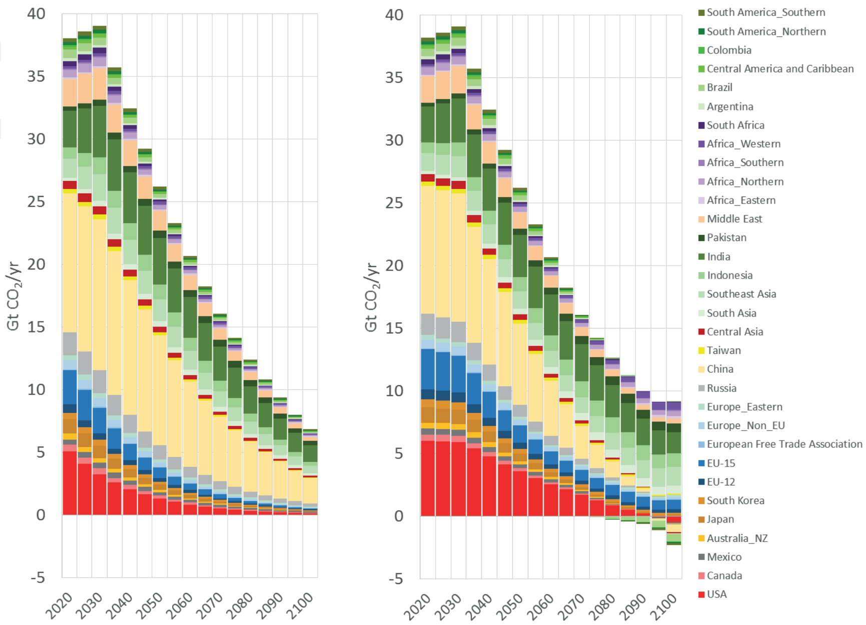


With more ambitious post-2030 mitigation actions, all regions, including regions with less robust NDCs, have a significant reduction in CO_2 emissions (Panel A of Figure 12). Compared with continued ambition scenarios, the shadow prices of carbon in the increased ambition scenarios are much higher and more consistent across regions, as all regions have more robust mitigation efforts. As shown in Panel B of Figure 12, the shadow prices of carbon in the I-NDC-Increased scenario range from \$95/tCO_2 to \$159/tCO_2 in 2050 and \$281/tCO_2 to \$338/tCO_2 in 2100. In the C-NDC-Increased scenario, the common shadow prices of carbon are \$110/tCO_2 and \$304/tCO_2 in 2050 and 2100 respectively.

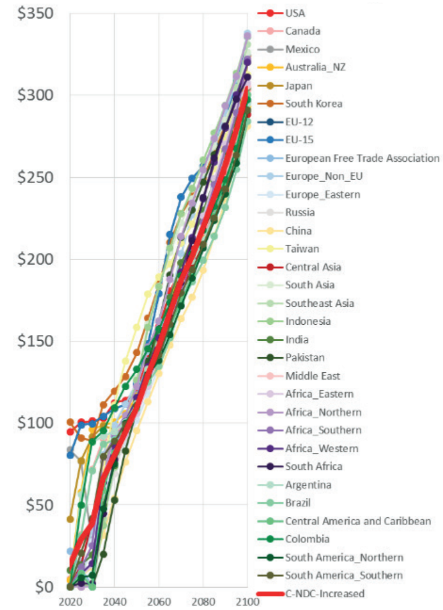
The region-by-region difference between independent and cooperative mitigation efforts is shown in Panel C of Figure 12. Compared with the continued ambition scenarios, the size of the virtual physical carbon market is much smaller now—about 3.8 GtCO_2/year in 2050 and 5.3 GtCO_2/year in 2100—because of more ambitious mitigation efforts in each of the 32 regions. However, the financial flow is more significant due to the higher shadow price of carbon. The market size in financial values is about \$419 billion in 2050 and reaches \$1.6 trillion in 2100. The potential buyers and sellers also change, especially in the second half of the century. With a large-scale energy system and more flexibility of fuel switching and reducing carbon emissions at lower costs, China is the biggest seller in the virtual carbon market throughout the century, and the U.S. also becomes a seller towards the end of the century.

FIGURE 12 CO_2 emissions and carbon market with more ambitious post-2030 mitigation

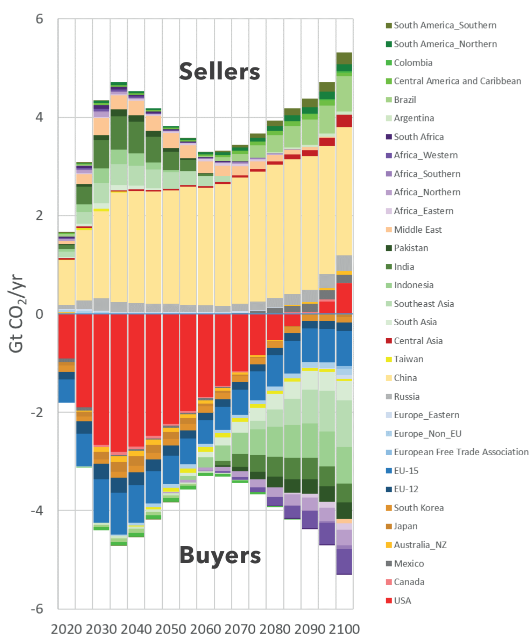
Panel A: I-NDC increased scenario CO_2 emissions   C-NDC increased scenario CO_2 emissions



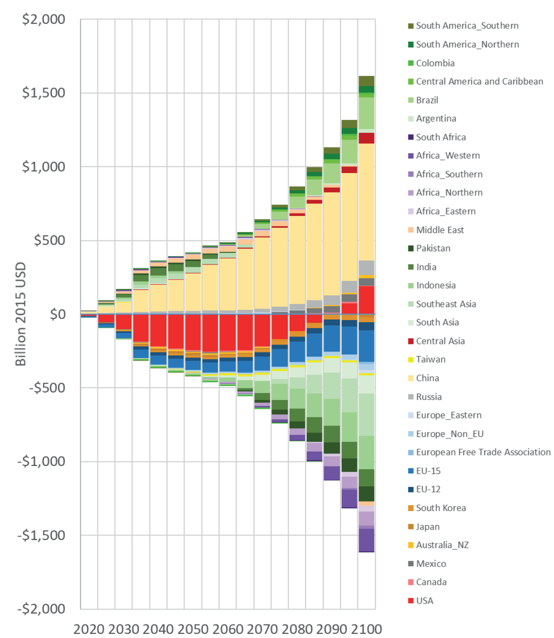
Panel B: Shadow price of CO_2



Panel C: Buyers and sellers under Article 6



Panel D: Emissions trading market size



DISCUSSION

Substantial potential exists for parties to work together via Article 6 to either lower the costs of achieving their pledges under the Paris Agreement or increase their ambition in the first commitment period. Achieving that potential remains a formidable challenge.

In the near term, just writing the rules has proved difficult. It is not obvious how to facilitate the creation and trade of ITMOs under Article 6 given the heterogeneity in targets and policies across NDCs (Das, 2015; Hood and Soo, 2017; Mehling *et al.*, 2018; Rose *et al.*, 2018). Metcalf and Weisbach (2011) initiated an active vein of the economics literature (e.g, Bodansky *et al.*, 2016) that investigates how to establish linkages between disparate programs, such as emissions trading systems and carbon taxes or regulatory schemes, while avoiding double-counting or emissions leakage.

In order to meet the Paris goals, initial commitments need to be enhanced in second and subsequent commitment periods. To limit climate change to 1.5°C or 2°C, it is essential that these cost savings translate into enhanced ambition, rather than simply rewarding lack of further ambition after countries achieve initial pledges (Metcalf and Weisbach, 2011; Calvin *et al.*, 2015; Ostrom, 2010; Lutter and Shogren, 2002; Becker, 2000; Höhne *et al.*, 2017). Rules to guard against this could include options such as limiting ITMO sales by an inverse proportion to actual emissions, or the phase-in of ratcheting mechanisms. This may be necessary to avoid the linkage of programs leading to an increase in overall emissions. Article 6 might also provide peer pressure insofar as climate clubs emerge, since many countries say that they will only link or import from countries that have credible NDCs (Mehling *et al.*, 2018; Iyer *et al.*, 2015; La Hoz Theuer, 2018; Peters *et al.*, 2017).

The challenges of realizing the full potential cost savings and enhanced ambition of Article 6 should not be underestimated. However, Article 6 may become a necessary tool if NDCs are to approach zero. Since parties will have different capacities for net-negative emissions and different amounts of residual unabatable emissions, Article 6 trading will likely be necessary to incentivize parties with excess capacity to go net-negative to balance out remaining emissions from parties without the ability to mitigate to net zero. Furthermore, dynamic technology and capital investment effects need to be evaluated. Cooperation will tend to shift emissions mitigation to places with a comparative advantage along with capital investment and infrastructure for emissions mitigation. But it also shifts mitigation, capital and infrastructure investments away from regions with the highest ambition.

Using modeling tools to test the implications of rules to implement Article 6 is essential for a clear understanding of the feedbacks and interactions across scales. It has been demonstrated that rules that seem effective at project scales can behave very differently at macro scales (Calvin, *et al.* 2015; Rockström *et al.*, 2017). The issue of leakage will be important to explore including differential leakage across sectors.

The Paris Agreement Rulebook, under development and due for adoption at COP 25, is expected to elaborate the rules and implementation guidance needed to operationalize the Paris Agreement, including Article 6. Wisely written rules could result in substantial cost savings that translate into enhanced mitigation, while poorly written rules could frustrate the performance of the Paris Agreement.

FUTURE RESEARCH

There is a plethora of future research topics to explore on Article 6 and the Paris Agreement, some of which are amenable to quantitative methodologies, including integrated assessment models, while others are better suited for qualitative analysis. As an extension to this paper, the role of the land-use sector under Article 6 of the Paris Agreement would benefit from more quantitative analysis via an integrated assessment model. However, a qualitative analysis that describes protocols for offset quality related to the land-use sector and assesses strategies for addressing leakage of emissions would complement further quantitative analysis.

This paper explored a scenario that assumes that cost savings from international carbon trading were reinvested back into enhanced ambition. Further quantitative explorations regarding the implications of this assumption and potential mechanisms to encourage that outcome could be useful extensions. In particular, an elaboration on the extent to which cost savings from international trading under Article 6 increases the probability of achieving a 2°C or lower target would provide insights on how to fill the well-known emissions gap between current pledges and climate targets. In addition, a qualitative analysis that contemplates the extent to which countries will choose to reinvest cost savings into enhanced ambition, rather than simply keeping those savings, would test an underlying assumption of this paper and provide a starting point for creating incentives and rules that encourage countries participating in international carbon trading to assertively enhance their ambition.

The rigorous analysis of how market access through "carbon clubs" could encourage use of specific ratcheting mechanisms, intended to incentivize enhanced ambition over time, would likely be particularly helpful as negotiators continue their work to fill the well-known emissions gap. Characterizing these combinations of clubs and ratcheting mechanisms then modeling them in a quantitative framework is a promising area for future research and will facilitate the identification of actionable strategies that negotiators can incorporate into negotiating text.


#CLIMATESIGN

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