The Potential Role of Article 6 Compatible Carbon Markets in Reaching Net-Zero

Working Paper

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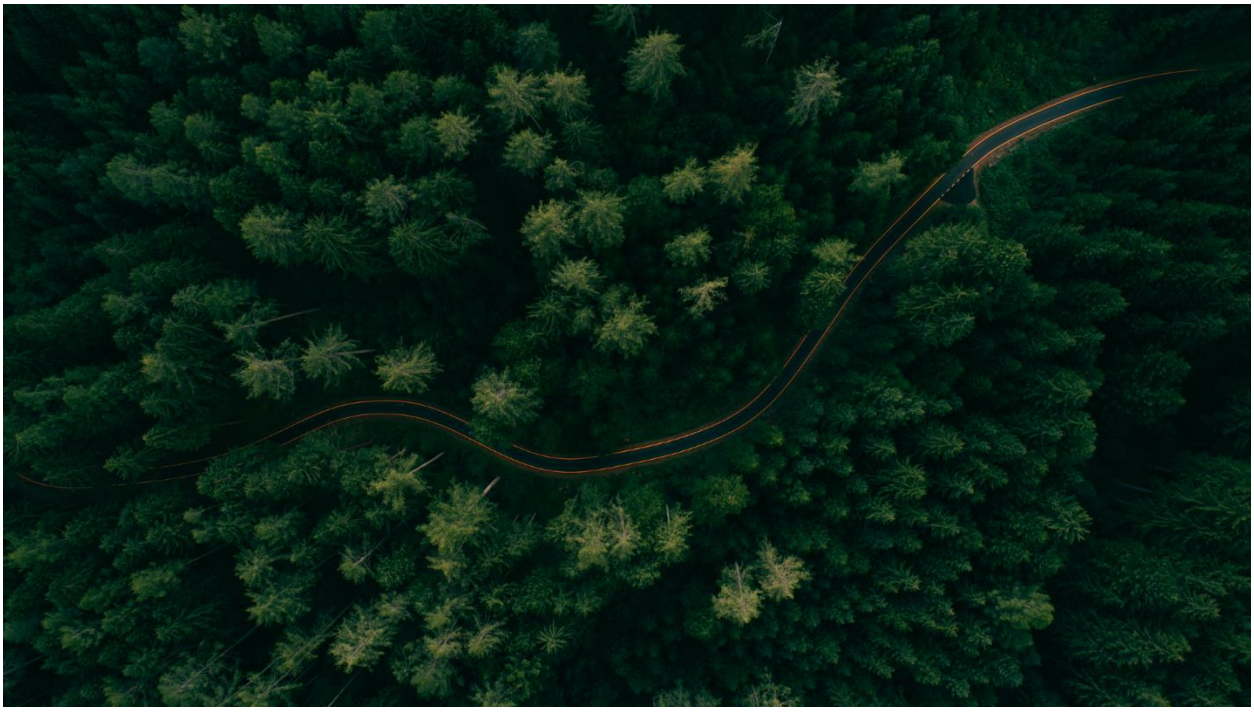
DISCLAIMER

The findings, interpretations, and conclusions expressed in this paper are those of the authors alone and do not necessarily reflect the views of either the research sponsors or the authors' home institutions.

SUMMARY

Article 6 of the Paris Agreement allows countries to work cooperatively to achieve emissions mitigation goals. In this paper, we explore the role of Article 6 in pathways to global net-zero CO_2 emissions in four scenarios: two Universal Net-Zero scenarios, where all countries commit to linearly reduce emissions to net-zero in 2050 with either independent or cooperative implementation, and two Staggered Net-Zero scenarios, where lower-income countries set a later date for their net-zero targets based on relative income differences, again with independent or cooperative implementation. In the cooperative scenarios, we allow full cooperation through carbon markets sanctioned under Article 6, without double counting or leakage and assuming accounting guidance is successfully agreed in Glasgow. We compare carbon prices, the flow of Internationally Transferred Mitigation Outcomes (ITMOs), and associated annual financial transfers under the cooperative implementation of net-zero targets. Preliminary results indicate that in both Universal Net-Zero and Staggered Net-Zero cooperative scenarios, countries with large endowments of land resources are more likely to become sellers. We also find that although physical ITMO transfer volumes decrease over time as countries' emissions get close to zero, the growth in carbon prices drives a significant increase in financial flows and the market value exceeds $1 trillion[1] per year in 2050. Most developed regions (such as the US, Europe, Japan, and South Korea) and the Middle East are buyers in both Universal Net-Zero and Staggered Net-Zero cooperative scenarios, with varying degrees of trade volumes. Some developing regions (such as India and Southeast Asia) are buyers in the Universal Net-Zero scenarios, raising equity concerns; whereas in Staggered Net-Zero scenarios, most developing regions (such as China, India, most of Africa and Latin America) are sellers. The buyer-seller dynamics imply a potential shift in capital investment from developed to developing regions in the Staggered Net-Zero scenarios, which can incentivize technology innovation and accelerate sustainable development in developing regions.



[1] All financial values mentioned in this report are in 2015 USD.

INTRODUCTION

The Paris Agreement of 2015 established under the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations, 1992) aims to hold "the increase in global average temperature to well below 2°C above pre-industrial levels and [to pursue] efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (United Nations, 2015). Under the Paris Agreement, each country pledges a Nationally Determined Contribution (NDC) reflecting near-term (through 2025 or 2030) intentions to reduce national emissions toward meeting the long-term Paris goal with regular review and ambition enhancement. The Intergovernmental Panel on Climate Change (IPCC) (2018) showed that if global CO_2 emissions decline to net-zero around the year 2050 (2045 to 2065), the Paris Agreement goal of limiting climate change to 1.5°C might be achieved. While current pledges are insufficient to limit average surface temperature to 1.5°C (IPCC, 2021; Kriegler et al., 2018; UNEP, 2020), many countries have signaled their intention to increase ambition. Table 1 presents the net-zero pledges by region (as of June 2021).

Table 1: Current Midcentury Net-Zero Commitments[2]

Net-Zero Commitment	GCAM Regions
Net-zero by 2050	Australia/New Zealand Brazil Canada EU-12, EU-15, European Free Trade Association Japan South Africa South Korea USA
Net-zero by 2060	China

The intent of Article 6 of the Paris Agreement is to facilitate enhanced ambitions through gains in efficiency by reducing the variability in the marginal cost of abatement across countries (Aldy et al., 2016; Mani et al., 2018), allowing Parties to cooperatively implement NDCs, either through working together directly or using internationally transferred mitigation outcomes (ITMOs), as long as Parties avoid double-counting (Schneider et al., 2019). Article 6 allows for many cooperative systems, including linkage among homogeneous policies (e.g., multiple market-based policies); linkage 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; Nordhaus, 2019). The share of Parties indicating planned or possible use of voluntary cooperation through Article 6 has nearly doubled, from 44% to 87% in the new or updated NDC submissions (UNFCCC, 2021). Edmonds, et al. (2021) showed that in the first commitment period to 2030, Article 6 held substantial potential to lower the cost of mitigation and deliver substantially enhanced ambition if these cost savings were reinvested in emissions mitigation.

Reaching a planetary net-zero CO_2 emissions mitigation goal requires that countries with emissions greater than zero would need to be balanced by countries whose emissions were less than zero. Van Soest et al. (2021) looked at cost-optimal emissions phase-out years, without fairness considerations for both 1.5 °C and 2°C targets (relative to pre-industrial levels, with at least 66% probability of achieving the targets) across six integrated assessment models. They found significant variation in the timing in which countries reached net-zero emissions, implying the potential for Article 6 to contribute to achieving a global net-zero goal.

The current set of NDCs is heterogeneous, making it challenging to form well-defined instruments to mitigate emissions effectively and comprehensively. However, as emissions decline toward zero, Parties will need to implement measures that are clear, effective, and comprehensive across all emissions sources and gases. This creates conditions in which the most effective markets can form.

[2] See more on GCAM in the Approach section. The analysis was conducted in June 2021 and therefore, Table 1 only lists GCAM regions with net-zero pledges by June 2021. The number of Parties with net-zero pledges increases between June and October; as of October 15, 2021, 56 parities, representing 67 countries, have communicated a net-zero target (Climate Watch Data, 2021).

In this paper, we explore the implications of achieving net-zero targets through Article 6 cooperation and compare it to alternative scenarios in which all Parties independently reduce emissions linearly to zero. In the **Universal Net-Zero** scenarios, we assume that all countries adopt a net-zero CO_2 target year of 2050 and in the **Staggered Net-Zero** scenarios we assume that countries with lower real per capita income achieve net-zero at later dates. We are not advocating for a top-down allocation of net-zero goals based on per capita income, because NDCs are by definition nationally determined. Rather, we explore the Staggered Net-Zero scenarios to understand how a staggered set of net-zero commitments could change emissions mitigation outcomes, as well as the magnitude, value, and other patterns of ITMO transfers under Article 6, in the three decades leading to 2050.

APPROACH

We craft four scenarios as shown in Table 2 to explore independent implementation and cooperative implementation on two types of schedule: a Universal Net-Zero schedule, where all countries meet net-zero by 2050, and a Staggered Net-Zero schedule, where countries reach net-zero at different times.

Table 2: Scenario Design

	Universal Net-Zero Pathway	Staggered Net-Zero Pathway
Independent	All countries take on net-zero CO_2 emissions targets for the year 2050 with linear declines from 2020 emissions to net-zero in 2050. Emissions mitigation is undertaken by each country independently.	All countries take on net-zero CO_2 emissions targets, but some countries take on targets for years other than 2050. Emissions of individual countries decline linearly from 2020 to net-zero in different years, as set by an income-based equity principle. All targets are implemented independently.
Cooperative	All countries take on net-zero CO_2 emissions targets for the year 2050 with linear declines from 2020 emissions to net-zero in 2050. All targets are implemented cooperatively.	All countries take on net-zero CO_2 emissions targets, but some countries take on targets for years other than 2050, as set by an income-based equity principle. All targets are implemented cooperatively.

The Staggered Net-Zero scenarios relax the assumption that all countries reach net-zero simultaneously in 2050. Net-zero emissions are achieved later than 2050 in some regions, staggered according to their economic development. While this delay in achieving net-zero emissions leads to higher transient climate forcing, it is still consistent with the Paris goal of limiting climate change to “well below” 2°C.

The Staggered Net-Zero scenarios require assumptions about when countries commit to achieving net-zero emissions. While many Parties have announced net-zero intentions, other Parties have not. If some countries take longer than 2050 to reach net zero, then others will need to go faster to avoid a reduction in global ambition levels. For Parties with announced net-zero timing, we bring forward that Party’s announcement by 5 years. For those that have not yet announced a net-zero intention, we create a hypothetical net-zero commitment based on that Party’s per capita income, assuming that per capita income is a rough reflection of mitigation capacity.

At the time this modeling was conducted, the country with the lowest per capita emissions and a net-zero target was Brazil. Using the logic that if Brazil can contribute a net-zero target at this income level, we assumed that other regions should be able to contribute a net-zero target when they reach Brazil’s per capita income level. These assumptions are arbitrary; ultimately, it is up to each Party to determine its own contribution to meeting Paris goals.

In the Staggered Net-Zero scenarios, this approach sets the following assumptions:

- **If a region currently has a net-zero target**, then its commitment is moved to 5 years earlier.
- **If a region currently does not have a target year**, then its target year is determined by comparing its projected 2050 per capita income to Brazil's projected 2050 per capita income.
    - If a country's income in 2050 is equal to or higher than Brazil's in 2050, then we assume it sets a target to reach net-zero emissions in 2050.
    - However, if a country's national income in 2050 is projected to be lower than Brazil's, we assume it will reach net-zero emissions when its income reaches the income of Brazil in 2050.

This principle allows us to simulate increased early ambition in high-income regions and net-zero target setting in lower-income countries based on their path of economic growth and examine potential changes to the global carbon market.

Table 3 highlights each region's assumed net-zero emissions year targets under the Staggered Net-Zero scenarios. This table also includes the share of global 2020 CO_2 emissions covered by net-zero targets, indicating the progress toward global net-zero emissions.

Table 3: Net-Zero Emissions Goals Based on Per Capita Income

Net-Zero Year	GCAM Region	Share of 2020 Global CO_2 Emissions Covered by Net-Zero Targets
2045	Australia_NewZealand*, Brazil*, Canada*, EU-12*, EU-15*, European Free Trade Association*, Japan*, South Africa*, South Korea*, USA*	33%
2050	Argentina, Colombia, Europe_Eastern, Europe_Non_EU, Mexico, Middle East, Russia, South America_Southern	48%
2055	Africa_Northern, Central Asia, China*, Indonesia	86%
2060	India, Southeast Asia	97%
2065	Central America and the Caribbean	>97%
2080	Pakistan, South Asia	>97%
2085	Africa_Eastern, Africa_Western	>97%
2090	Africa_Southern	>97%
2125	South America_Northern	100%

*Regions with net-zero pledges at the time this study was conducted.

We see that in the Staggered Net-Zero scenarios, close to 100% of global emissions today are covered by net-zero targets post-2060 versus post-2050 in the Universal Net-Zero scenarios. Northern Africa, China, Central Asia, Indonesia, India, and Southeast Asia account for 49% of 2020 emissions and help close most of the gap to global net-zero in the decade following 2050. In terms of temperature change, global mean temperature rise peaks at 1.61°C in 2050 and declines to 1.56°C by 2100 in the Universal Net-Zero scenarios, while in the Staggered Net-Zero scenarios global temperature rise peaks at 1.63°C in 2050 and declines to 1.58°C by 2100.

We use the Global Change Analysis Model (GCAM), v.5.3 (JGCRI, 2020) to develop net-zero scenarios. GCAM is an open-source, integrated assessment model, with a global scope with disaggregation to 32 geopolitical regions (Calvin et al., 2019; Clarke and Edmonds, 1993; Edmonds and Reilly, 1983). It links the energy, economy, agriculture and land-use, water, and climate systems within a unified computational framework that solves all systems simultaneously and consistently. The source code and assumptions of GCAM are available on Github (https://github.com/JGCRI/gcam-core/releases). The version of the model used in our study is an updated version of the one used in Fawcett et al. (2015). Full GCAM 5.3 model documentation is also available online (http://jgcri.github.io/gcam-doc/v5.3/toc.html).

GCAM is a dynamic-recursive model that solves each 5-year time step sequentially. The primary function of the GCAM solver is to find a vector of prices that simultaneously clears all markets in the system. GCAM is not a computable general equilibrium model. It is a hierarchical model which takes external assumptions about aggregate labor productivity growth and population in each region to establish the level of aggregate economic activity and then uses that information in combination with assumptions about technology, resource endowments, demand preferences, and policies to produce supplies and demands for energy, agriculture, land, and hydrologic systems. The modeled scenarios use the GCAM representation of the Shared Socioeconomic Pathways Scenario 2 (SSP2) (Calvin, et al., 2017), with modifications to reflect the impact of the COVID-19 pandemic on economic growth.

RESULTS

Emissions Pathways, Carbon Prices and Market Transfers

Universal Net-Zero

We first consider the case in which all countries take on emissions mitigation pledges to achieve net-zero CO_2 emissions in 2050. With or without cooperative implementation under Article 6, all countries' emissions decline toward zero, leaving relatively little potential emissions trading volume close to 2050 Figure 1, Panels a and b). However, the marginal cost of achieving net-zero, as represented by the implied carbon price (Figure 1, Panel c), varies by almost an order of magnitude under independent implementation. The wide variation in marginal costs between countries creates the potential for gains to trade in the Article 6 compatible global carbon market.

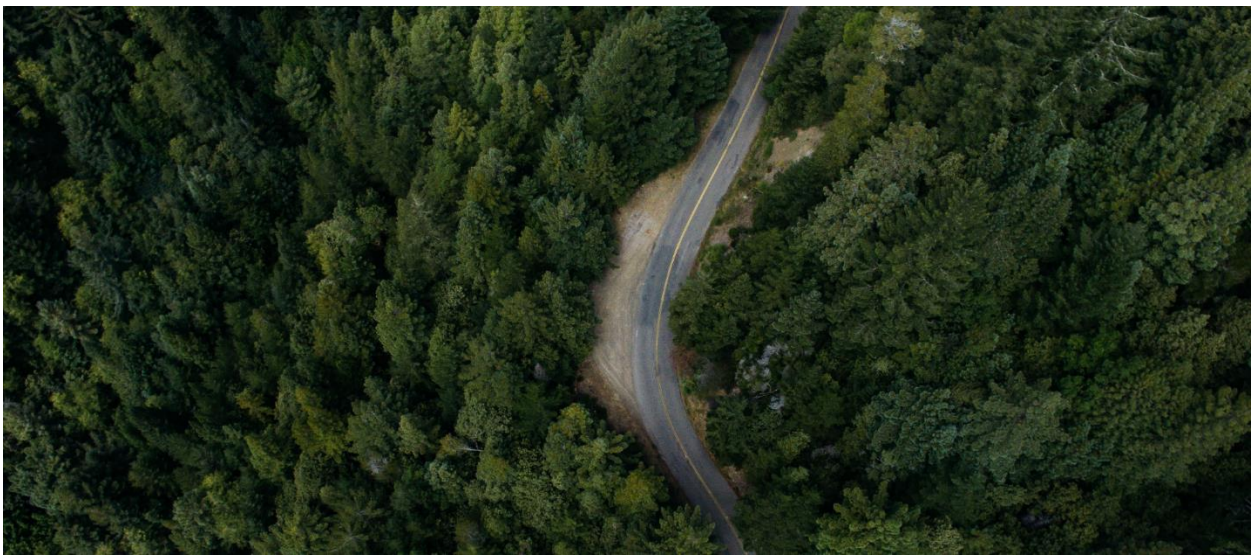
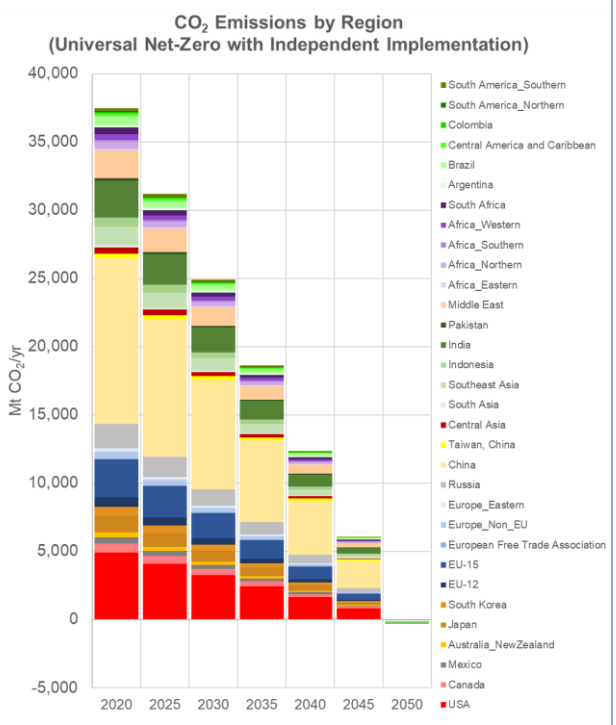
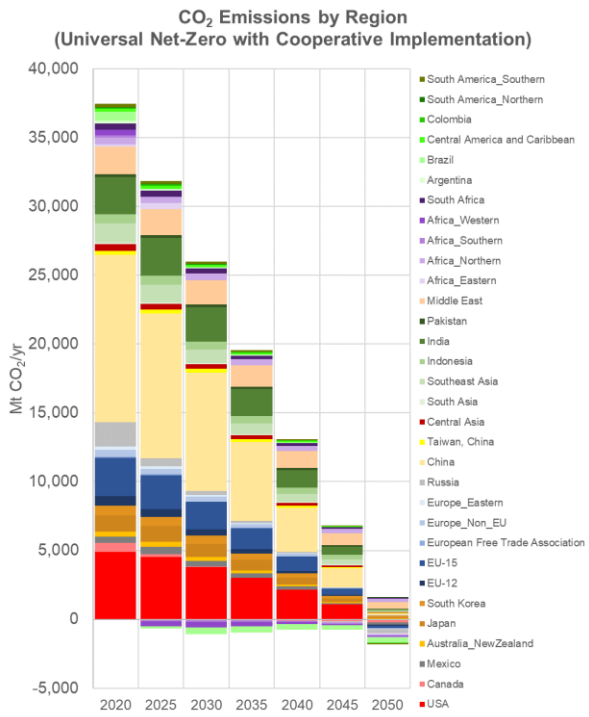


Figure 1: Regional emissions and carbon prices in Universal Net-Zero scenarios

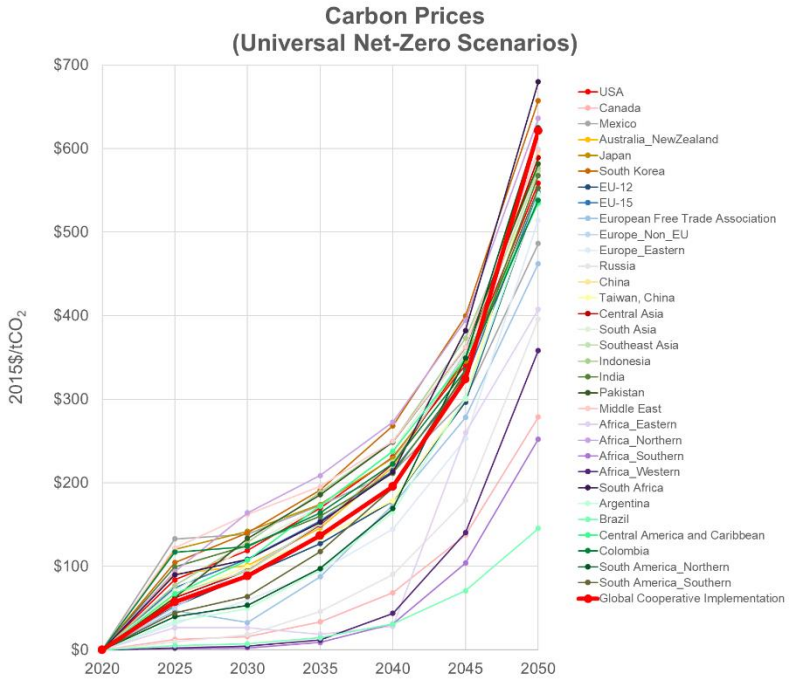
Panel a. Independent implementation of Universal Net-Zero CO_2 emission pathways



Panel b. Cooperative implementation of Universal Net-Zero CO_2 emission pathways



Panel c. Marginal costs of Universal Net-Zero CO_2 emission pathways with Independent and Cooperative Implementation



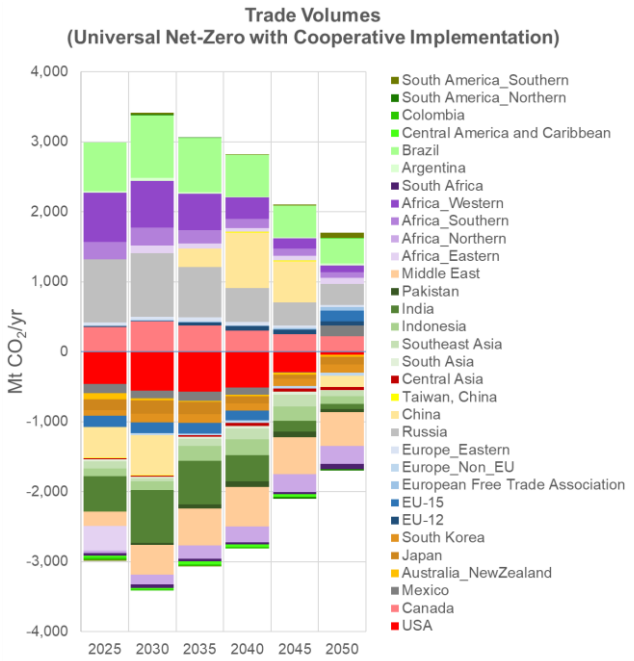
Potential physical ITMO transfers are 1.7 $GtCO_2$ in 2050, roughly half of the market volume in 2030. On the other hand, potential financial transfers are approximately $1 trillion per year in 2050, more than three times the financial transfers in 2030. The increase in financial flows is driven by rising marginal abatement costs in some regions as emissions decline toward net-zero. In the Universal Net-Zero scenario with cooperative implementation, the global carbon price increases from \$90/tCO_2 in 2030 to \$620/tCO_2 in 2050.

The most important role of Article 6 may be its ability to enable countries with the greatest challenges to emissions mitigation to engage cooperatively to meet zero-emissions targets without incurring the most extreme marginal costs. Buyers and sellers under the Universal Net-Zero scenario with cooperative implementation are shown in Figure. Potential physical emissions transfers in 2050 are shown in Figure 2 Panel c, while potential financial transfers are shown in Panel d.

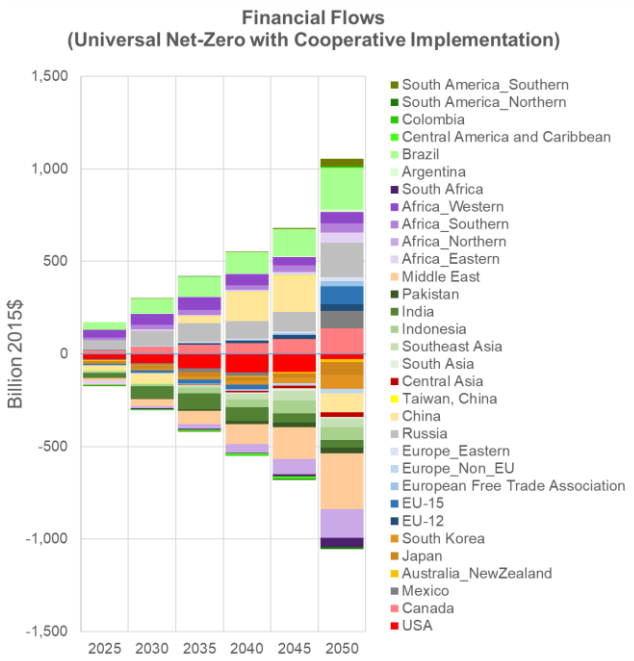
We see that the largest sellers of emissions mitigation (Canada, the Russian Federation, and Brazil) all have significant land resources, while the relatively land constrained or highly populous regions become buyers – the largest being the Middle East and India. South and Southeast Asian regions also emerge as buyers, even with their low-income status. Thus, the Universal Net-Zero scenarios raise serious equity concerns. Some countries with high marginal costs, which in principle would be buyers, would undoubtedly struggle to finance their purchases. This could simply result in a failure to achieve their ambitious targets by 2050.

Figure 2: Universal Net-Zero potential Article 6 market: physical and financial transfers

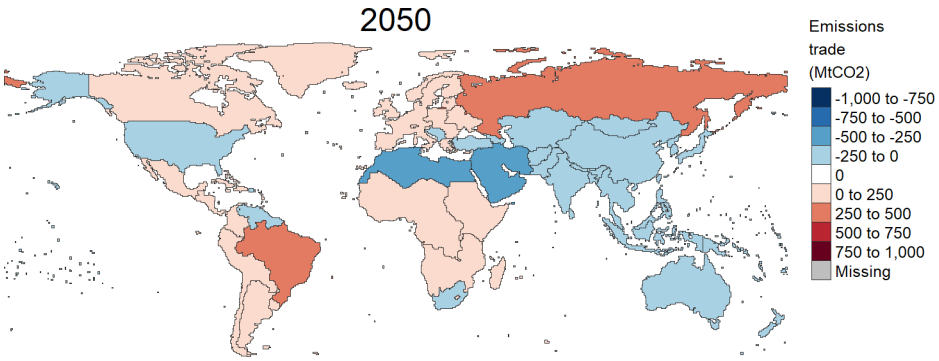
Panel a: Emissions transfers by year
(Seller >0; Buyer <0)



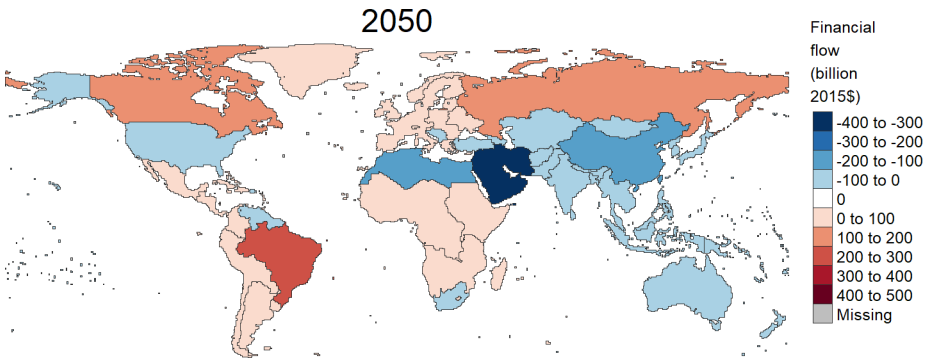
Panel b: Financial transfers by year
(Seller >0; Buyer <0)



Panel c. Geographic distribution of physical emissions changes in 2050 in Universal Net-Zero scenario with cooperative implementation (Potential buyers and sellers)



Panel d. Geographic distribution of financial flows in 2050 in Universal Net-Zero scenario with cooperative implementation (Potential buyers and sellers)



Staggered Net-Zero

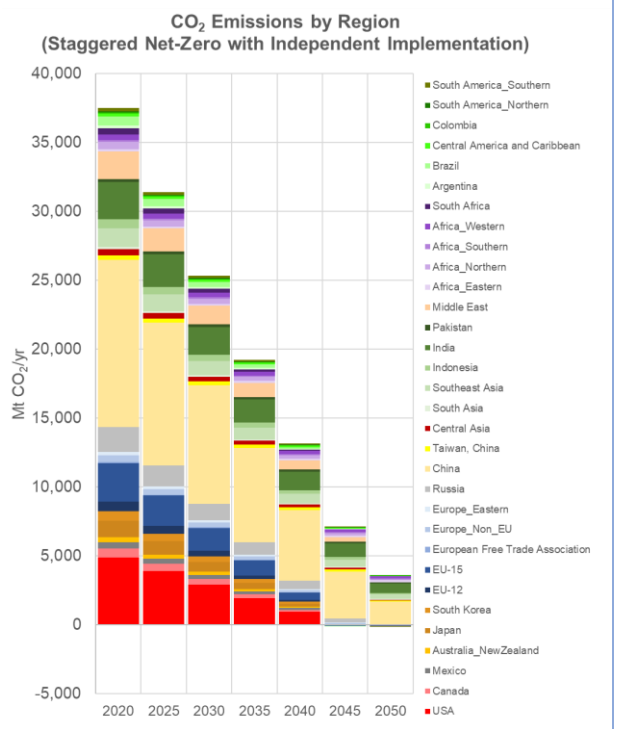
While the world in 2050 will be substantially different from the world today, it is hard to imagine that countries with relatively lower per capita income would be buying emissions mitigation credits from countries with relatively higher per capita income. This is why an assumption for all countries to achieve net-zero at the same time creates significant equity and feasibility issues.

To address this inequity, we developed scenarios to stagger net-zero dates for countries based on their per capita income, as described in Table 3. In this case, regions with existing net-zero goals reduce their emissions to zero or slightly below zero by 2050, and emissions from other regions also decline rapidly between 2020 and 2050.

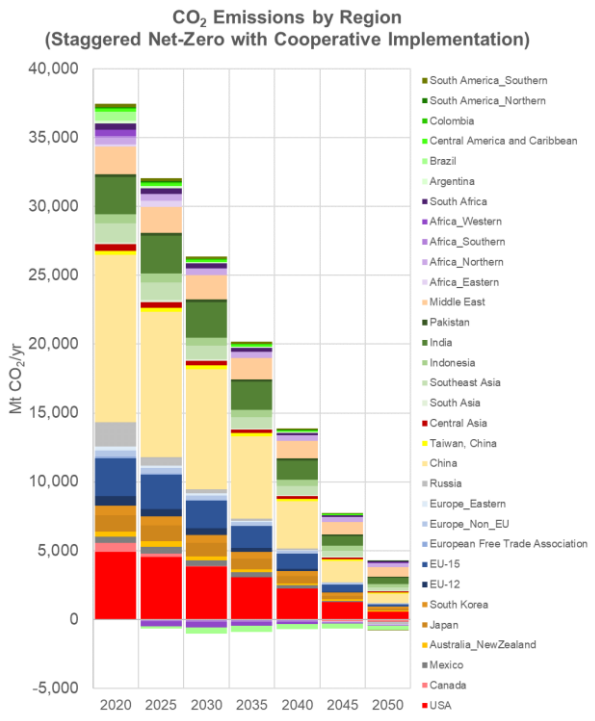
Under the Staggered Net-Zero scenarios global CO_2 emissions in 2050 reach approximately 3.5 $GtCO_2$, a more than 90% emissions reduction from the current level (Figure 3, Panels a and b). To achieve this level of emissions reduction, all regions need to significantly increase their mitigation efforts, and as a result abatement costs rise rapidly. When regions implement their net-zero targets independently, a wide range of marginal costs persists across regions (Figure 3, Panel c), which indicates potential gains to trade under Article 6.

Figure 3: Regional emissions and carbon prices in Staggered Net-Zero scenarios

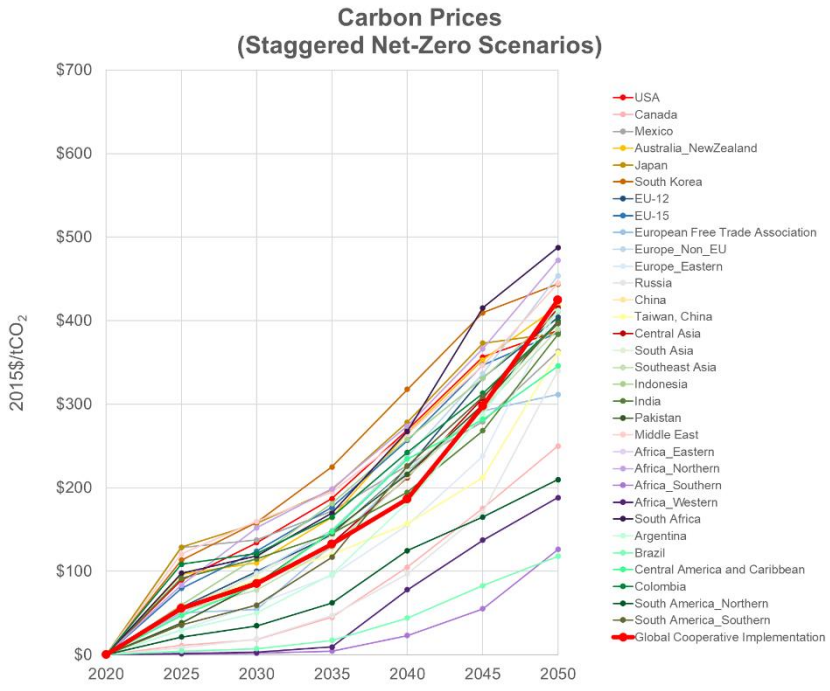
Panel a. Independent implementation of Staggered Net-Zero CO_2 emission pathways



Panel b. Cooperative implementation of Staggered Net-Zero CO_2 emission pathways



Panel c. Marginal costs of Staggered Net-Zero CO_2 emission pathways with independent and cooperative implementation



The physical ITMO transfers, generated when the Staggered Net-Zero scenario is implemented cooperatively, are similar in scale to the ITMO transfers under the Universal Net-Zero scenario with cooperative implementation in 2030: around 3.5 $GtCO_2$. However, in 2050 the physical trade volumes are 40% higher, around 2.4 $GtCO_2$ in Staggered Net-Zero scenario with cooperative implementation, compared to 1.7 $GtCO_2$ in the Universal Net-Zero scenario with cooperative implementation. This is because, in the Staggered Net-Zero scenario, there is greater variation in regional emissions, allowing for more flexibility through trade.

In both the Staggered Net-Zero and Universal Net-Zero scenarios, carbon prices rise sharply with time. In the Staggered Net-Zero scenario with cooperative implementation the global carbon price increases from $\$85/tCO_2$ in 2030 to $\$420/tCO_2$ in 2050. The cooperative carbon price is lower in the Staggered Net-Zero scenario than in the Universal Net-Zero scenario since the Staggered Net-Zero targets imply higher emissions in each period under the Staggered Net-Zero compared to the Universal Net-Zero scenario.

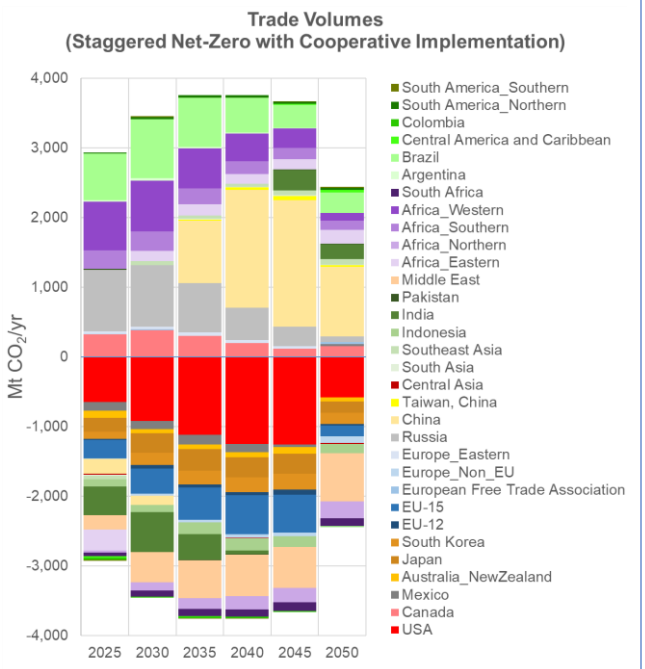
The increasing carbon price offsets the decreasing transfers of physical emissions mitigation as emissions decline toward zero. In the Staggered Net-Zero scenario with cooperative implementation financial transfers grow from $300 billion per year in 2030 to $1 trillion per year in 2050.

The delayed net-zero target dates in the Staggered Net-Zero scenarios also substantially change the buyer and seller dynamics in the lead-up to 2050. For example, China and India shift from buying to selling and the US becomes a large buyer to achieve its increased ambition. Latin America and the Caribbean become sellers along with most of Africa. On the other hand, Canadian, Russian, and Brazilian sales are greatly diminished before 2050 (Figure 4).

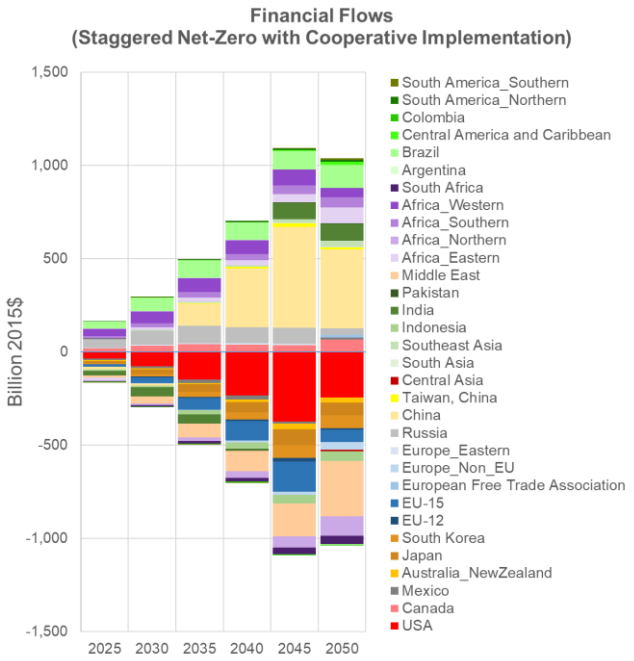
Modelling the Staggered Net-Zero scenario with cooperative implementation helps illustrate the potential impact of net-zero commitments on buyer-seller dynamics, the changes in financial flows to key regions, and the potential cooperative carbon prices in a world with differentiated targets. Most notably, we see growth in investment flows from developed regions to developing regions (for example, China, India, and most of Southeast Asia). This shift in financial flows can create ancillary benefits in developing regions, improving air quality, accelerating renewable energy deployment, and facilitating energy infrastructure investment. In addition, this shift can encourage technology innovation in developing countries and help enhance their ambition in the long run.

Figure 4: Staggered Net-Zero potential Article 6 market: physical and financial transfers

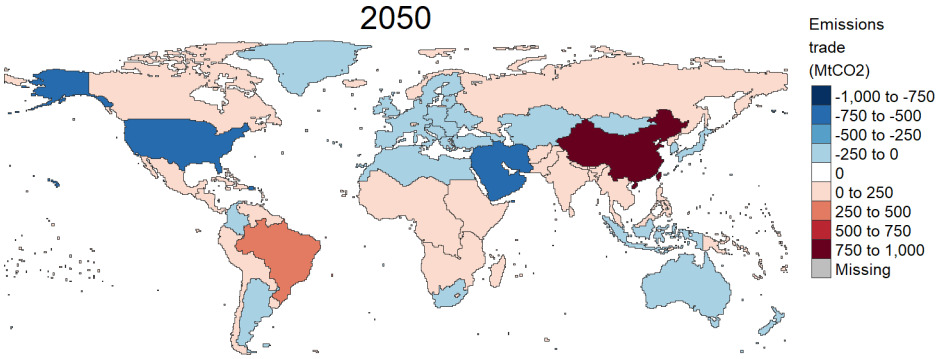
Panel a: Emissions transfers by year
(Seller >0; Buyer <0)



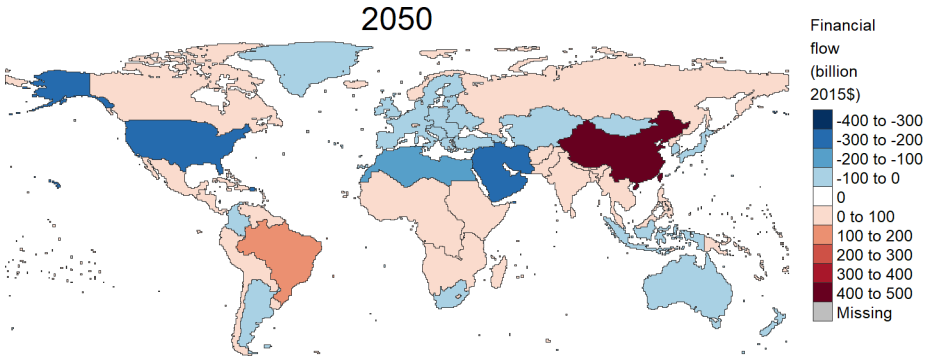
Panel b: Financial transfers by year
(Seller >0; Buyer <0)



Panel c. Geographic distribution of physical emissions changes in 2050 in Staggered Net-Zero scenario with cooperative implementation (Potential buyers and sellers)



Panel d. Geographic distribution of financial flows in 2050 in Staggered Net-Zero scenario with cooperative implementation (Potential buyers and sellers)



Implications For Nature-Based Solutions And Carbon Removals

In all net-zero scenarios, we find that Article 6 buyer-seller dynamics are heavily influenced by nature-based solutions and carbon sequestration. Nature-based solutions include decreased deforestation, increased afforestation and reforestation. Nature-based solutions are an important means of emissions mitigation in all four scenarios explored in this paper. However, their role waxes and wanes across scenarios and time. Forests ultimately grow to maturity and become an unchanging stock of carbon. At maturity, forests can no longer provide net-carbon uptake. If managed sustainably, bioenergy crops can remove carbon from the atmosphere relatively indefinitely, offsetting potential carbon emissions from fossil fuels. Furthermore, if CO_2 emissions from the combustion of bioenergy are captured and permanently stored, then terrestrial systems can deliver negative emissions. Therefore, decreased deforestation and increased afforestation and reforestation are relatively low-cost, near-term emissions mitigation strategies.

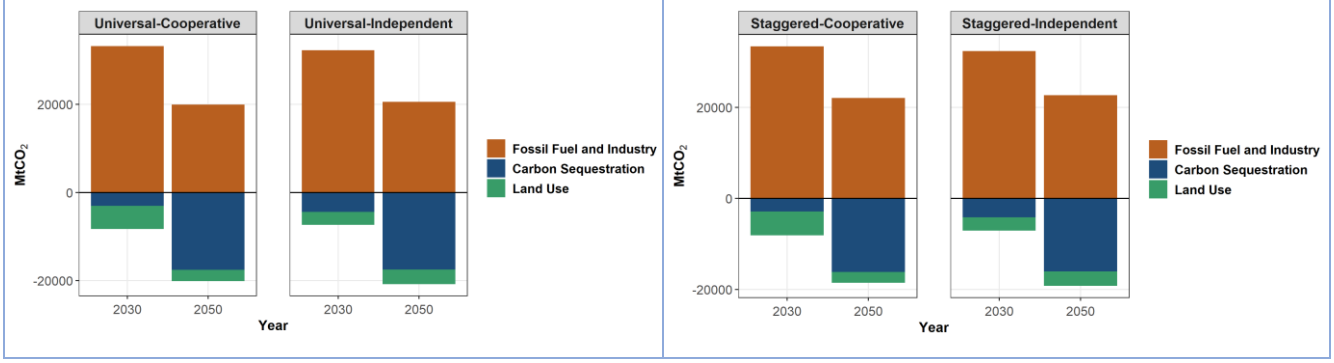
Carbon markets provide incentives for Parties with large land-use potential to utilize nature-based solutions to generate credits to be sold internationally. These credits can be purchased by countries with higher abatement costs. Our cooperative net-zero scenarios exhibit significant expansion in the use of land sinks to mitigate carbon emissions, especially in the near term. In 2030, in the Universal Net-Zero scenarios land-use emissions change from -2.9 $GtCO_2$ per year under independent implementation to -5.3 $GtCO_2$ per year under cooperative implementation; the same magnitude of change is also observed in the Staggered Net-Zero scenarios. As a result, global fossil fuel and industrial emissions slightly increase and the deployment of carbon capture and storage (CCS) technologies slightly decreases in 2030 with cooperative implementation under Article 6 (Figure 5).

As mentioned above, the role of nature-based solutions gradually declines over time. At the same time, carbon removal technologies become increasingly important. In 2050, with cooperative implementation of net-zero targets, there would be more CCS deployment (including bioenergy with CCS) and less CO_2 emissions from fossil fuel and industrial sources, as shown in Figure 5.

Figure 5. Global CO_2 emissions and carbon sequestration in 2030 and 2050

Panel a. Global CO_2 emissions and carbon sequestration in the Universal Net-Zero scenarios

Panel b. Global CO_2 emissions and carbon sequestration in the Staggered Net-Zero scenarios



CONCLUSION

Cooperative implementation of net-zero targets holds the potential to allow Parties to achieve net-zero targets with greater economic efficiency. The magnitude, value, and patterns of emissions mitigation transactions in reaching a global net-zero target are dynamic and depend on several factors, such as the use of carbon dioxide removal technologies and the timing of reaching net-zero in each region. Nature-based solutions play an important role in emissions trading and achieving net-zero targets. Regions with large land endowments tend to be sellers, regardless of the timing of reaching net-zero emissions. Cooperative implementation of net-zero targets can significantly increase afforestation and reforestation and decrease deforestation in the scenarios examined in this paper, especially in earlier years. As a forest grows and matures, its contribution to nature-based emissions mitigation gradually diminishes; at the same time, carbon removal technologies become increasingly important.

As countries' emissions get closer to zero, emissions transfers in cooperative implementation scenarios become smaller, but each transaction is more valuable, leading to growth in financial flows. The size of the global carbon market is around $1 trillion per year in 2050, indicating significant redistribution of capital investment across regions. This has important implications for both mitigation and sustainable development. Cooperative implementation of net-zero targets could shift capital investment toward selling regions, affect local air quality and other sustainability metrics for both buyers and sellers, and shift costs and potential incentives for technological innovation.

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