Estimating the Power of International Carbon Markets to Increase Global Climate Ambition

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Abstract

By helping achieve emissions targets more inexpensively than expected, emissions trading systems can lower political resistance to more ambitious targets, enabling deeper and faster cuts in climate pollution over time. Using a dynamic global partial-equilibrium carbon market model, we quantify cost savings under scenarios for emissions trading both within and across countries, as well as the corresponding potential to escalate reductions if those cost savings were translated into greater mitigation. We examine the potential for emissions trading to allocate reductions cost-effectively over time and also assess the possible impact of including emissions reductions from avoided deforestation within international carbon markets. Finally, given that substantial political and implementation hurdles remain to full international trading, we evaluate scenarios in which future policy developments are uncertain as well as scenarios in which only partial subsets of the nations participate in international market cooperation. We find the global use of carbon markets could allow the world to nearly double climate ambition relative to current Paris pledges (NDCs) over 2020–2035, without increasing total global costs compared to a base case without international markets. Since avoided deforestation is such a large source of low-cost mitigation, linking reduced deforestation to an international carbon market is a key driver of the potential ambition gains. Significant ambition gains remain under partial coverage scenarios with less than half of global emissions linked via markets, based on a "heat map" analysis of countries' market readiness, and scenarios with policy uncertainty that causes market actors to delay mitigation.

1. Introduction

It is widely understood that expanding the scope of carbon markets both subnationally and internationally can lower the costs of achieving global emissions targets, by enabling businesses and individuals to tap the lowest cost sources of emissions reduction available (e.g. Nordhaus and Boyer 1999; Böhringer 2000; Fujimori et al. 2016; Hof et al. 2017; Ranson and Stavins 2013; Doda and Taschini 2017; Liu et al. 2019; Parry et al. 2018). What is less commonly emphasized—but potentially more important for the health of the climate and the future of the planet over the longer term—is how cost savings from emissions trading could translate into deeper cuts in greenhouse gases. By lowering total abatement costs and creating economic opportunities for firms and governments to benefit from climate policies, carbon markets offer the potential to boost climate ambition.

Although climate goals are typically established on the basis of emissions targets, rather than expenditure targets *per se*, implementation costs are a key consideration for industry and other stakeholders that hold political sway. Moreover, climate policies are established iteratively over time. Carbon markets thus have the potential to lower the political resistance to setting more ambitious targets in the future by spurring innovation and helping to achieve initial targets more easily and at lower cost than expected. This conjecture is consistent with practical experience. Under every Emissions Trading System (ETS) to date, emissions have fallen faster and at lower cost than expected (Haites 2018). While multiple factors have contributed to this phenomenon, periods of low prices and large "surpluses" (banks) of allowances have been generally followed by decisions to adopt more ambitious long-term targets under the European Union Emissions Trading System (EU ETS), the Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade program. This contrasts with the typical experience with carbon taxes which are usually low but rarely adjusted (Haites 2018).

While a number of studies have analyzed countries' current pledges under the Paris Agreement (their Nationally Determined Contributions; NDCs) and found that, if successfully implemented, they would significantly reduce global emissions below a 2030 baseline, a significant ambition gap between current pledges and a pathway consistent with 2°C temperature rise remains (Akimoto et al. 2017; Kaya et al. 2016; Kitous and Keramidas 2015; Liu et al. 2019; Rogelj et al. 2016; Vandyck et al. 2016). Even if NDC implementation would significantly reduce the chances of global temperature increases greater than 4°C, their chances of stabilizing temperatures below 2°C are estimated to remain below 10% if current ambition levels persist (Fawcett et al. 2015). The recent Intergovernmental Panel on Climate Change (IPCC) (2018) report on the benefits of limiting global temperature rise to 1.5°C versus 2.0°C starkly reveals the urgency of increasing global climate ambition. Our analysis explores the potential contribution of alternative scenarios for international emissions trading to help close the "emissions gap" to increase the chances of stabilizing temperatures below 2ºC (e.g. UNEP 2017).

In this paper, we apply a partial-equilibrium carbon market model to analyze the potential global cost savings under a set of scenarios for the development of global and regional linked carbon markets over 2020–2035. Total cost reductions are evaluated relative to a base case of current policies and measures under which the European Union (EU) and other individual nations achieve their current NDCs in a close to cost-effective manner (similar to what would be achieved under a comprehensive domestic emissions trading system). We then examine the potential to "reinvest" the corresponding savings into raising global mitigation ambition, while breaking even on overall costs.

Other studies have estimated the potential cost savings from international carbon market linkages under the Paris Agreement (World Bank, Ecofys and Vivid Economics 2016; Fujimori et al. 2016; Rose et al. 2018; Hof et al. 2017). Our study differs in several respects from these past studies. First, our study focuses on the potential cost savings to contribute to greater ambition, examining the cumulative period from 2020 to 2035.[1] Second, in order to more comprehensively evaluate the potential of expanding carbon markets to contribute to greater ambition, we consider the potential of the energy (including transport), industry, and avoided deforestation and the six major greenhouse gases (carbon dioxide, methane, nitrous oxide, SF6, HFC and PFC) to contribute to emissions reductions. We thus expand the scope of analysis beyond just fossil carbon emissions and energy, which have been the focus of most other analyses, with the notable exception of Fujimori et al. (2016). Other studies, such as Hof et al. (2017), have included land use emissions in baseline reference scenarios, as well as NDC emissions targets, but do not explicitly model the cost of reducing emissions from the land sector. Our analysis is the first to examine the major role of avoiding tropical deforestation (i.e. Reducing Emissions from Tropical Deforestation and forest Degradation; REDD+) to contribute to cost savings via international market linkages under the Paris Agreement.

Third, we consider not only greater "where" flexibility, by adding additional sectors and gases, but additional "when" flexibility as well. Our analysis is the first to evaluate the benefits of linking markets under the Paris Agreement with an explicitly dynamic model, taking into account the possibility to carry forward ("bank") emissions permits over the 2020–2035 period to minimize costs in an intertemporal context according to expectations of future emissions limits. Such intertemporal flexibility is a key attribute of the cost-effectiveness of emissions trading systems (PMR-ICAP 2016; Schmalensee and Stavins 2017). While many parties currently do not consider banking to be an acceptable arrangement for meeting current NDCs, the power of markets to drive earlier and faster emissions reductions via banking could play a critical role in facilitating the ratcheting down of emissions targets over time.

Finally, we analyze an idealized global market scenario as a benchmark, but also evaluate more limited carbon market scenarios with constrained geographic and sectoral scope and where market actors do not have perfect foresight. We base our scenarios on a "heat map" analysis that identifies which countries are most prepared and inclined to implement carbon markets in the near term. As part of our intertemporal optimization, we also examine the impact of limited market certainty over future carbon market developments, which serves to delay mitigation and hamper cost-effectiveness. By considering these real-world constraints, we compare the idealized market case with potentially more realistic carbon market scenarios based on limited geographic coverage and ongoing policy uncertainty.

[1] The World Bank, Ecofys, and Vivid Economics (2016) study also estimated the additional reductions that could be secured with the cost savings from linkage, albeit for only one year (2030), rather than cumulatively over time.

Assuming well-designed policies with accurate accounting rules and clear policy signals, we find the global use of carbon markets could allow the world to nearly double climate ambition, measured in terms of cumulative global mitigation over 2020–2035, in comparison to a pathway based on current Paris Agreement pledges (NDCs). Significant ambition gains remain under scenarios with less than half of global emissions linked via markets as well as with policy uncertainty that leads to delayed mitigation relative to the least-cost scenarios. Because avoided deforestation is a large source of low-cost mitigation, linking reduced deforestation to carbon markets is a major estimated driver of the potential ambition gains.

Section 2 below describes our methods, covering the modeling framework, associated assumptions, data and scenario construction. Section 3 presents our results. Section 4 provides discussion and we then conclude with a discussion of policy implications.

2. Methods

We develop and apply a partial equilibrium model of potential future carbon markets to examine emissions trends and abatement opportunities from 2020 through 2035 across the 28 EU countries and 34 other countries/regions, encompassing the energy (including transportation) and industry sectors, as well as avoided tropical deforestation. The model balances demand and supply for emissions abatement across multiple sources and sectors in a dynamic framework. The market demand for emissions reductions derives from the annual greenhouse gas (GHG) emissions (considering carbon dioxide, methane, nitrous oxide, SF6, HFC and PFC) under an estimated emissions trajectory, assumed to establish a "cap" for each country (and sector within each country) consistent with meeting the NDC. These trajectories determine each country and subsector's yearly and cumulative need for abatement under its NDC relative to a business-as-usual (BAU) trajectory from 2020 through 2035. The demand for abatement in each year (exclusive of banking, as discussed below) is the aggregation of these abatement requirements across the participating countries (and sectors within them), as well as from the international aviation sector based on commitments under the International Civil Aviation Organization (ICAO). In turn, the supply of abatement is an aggregation of the estimated marginal abatement costs (MACs) for each year from the different sectors and geographic regions included in a particular market scenario.

In the case of international markets, demand and supply are aggregated across the participating regions and all countries (including international aviation) are assumed to meet their international mitigation commitments. Only surplus emissions reductions over and beyond what is needed to achieve an NDC can be exported. This is consistent with an international market scenario in which there is fully transparent accounting, with appropriate "corresponding adjustments" to ensure that emissions reductions traded internationally only count towards one international commitment, either of a country or of ICAO.

The model solves for an inter-temporal equilibrium under alternative hypothetical markets for emissions units in in which two conditions are met in every year: (1) the market clears (i.e., the quantity of emissions reductions demanded at the current price, including banked tons, equals the quantity supplied at that price); and (2) the present value of the international unit price is equal in every period (i.e., the price rises at the market rate of interest). A real interest rate of 5% was assumed as the starting point for this analysis, but additional analyses were conducted to examine the sensitivity to this assumption. Furthermore, the model is solved using a mid-term 2035 time-horizon to capture in a limited fashion the impact that future compliance periods might have in the near-term, based on the degree of market foresight.

Table 1. Key assumptions for modelled scenarios

- Mitigation potentials include energy (including transport) and industry sectors, as well as avoided tropical deforestation, and the six major greenhouse gases (carbon dioxide, methane, nitrous oxide, SF6, HFC and PFC).
- Nations achieve their NDC emissions reductions targets based on an annual trajectory that establishes an absolute limit on emissions for each sector; similarly international aviation meets its international mitigation commitments under ICAO.
- Trading occurs based on a least-cost approach across participating nations and sectors based on marginal abatement cost curves.
- Full accounting transparency is in place for all trades of emissions reductions such that all traded units represent real mitigation and there is no double counting of reductions towards more than one international commitment.
- Banking (carry forward) of emissions units (based on emissions below the annualized target trajectory of NDCs) is permitted and occurs to the point where banked units appreciate at the rate of interest (plus a risk premium in the case of policy uncertainty).

Our analysis is grounded in the emissions projections and estimated marginal abatement cost curves from the Prospective Outlook on Long-term Energy Systems (POLES) model, a global energy-economic simulation model widely used by the European Commission, which examines the energy, transport and industry sectors, including CO_2 as well as non-CO_2 gases (e.g. Kitous et al. 2016). These data were obtained from Enerdata, which updates and commercializes these estimates. We supplemented the data from POLES with estimates for the costs of REDD+, based on the global land-use modeling cluster of the International Institute of Applied Systems Analysis (IIASA), as described in Gusti, Khabarov and Forsell (2015). Emissions from the global agricultural sector were added into the estimate of global BAU emissions based on projections from the Food and Agriculture Organization (FAO) of the United Nations,[2] but mitigation potential from agriculture was not included in this analysis.

We explore the impact of using international markets to meet NDC goals by comparing compliance costs under a range of market scenarios relative to a "base case" where all the nations in a particular market scenario meet their current NDCs through 2035 through domestic action alone. For each scenario, we calculate the amount of emissions reductions that are economically feasible without increasing costs relative to a base case of sector-specific strategies, without the use of trading to take advantage of cost differentials among either countries or sectors.

For the base case, we first estimate total global costs for meeting countries' Paris Agreement pledges given their existing use of markets and estimates of current sectoral plans and policies. Next, we quantify the cost savings under different scenarios for market coverage and integration,

[2] Data available at: http://www.fao.org/faostat/en/#data/GT/visualize

where market actors can lower their costs of meeting emissions limits by taking advantage of cost differentials across sectors, countries, and over time, both within and across countries. We consider a set of idealized global market coverage scenarios where market actors have perfect information and estimate the potential cost savings and associated potential to increase climate ambition relative to the base case. We then compare those estimates to cases of more limited market participation across countries and where market actors have incomplete market information. All scenarios are assessed with and without the inclusion of emission reductions from tropical forests (known as REDD+). Our assumptions and scenarios are further detailed below.

Estimating NDC Ambition Targets. The starting point of our analysis is a projection of BAU emissions and an estimate of current mitigation ambition under each nation's current NDC pledges under the Paris Agreement. This follows the "Enerblue" scenario from Enerdata, which reflects the current NDC pledges under Paris Agreement. For the forestry and land-use sector, we follow the estimated BAU projections for each country developed by IIASA. We then estimate the contribution of the sector to each country's NDC based on the country and global estimates from Forsell et al. (2016). Demand from the implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) under ICAO was incorporated based on estimates from an interactive tool developed by the Environmental Defense Fund (EDF) that estimates overall coverage and demand from CORSIA, according to current levels of participation.[3]

The black line in Figure 1 below shows global BAU emissions across all sectors, while the blue line shows emissions if countries achieve the current level of mitigation ambition from the NDCs across all sectors. We estimate that currently pledged efforts entail a cumulative global reduction of roughly 77 billion tons of CO_2e relative to BAU from 2020 through 2035, with over a quarter (27%) of these reductions estimated to come from efforts pledged from the land sector. This scenario roughly stabilizes global emissions at current levels, beginning to "turn the corner" on global emissions in 2024 and reducing emissions to just under 2017 levels by 2035.

While beginning to bend absolute emissions downward, this trajectory achieves less than a quarter of the reductions needed for the pathway shown in green, consistent with keeping global temperatures from rising more than 2°C (based on Enerdata's "Energreen" scenario). An alternative "intermediate ambition" scenario (the dashed black line), gets about three-quarters of the reductions needed for the trajectory limiting warming to no more than 2°C. This scenario steps down to the green line in five-year intervals, as might occur via the "global stocktakes" with an expected ratcheting up of NDC ambition, as envisioned in the Paris Agreement. The required reductions under the ambition levels of the NDC, "intermediate," and "2°C" scenarios are 77, 185, and 249 billion tons of CO_2e, respectively.

[3] The tool is available at: https://www.edf.org/climate/icaos-market-based-measure

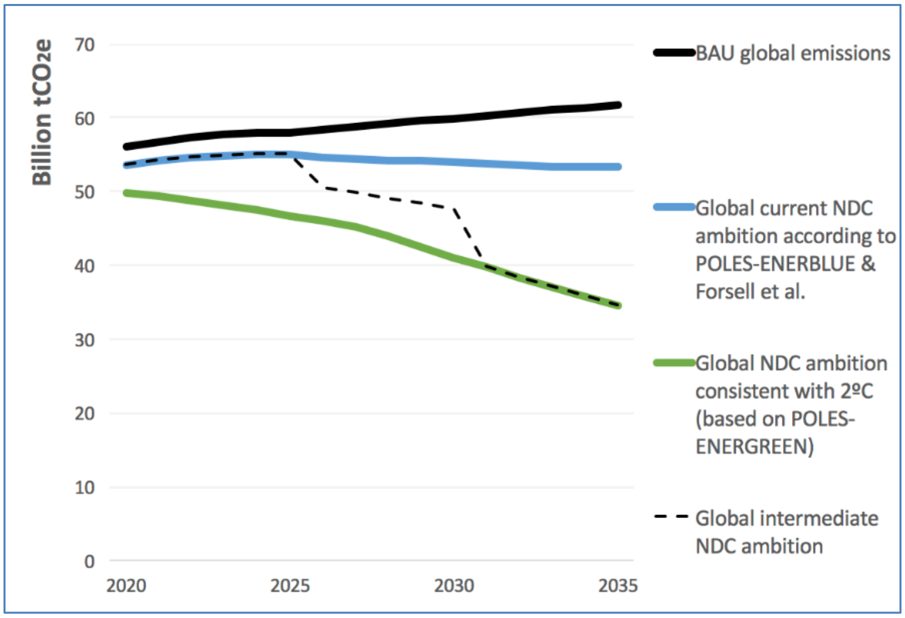

Figure 1. Global emissions under business-as-usual (BAU), Paris Agreement pledges, and ambition consistent with a 2°C limit.

Compliance Cost Base Case. In order to establish a point of comparison for our trading scenarios, we estimate the costs of meeting current NDCs under a "base case" scenario of sector-by-sector country policies. This case is limited to existing use of markets (e.g., the EU ETS) and a projected mix of sector-by-sector polices and measures, based on current policy proposals for each country and assumptions of conversion over time across. This includes annual projections of energy efficiency requirements, renewable energy mandates, and transport-, industry-, and land-use-specific regulations varying across each country.[4]

Domestic Markets Scenario. We then consider the case where each country can meet the cumulative reductions required by their NDCs at least-cost domestically via a carbon market or other carbon pricing approach that achieves their target at least cost. Our model ensures marginal abatement costs are equalized across sectors and also that market actors can optimally select the timing of their emissions reductions to achieve cumulative reductions at least-cost, assuming a discount rate of 5% to account for the cost of capital. This captures the ability of market actors to "bank" emissions units and save them for use in later periods when caps may be tighter and corresponding mitigation costs higher. This type of "when" flexibility is typically allowed in carbon markets and generally important for enabling cost effectiveness.

Full Global Markets Scenarios, with and without REDD+. We then analyze costs under a fully global market where market actors can trade across all countries and regions, as well as cost-effectively select the timing of mitigation over time. To isolate the potential importance of including market-based approaches to REDD+, which has been left out of compliance carbon markets to date, we consider a case where market actors can use emissions reductions from land-

[4] This scenario is based on Enerdata's "Enerblue" scenario for the energy, transport and industry sectors complemented with our own estimates for the forest and land-use sectors calibrated to match global estimates from IIASA.

use for their own NDCs but can only trade emissions internationally across the energy, transport, and industry sectors. We then examine the added benefit of allowing further trading of reductions from REDD+.

Robustness test. We then test the robustness of cost saving estimates under the full global market scenario using a sensitivity analysis in which market actors are uncertain about the future and therefore delay emissions reductions relative to the least-cost scenario. Regulatory and policy uncertainty will tend to induce market actors to adopt a wait-and-see attitude to mitigation investments, which will depress near-term market demand. We model such a case based on the inclusion of a risk premium, which gradually declines over time but lowers the benefit of banking emissions reductions for use in future periods compared to the case with full market certainty. Following the scenario of Golub, Lubowski, Piris-Cabezas (2017, work of the author), we assume the risk premium falls at five-year intervals, to reflect greater information that increases certainty over future policy. In particular, we assume an interest or "discount" rate, starting at 20% in 2020, falling to 15% in 2025 and 10% in 2030. We solve the model iteratively over 2020–2035, 2025–2035 and 2030–2035, carrying over the amount of emissions reductions banked for future compliance periods from the previous runs.

Partial Markets Coverage. We consider three cases for partial market development, building from the "heat map" analysis discussed in Section 2 below, ranking countries by their societal readiness and strategic value with respect to carbon market pricing advocacy. Notably, the heat map analysis ranks countries based on their readiness and importance in terms of emissions (both directly and via links to other important countries), rather than in terms of their ability to maximize gains from trade in a market system. All countries continue to be engaged in meeting their NDCs, but partial carbon market development only enables certain countries to take advantage of potential cost reductions. All scenarios also include implementation of CORSIA under ICAO based on current levels of participation. Given the pivotal role of REDD+, for each partial markets scenario, we also model scenarios where the limited global markets open up additional REDD+ from the rest of the world.[5]

Global 'Heat Map' Scenario. This scenario involves a global market based on the economy-wide coverage of the EU, United States, and China and the next 25 highest-ranking countries from our heat map analysis (see Appendix). This results in an estimated 79% coverage of current global emissions. This percentage declines slightly over time as the emissions from some of the countries not included in the heat map are growing relative fast, including in terms of emissions from deforestation.

Asia-Pacific Scenario. This scenario envisions the regional evolution of a carbon market in Asia (as could emerge around China and South Korea), bringing in the highest-ranking countries from the heat map analysis in the Asia-Pacific region, as well as linking with Kazakhstan (but excluding South Asia). This includes economy-wide coverage of China, Thailand, Vietnam, Indonesia, Malaysia, South Korea, Japan, Singapore, Philippines, Kazakhstan, Australia, and New Zealand. This regional market development is assumed to catalyze coverage of all sectors

[5] In the Asia-Pacific case, described below, we consider additional REDD+ net of NDC from Brazil, Mexico, Colombia, Peru and 50% of the rest of the world. In the Americas case, described below, we consider additional REDD+ net of NDC from Indonesia, Thailand and Malaysia and 50% of the rest of the world.

in China. The scenario also includes participation from the EU as well as the U.S., but with their coverage limited to the power and industrial sectors (as per the current coverage of the EU ETS). This scenario results in estimated coverage of 42% of current emissions.

Americas Scenario. This scenario explores the potential impact of the Western Climate Initiative and the Pacific Alliance leading to a greater coverage throughout the Americas, bringing in all the highest-ranking countries from the heat map analysis across the Americas, including both the United States and Brazil. This scenario includes 100% coverage of the U.S., Canada, Mexico, Colombia, Peru, Chile, Argentina, and Brazil. The scenario also includes participation from the EU as well as China, but as above, with their coverage limited to the power and industrial sectors, as per the current coverage of the EU ETS. This scenario results in an estimated coverage of about 36% of current global emissions. These three scenarios are represented in the three world maps in Figures 2a, 2b and 2c below.

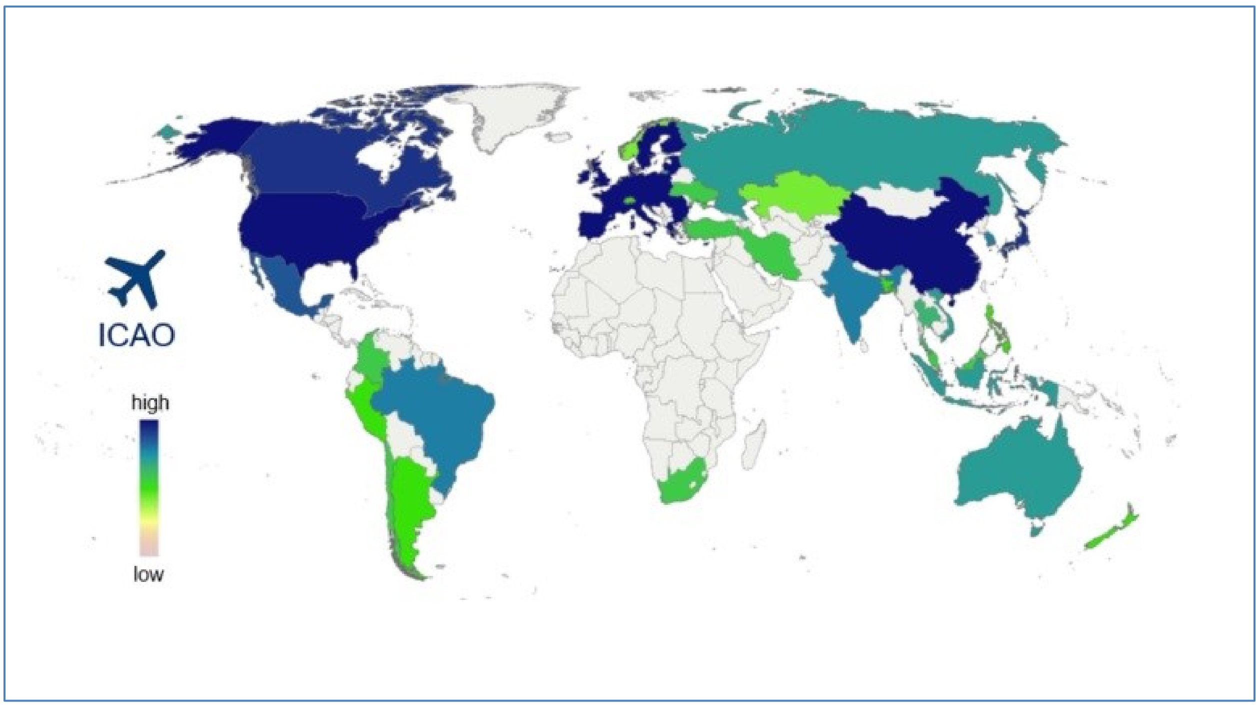

Figure 2a: Global 'Heat Map' Market Scenario

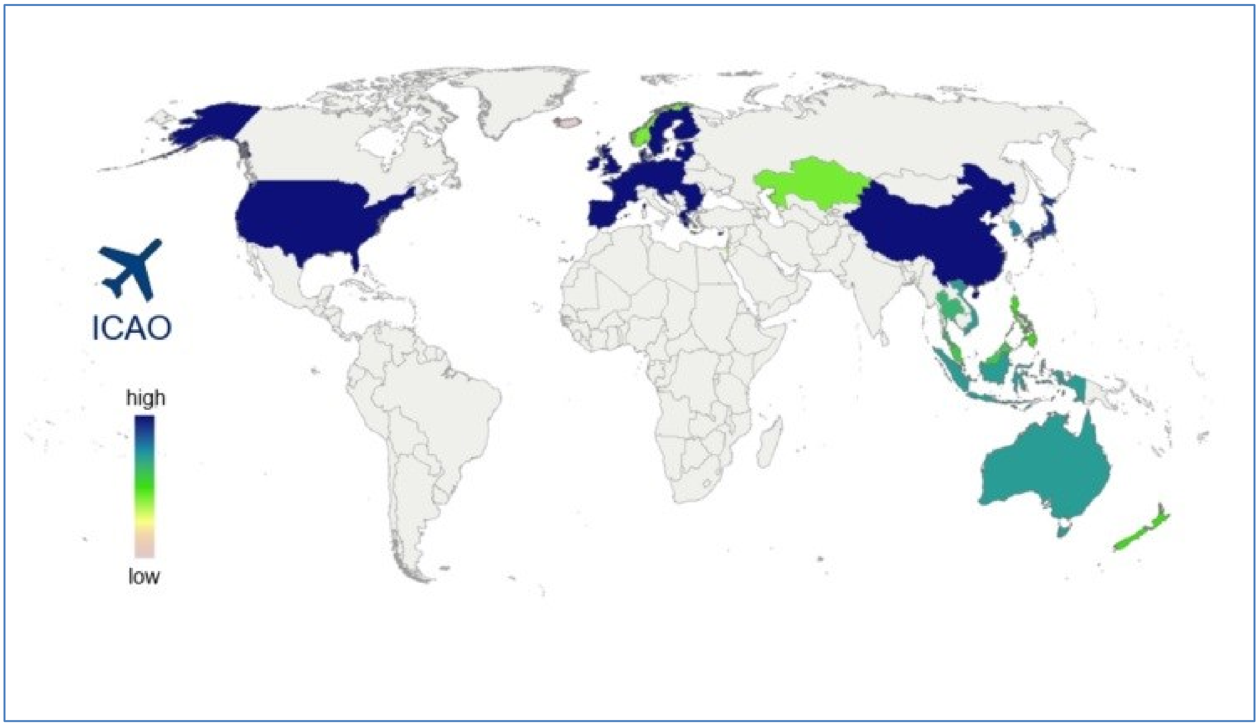

Figure 2b: Asia-Pacific Market Scenario

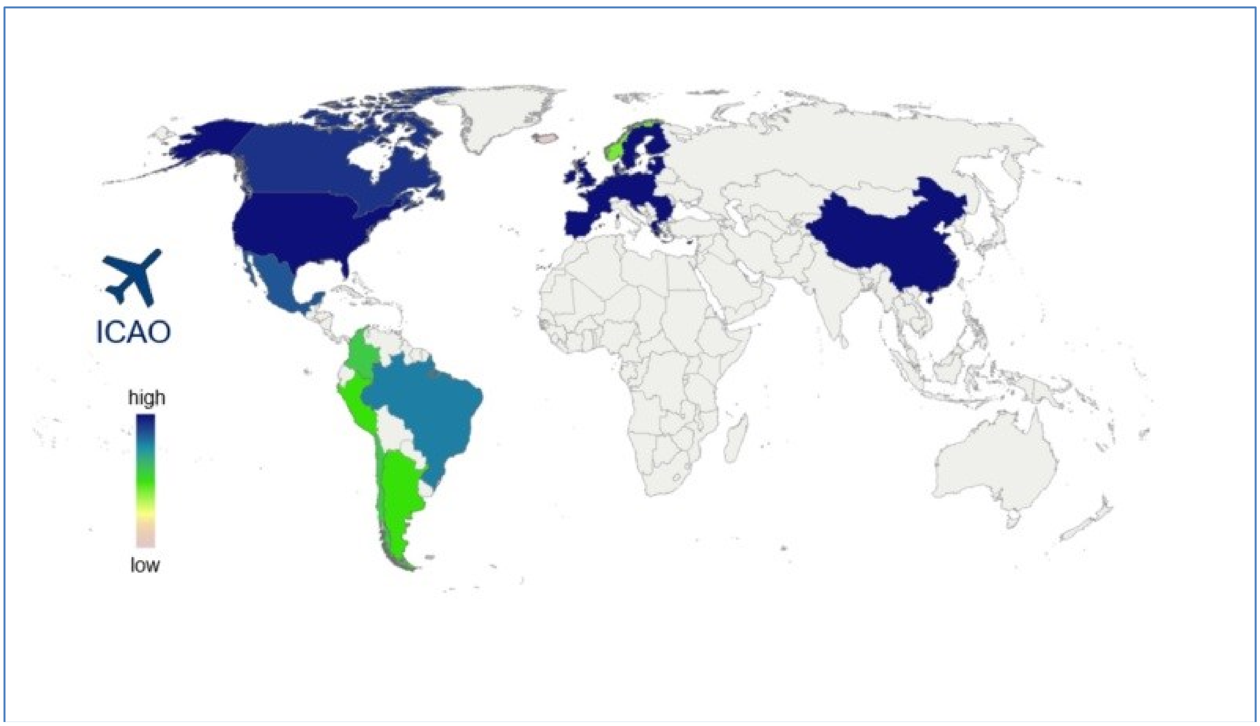

Figure 2c: Americas Market Scenario

Note: scenarios are based on top-ranked countries from 'Heat map' analysis discussed in Appendix A, with colors based on the Carbon Markets Societal Readiness and Strategic Priority score for each country from lowest (pink) to highest (dark blue). All scenarios include the international aviation market under CORSIA. Coverage of EU is limited to the power and industrial sectors in the Asia-Pacific and Americas scenarios. Coverage of the US and China is *limited to the power and industrial sectors in the Asia-Pacific and Americas scenarios, respectively. Unless otherwise noted, coverage is economy-wide.*

3. Results

Across all scenarios, our results indicate significant cost savings associated with market linkages, with global trading including REDD+ resulting in the largest potential cost savings. Reinvesting such cost savings into further emissions reductions yields potential increases in global ambition ranging from 18–70 billion tons CO_2e of cumulative additional mitigation over 2020–2035, producing a 24% to 91% increase in ambition, as described below.[6]

Base Case. Our estimate of the global cost required to meet current NDC ambition without carbon trading (2020–2035) had an estimated global price tag of US $520 billion in current dollar terms (based on a 5% interest rate) or about 0.67% of global gross domestic product (GDP) in 2017.

Domestic Markets. Our estimates of the total cost savings from implementing domestic carbon markets in all nations yield 4% reduction in total mitigation costs relative to the base case. These cost savings are limited given that mitigation ambition is relatively low and the NDC base case scenario already includes contributions across all sectors, including a large contribution from the land-use sector and cost-effective achievement of NDCs within, if not across, each of the modelled sectors. Given these assumptions, the base case is therefore already akin to the result achieved under use of carbon pricing. If we were to develop a model with greater granularity for non-market policies within each country and sector, the cost savings from implementing domestic markets would likely be substantially larger.

*Full Global Markets Scenarios, with and without REDD***+.** Our scenario modelling a fully global carbon market that channels the same total global resources in the most cost-effective fashion lowers total costs by an estimated 62%—from over half a trillion to $197 billion current dollar terms—in the case of a global market for energy, transport, and industry sectors (but where REDD+ is restricted to domestic use only). Costs fall an additional 43% from $197 to $111 billion, such that overall cost savings are 79% relative to the base case, when the global market al.so includes REDD+. These costs savings occur because there is a large spread in ambition across countries (and in some cases across sectors at the country level), resulting in lack of cost-effectiveness globally. Figure 3 shows the wide spread in modelled carbon prices under the base case.

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[6] The lower bound corresponds to a scenario with partial coverage and without REDD+ (Asia-Pacific scenario). The upper bound corresponds to the scenario with global coverage with REDD+.

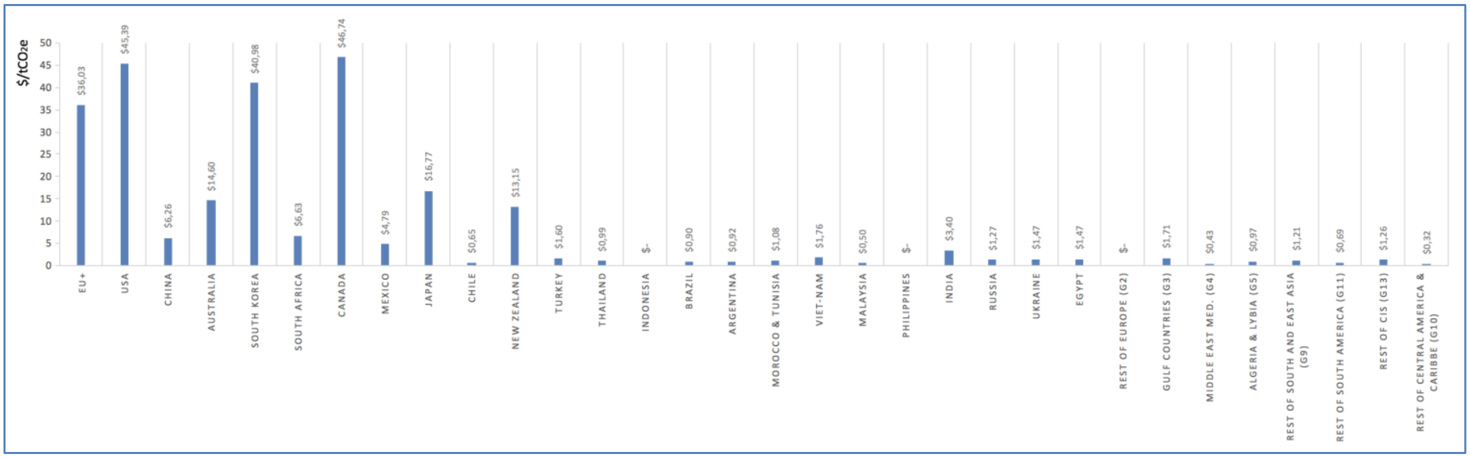

Figure 3. Spread in ambition across countries, as shown by estimated carbon price in 2020, assuming domestic trading across energy and industry. ($/t$CO_2$e)

Robustness test. Modelling information uncertainty with a “risk premium” increases costs by 18% to $131 billion (in current dollar terms) in the case of a full global market with REDD+. Even so, this still achieves 95% of the cost savings as under the case of full certainty and thus enabling equivalent increases in the level of mitigation ambition.

Greater climate ambition. Translating the prospective costs savings into the potential for greater climate ambition, while still “breaking even” on costs relative to the base case, yields the total global mitigation levels shown in Figure 4. A global market without and with REDD+, respectively, offers the opportunity to raise total cumulative reductions over 2020–2035 from 77 to 109 and 147 billion tons of CO_2e, without any added costs compared to the base case. This means the costs savings from trading could cover the costs of increased ambition by 42% if trading is limited to the industrial and energy sectors. In the scenario with market-based REDD+, overall ambition could thus increase by 70 billion tons or almost double (91%) relative to the base case, while keeping total costs the same.

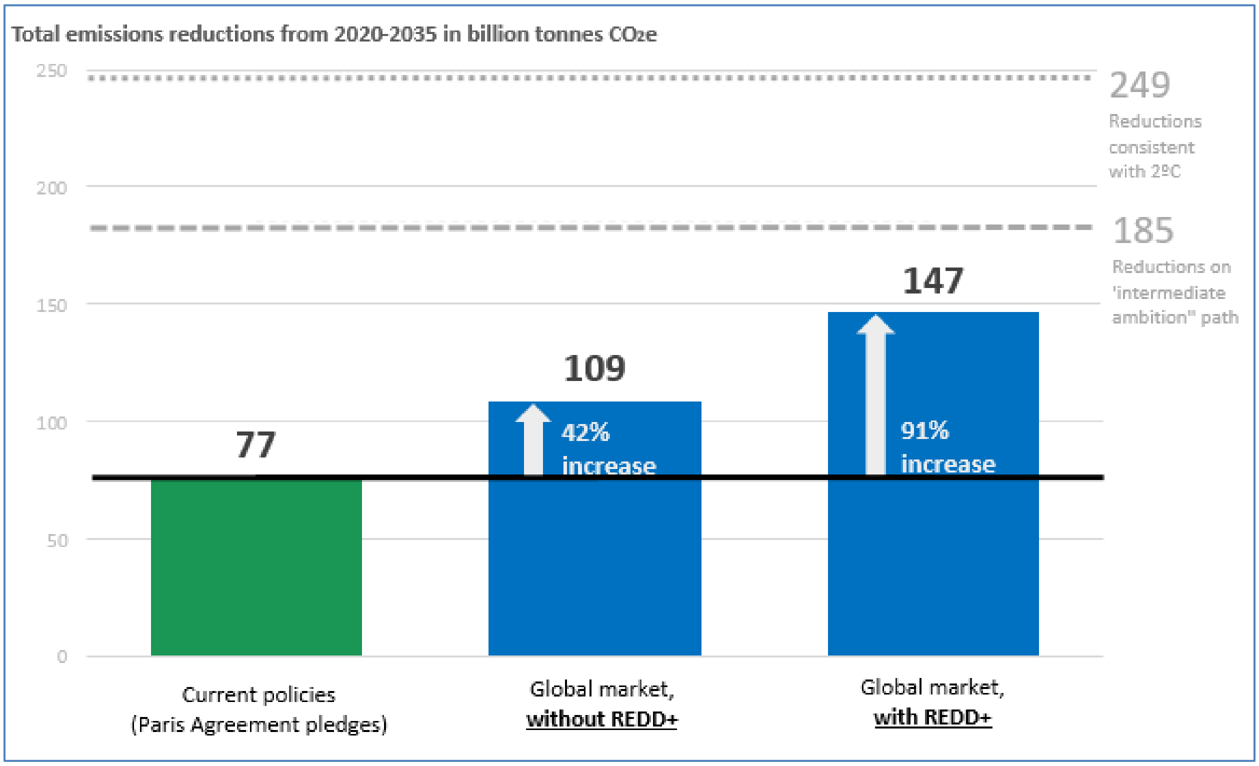

Figure 4. Global carbon markets can enable almost double the emissions reductions for the same cost as the current Paris Agreement pledges (shown in green). Cumulative mitigation over 2020-2035 shown in blue under global market scenarios.

Because of its large potential supply and relatively low cost, we find that market-based REDD+ could play a pivotal role in enabling greater global climate ambition. The cost savings from REDD+ enable 38 billion tons (or 54%) of the total increase in ambition of 70 billion tons possible with full global trading. Including market-based REDD+ in the global market not only lowers costs significantly, but also provides a large additional pool of low-cost reductions that can be "bought" with the resulting cost savings. These additional reductions are over and above the contributions from REDD+ in the base case scenario where REDD+ comprises 27% of the estimated reductions under current levels of NDCs. In total, REDD+ amounts to 52% of the cost-effective reductions over 2020–2035 in the case of global "cost break-even" ambition with full global trading. REDD+ accounts for 55% of the total cost-effective emissions reductions under current levels of NDC ambition over 2020–2035. The relative share of reductions stemming from REDD+ fall at higher levels of ambition, as more reductions are required from both REDD+ as well as the other sectors worldwide.

Partial Coverage Scenarios. We find that the global heat map, Asia-Pacific, and Americas scenarios reduce costs by 51%, 49%, and 51% relative to the base case without markets. The cost savings rise to 63%, 56%, and 59%, respectively, when trading includes market participation from additional countries (beyond those in each scenario) via REDD+. The Americas and Asia-Pacific scenarios lead to 47% to 52% of global coverage by carbon markets by 2030 respectively.

Notably, the cost savings from the Asia-Pacific and Americas markets are relatively similar, despite the lower coverage of global emissions under the former scenario. This similarity stems from the relatively more ambitious NDCs in the U.S. and Canada, compared to those in China, as shown by the estimated carbon prices in Figure 3 above. This is because the gains from trade result from the interaction of both demand and supply for reductions—that is, not only the availability of low-cost reductions but also the demand for these reductions driven by more ambitious NDCs and higher costs in countries that would be net buyers in a market.

Our results with partial market coverage are summarized in Figure 5 below, including a comparison to the break-even ambition enabled by a full global market, as discussed above. We find that the Asia-Pacific and Americas markets both enable similar increases in ambition, enabling about a quarter to a third of the increase in ambition relative to the case of full global trading. This enables the world to reach about two-thirds of the total potential reductions under the case of full trading.

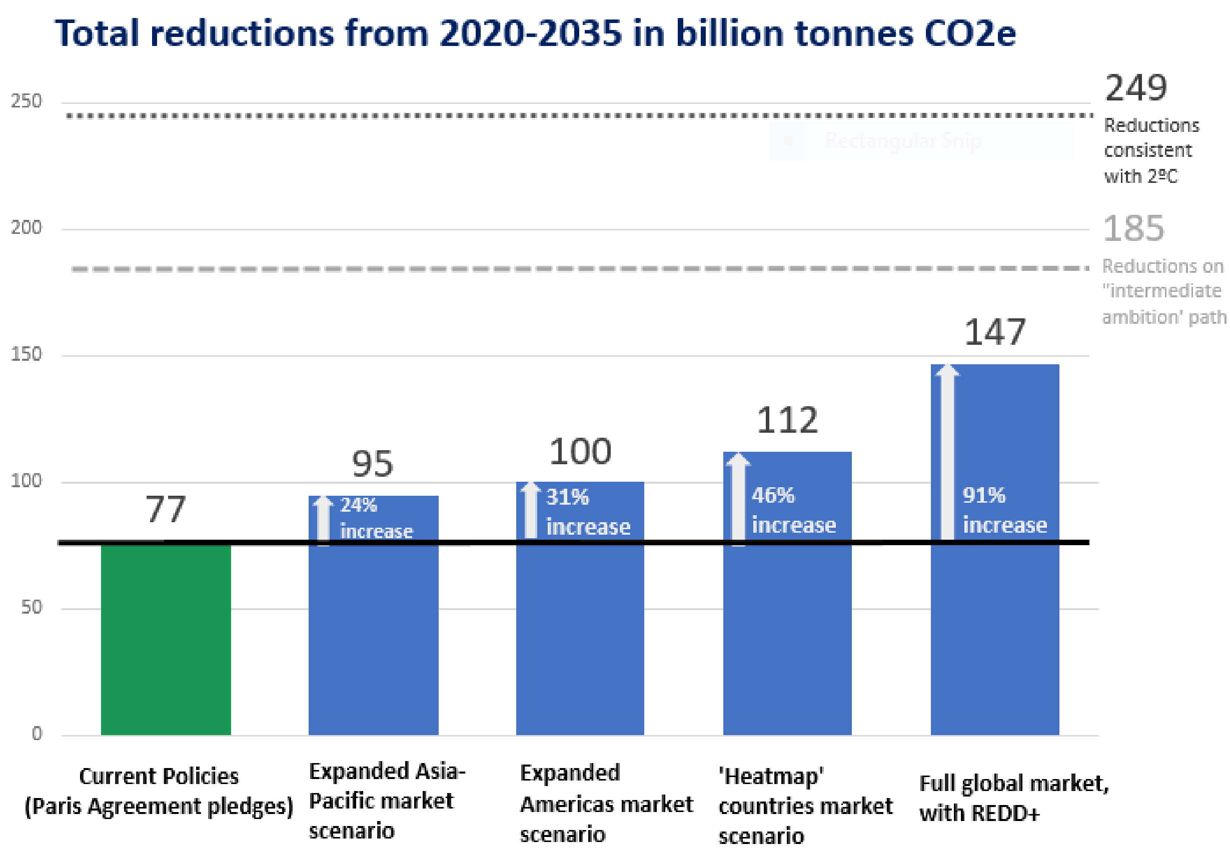

Figure 5: International carbon markets can enable greater emissions reductions for the same cost relative to current Paris Agreement pledges.

The global market with all of the heat map countries enables about half of the increase in ambition, enabling the world to reach more than three quarters of the level of ambition attainable in the case of full trading (without increasing costs relative to the base case of the current Paris Agreement pledges). When additional countries can participate via REDD+ (Figure 6), the gap is further narrowed such that the two regional market scenarios and the ‘Heat map’ market scenario enable 57–59% and 84% of the increase in ambition, respectively, relative to the full trading case. This represents an increase of 52%, 53% and 77%, respectively, relative to total emissions reductions under current policies as depicted in Figure 6. In these cases, the world can reach 80% to 92% of the total reductions under the full trading case.

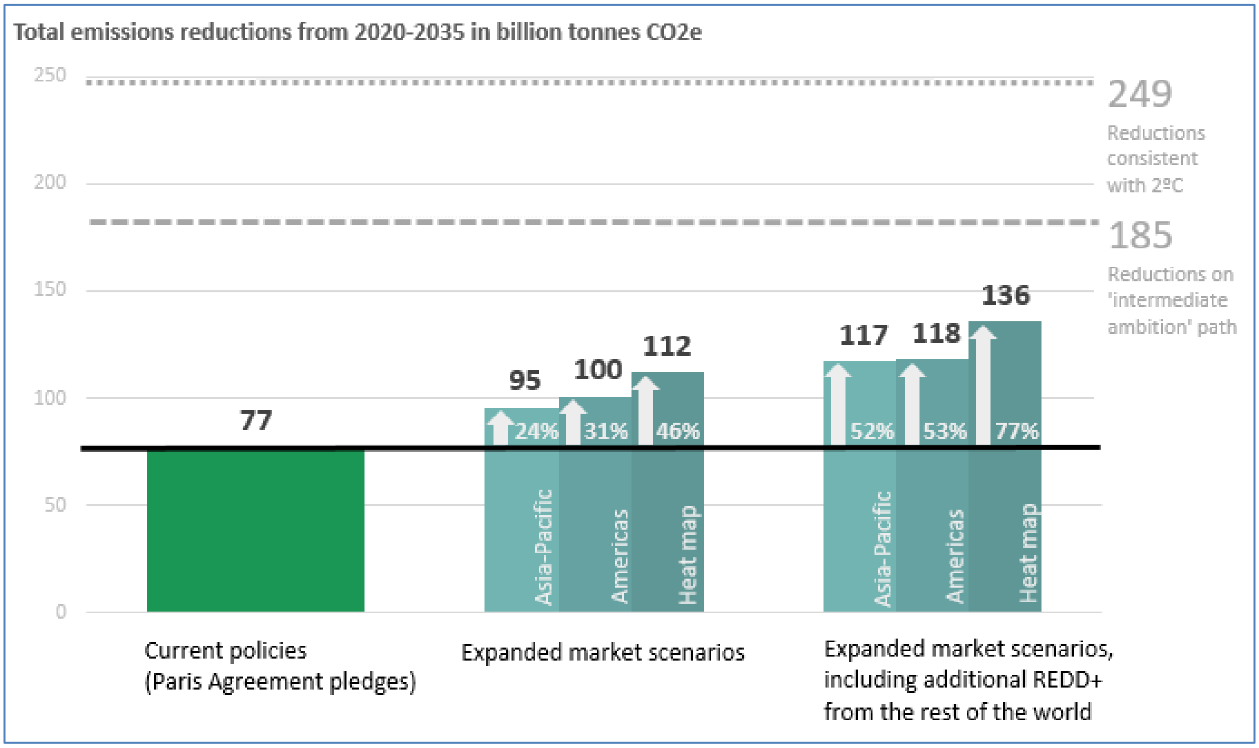

Figure 6: Impact of including REDD+ on partial coverage scenarios

Underlying carbon prices. Table 2 below summarizes modeled carbon price signals across the different global market scenarios. Assuming market actors fully anticipate future policies and there is a globally integrated carbon market, estimated carbon prices range from \$3.7/tCO_2e to \$33.9/tCO_2e in 2020 (rising 5% per year afterwards), depending on whether market demand is set by only the current NDCs or from an expectation of required action consistent with 2°C. Under a potentially more realistic "cost break-even" scenario where global mitigation ambition is increased in line with the cost savings resulting from market linkages, the carbon price starts at \$10.4 in 2020 (rising 5% per year afterwards). An "intermediate" ambition scenario (as shown in Figure 1) in which there is delayed transition to the two-degree consistent pathway results in a carbon price of \$19.4/tCO_2e in 2020 rising 5% per year afterwards.

Table 2. Summary of modeled carbon prices under alternative global market scenarios (\$/tCO_2e).

	REDD+	Ambition	2020	2025	2030	2035
Global	Global REDD+	Current NDC	\$3.7	\$4.7	\$5.9	\$7.6
	None	Current NDC	\$7.4	\$9.4	\$12.0	\$15.3
	Global REDD+	Extended	\$10.4	\$13.2	\$16.9	\$21.6

	(cost break-even)				
Global REDD+	Intermediate NDC	$19.4	$24.7	$31.6	$40.3
Global REDD+	Compatible with 2ºC	$33.9	$43.2	$55.2	$70.4

Table 3 below summarizes the modeled carbon prices under alternative partial market scenarios. The analysis finds that price is sensitive to the inclusion of REDD+, particularly if REDD+ is available for international trading (as contrasted with domestic use only). For the "cost break-even" scenarios, with REDD+ supply limited to the core market participants, market prices range between $13.5 and $16.8 per ton of CO_2e in 2020 rising 5% per year afterwards. With extended REDD+ supply from additional countries, market prices range between $11.4 and $14.2 per ton of CO_2e in 2020 rising 5% per year afterwards.

Table 3. Summary of modeled carbon prices under alternative partial market scenarios (\$/tCO_2e).

	REDD+	Ambition	2020	2025	2030	2035
Heat map	No	Current NDC	$9.22	$11.77	$15.02	$19.17
	Heat map countries	Current NDC	$6.60	$8.42	$10.75	$13.72
	Heat map countries	Extended (cost break-even)	$13.50	$17.23	$21.99	$28.07
	Extended	Extended (cost break-even)	$11.57	$14.77	$18.85	$24.05
Asia-Pacific	No	Current NDC	$10.95	$13.98	$17.84	$22.76
	Asia-Pacific countries	Current NDC	$9.48	$12.10	$15.44	$19.71
	Asia-Pacific countries	Extended (cost break-even)	$15.78	$20.14	$25.70	$32.81
	Extended	Extended (cost break-even)	$11.44	$14.60	$18.63	$23.78
America s	No	Current NDC	$13.53	$17.30	$22.00	$28.10
	Americas countries	Current NDC	$8.44	$10.80	$13.70	$17.50
	Americas countries	Extended (cost break-even)	$16.56	$21.10	$27.00	$34.40
	Extended	Extended (cost break-even)	$14.24	$18.20	$23.20	$29.60

4. Discussion

Our results of the potential cost savings from a fully global market range from 62–79%, depending on the inclusion of REDD+, are consistent with other studies, notably Fujimori et al. (2016), despite their different methodology which was not explicitly intertemporal. Fujimori et al.'s study is based on Asia-Pacific Integrated Model/Computable General Equilibrium

(AIM/CGE) and estimates that a global market, inclusive of land use, based on current NDCs would reduce global welfare loss by 75% and produce a price of around \$9/tCO_2 in 2030, also comparable with our estimates.

Our estimated percentage savings are also in line with Rose et al.'s (2018) analysis of a global carbon market for power and industry sectors that evolves in a stepwise manner to help meet NDCs. They estimate cost savings ranging from 59%, 75% and 72%, as markets progressively integrate by 2020, 2025 and 2030, up to the point where 50% of global emissions are covered. Nevertheless, Rose et al.'s study generates significantly higher prices compared to our idealized case, perhaps as their analysis considers a market with more restricted scope and is not intertemporal in nature.

Hof et al.'s analysis (2017) similarly finds that allowing for global emissions trading under their mid-range scenario of baseline emissions reduces the costs of NDC implementation by 56% for unconditional NDC targets and by 44% for conditional NDC targets. These estimated cost reductions are more modest than our findings and the findings in the above studies, but they also note that their assumed implementation costs are found to be quite sensitive to underlying assumptions about socioeconomic developments. In addition, their study does not include reductions from LULUCF, which have significantly contributed to the cost savings from allowing global trading in our model.

In terms of the potential to use cost savings to increase ambition, we estimate greater potential savings from markets—and correspondingly greater potential to help finance additional emissions reductions—compared to a report by the World Bank, Ecofys and Vivid Economics (2016). That report estimates that international emission trading could reduce the total abatement costs of achieving current Paris pledges by about a third by 2030, while cutting total mitigation costs in half by 2050 in a 2°C consistent scenario. Our analysis (along with Fujimori's) considers a broader range of mitigation activities. While the World Bank considers CO_2 emissions from the energy and industrial sectors, we consider all GHGs and the potential role of REDD+ in an international market. We also consider a longer time period (2020–2035, versus 2030 only).

Our analysis reported in this paper still potentially underestimates the benefits of markets, as we did not consider opportunities for trading of non-CO_2 emissions from agricultural activities and we limited our consideration of forestry to reducing deforestation and degradation, without including the potential of reforestation and improved forest management. Furthermore, our analysis only considers cost savings from an equalization of expected marginal abatement costs across countries, without consideration of the potential benefits from ongoing buffering idiosyncratic market or policy shocks across countries, which Doda and Taschini (2017) estimate can produce significant added savings.

Moreover, our estimated increase in ambition is due mostly to the gains from international trade, and not the increase in use of domestic markets to meet national targets. Expanding the use of markets from the base case to the "full trading" scenario can be divided into two steps: first, broadening the use of emission trading as an instrument of domestic policy, with the "full trading" scenario assuming that every country in the world uses an internal carbon market to meet its NDC; second, linking those markets through international trading. Both steps yield cost savings, and thus potential increases in ambition. Our modeling suggests that the lion's share of the gains from global markets are due to international linking, with a much smaller share coming from increased use of domestic carbon markets. While this conclusion needs further analysis, it has potentially striking implications, suggesting that carbon pricing policies that encourage international cooperation—such as carbon markets—may be able to capture significantly more cost savings, and thus increased ambition, than carbon pricing policies that are less prone to linkage.

This finding comes with an important qualification due to the nature of our model. While the model is fairly disaggregated among countries, it is relatively coarse within countries, because only four sectors are modeled: energy, transport, industry, and forestry and land-use. Because our model assumes least-cost abatement in each sector within each country (including within the EU-region aggregate), it effectively assumes the use of within-sector emission trading or other market-based policies, rather than more costly command-and-control measures. More fine-grained sectoral coverage would yield greater estimated cost savings due to greater within-country trading. Nonetheless, a striking conclusion from our analysis is that virtually the entire cost savings (96 percent) are due to international linking, with just 4 percent of estimated cost savings coming from increased use of domestic trading. At the very least, this suggests that the potential for gains from international trade are significantly greater than the gains from intersectoral trade within each country.

5. Conclusion

Experience with several Emissions Trading Systems (ETS) to date suggests that by helping to achieve initial targets more easily and economically than expected, carbon markets can lower political resistance to setting more ambitious targets in the future. Our analysis explores this potential with respect to Paris Agreement targets. We consider cumulative mitigation over 2020–2035, rather than single-year targets alone, and also examine a broader set of sectors and gases, compared to other studies of post-Paris international carbon markets. In particular, we provide the first evaluation of the extent to which including avoided deforestation (REDD+) in international carbon markets can enable greater climate ambition under the Paris Agreement.

We find that the global use of emissions trading, based on well-designed accounting rules and the banking (carry-forward) of emissions units over 2020–2035 could allow the world to nearly double climate ambition relative to current NDCs without increasing aggregate costs. In particular, we estimate that holding total discounted abatement cost constant, cumulative emissions reductions over the period 2020–2035 would increase from 77 Gt CO2e in the base case to 147 Gt CO2e in a scenario with full global emission trading—an increase of 91 percent. A large share of the gains come from the inclusion of REDD+. This suggests that the development of well-designed and high-integrity approaches for international market cooperation, as envisioned under Article 6 of the Paris Agreement, as well as the inclusion of REDD+, merit significant policy attention as a means of closing the global emissions gap.

The large boost in ambition possible as a result of international emissions trading is promising. However, even in the case with REDD+ in a full global market, the cost savings from carbon markets in the "break-even" scenarios do not yield enough ambition relative to what is necessary to avoid dangerous warming, as shown by the 2°C scenario. On the one hand, breaking even on costs compared to current levels of ambition could be seen as a relatively low bar for increasing total commitments. Yet, just based on this requirement, global trading gets 80% of the way to the intermediate scenario and 60% of the way to the 2°C scenario.

A fully global carbon market is likely unrealistic in the medium term, given differences in country readiness as well as political hurdles to linking markets, particularly when these could entail large financial resource transfers among countries. Even so, our partial sector coverage models indicate that even limited trading conditions evolving around regional lines—potentially consistent with ongoing cooperation on trade, environmental quality, migration and other regional strategic issues—can boost climate ambition measurably. Thus, our results give support to the continued promotion of carbon markets worldwide as a valuable tool in the global effort to reduce emissions at scale.

In addition, total ambition could be further increased by expanding global carbon market coverage through allowing additional cost-effective emissions reductions from sectors not contemplated in this modeling exercise—namely, agriculture and other forest-based measures such as reforestation and sustainable forest management. Furthermore, if forward-looking market actors can anticipate this eventual ratcheting-up of ambition, they would have incentives to act early to take advantage of lower cost abatement opportunities in order to avoid future cost increases. This has the potential to activate a virtuous circle that could further help close the near-term ambition gap and get the world on track towards meeting the Paris Agreement goal.

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Appendix: Heat Map Analysis

To help focus on priority geographies, we developed a heat map tool to systematically evaluate the suitability and strategic value of different countries for carbon pricing advocacy efforts. Though the index is a coarse measure that abstracts from many important nuances, the goal was to develop a uniform set of quantitative criteria to consistently compare a broad set of countries.

The "heat map" of priority jurisdictions shown below (Figures 8a and 8b) illustrates the results of our analysis, which ranks countries on a composite "Carbon Markets Readiness and Priority" index (color scale from pink, indicating lower values, to dark blue, indicating the highest values), as shown in the scale to the left of the maps. Figures 8a and 8b, respectively, display results including and excluding the EU, U.S., and China.

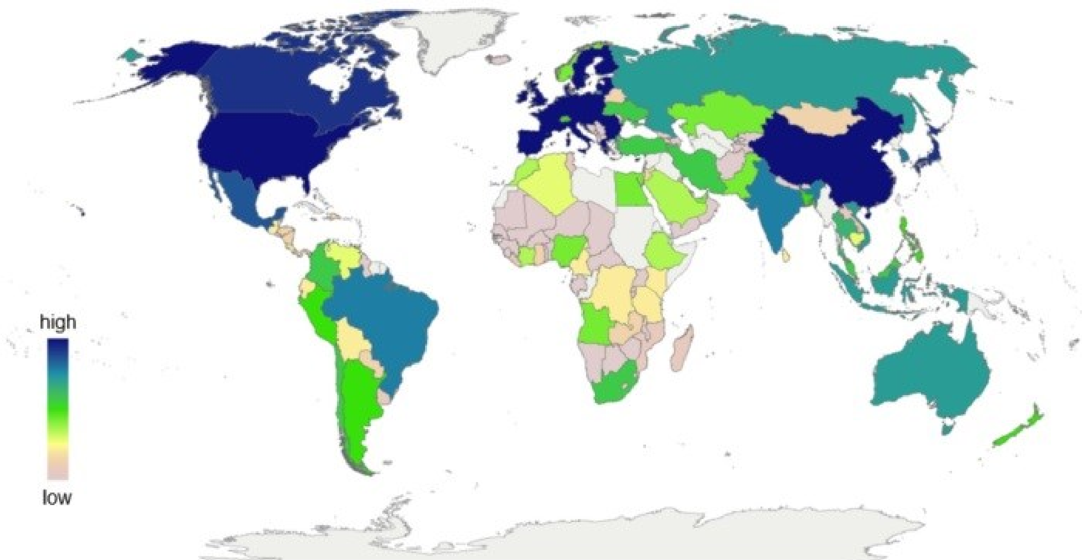

Figure 8a. Heat map of carbon markets societal readiness and strategic priority.

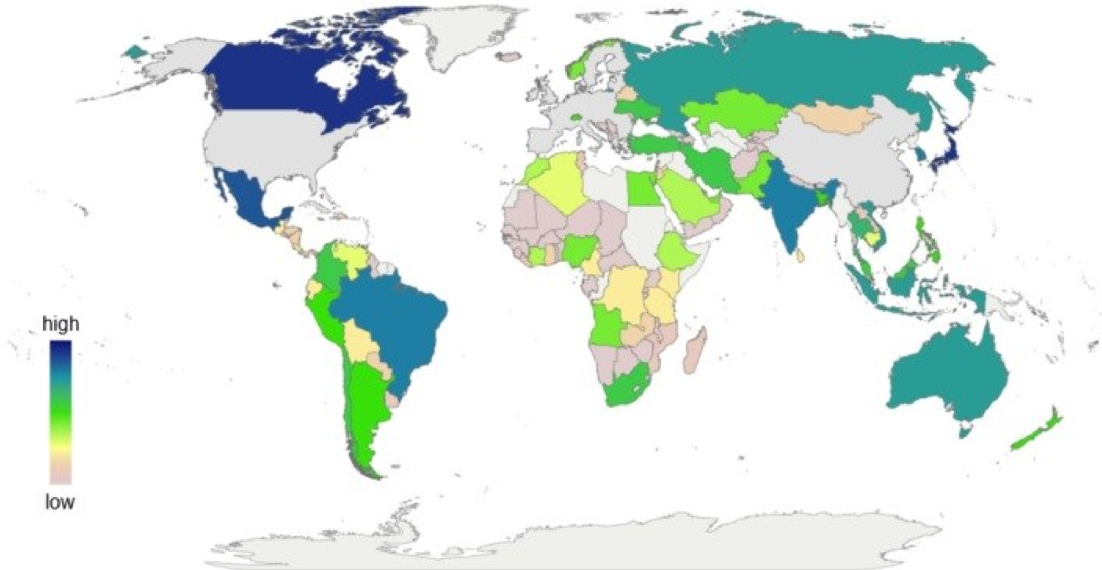

Figure 8b. Heat map of carbon markets societal readiness and strategic priority, outside the "Big Three" (EU, U.S., and China).
Note: Colors are based on the Carbon Markets Societal Readiness and Strategic Priority score for each country, ordered from lowest (pink) to highest (dark blue), as shown in scale to left of maps. Figure 7a includes all countries, while 7b rescales the colors after excluding the "Big Three" of EU, U.S., and China.

The EU, U.S., and China are the darkest blue colored countries on the map, respectively ranking first, second, and third overall in terms of the final societal readiness and strategic priority score and ranking in the top four on all other sub-component scores. We developed this index using 50 different variables from 31 different datasets covering 131 jurisdictions. The weighted composite index allows us to score, rank, and map all nations worldwide.

In short, the construction of the heat map index involves two major steps (as seen in Figure 9below): first, assessing the country's raw societal readiness, and second, applying a set of filters to ensure the countries that score highest on societal readiness are also strategically relevant for their relative share of global emissions, interrelation with other important countries ("network influence"), and expressed interest in carbon markets.

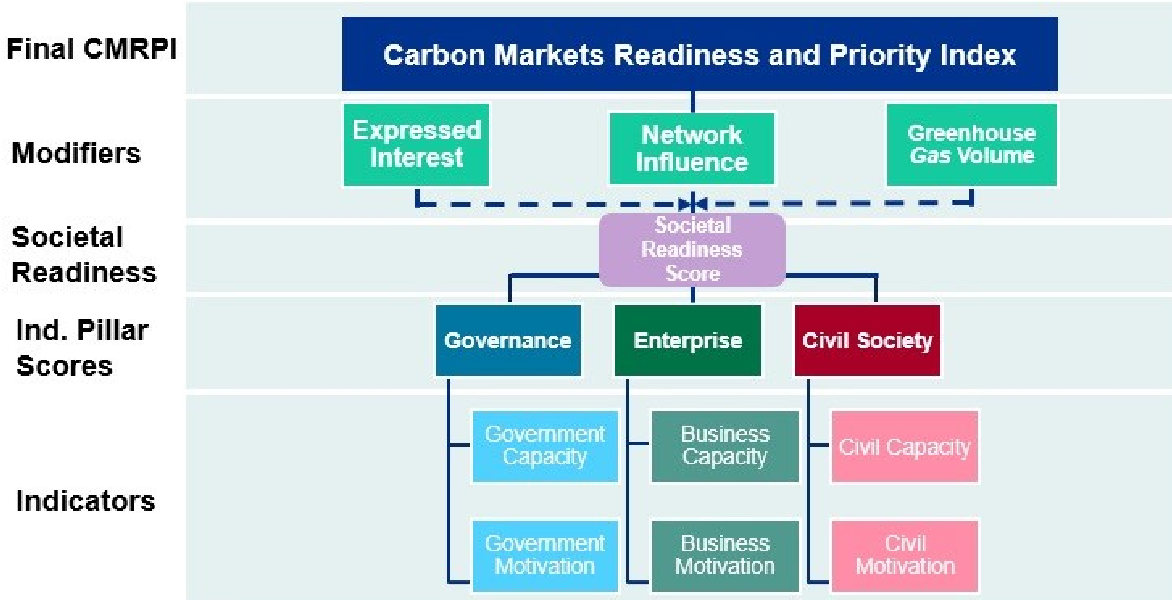

Figure 9. Carbon Markets Readiness and Priority Index Structure Diagram

Societal Readiness Score. The "Societal Readiness" score assesses how apt institutions and stakeholders across government, business, and civil society sectors (the three "Pillars") are to deliver on carbon pricing policies. The Societal Readiness score is a weighted average of capacity and motivation factors across the three Pillars of society (see Table 2 below) for a full list of input variables to each Pillar).

This approach aims to capture the importance of business and civil society actors, in addition to government, for effective and sustainable development of carbon pricing policies. By dividing each Pillar into its capacity and motivation scores, the approach further seeks to capture that successful implementation of carbon pricing policies should require the confluence of both "demand" drivers for these policies, given the underlying interests of different stakeholders, and the capacity to "supply" such policies via relevant institutions, legal frameworks, and politically salient constituencies.

Strategic Relevance Filter. In addition to the raw "societal readiness" score, we apply three score modifiers that rescale the values to reflect the strategic relevance of each country for achieving global climate goals, which could also affect the propensity of that country to participate in carbon pricing initiatives due to internal and external pressures:

Greenhouse Gas Volume Modifier: Captures the current GHG emissions from each country, including from the land-use sector, to reflect the strategic value of targeting high–total emission countries;

Expressed Interest Modifier: Captures interest demonstrated by political leaders in market-based mechanisms to control carbon emissions. This approach includes various indications of interest, such as mention of markets in the country's NDC and its participation in the World Bank–

managed Partnership for Market Readiness (PMR). As this measure is intended to capture potential for *future* adoption of a market-based system, it does not include current adoption of a carbon market nationally or sub-nationally (e.g., in the U.S., China, Japan, Canada, and South Korea) as part of the score. However, it does include considerations or adoption of a carbon tax and whether this tax includes an offsetting approach (e.g., in Colombia), given the potential role of a tax as a stepping stone toward a broader market-based system.

Network Influence Modifier: Captures the degree of connectedness to other priority countries. This modifier recognizes that countries may be of strategic importance due to their ability to exert influence and catalyze action in other priority countries. A country's network of relationships is proxied in terms of trade relations (as captured by absolute volume of trade in goods) with the priority countries under consideration. Alternative measures of network influence were calculated, taking into account the expressed interest considerations both individually and jointly.

More details on the individual components of the score and how each modifier was calculated are provide in the Methodological Notes below.

Table A1 below provides a "dashboard" that breaks down the heat map results for the top 25 countries, excluding the "Big Three" (EU, U.S., and China). The score magnitude and overall ranking of each layer of the final Index can be individually assessed in the columns titled "Societal Readiness" (Total Pillar Score), "Expressed Interest," "Total GHGs," and "Network Influence."

Table A1: Carbon Markets Readiness and Priority Dashboard: Top 25 Ranking Nations, excluding China, United States, and EU (with Norway & Switzerland)

Rank	Country	Composite Readiness and Priority (Z-Score*)	Societal Readiness	Expressed Interest	Total GHGs	Network Influence
			Numerical and percentile ranking**			
1	Japan	0.757	● 2	● 5	● 5	● 1
2	Canada	0.403	● 1	◕ 8	◕ 6	● 2
3	Mexico	0.265	◑ 21	● 2	◕ 7	● 3
4	India	0.068	◕ 8	◔ 23	● 1	◕ 8
5	South Korea	0.015	◕ 7	◑ 19	◕ 9	● 4
6	Brazil	-0.033	◑ 17	◕ 13	● 3	◕ 10
7	Indonesia	-0.096	◑ 22	◕ 11	● 4	◑ 13
8	Vietnam	-0.145	◔ 33	◕ 12	◔ 19	● 5
9	Russia	-0.155	◑ 19	○ 119	● 2	◑ 12
10	Australia	-0.155	● 3	○ 52	◕ 10	◕ 6
11	Thailand	-0.160	◔ 34	◑ 16	◑ 15	◕ 9
12	Iran	-0.179	○ 57	◔ 24	◕ 8	◑ 16
13	Ukraine	-0.181	○ 52	● 6	◔ 18	◔ 20
14	Turkey	-0.181	◔ 44	◑ 18	◑ 16	◔ 17
15	Chile	-0.183	◕ 15	● 3	○ 42	◑ 15
16	Malaysia	-0.184	◕ 13	○ 113	◑ 12	◑ 11
17	Colombia	-0.184	◔ 31	● 1	◔ 26	○ 26
18	South Africa	-0.186	◕ 14	○ 53	◑ 14	◔ 22
19	Singapore	-0.188	● 5	◔ 26	○ 66	◕ 7
20	Argentina	-0.189	○ 56	◔ 44	◑ 17	○ 25
21	Peru	-0.190	○ 72	◑ 14	○ 35	○ 24
22	New Zealand	-0.190	● 4	◕ 10	○ 47	○ 28
23	Philippines	-0.190	◑ 27	○ 53	◔ 30	◔ 19
24	Bangladesh	-0.191	◔ 42	◔ 32	○ 36	◔ 21
25	Kazakhstan	-0.191	○ 58	◑ 20	◔ 25	○ 42

*Note: * The Z-score shows the final score in terms of the number of standard deviations from the mean across the full set of countries. **Numbers indicate numerical rank while circles represent the z-score quintiles for each nation's raw readiness and modifier scores, with fuller circles indicating higher z-score ranking and an empty circle indicating z-scores in the bottom quintile.*

The top 25 nations represent a range of development profiles and geographic regions, but in comparison to other nations are richer in trade with other major emitters, and more proactive in promoting climate policy and carbon pricing. The score also captures all countries that are already implementing carbon pricing at the national (South Korea, New Zealand, and Kazakhstan) or subnational (Canada, Japan) levels, countries implementing carbon taxes (Colombia, Chile, Mexico, and Japan), as well as Australia, which had a carbon market and now has an offset-based system at the national level.

Heat Map Results

As the map shows, the EU, United States, and China are the highest priorities, respectively ranking first, second, and third overall in terms of the final societal readiness and strategic priority score and ranking in the top four on all other sub-component scores. Among the rest of the world, the top ranking countries are Japan, Canada, Mexico, India, and South Korea, with a relatively high confluence of all factors, Brazil and Indonesia follow after, with particularly high GHG emissions from deforestation. The next highest ranking countries are Vietnam, *Russia*, Australia, Thailand, *Iran*, *Ukraine*, *Turkey*, Chile, *Malaysia*, and Colombia, respectively, with countries in *italics* likely being more challenging due to comparatively low values for societal readiness and (for Russia and Malaysia) expressed interest.

Additional insights are provided by the component rankings (see Table A1 above). Though relatively low in GHG emissions in itself, Vietnam stands out for its network influence with large emitters (US, China, and Japan), South Africa follows next, notable as the sole candidate from Africa and for its relatively high societal readiness value. In terms of societal readiness, Japan, Canada, Australia, Singapore, and South Korea are highest, but the other modifiers affect the relative rankings. Kazakhstan is notable as a country with a relatively low societal readiness index value that is nonetheless implementing a carbon market (after a period of suspension). Finally. some regional groupings emerge, as discussed below.

The Americas. Based on high levels of by expressed interest compared to other nations, Mexico, followed by Chile and Colombia, stand out as potential near-term prospects for developing new carbon markets. Chile is particularly notable, making the list due to high scores on expressed interest and other dimensions, despite relatively low GHG emissions. Brazil is one of the world's largest emitters and a country with a large economy deeply enmeshed in global trade networks, while Argentina and Peru also make the top 25. Highly-ranked Canada is a potential priority to help expand and consolidate these systems.

Southeast and East Asia. Japan, Indonesia, Vietnam, and Thailand stand out as leading candidates. South Korea, also highly ranked, has already implemented a carbon market and could be an important regional catalyst, while China, as it develops its own market, can present a long-term anchor for the region. Singapore is much lower down the list (#19), largely given its low emissions, but stands out as a potentially nearer-term prospect given its very high societal readiness and network influence factors.

Methodological Details

Below, we provide additional methodological details on the heat map analysis. The Carbon Markets Readiness and Priority index scores and ranks 132 nations on the potential for and payoff of implementing a carbon market in the near and medium term. Our index model is comprised of two main components: The Societal Readiness Score, which evaluates core institutional readiness across three Pillars (Governance, Enterprise, and Civil Society); and a strategic relevance filter incorporating three Modifiers, which assess regional influence via trade networks, demonstrated political interest, and overall climate impact via GHG emissions volumes.

We used a weighted composite index approach to score and rank nations worldwide in accordance with their estimated "Carbon Markets Readiness and Priority." Indices were aggregated using 50 different variables from 31 different datasets covering 131 jurisdictions worldwide (see Table 2 for a list of variables and data sources). Rather than treat EU member nations individually, we constructed a composite score for the European Union using GDP-weighted averages (for indices and non-additive variables) and weighted sums (for additive variables) for all of the EU-28 member nations.

All input data was adjusted using min-max normalization to reach a common zero-to-one scale prior to aggregation:

X = the set of all country scores for a given variable

x_i = the score from variable X for a given country i

$n_i = \frac{x_i - \min(X)}{\max(X) - \min(X)}$ is the normalized score of variable X for country i

We chose this method for all steps in our model for which normalization is used, as it eradicates negative values from the data—thus allowing us to multiply in Modifiers (as noted below) without the sign of the score unintentionally cancelling out.

The Three Pillars of Societal Readiness: Governance, Enterprise, Civil

The ***Societal Readiness Score*** is a composite of three Pillars, representing a core societal group relevant to carbon pricing: Governance, Enterprise, and Civil Society. Each Pillar is comprised of two aggregated "Indicators" representing the Capacity and Motivation of each. The input data to each Indicator are listed in Table 2 below. Each Indicator is a simple average of all normalized input data. If a nation is missing data for all inputs to an indicator, that nation is dropped. In turn, each of the three Pillar scores is a weighted average of its corresponding Capacity and Motivation scores—in this context, both Indicators are given an equal weight.

The rationale behind including and equally weighting both Capacity and Motivation is that while a nation may have all the structural requirements to successfully implement and govern a carbon market, insufficient political or civil will—or pressure from major enterprises—can present roadblocks to the establishment of carbon pricing mechanisms. Similarly, strong political will, or large economic benefits to carbon pricing, can lead to important steps taken toward a carbon market, even in a nation that ranks lower in terms of political and economic sophistication and development.

Together, and across all three Pillars, these scores create what we call the "raw readiness" of a given country—represented by the *Societal Readiness Score***.** The Societal Readiness Score is a weighted average of the final scores of each Pillar, with the Governance Pillar given a higher weight (50%) than the Enterprise and Civil scores (25% each).

Strategic Relevance Filter. In addition to the raw Societal Readiness Score, we include a strategic relevance filter based on three score Modifiers that capture market readiness propensity beyond institutional capacity alone.

The *Expressed Interest* modifier captures the interest demonstrated by policymakers toward implementing a market-based mechanism to control carbon emissions. This is a simple average of five normalized variables: participation in the Carbon Pricing Leadership Coalition; Participation and extent of progress within the World Bank's PMR; the extent of domestic climate legislation already in place; whether the country has expressed support for a market-based approach to emissions reductions in their NDC submitted for the 2016 Paris Agreement on Climate Change; and the presence and current status of a national and/or subnational carbon tax or tax plus offset system. The latter is included as a potential stepping stone toward developing broader carbon pricing frameworks.

The *Greenhouse Gas Volume* modifier captures the share of the world's annual global emissions for which each country is responsible; thus, the climate change mitigation impact of implementing a strong pricing scheme in that region. The emissions data used were World Resources Institute (WRI) CAIT Data excluding land-use change emissions. supplemented with forest loss emissions from Global Forest Watch.[7] For those nations without Global Forest Watch Data, WRI CAIT GHG emissions estimates alone were used.

Both the Expressed Interest and Greenhouse Gas Volume modifiers were normalized using the min-max method, and multiplied with the Societal Readiness score for each country in our dataset.

The *Network Influence* modifier captures each nation's total volume of trade with the Top 20 scoring nations when including the Societal Readiness Score and both the Expressed Interest and Greenhouse Gas Volume modifiers—weighted by the normalized input score of the Top 20 nations. We performed a sensitivity analysis using just Societal Readiness Score as an input to Network Influence, and multiplying the Expressed Interest and Greenhouse Gas Volume modifiers afterwards—but the final set of top ranking countries only minimally changed. We computed final scores using Expressed Interest and Greenhouse Gas Volume modifiers as inputs to capture the role of both factors in the evaluation of the network relationship with strategically important countries. The final output score is computed as follows:

S = Vector of scores for top 20 ranked nations (with or without modifiers included), i.e.:

$$S = [s_1, \quad s_2, \quad \ldots \quad s_{20}]$$

NS = Vector of Normalized Scores for top 20 ranked nations as given by:

$$ns_i = \frac{s_i - \min(S)}{\max(S) - \min(S)}$$ = normalized final score for top 20 ranking nations

$$NS = [ns_1, \quad ns_2, \quad \ldots \quad ns_{20}]$$

C = set of all i reporting nations in full dataset

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[7] http://cait.wri.org/historical; http://data.globalforestwatch.org/

$$C = [c_1, \quad c_2, \quad \ldots \quad c_i]$$

$T_{ci,sj}$ = Matrix of total trading volume in goods for each reporting nation c_i in full dataset with each Top 20 ranking nation (s_j):

$$T_{ci,sj} = \begin{array}{c} c_1 \\ c_2 \\ \ldots \\ c_i \end{array} \begin{bmatrix} t_{c1,s1} & t_{c1,s2} & \ldots & t_{c1,s20} \\ t_{c2,s1} & & & \ldots \\ \ldots & & & \ldots \\ t_{ci,s1} & \ldots & \ldots & t_{ci,s20} \end{bmatrix}$$

To compute the Network Influence Modifier (nim_i), the trading matrix $T_{ci,sj}$ is weighted via matrix multiplication with the vector of normalized scores for Top 20 nations NS:

$$NIM = T_{ci,sj} \bullet NS = \begin{array}{c} c_1 \\ c_2 \\ \ldots \\ c_i \end{array} \begin{bmatrix} t_{c1,s1} & t_{c1,s2} & \ldots & t_{c1,s20} \\ t_{c2,s1} & & & \ldots \\ \ldots & & & \ldots \\ t_{ci,s1} & \ldots & \ldots & t_{ci,s20} \end{bmatrix} \bullet \begin{bmatrix} ns_1 \\ ns_2 \\ \ldots \\ ns_{20} \end{bmatrix} = \begin{bmatrix} nim_{c1} \\ nim_{c2} \\ \ldots \\ nim_{ci} \end{bmatrix}$$

The final score including Expressed Interest, therefore, is the raw Total Composite Score with or without GHG and/or EI modifiers multiplied by the Network Influence Modifier:

$s_i = t_i * nim_{ci}$ = Final Score, including Network Influence Modifier

Table 9. Carbon Markets Heat Map: Data Elements and Sources

Description	Date	Units	Source
MODIFIERS			
i. Expressed Interest			
i.a. CPLC membership	2017	Unit	Carbon Pricing Leadership Coalition
i.b. PMR Country Status	2017	Unit	Partnership for Market Readiness
i.c. Climate Legislation Score	2017	Score	LSE Grantham Institute
i.d. NDC Market Mention	2016	Score	World Bank
i.e. Status of a Carbon Tax	2017	Score	World Bank
ii. Greenhouse Gases			
ii.a. Total GHG emissions. excluding land-use change and forestry	2013	$MtCO_2e$	World Resources Institute CAIT
ii.b. Total CO_2 emissions from deforestation and forest degradation	2013	$MtCO_2e$	Global Forest Watch
iii. Network Influence			
iii.a. Score-weighted trade in goods (imports and exports) between all reporting nations	2016	US$	UN COMTRADE
1. GOVERNMENT PILLAR			
1.1 Government Capacity			
1.1a. Demonstrated use of market-based instruments for fisheries. air pollution. water quality. forest protection. agricultural use. or other environmental issues	*variable*	binary	Schomers and Matzdorf. "Payments for Ecosystem Services: A Review and Comparison of Developing and Industrialized Countries." Ecosystem Services. 2013 Le Gallic. B.. "The Use of Market-Like Instruments in OECD Countries: Key Insights from an Organizational

			Framework." IIFET 2004 Japan Proceedings. 2004. Brauer. et al. "The Use of Market Incentives to Preserve Biodiversity." EcoLogic. 2006. Chu. C.. "Thirty Years Later: the Global Growth of ITQs and their influence on stock status in marine fisheries." Fish and Fisheries. 2008.
1.1b. Transparency International Corruption Perceptions Index	2016	aggregate index	Transparency International
1.1c. Number of admitted observers to the COP; government / public sector	2016	count	UNFCCC
1.1d. Number of signatories to the UN Global Compact; government / public sector	2016	count	UN Global Compact
1.1e. World Bank Governance Indicators - Control of Corruption	2015	index	World Bank Governance Indicators
1.1f. World Bank Governance Indicators - Government Effectiveness	2015	index	*see above*
1.1g. World Bank Governance Indicators - Political Stability - Absence of violence / Terrorism	2015	index	*see above*
1.1h. World Bank Governance Indicators - Regulatory Quality	2015	index	*see above*
1.1i. World Bank Governance Indicators - Rule of Law	2015	index	*see above*
1.1j. WEF Global Competitiveness Index - Indicator 1.A.2 "Ethics and Corruption"	2016	index	World Economic Forum Global Competitiveness Index
1.1k. WEF Global Competitiveness Index - Indicator 1.A.3 "Undue Influence"	2016	index	*see above*

1.1l. WEF Global Competitiveness Index - Indicator 1.A.4 "Public Sector Performance"	2016	index	*see above*
1.1m. WEF Global Competitiveness Index - Indicator 1.A.5 "Security"	2016	index	*see above*
1.1n. Average Trust in Institutions. General Population (Edelman Trust Barometer)	2017	aggregate index	*see above*
1.2 Government Motivation			
1.2a. Yale Environmental Protection Index - Climate Indicator - Trend in Carbon Intensity	2016	index	Yale Environmental Protection Index
1.2b. Yale Environmental Protection Index 2016 - Climate Indicator - CO_2 Emissions/KwH	2016	index	*see above*
1.2c. WB State and Trends - Share of Total Revenue from full coverage of carbon pricing	2016	US$	World Bank State and Trends of Carbon Pricing
1.2d. WB State and Trends - Share of Total Cost from full coverage of carbon pricing	2016	US$	*see above*
1.2e. Total trade with countries with emissions trading systems (GDP per capita)	*variable*	current US$	UN COMTRADE Trade Europa TSE
1.2f. WEF Executive Opinion Survey - Enforcement of Environmental Regulations	2015	score	World Economic Forum Executive Opinion Survey
1.2g. WEF Executive Opinion Survey - Stringency of Environmental Regulations	2015	score	*see above*
1.2h. WEF Executive Opinion Survey - Number of Ratified International Treaties	2015	score	*see above*

2. ENTERPRISE PILLAR			
2.1 Business Capacity			
2.1a. Number of Admitted NGOs as observers to the COP; business / private sector organizations	2016	count	UNFCCC
2.1b. Number of Signatories to the UN Global Compact; business / private sector organizations	2016	count	UN Global Compact
2.1c. World Bank Extent of Corporate Transparency index	2017	rank	World Bank Ease of Doing Business Indicators
2.1d. WEF Global Competitiveness Index - Indicator 1.B "Private Institutions" (corporate ethics and accountability)	2016	aggregate index	World Economic Forum Global Competitiveness Index
2.1e. WEF Global Competitiveness Index -Pillar 3 - Macroeconomic environment	2016	aggregate index	*see above*
2.1f. WEF Global Competitiveness Index - Pillar 8 - Financial Market Efficiency	2016	aggregate index	*see above*
2.1g. WEF Global Competitiveness Index - Pillar 11 - Business Sophistication	2016	aggregate index	*see above*
2.1h. Herfindahl-Hirschmann Market Concentration Index	2015	score	World Bank
2.2 Business Motivation			
2.2a. Global Cleantech Innovation Index	2017	aggregate index	i3Connect
2.2b. Renewable Energy Country Attractiveness Index	2014	aggregate index	EY
2.2c. WEF Global Competitiveness Index - Pillar 12 - Innovation	2016	aggregate index	World Economic Forum Global Competitiveness Index

2.2d. Carbon Disclosure Project - Average Disclosure scores. by country	2014	index	Carbon Disclosure Project
3. CIVIL SOCIETY PILLAR			
3.1 Civil Capacity			
Number of Admitted NGOs as observers to the COP; civil sector organizations	2016	count	UNFCCC
Number of Signatories to the UN Global Compact; civil sector organizations	2016	count	UN Global Compact
Environmental Democracy Index: Legal Score	2016	aggregate Index	Environmental Democracy Index
Environmental Democracy Index: Practice Score	2016	score	*see above*
World Bank Governance Indicators - Voice and Accountability	2015	aggregate index	World Bank Governance Indicators
Total number of registered economic Institutions	2017	count	EDIRC
OECD - Graduates by Field of Education - Environmental Protection	2011	count	OECD.stat
WEF Global Competitiveness Index - Pillar - Higher Education	2016	aggregate index	World Economic Forum Global Competitiveness Index
KPMG Global Change Readiness Index - civil society capability rank	2015	rank	KPMG
3.2 Civil Motivation			
Pew Global Opinion Survey - Concern about Climate Change	2015	rank	PEW Global
Yale Environmental Protection Index - Air Pollution Indicator - Average Exposure to PM2.5	2016	score	Yale Environmental Protection Index

Yale Environmental Protection Index - Air Pollution Indicator - Average Exposure to PM2.5	2016	score	*see above*