



Carbon prices under carbon market scenarios consistent with the Paris Agreement: Implications for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSA)

*Analysis conducted by Pedro Piris-Cabezas, Ruben Lubowski and Gabriela Leslie of the Environmental Defense Fund (EDF)**

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Executive Summary

This report analyzes alternative scenarios for the demand for and supply of greenhouse gas emissions units and the resulting carbon price ranges facing the Carbon Offsetting and Reduction Scheme for International Aviation (CORSA). The International Civil Aviation Organization (ICAO), the United Nations specialized agency for international air transport, agreed on CORSA in 2016 as part of a package of policies to help achieve its goal of carbon-neutral growth for international aviation over 2021-2035.¹ The current study explicitly examines emissions unit demand and supply in the context of broader carbon markets expected to emerge as the 2015 Paris Agreement² moves forward.

The projected demand for emissions units from the implementation of CORSA is based on an interactive tool from the Environmental Defense Fund (EDF) that estimates overall coverage and demand from CORSA in light of current levels of anticipated participation.³

We estimate carbon prices by applying EDF's carbon market modeling framework to consider various scenarios for domestic and international emission trading. The EDF carbon market tool balances demand and supply of emissions reductions from multiple sources and sectors in a dynamic framework.

We examine the price of emissions reduction units in CORSA in a context where airlines will face competing demand for units from other sectors covered under each nation's current Nationally Determined Contributions (NDC) pledges. As demand for emissions units from other sectors is established by the NDC pledges, all units estimated to be available for aviation are analyzed "net of" NDC obligations and therefore not double counted. While beginning to bend absolute emissions downward, the ambition embodied in

¹ ICAO Resolution A39-3: Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme, available at: https://www.icao.int/environmental-protection/Documents/Resolution_A39_3.pdf

² Text available at http://unfccc.int/paris_agreement/items/9485.php

³ The tool is available at: <https://www.edf.org/climate/icaos-market-based-measure>. Anticipated participation is at <https://www.icao.int/environmental-protection/Pages/market-based-measures.aspx>

the current NDC pledges follows a trajectory that achieves less than a quarter of the reductions needed for the pathway consistent with at least an even chance of keeping global temperatures from rising more than 2°C. As a result, in addition to modeling this scenario with the current NDC ambition, we also model supply, demand and price in a more stringent scenario where the market participants anticipate the ratcheting-up of NDC ambition and in a scenario consistent with 2°C. This scenario underscores that achieving the Paris two-degree objective will require significantly more mitigation, an event that market participants could anticipate when adopting mitigation strategies, resulting in higher carbon prices than are likely to emerge with the current NDC pledges.

Table 1 and 2 below summarize CORSIA's modeled carbon price signals under alternative scenarios for expanding international carbon markets under the Paris Agreement. 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 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.

While anticipation of a future transition to greater mitigation action thus raises modeled carbon prices, in practice, 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 and resulting prices. We introduce regulatory uncertainty into the analysis in the form of a gradually declining risk-premium on mitigation investments and, as an illustration, conduct a sensitivity test of the "intermediate" ambition scenario. With regulatory uncertainty that limits market anticipation, the modeled carbon price starts at \$6.3/tCO_{2e} in 2020 (compared to the \$19.4 with full certainty), but then rises faster, growing annually at 5% plus the risk premium, to reach \$72.8/tCO_{2e} in 2035 (compared to \$40.3 in the full certainty case).

We also consider the sensitivity of prices to the availability of emissions units from Reduced Emissions from Deforestation and forest Degradation (REDD+), a potentially large and cost-effective source of emissions reductions. The availability of REDD+ has an important influence on carbon prices, with carbon prices doubling from \$3.7 to \$7.4 in the NDC scenario without integration of REDD+ in the international market.

Finally, in light of the political hurdles to linking markets and differences in market-readiness of potential participating countries, we examine how scenarios for a less-than fully integrated global carbon market might affect carbon price paths for CORSIA in the medium term. Less-than-global scenarios for market development result in slightly higher carbon prices as the potential gains from trade are constrained. For example, under our partial market scenarios with "cost break-even" ambition worldwide and a larger supply of units, carbon market prices range between \$11.4 and \$14.2 per ton of CO_{2e} in 2020, rising 5% per year afterwards.

Carbon prices facing CORSIA will thus depend on the evolution of mitigation ambition and integration of international carbon markets in a context where airlines will face competing demand for emissions units from other sectors as the Paris Agreement moves forward. Given the relatively small demand for emissions reductions from international aviation (1.4% of the "intermediate" global mitigation ambition scenario considered), we conclude that airlines in CORSIA will likely be carbon-price "takers" (as contrasted with carbon-price "makers") at least in the mid- to long-term when international carbon markets are expected

to be more developed than to date. Nevertheless, in the nearer term, CORSIA might be able to benefit from access to cost-effective units (e.g. REDD+) prior to their full integration into other markets. CORSIA's regulatory certainty could also give airlines a comparative advantage in accessing units when carbon prices could be relatively low due to lack of regulatory certainty.

Table 1. Summary of modeled carbon prices under alternative global market scenarios (\$/tCO₂e).

Market Scope	Mitigation Ambition	Anticipation	REDD+	2020	2025	2030	2035
Global	Current NDC	Full	Global	\$3.7	\$4.7	\$5.9	\$7.6
	Current NDC	Full	None	\$7.4	\$9.4	\$12.0	\$15.3
	Extended ambition (cost break-even)	Full	Global	\$10.4	\$13.2	\$16.9	\$21.6
	Intermediate ambition	Full	Global	\$19.4	\$24.7	\$31.6	\$40.3
	Intermediate ambition	Limited	Global	\$6.3	\$20.0	\$45.2	\$72.8
	Compatible with 2°C	Full	Global	\$33.9	\$43.2	\$55.2	\$70.4

Note: Mitigation ambition scenarios described in text below. The limited anticipation scenario introduces regulatory uncertainty via a decreasing risk premium for carbon market investments.

Table 2. Summary of modeled carbon prices under alternative partial market scenarios (\$/tCO₂e).

Market Scope	Mitigation Ambition	Anticipation	REDD+	2020	2025	2030	2035
'Heat map' scenario	Current NDC	Full	None	\$9.2	\$11.8	\$15.0	\$19.2
	Current NDC	Full	Limited	\$6.6	\$8.4	\$10.8	\$13.7
	Extended ambition (cost break-even)	Full	Limited	\$13.5	\$17.2	\$22.0	\$28.1
	Extended ambition (cost break-even)	Full	Extended	\$11.6	\$14.8	\$18.9	\$24.1
Asia-Pacific scenario	Current NDC	Full	None	\$11.0	\$14.0	\$17.8	\$22.8
	Current NDC	Full	Limited	\$9.5	\$12.1	\$15.4	\$19.7
	Extended ambition (cost break-even)	Full	Limited	\$15.8	\$20.1	\$25.7	\$32.8
	Extended ambition (cost break-even)	Full	Extended	\$11.4	\$14.6	\$18.6	\$23.8
Americas scenario	Current NDC	Full	None	\$13.5	\$17.3	\$22.0	\$28.1
	Current NDC	Full	Limited	\$8.4	\$10.8	\$13.7	\$17.5
	Extended ambition (cost break-even)	Full	Limited	\$16.6	\$21.1	\$27.0	\$34.4
	Extended ambition (cost break-even)	Full	Extended	\$14.2	\$18.2	\$23.2	\$29.6

Note: Mitigation ambition and partial market scope scenarios are described in the text below. 'Limited' REDD+ scenarios include REDD+ limited to the countries within the "Heat map," "Asia-Pacific" and 'Americas' market scenarios, respectively, while the "extended" REDD+ scenarios include additional REDD+ from other regions.

Modeling framework

We apply a partial equilibrium model of carbon markets to examine emissions trends and abatement opportunities from 2017 through 2035 across the 28 European Union (EU) countries and 34 other countries/regions, encompassing the energy, transportation, industry, and forest and land-use sectors. We model the international carbon market using the EDF carbon market tool, which balances demand and supply of emissions reductions from multiple sources and sectors in a dynamic framework. The market demand for emissions permits derives from the overall limits on greenhouse gas (GHG) emissions established by governments, and the evolution of these limits over time. The supply is an aggregation of the estimated marginal abatement costs (MACs) for each year from the different sectors and geographic regions that are part of the modeled market.

The model solves for an inter-temporal equilibrium in which two conditions are met in every year:⁴ (1) the market clears (i.e., the quantity of credits demanded at the current price, including banked tons, equals the quantity supplied at that price); and (2) the present value of the international credit 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 (as discussed further below). As a sensitivity scenario, we also model the carbon market based on a “risk premium,” on top the real interest rate of 5%. The “risk premium” gradually declines over time, lowering the benefit of banking emissions reductions for use in future periods compared to the case with full market certainty

We ground our analysis in the emissions projections and estimated MACs from the Prospective Outlook on Long-term Energy Systems (POLES) model, a global energy-economic simulation model widely used by the European Commission that examines the energy, transport, and industry sectors, including CO₂ as well as non-CO₂ gases. These data were obtained from Enerdata, a firm that updates and commercializes the estimates. We supplemented the data from POLES with estimates for the costs of Reducing Emissions from Deforestation and Degradation (REDD+), based on the global land-use modeling cluster of the International Institute of Applied Systems Analysis (IIASA).⁵ Emissions from the global agricultural sector were added into the estimate of global business as usual (BAU) emissions based on projections from the Food and Agriculture Organization (FAO) of the United Nations,⁶ but mitigation potential from agriculture was not included in this analysis.

Global mitigation ambition in perspective

The starting point of our analysis is a projection of BAU emissions and an estimate of current mitigation ambition under each nation’s current Nationally Determined Contributions (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

⁴ The carbon market modeling methodology is further detailed in Piris-Cabezas, P. and N. Keohane. 2008. “Reducing Emissions from Deforestation and Forest Degradation: Implications for the Carbon Market.” Environmental Defense Fund. Washington, DC.

⁵ Results are described in: Gusti, M., N. Khabarov, and N. Forsell. (2015). “Sensitivity of marginal abatement cost curves to variation of G4M parameters.” In: Proceedings, 4th International Workshop on Uncertainty in Atmospheric Emissions, 7-9 October 2015, Krakow, Poland. pp. 152-158 Warsaw, Poland: Systems Research Institute, Polish Academy of Sciences. ISBN 83-894-7557-X.

⁶ Data available at: <http://www.fao.org/faostat/en/#data/GT/visualize>

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).⁷ The projection of BAU emissions includes BAU emissions from international aviation based on ICAO's central forecast and assuming CORSIA generates a carbon price signal that generates enough in-sector reduction in combination with other measures and policies to be consistent with the potential contribution from technology improvements, and improved air traffic management (ATM) and infrastructure use considered in ICAO's optimistic scenario⁸.

The black line in Figure 1 below shows global BAU emissions across all sectors including international aviation⁹, and 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 CO₂e¹⁰ relative to BAU from 2020 through 2035, with over a quarter (27%) of these reductions stemming from estimated reductions 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, which is a pathway that appears consistent with at least an even chance of keeping global temperatures from rising more than 2°C¹¹. 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 CO₂e, respectively. The analysis underscores that achieving the Paris two-degree objective will require significantly more mitigation, and hence higher costs.

According to EDF's interactive tool for CORSIA, the estimated demand under current country participation pledges is around 2.5 billion tons through 2035. CORSIA demand for abatement units is relatively small and amounts to 3.3% of the total reductions under the ambition level of the NDC, 1.4% of the "intermediate" scenario, and 1% of the "2°C" scenario. Given the relatively small demand, we can conclude that CORSIA will be carbon-price taker at least in the mid- to long-term when carbon markets are expected to be more developed than to date, and that CORSIA's regulatory certainty could give airlines a comparative advantage in the short-term when carbon prices could be relatively lower due to lack of regulatory certainty.

⁷ Forsell N, Turkovska O, Gusti M, Obersteiner M, Elzen M den, Havlik P. (2016). "Assessing the INDCs' land use, land use change, and forest emission projections." Carbon Balance and Management;11:26.

⁸ The 2.5 GtCO₂ demand relies on the assumption of substantial fuel efficiency improvements (both from aircraft technology, ATM and ATM).infrastructure use). Those improvements will be encouraged by either the set of policies ICAO and States have adopted (such as the CO₂ Standard) and/or the carbon price signal under CORSIA. If the carbon price signal is weak and the complementary measures do not deliver significant fuel efficiency improvements, demand from CORSIA will be higher than 2.5 GtCO₂e ICAO's scenarios are described in: https://www.icao.int/Meetings/a38/Documents/WP/wp026_en.pdf

⁹ International shipping is not included in these scenarios at this time. We hope to include it in a future iteration.

¹⁰ All emissions figures in this analysis are in metric tons of CO₂-equivalent using standard 100-year global warming potentials.

¹¹ This follows the Energreen scenario from Enerdata.

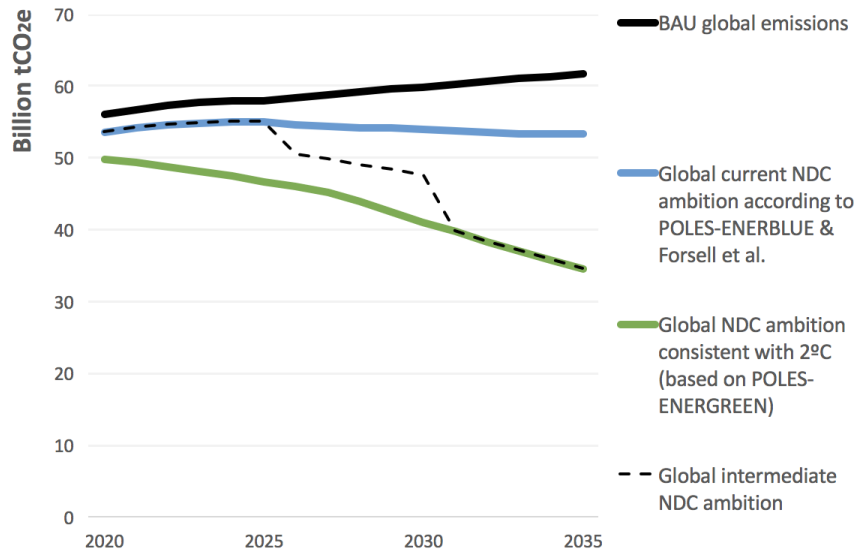


Figure 1. Global emissions under BAU, NDCs under the Paris Agreement, and ambition consistent with a 2°C limit.

We model the international carbon market under the three ambition scenarios using the EDF carbon market tool, which balances demand and supply of emissions reductions from multiple sources and sectors in a dynamic framework. We solve the model using a mid-term 2035 time-horizon to match CORSIA’s time-horizon and to constrain the impact future compliance periods might have in the near-term.

Figure 2 below depicts the global carbon price estimates and provides a broad range of carbon prices. The lower bound and the upper bound are set by the current NDC ambition pledges scenario and the “2°C” scenario with a carbon price of \$3.7/tCO₂e and \$33.9/tCO₂e in 2020 (rising 5% per year afterwards) respectively. The intermediate ambition scenario results in a carbon price of around \$19.4/tCO₂e in 2020 rising 5% per year afterwards.

The lower bound carbon price thus corresponds to a scenario in which market actors do not consider any the future ratcheting-up of ambition and therefore delay potentially cost-effective emissions reductions. If market actors anticipate the future ratcheting-up of ambition and are able to “bank” or save emissions units for use in the future, they could have incentives to act early to take advantage of lower-cost abatement opportunities, in order to avoid future cost increases. Forward-looking actors would thus accelerate their mitigation investments, with significant further potential to help close the near-term ambition gap relative to the 2°C objective of the Paris Agreement and raising the associated carbon prices.

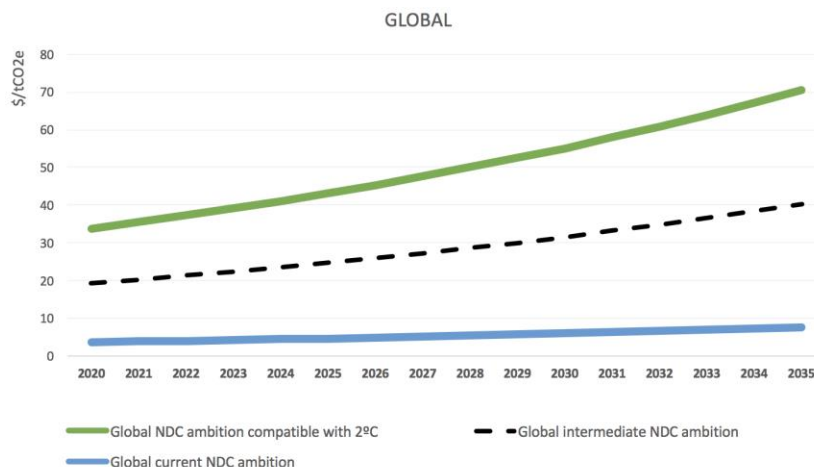


Figure 2. Global carbon price estimates as a function of NDC stringency using EDF partial equilibrium model with banking (intertemporal optimization) and 2035 as time horizon.

While anticipation of a future transition to greater mitigation action thus raises modeled carbon prices, in practice, 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 and resulting prices. We introduce regulatory uncertainty into the analysis in the form of a gradually declining risk-premium on mitigation investments and, as an illustration, conduct a sensitivity test of the “intermediate” ambition scenario.

The modeled “risk premium” 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. 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 2030.¹² 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.

Figure 3 depicts the carbon price for the intermediate NDC ambition scenario, with different responses of market participants to future demand. With regulatory uncertainty that limits market anticipation, the modeled carbon price starts at \$6.3/tCO₂e in 2020 (compared to the \$19.4 with full certainty), but then rises faster, growing annually at 5% plus the risk premium, to reach \$72.8/ tCO₂in 2035 (compared to \$40.3 in the full certainty case).

¹² The use of 20% interest rate is consistent with analyses of the risk premium embedded due to policy uncertainty under the European Union Emissions Trading System (EU ETS) from: P. Piris-Cabezas and R. Lubowski. (2013). “Increasing Demand by Raising Long Term Expectations: The Importance of a 2030 Target for the European Union’s Climate Policy.” Environmental Defense Fund. Washington, DC.

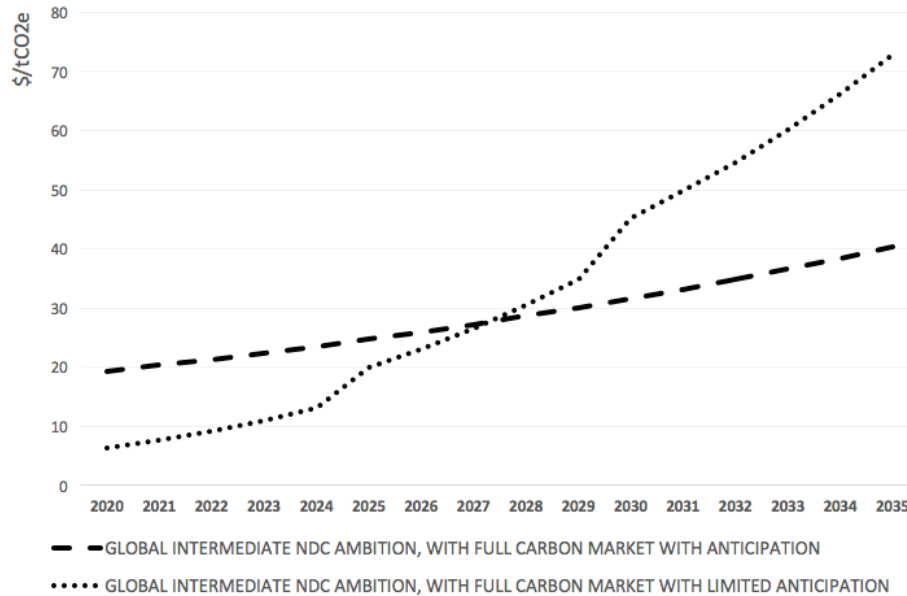


Figure 3. Carbon price for global coverage, with different responses of market participants to future demand (Intermediate NDC ambition)

The lower bound carbon price in Figure 2 is the result of (1) the low emissions reductions estimated for the current NDC scenario fall well short of what would be necessary to put the world on a trajectory consistent with an even chance of keeping the rise in average global temperatures below 2°C by the end of the century (the stated objective of the Paris Agreement), and (2) the significant contribution of global carbon markets to reduce compliance costs and the marginal carbon price.

In practice expanding the use of carbon markets internationally linked would likely only occur under a scenario involving an increase in ambition worldwide, notably among the countries with relatively low NDC ambition pledges. Otherwise countries and regions with relatively stringent NDC pledges will not be willing to link their carbon markets internationally. As a result, we understand that the lower bound carbon price in Figure 2 is not representative. In the next section, we explore alternative lower bound carbon price references derived from an increase in ambition as a result of the gain from international carbon markets.

Carbon markets with fully global coverage and increased ambition based on cost-savings derived from international linking

Starting from the NDC ambition scenario described above, we analyze the costs of meeting these targets and the resulting carbon price under different scenarios for carbon market coverage and integration with and across countries. We then consider a set of idealized scenarios of global market coverage and perfect information of market actors, and estimate the potential cost savings and associated potential to increase climate ambition relative to the base case to determine representative carbon price pathways. These scenarios provide a benchmark for analyzing cases based on potentially more realistic assumptions, with more restricted market development, considered in the next section.

Domestic markets. We consider the case where each country can meet the cumulative reductions required

by its NDC at least cost domestically via a carbon market or other carbon pricing approach that achieves its target at least cost. Our model ensures MACs 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 effectiveness¹³.



Figure 4. Net present value of compliance costs for the period 2020-2035 (Billion US\$)

Full global markets, including and not including REDD+. We 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 two additional cases. In the first case, market actors can use emissions reductions from land-use for their own NDCs but can only trade internationally those emission reductions that originate in the energy, transport, and industry sectors. We then examine the added benefit of allowing international trading of REDD+ reductions. In each case, we constrain the model such that the market utilizes only REDD+ that is achieved at-scale, i.e., at jurisdictional level; is done in accordance with the multilaterally agreed Warsaw Framework for REDD+;¹⁴ and results in reductions beyond those identified in NDCs.

In the first case, that is, of a fully global carbon market channeling the same total global resources in the most cost-effective fashion, the inclusion of REDD+ - restricted to domestic use only - could lower total costs by an estimated 62% (Figure 4)—from over half a trillion to \$197 billion current dollar terms. In the second case, that is, of a fully global carbon market that includes international transactions in REDD+,

¹³ For a discussion on the cost-effectiveness of banking see: V. Bellassen, R. Crassous, L. Dietzsch and S. Schwartzman, “Reducing Emissions from Deforestation and Degradation: What Contribution from Carbon Markets?”, *Research on the Economics of Climate Change* Issue n°14 (September 2008), available at http://www.cdclimat.com/IMG/pdf/14_Etude_Climat_EN_Deforestation_and_carbon_markets.pdf

¹⁴ The Nineteenth Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP 19), held in November 2013 in Warsaw, Poland, adopted the 7 decisions of the Warsaw Framework for REDD-plus. See http://unfccc.int/land_use_and_climate_change/redd/items/8180.php

modeled costs fall an additional 43% from \$197 to \$111 billion, such that overall cost savings are 79% relative to the base case (Figure 4).

Why does international trading, whether including REDD+ or not, result in the significant cost savings shown in Figure 4? These costs savings arise because there is a large spread in both the cost of mitigation opportunities and of NDC ambition across countries (and in some cases across sectors at the country level), resulting in lack of cost-effectiveness globally. Figure 5 below shows the wide spread in modeled carbon prices under countries' current NDCs.

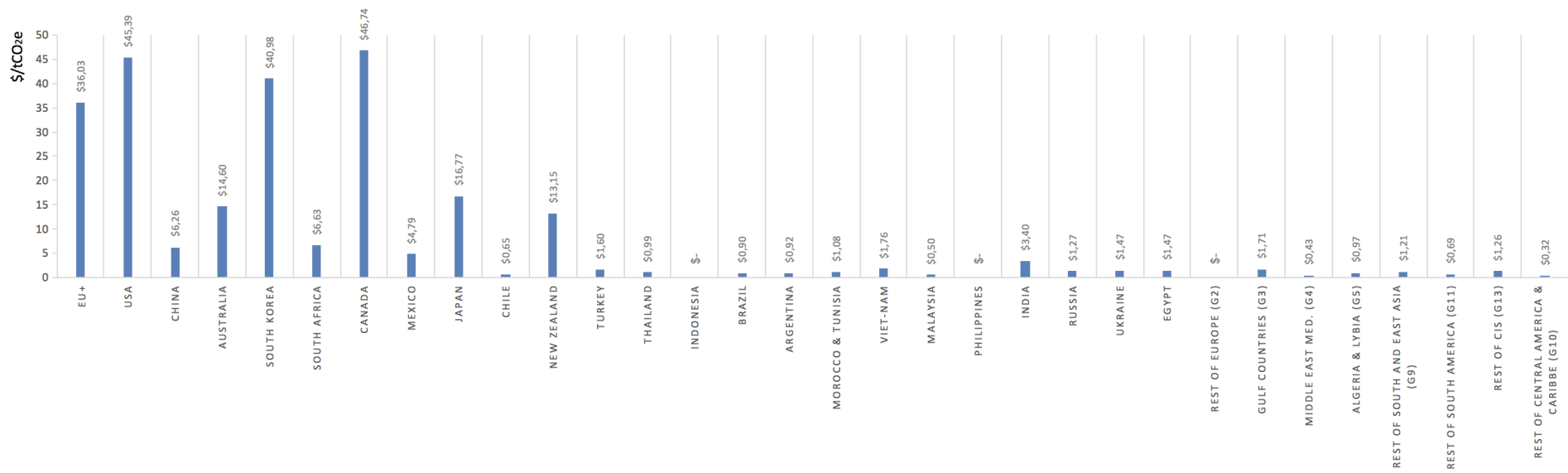


Figure 5. Spread in ambition across countries, as shown by estimated carbon price in 2020, assuming domestic trading across energy and industry. (\$/tCO₂e)

The potential cost savings results are robust to a sensitivity analysis in which market actors are uncertain about the future and therefore delay emissions reductions relative to the least-cost scenario. As noted above, we model such a case based on 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. This added realism increases costs to \$131 billion (in current dollar terms) in the case of a full global market, still achieving 95% of the cost savings as under the case of full certainty and thus enabling equivalent increases in the level of mitigation ambition.

Translating the prospective costs savings into the potential for greater climate ambition, while still “breaking even” on costs relative to the base case, results a representative carbon price pathway (Figure 6). Global trading 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 CO₂e, 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 (92%) relative to the base case, while keeping total costs the same¹⁵.

Because of its large potential and relatively low cost, we find that market-based national-scale REDD+ (REDD+ for short) 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 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. This is in addition to achieving 27% of the reductions already included in the base case for meeting 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.

Figure 6 depicts the modeled marginal carbon prices for the global markets, including and not including REDD+ as well as for the case of global “cost break-even” ambition with full global trading.

¹⁵ P. Piris-Cabezas and R. Lubowski. (2018). “Catalyzing carbon markets globally to realize the promise of Paris: The power of markets to increase ambition.” Environmental Defense Fund. Washington, DC. Manuscript.

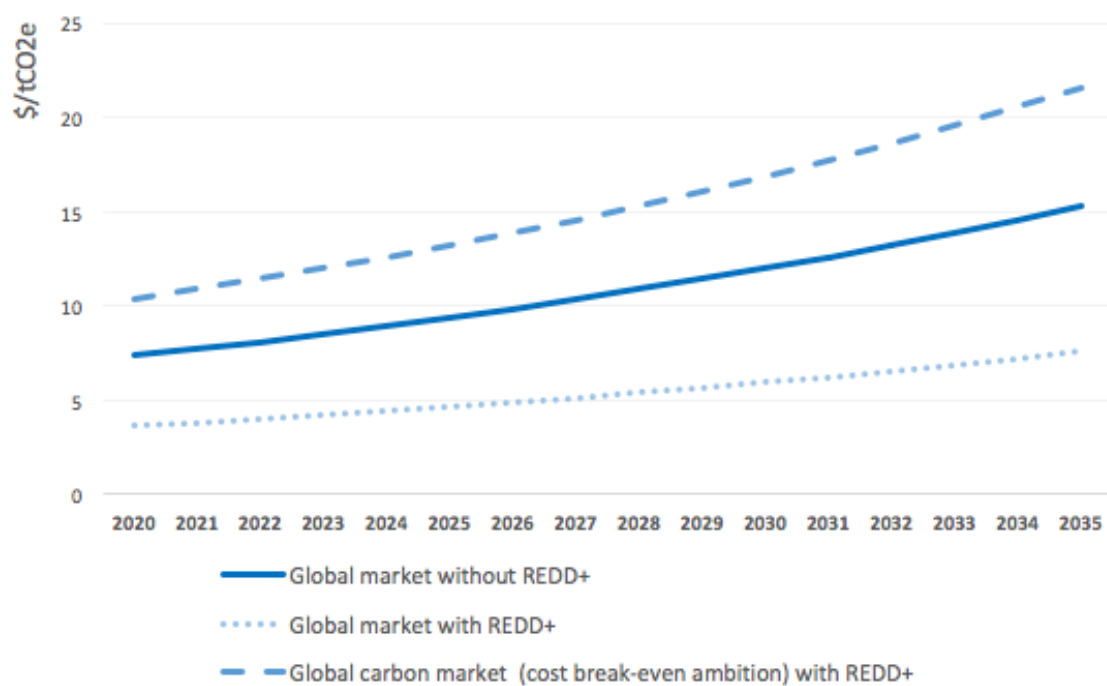


Figure 6. Global carbon market: Carbon price 2020-2035.

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.

If forward-looking market actors can credibly anticipate the eventual ratcheting-up of ambition, they would have incentives to take early action to avoid future cost increases. This has the potential to close the near-term ambition gap further. 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.

On the other hand, 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. As a result, the next section considers the robustness of results for more limited scenarios for international carbon market development.

International carbon markets with partial global coverage

In this section we consider three cases for partial market development, building from a “heat map” ranking countries by their societal readiness and strategic value with respect to carbon market pricing advocacy¹⁶. 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.

¹⁶ G. Leslie and R. Lubowski. (2018). “Strategic assessment of priority jurisdictions to advance carbon pricing: A carbon markets heat map” Environmental Defense Fund. Washington, DC. Manuscript.

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.

Global ‘heat map’ market 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. 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 the forest sector.

Asia-Pacific market 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 imagined to catalyze coverage of all sectors 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 market 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 7a, 7b and 7c below.

Figure 7a: Global ‘Heat Map’ Market Scenario

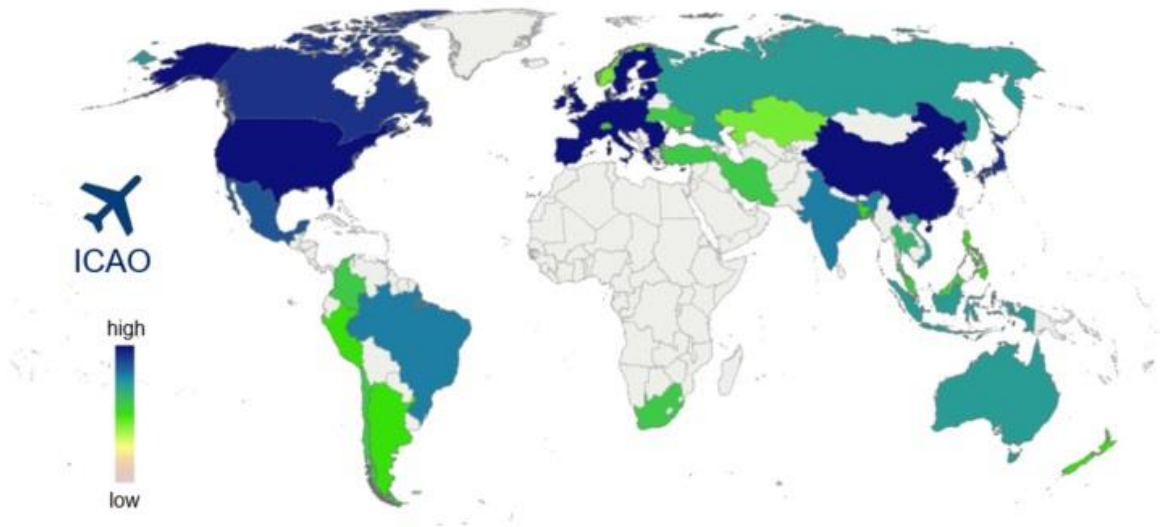


Figure 7b: Asia-Pacific Market Scenario

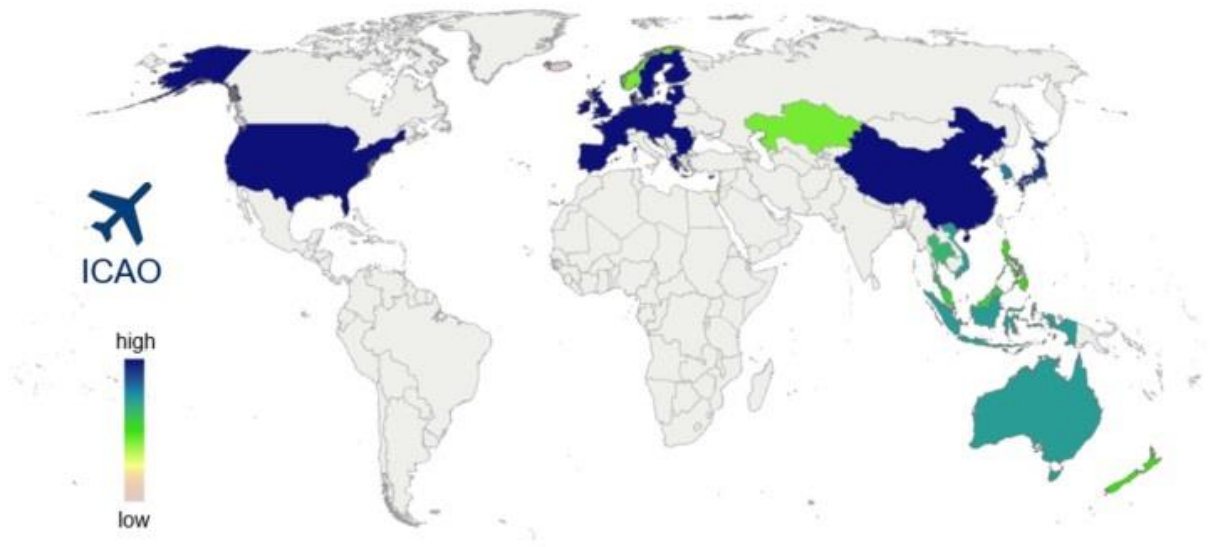
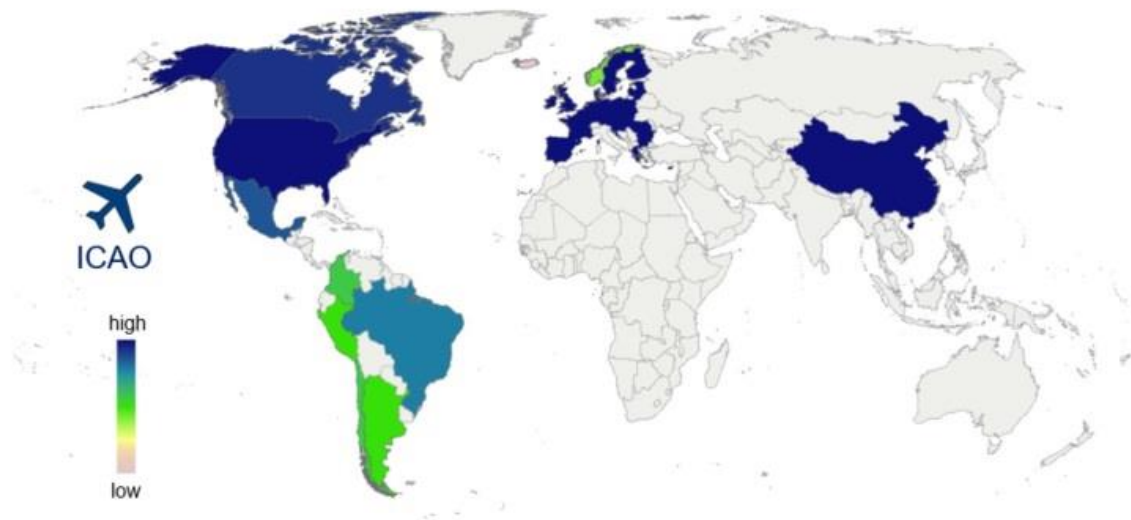


Figure 7c: Americas Market Scenario



Figures 7 a, b, c. Countries under ‘heat map’ (7a), Asia-Pacific (7b) and Americas (7c) market scenarios.

Note: Scenarios are based on top-ranked countries from ‘heat map’ analysis discussed above, with colors based on the associated score for each country, ordered from lowest (pink) to highest (dark blue), as shown in scale to left of maps. All scenarios include the international aviation market (under ICAO). Coverage of EU is limited to the power and industrial sectors in the Asia-Pacific and Americas market scenarios. Coverage of the US and China is limited to the power and industrial sectors in the Asia-Pacific and Americas market scenarios, respectively. Unless otherwise noted, coverage is economy-wide.

As before, to estimate the representative carbon price, we analyze the cost savings possible under these scenarios relative to the base case of current policies and measures consistent with the NDCs, and examine the potential to reinvest these savings in raising global mitigation ambition while breaking even on costs.

We find that the global heat map, Asia-Pacific, and Americas scenarios reduce costs by 51%, 49%, and 51%, respectively, 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+.

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 2 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.

Additional REDD+. Given the pivotal role of REDD+, we also model scenarios where the limited

global markets described above open up additional REDD+ from the rest of the world.¹⁷ The Americas and Asia-Pacific scenarios lead to 47% and 52% of global coverage by carbon markets by 2030, respectively.

These scenarios are consistent with the overall goal of the High-Level Commission on Carbon Prices to double the coverage of carbon pricing by 2020 and double again within the next decade to reach 50% coverage of emissions by 2030. An initial examination of potential scenarios for meeting this objective was provided in EDF-IETA (2016).¹⁸

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.

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. In these cases, the world can reach about 80% and 92% of the total reductions under the full trading case¹⁹.

Figure 8 below provides an overview of the resulting carbon prices for all the scenarios considered under this section. These are summarized in Table 2 above. 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 CO₂e 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 CO₂e in 2020 rising 5% per year afterwards.

Figure 8a: Global 'Heat Map' Market Scenario

¹⁷ In the Asia-Pacific case, we consider additional REDD+ net of NDC from Brazil, Mexico, Colombia, Peru and 50% of the rest of the world. In the Americas case, we consider additional REDD+ net of NDC from Indonesia, Thailand and Malaysia and 50% of the rest of the world.

¹⁸ EDF-IETA (2016). *Doubling Down on Carbon Pricing: Laying the Foundation for Greater Ambition*. Environmental Defense Fund and International Emissions Trading Association. Washington, DC (2016).

¹⁹ P. Piris-Cabezas and R. Lubowski (2018) "Catalyzing carbon markets globally to realize the promise of Paris: The power of markets to increase ambition." Environmental Defense Fund. Washington, DC. Manuscript.

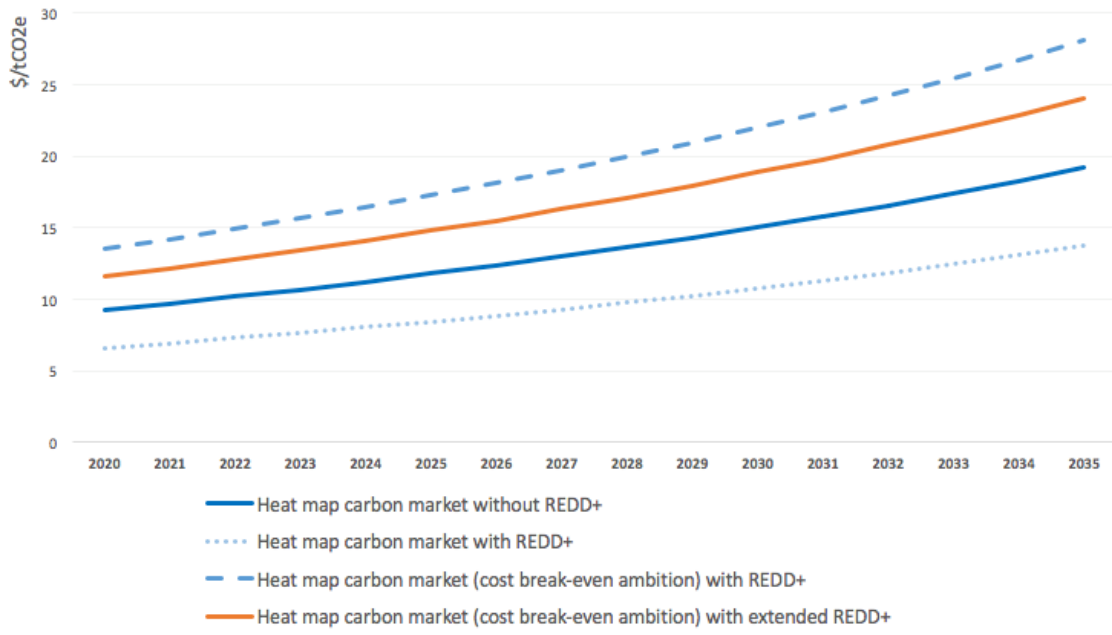


Figure 8b: Global 'Asia-Pacific' Market Scenario

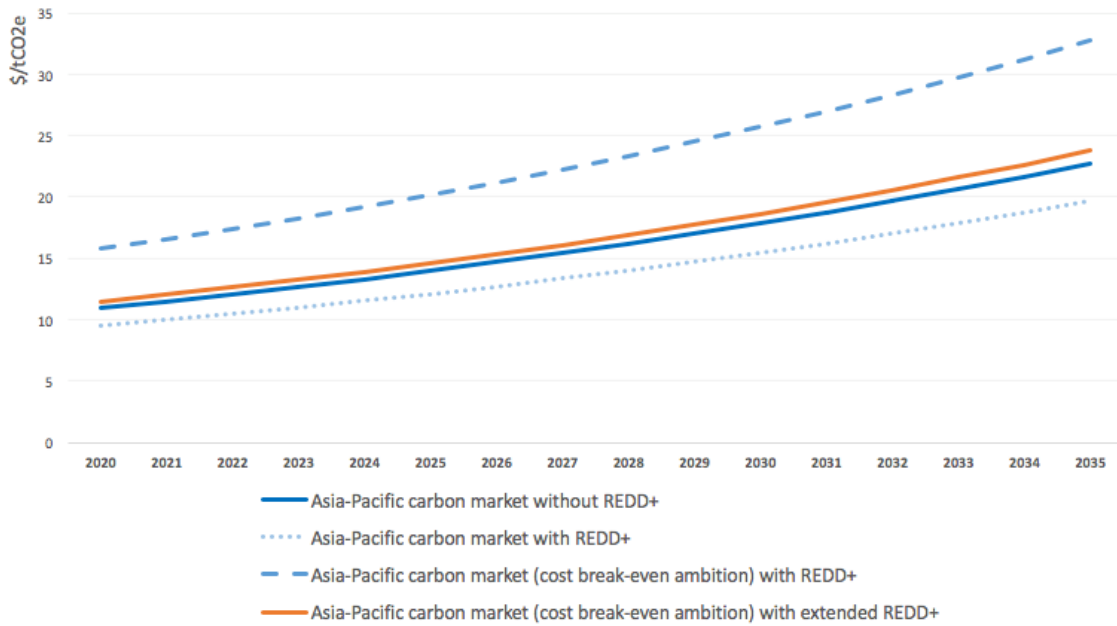
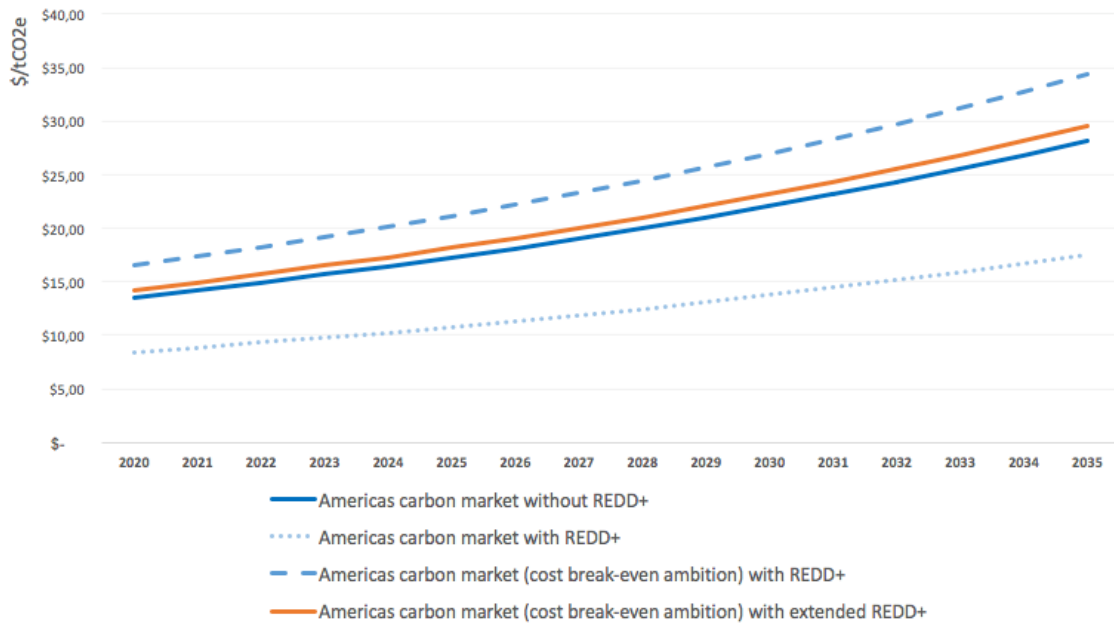


Figure 8c: Global 'Americas' Market Scenario



Figures 8 a, b, c. Carbon price scenarios for “Heat map” (8a), Asia-Pacific (8b) and Americas (8c) market scenarios: Carbon price 2020-2035 (\$/tCO₂e)

Conclusion

The foregoing analysis indicates that in a context where airlines will face competing demand for emissions units from other sectors as the Paris Agreement moves forward, airlines in CORSIA will likely be carbon-price “takers” (as contrasted with carbon-price “makers”) at least in the mid- to long-term when carbon markets are expected to be more developed than to date. The analysis is sensitive to the ambition of Nationally Determined Contributions (NDCs) under the Paris Agreement – stronger NDCs could drive carbon prices upward, and airlines may wish to anticipate those kinds of shifts. The analysis also finds that “banking,” or the ability to save unused emissions units for use in future years, makes a significant difference in the prices airlines may face.

The analysis finds that price is sensitive to the inclusion of Reducing Emissions from Deforestation and Degradation (REDD+), particularly if REDD+ is available for international trading (as contrasted with domestic use only). Based on the consideration of a “heat map” indicating the rate at which jurisdictions are likely to move to carbon markets, the analysis also finds that CORSIA is sensitive to the rate of uptake of carbon markets globally. For the scenarios with full regulatory certainty, increased NDC ambition worldwide (in line with use of cost-savings from global trading), and the larger supply of units, carbon market prices range between \$11.4 and \$14.2 per ton of CO₂e in 2020 rising 5% per year afterwards. The analysis also suggests that CORSIA’s regulatory certainty could give airlines a comparative advantage in the short-term when not all units (e.g. REDD+) may be integrated into international markets and where carbon prices could be relatively low due in part to lack of regulatory certainty in other markets.