Cost-Effective Emissions Reductions beyond Brazil's International Target: Estimation and Valuation of Brazil's Potential Climate Asset*

August 24, 2016

EXECUTIVE SUMMARY

- Brazil could achieve its 2020, 2025 and 2030 emissions reductions at a cost of $26 billion (present value), based on opportunity costs of reducing deforestation and small, cost-effective reductions in other sectors;
- Implementing the Paris Agreement and a Market-Based Measure to neutralize emissions above 2020 levels from international aviation would increase demand for emissions reductions and, if effected through cap-and-trade systems, increase carbon prices substantially;
- Conservative projections of future carbon prices show that Brazil could exceed its existing targets (the 2020 target, and Nationally Determined Contribution (NDC) presented in Paris), and generate substantial revenue trading the surplus reductions;
- The value of the environmental asset created by exceeding the NDC target depends on carbon prices at the time reductions are sold or otherwise monetized. Making cost-effective reductions at modelled opportunity costs and carbon prices would generate net revenue of $19 billion (present value) from 2016 – 2020 (excluding the the estimated cost of restoring 12 million hectares of forest as proposed under the NDC).
- If Brazil invested more in achieving further near-term reductions (mostly pre-2020) it could capture higher future carbon prices using, e.g., appropriate financial instruments such as call options and generate an additional $27 billion net revenue (present value) at 2020 – 2030 carbon prices, and $40 billion at 2030-2035 carbon prices, resulting in a total net value of $36 to $58 billion (excluding the cost of reforestation).

INTRODUCTION

Having reduced Amazon deforestation by around 75% over the past decade relative to a historical level (1996-2005), Brazil has avoided more than 5.5 billion tons of CO_2 emissions and become the global leader in greenhouse gas emissions reductions.[1] Under the Paris Agreement, Brazil has made a pledge (its Nationally

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[1] Based on deforestation rates from PRODES –Brazil's satellite-based deforestation monitoring systems maintained by the National Institute for Space Research (INPE)— and carbon density assumptions and historical baseline described in Decreto nº 7.390, Dec. 9, 2010.

Determined Contribution; NDC), to reduce absolute economy-wide emissions relative to 2005 levels by 37% by 2025, with an indicative goal of reducing 43% by 2030. This paper summarizes modeling results on the costs and potential benefits of different scenarios for Brazil's achievement of its emissions reduction target over the period 2016-2030, considering opportunities to realize value for any reductions beyond its NDC. With access to international carbon markets or other appropriate climate finance mechanisms, Brazil could achieve net zero deforestation while creating new opportunities to finance green development and supporting—rather than hindering—Brazil's ability to meet its international climate commitments.

The Paris Agreement enables international trading of mitigation outcomes, under the proviso that any reduction can only be counted towards one party's international commitments (i.e. "no double counting"). This creates a distinction between mitigation outcomes that countries will need for their own NCDs and potentially surplus reductions that could have added value in an international marketplace. Brazil has the potential to cost-effectively achieve even more emissions reductions than are needed to meet this objective. The potential for these surplus emissions reductions represent an environmental asset that deserves both domestic and international recognition.

There are a number of options for compensating the surplus emissions reductions (Table 1). These options have advantages and disadvantages. The options that rely on existing mechanisms such as the Green Climate Fund, Public REDD+ or Budgetary contributions are either designed with limited lifespans and/or subject to competition with other multiple purposes, potentially limiting its feasibility. The options that could provide large volumes of resources in a sustainable fashion --namely, the Carbon Market and a Hybrid Public-Private Regime that combines both Public REDD+ and the Carbon Market -- currently face opposition from some sectors of the Brazilian Government. To inform discussions over potential financial approaches, this study provides estimates of the cost of achieving the emissions reductions necessary for meeting Brazil's INDC and quantifies an economic value to the potential surplus emissions reductions using projected international carbon prices as an indicator of the value of these reductions.

Table 1. Options for compensating surplus emissions reductions.

Options	Advantages	Disadvantages
Green Climate Fund	Approved by UNFCCC	Competition with multiple countries and purposes
Public REDD+	Another US$5 Billion approved in Paris	Limited lifespan
Budgets	Under the control of federal, state governments	Crisis, cuts, competing priorities
Carbon market	If Paris Agreement is implemented carbon prices are expected to rise. Long lifespan and large volume of resources	Opposition from some sectors of the Government
Hybrid Regime	Maximizes resources	Opposition from some sectors of the Government

We analyze the costs and potential climate asset value from different sets of scenarios for Brazil's achievement of its emissions reduction target over the period 2016-2030.[2] In particular, we evaluate the potential costs and benefits of a strategy where Brazil:

i) Achieves its NDC goals in 2025 and 2030 (based on a linear reduction pathway over intervening years) without generating any surplus emissions reductions (**Scenario 1**);
ii) Potentially generates a surplus beyond a multi-year budget based on achieving its NDC (**Scenario 2)**. This scenario considers mitigation options that are cost-effective, i.e., those with abatement costs equal to or lower than the forecasted carbon prices for the international market. We run sensitivity analysis for Scenario 2 and also estimate the carbon price for which the cost of all emissions reductions breaks even with the economic value of the surplus.
iii) Achieves further reductions from avoided deforestation and other cost-effective mitigation in the near-term and realizes value for them by capturing higher carbon prices forecasted in the future (**Scenarios 3 and 4**).

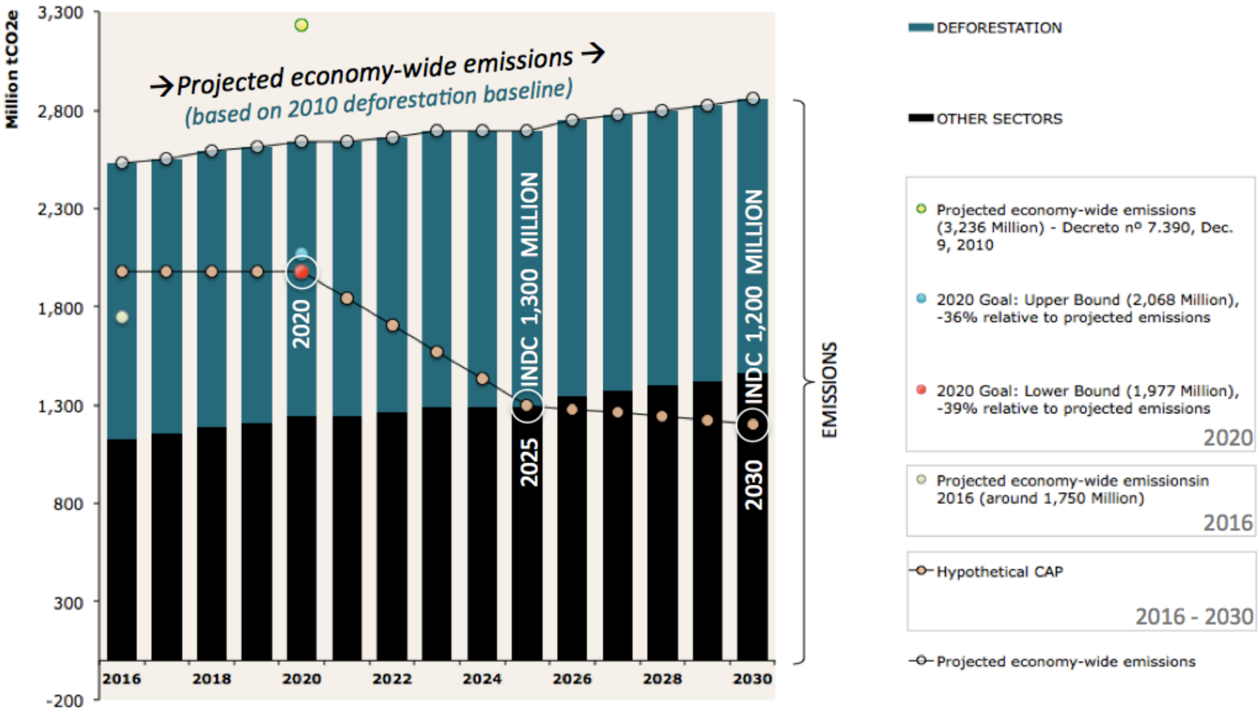
In order to determine the cost of reductions necessary to meet the NDC, the first step is to develop a reference case or "business as usual" (BAU) emission projection in the absence of policy. Second, in order to estimate any potential additional surplus reductions available across the Brazilian economy, we also must transform the current single-year targets adopted by Brazil into a hypothetical economy-wide multi-year emissions budget.

Reference case of projected emissions

We construct an economy-wide BAU reference case for emissions through 2030 assuming constant annual deforestation emissions according to the government's historical (1996-2005) baseline for deforestation, as per the approach for the Amazon Fund. As codified in Decree No 7.390, December 9, 2010, this baseline results in a reference case for deforestation emissions of 1,404 $MtCO_2$ per year. These deforestation emissions are shown as the blue bars in Figure 1. We adopt the BAU projection without any carbon price from the POLES model estimates for the energy, industry and transport in Brazil,[3] as well as BAU estimates for the agriculture and waste sectors from World Bank (2010). Total projected emissions from the non-forest sectors are shown as the black bars in Figure 1. Combining these forest and non-forest sector emissions total economy-wide emissions under the reference case (shown with light grey circles at the top of Figure 1) are 2.5 $GtCO_2e$ in 2016, rising by about 0.9% per year to 2.8 $GtCO_2e$ in 2030. The actual economy-wide emissions in 2016 are estimated to be around 1,750 $GtCO_2$ assuming that the actual deforestation rate is similar to that from previous years. This difference between current emissions and the reference level reflects the fact that deforestation emissions have already declined significantly relative to the official historical reference level.

[3] The POLES model is the result of the collaboration of: LEPII (formerly IEPE - Institute of Energy Policy and Economics in Grenoble, France); EC's Joint Research Centre, The Institute for Prospective Technological Studies (IPTS); and Enerdata. POLES is a world energy-economy partial equilibrium simulation model of the energy sector with 2050 as time horizon. It has complete modeling from upstream production to final user demand and greenhouse gas emissions. The simulation process uses year-by-year dynamic recursive modeling with endogenous international energy prices and lagged adjustments of supply and demand by world region.

Figure 1 – Projected economy-wide emissions and hypothetical economy-wide multi-year budget.



Source: EDF analysis based on POLES model, "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

Hypothetical multi-year emissions budget

We next construct a hypothetical multi-year emissions budget or cap, as shown as the line with orange circles in Figure 1, to be able to estimate the magnitude of any potential surplus not needed to meet Brazil's domestic commitments under the NDC as well as prior to 2020. We assume a hypothetical economy-wide multi-year budget for 2016-2030 drawing on the point targets in both the government's unilateral target from the National Climate Change Plan (NCCP) of 2008, which set a goal for 2020, and the intended nationally determined contribution (INDC)[4] submitted to the UNFCCC in 2015 in preparation for the Paris Agreement, which set goals for 2025 and 2030. For 2020 we consider the lower bound of government unilateral target of 1.977 billion tons of CO_2-equivalent ($GtCO_2e$), i.e., a 38.9% reduction relative to the projected economy-wide emissions of 3.236 $GtCO_2e$ in 2020, as enumerated in Brazil's federal law (Decreto nº 7.390, Dec. 9, 2010). For 2025 and 2030 we take the absolute targets from the NDC of 1.3 $GtCO_2e$ and 1.2 $GtCO_2e$ respectively[5]. The year-by-year limits on emissions are drawn assuming linear interpolation between consecutive point targets. Based on Brazil's pledged reduction relative to 2005 of 37% and 43% in 2025 and 2030 respectively, this hypothetical limit involves a cumulative total of required emission reductions below the modeled reference level of about 16.4 $GtCO_2e$ or about 1640 MtCO2e per year over 2020-2030.

In addition, for the period before the Paris Agreement's entry into force in 2020, we use the point target for 2020 as the basis for a flat reference line for any potential "early action" reductions achieved over the period 2016-2020. This ensures that any "early action" mitigation that could be achieved would only be considered "surplus" if it were not be double counted towards meeting the NCCP 2020 goal.

[4] http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf

[5] See discussion on the effect of updated 2005 emissions inventories on the INDC 2025 and 2030 goals in chapter 2.6, page 34 of the MILES report (2015):
Spencer et al. (2015), "Beyond the numbers: Understanding the transformation induced by INDCs", STUDIES N°05/2015. IDDRI - MILES PROJECT CONSORTIUM, 2015, available at: http://www.iddri.org/Publications/Collections/Analyses/MILES%20report.pdf

Estimating costs of achieving Brazil NDC

We estimate the least-cost solution for Brazil to meet its NDC (in scenario 2) and additional surplus reductions (scenarios 2-4). Our analysis for the costs of Brazil's mitigation potential and associated costs is based on estimated mitigation cost curves from different sources. We use cost curves based on the opportunity costs of avoiding deforestation across the Legal Amazon and all other biomes of Brazil from the SimBrazil model of Britaldo Soares-Filho at the Federal University of Minas Gerais. We consider mitigation costs from the POLES model for energy, industry and transport, and assume that the country can achieve reductions in emissions from agriculture (both livestock and cropland management) emissions as identified in the low-carbon case study scenario developed by the World Bank (2010). Similarly, we draw on World Bank (2010) for estimated mitigation cost curves from the waste sectors.

We also consider that Brazil achieves the increases in reforestation, with corresponding uptake of carbon, as required to meet its NDC. In particular, Brazil's NDC establishes a goal of restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes. This goal appears to include reforestation projects such as those required for compliance with Brazil's Forest Code as well as under the Plano ABC and the *Plano Setorial de Redução de Emissões da Siderurgia*. For illustration purposes, under the Forest Code – after accounting for the potential for non-compliance properties to achieve compliance with the Forest Code through a proposed compensation mechanism of "environmental reserve quotas" (*cotas de reserva ambiental*; CRA)— Brazilian landowners need to restore at least 11.8 million hectares in the coming years.[6,7] A large share of the 12 million ha goal would need to be in compliance with the requirements established under the Forest Code.

For the purpose of our analysis, we consider that two thirds of the 12 million hectares goal for 2030 is achieved through restoration purposes with native species, as required under the Forest Code, and the rest with plantations for other purposes. We assume a gradual expansion of the reforested areas to attain 12 million hectares by 2030. We assume that native species can sequester on average 2.59 tC/ha/year meanwhile commercial species 10 tC/ha/year[8], resulting in carbon sequestration of 1.8 $GtCO_2e$, cumulatively through 2030.

It is beyond the scope of this analysis to generate an estimate of the cost of restoration. According to estimates from Instituto Escolhas (2016), the net cost of reforesting 12 million ha is uncertain and would range from scenarios with negative costs to scenarios with net costs of up to $9 billion depending on the discount rate and the underlying assumptions.[9]

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[6] Soares-Filho et al., 2014, "Cracking Brazil's Forest Code", *Science*, 25 Apr 2014: 363-364

7 The 11.8 million hectares is the result of subtracting from the 21 million ha (ibid.) of mandatory restoration under the Forest Code the share that could be potentially abate through the CRA market –i.e., 56% of the Legal Reserve debt, which amounts to 78% of the total area that requires mandatory restoration (ibid.).

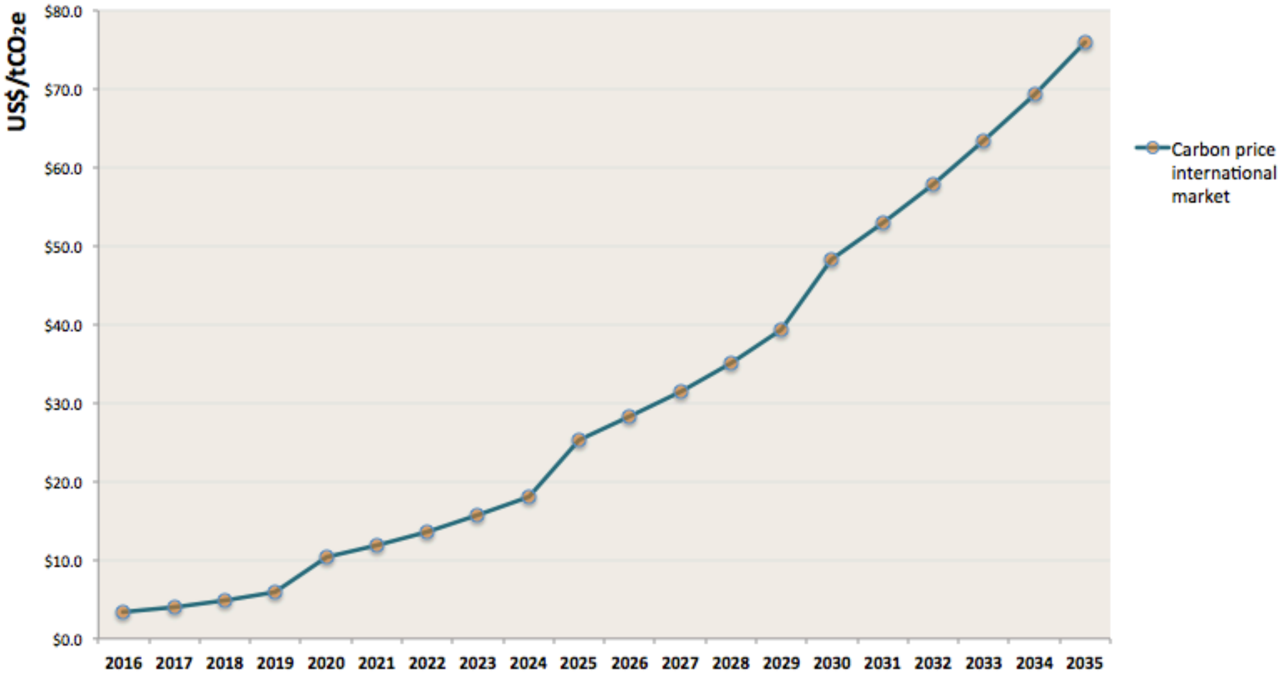
[8] Lima L., G. Reginato, D. Bartholomeu, "Levantamento de estimativas de absorção de carbono por florestas nativas e comerciais no Brasil", CEPEA, available at http://www.cepea.esalq.usp.br/pdf/DanielaBacchil03.pdf.

[9] For an estimate of the cost of restoration see Instituto Escolhas (2016) *How much does Brazil need to invest to recover 12 million hectares of forests?* São Paulo, Brazil. Available at: http://media.wix.com/ugd/92594f_d5afe32395f94b88be8aa5d4cd670c40.pdf (executive summary) and http://media.wix.com/ugd/92594f_b2ff80f3f82b4db3bf4388ad7d2ccbfd.pdf (full report). Instituto Escolhas provides estimates for the net cost of restoration ranging between US$5.7 billion and US$9 billion as a function of the shares of passive versus active restoration and the contribution of native species and commercial spices. These estimates imply a discount rate of 10%, a time horizon of 35 years and an exchange rate of US$ 1 for R$ 3.7. Lower discount rates result in smaller net costs and even negative costs as a result higher present value of future revenues from timber sales.

Modeling international carbon prices

For our scenarios 2-4, we consider the potential value that Brazil could realize from emissions reductions over and above the target level of the NDC. For this valuation, we develop an estimate of prices at which the international community will value reductions in carbon pollution over and above an NDC. In particular, we develop a projection of international carbon prices under a gradually evolving international policy environment consistent with the implementation of the Paris Agreement and measures to neutralize new emissions from civil aviation after 2020 (under negotiation in the International Civil Aviation Organization). We assume the implementation of the Paris Agreement involves a carbon market that gradually expands in terms of its coverage and the tightness of the emissions limits. Information about future climate policy is only incrementally revealed to market actors at 5-year intervals, in line with the ratchet mechanism of the Paris Agreement. Our projection of carbon prices is shown in Figure 3.

Figure 2– Estimated price for the global carbon market, with incrementally revealed information over climate policy



Note: Based on scenario and assumptions described in text, including 20-year rolling time horizon and interest or "discount" rate, starting at 20% over 2015-2020, falling to 15% over 2020-2025, and 10% over 2025-2030. Source: EDF analysis based on cost curves from the POLES model; "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

We model the international carbon market using the EDF carbon market tool, which considers the interaction of demand and supply of emissions reductions from multiple sources in an explicitly dynamic framework. The price and quantity of emissions permits each year is determined by the supply and demand for emissions reductions and the possibility of generating excess emissions reductions and saving ("banking") them for use in future periods is explicitly taken into account. The model solves for an inter-temporal equilibrium in which two conditions are met in every year: (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). The carbon market modeling methodology is further detailed in Piris-Cabezas and Keohane (2008) and Murray et al. (2009)[10].

The demand for emissions permits on the international carbon market is driven by the limits established by governments on greenhouse gas emissions and the evolution of these limits over time. The supply is given by the estimated marginal abatement costs for each year from the different sectors and geographic regions that are part of the market. For all countries other than Brazil, we use cost curves from the POLES model, for the energy, transport and industry sectors, as used by the European Commission for its international carbon market modeling[11,12]. We add cost curves for reducing deforestation from the rest of the world based on the global land-use modeling cluster of the International Institute of Applied Systems Analysis (IIASA), assuming a gradual phase-in through 2030.[13]

Between 2016 and 2019, the modelled international market includes California, and Canadian provinces (British Columbia, Manitoba, Ontario, Quebec), as well as early action crediting from Brazil. In 2020, Brazil adopts its emission reduction target and the EU, Norway, Switzerland, South Korea and international aviation sector join the global market. At the same time, we assume the rest of the world gradually phases into the market at the rate of 10% a year starting in 2020 to achieve a full global market by 2030. The gradual phase-in includes both potential buyers and sellers of reduced emissions from deforestation and forest degradation (REDD+) and other emission reductions from other developing countries.

With respect to the long-term stringency of international policy, we consider a scenario with global reductions for 2050 in line with the goal established by the G8 leaders at the July 9, 2009 Major Economies Forum. This calls for the G8 to reduce emissions by 80% or more by 2050 as part of a global reduction of 50% by 2050 relative to 2005 levels, with the aim of limiting warming to no more than two degrees Celsius above preindustrial levels. However, to model a gradual ramp-up of global policy, we assume a less ambitious global reduction trajectory up through 2030, which is on a straight line path between 2015 levels and a 25% reduction by 2050. The trajectory of the global cap then becomes steeper over 2030-2050. This global reduction scenario falls short of the long-term goals adopted in the Paris Agreement and results in conservative carbon price estimates.

If long-term targets are credible and anticipated, regulated entities have the incentive to over-comply with their current requirements and bank excess permits/credits for use in later periods when the carbon prices could be higher, as is likely the case with a tightening limits on emissions. When banking is allowed, rational expectations mean that allowance prices will increase at a constant rate of interest reflecting the real rate of return in the market. In our analysis, this interest rate is an exogenous parameter that must be chosen. If prices were expected to rise at any rate other than the market rate of return, this would provide systematic opportunities for investors to profit from buying or selling carbon permits. These profit opportunities would be expected to induce buying or selling until the arbitrage opportunities were eliminated. These assumptions are common practice in economic modeling of carbon markets.

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[10] Piris-Cabezas, Pedro and Nathaniel Keohane. 2008. "Reducing Emissions from Deforestation and Forest Degradation: Implications for the Carbon Market." Environmental Defense Fund. Washington, DC. Available at: http://www.edf.org/documents/7975_REDDandCarbonMarketAnalysisReport_EDF_0508.pdf.

[11] In particular, for this analysis we used updated cost curves released in October 2012 by ENERDATA. The POLES model generates worldwide MACCs broken down at the level of the main countries and regions (54 consuming countries + 12 regions) for the energy, industry, and transport sectors.

[12] The BAU estimates for energy consumption in Brazil is in line with the COPPE INDC no regrets scenario described in chapter 2.6 authored by researcher from COPPE UFRJ for the MILES report (see citation in footnote 5).

[13] For a detailed description of IIASA's global land-use modeling cluster see Gusty M., P. Havlik and M. Obersteiner. 2008. "Technical description of the IIASA model cluster", International Institute for Applied Systems Analysis, Laxenburg, Austria. Available at:http://www.obt.inpe.br/prodes/index.php

We adjust the standard modeling framework described above so as to provide more realistic analysis of how the carbon market is evolving and may continue to develop over the coming decades. As described further in Golub et al. (2016),[14] in the real world, market actors do not have perfect foresight and face significant uncertainties regarding what climate policies and mitigation costs will look like in 2020, through 2030, or beyond. These uncertainties create incentives to defer purchases and banking of emissions units and other investments that could result in sunk costs. This is consistent with empirical evidence that policy risk is depressing carbon prices in existing carbon markets, such as the European Union (e.g. Koch et al. 2014, 2016)[15].

To account for this reality, our modeling of the international market context limits the typical assumption of perfect foresight by modeling a global carbon policy that is only incrementally revealed to market actors. This step-wise learning about policy means market actors face uncertainty about the future and cannot select their most cost-effective mitigation strategy and levels of banking once and for all but, rather, need to adjust to new information as it arrives. Market actors face the risk of significant adjustment costs if prices go higher (or lower) than anticipated and thus have incentives to manage the potential risks through instruments such as option contracts, rather than direct purchases of credits.

To model this step-wise pattern of learning, we introduce a risk premium on top of the modeled interest rate, which is a key input into the model and assume it decreases in 5-year intervals matching the ratchet mechanism of the Paris Agreement, as greater certainty over the future emerges.

We assume a risk-free (real) interest rate of 5% and a risk-adjusted interest or "discount" rate, including a risk-premium, that starts at 20% over 2016-2020, falling to 15% over 2020-2025, and 10% over 2025-2030. The 20% risk-adjusted interest rate is chosen to be consistent with estimation of the risk premium embedded due to policy uncertainty under the current European Emissions Trading System (ETS)[16.] For the sake of realism, we also limit the foresight of market actors by assuming a planning horizon that is limited at 20 years. Thus, market actors in 2016 look ahead to 2035 and market actors in 2020 and 2025 look ahead to 2039 and 2044, respectively.

To model the effect of learning, we then run our model iteratively at 5-year steps. We first solve the model starting in 2016 with a 20% interest rate to estimate prices and banking in each year. This provides the conditions we estimate through 2020, which we then use to re-run the analysis with a 15% interest rate, starting in 2020. This then provides the conditions through 2025, which we then use to re-run the analysis with a 10% interest rate, starting in 2025. The result of this analysis is an estimated price path that rises in a step-wise fashion over time, as shown in Figure 3, with an estimated carbon price is \$3.4 in 2016 rising to \$49/tCO_2e by 2030 (and \$78/t by 2035) as carbon markets grow and policies become less uncertain. While prices are initially depressed due to the modelled uncertainties, prices eventually have to rise higher and faster under this scenario to compensate for the lost mitigation opportunities that are not undertaken in the early years due to the excessive risk. The price path also exhibits periodic jumps as the market adjusts to greater information that provides more certainty over future climate policies.

DESCRIPTION OF SCENARIOS AND RESULTS

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[14] Golub, Alexander, Ruben Lubowski, and Pedro Piris-Cabezas. 2016. "Balancing Risks from Climate Policy Uncertainties: The Role of Options and Reduced Emissions from Deforestation and Forest Degradation (REDD+)." Manuscript. In review.

[15] Koch, Nicolas, Sabine Fuss, Godefroy Grosjean, and Ottmar Edenhofer. 2014. "Causes of the EU ETS price drop: Recession, CDM,renewable policies or a bitofeverything?—New evidence." *Energy Policy* 73: 676–685;

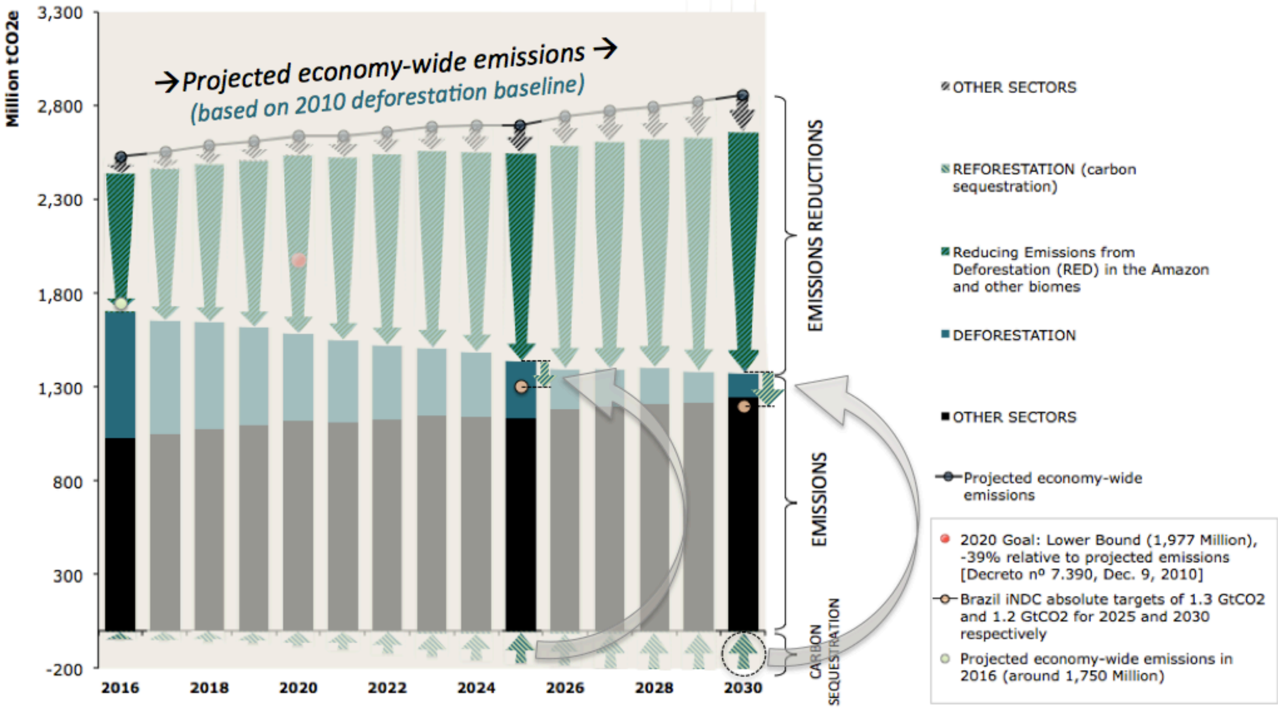
Koch, Nicolas, Godefroy Grosjean, Sabine Fuss, and Ottmar Edenhofer. 2016. "Politics Matters: Regulatory Events as Catalysts for Price Formation under Cap-and-Trade." *Journal of Environmental Economics and Management* 78:121-139.

[16] Pedro Piris-Cabezas and Ruben 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.

1. Meeting Brazil's current NDC (Scenario 1)

Under Scenario 1, the country reduces its emissions steadily to achieve its NDC goals in 2025 and 2030 without generating any surplus emissions reductions. The starting point is set by the forecasted emissions in 2016. Then emissions gradually decrease to achieve the NDC emissions targets of 1.3 $GtCO_2e$ and 1.2 $GtCO_2e$ in 2025 and 2030, respectively. These emissions goals are achieved in net terms, after accounting the additional carbon uptake (negative emissions) contributed by the reforestation program under the NDC. The negative emissions from reforestation are shown by the upward-pointing green arrows below the horizontal axis in Figure 3, with the corresponding adjustment of the NDC 2025 and 2030 targets also illustrated in Figure 1.

Figure 3 – Meeting Brazil's INDC, estimated required emissions reductions in Brazil over 2016-2030 (Scenario 1).



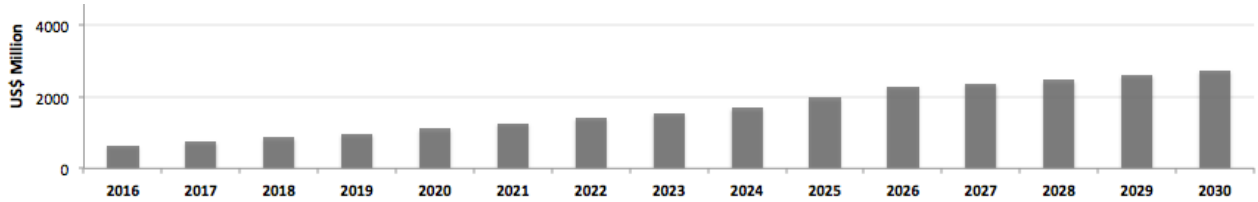
Note: While the 2020 voluntary goal for avoiding deforestation is achieved, emissions from legal deforestation still amount to 5.7 $GtCO_2$ over 2016-2030. Source: EDF analysis based on "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

Under scenario 1 Brazil achieves reductions of 17.5 billion ton starting in 2016 for an average of 1,160 $MtCO_2e$ of reductions per year. The cumulative reductions exceed by around 1 $GtCO_2e$ the hypothetical multi-year budget considered for scenarios 2 to 4 since this scenario assumes Brazil begins immediately to reduce emissions towards its NDC target, rather than waiting till 2020 when the NDC officially commences..

We assume that Brazil achieves this NDC trajectory with the least-cost mix of abatement across forests and all of the non-forest sectors. For simplicity, we do not consider the possibility of achieving more reductions than needed in certain years and banking them for use in later years. Under the least cost solution this entails that about 89% or 1,030 $MtCO_2e$ per year on average of the required reductions come from reductions in deforestation. The year-by-year reductions in deforestation emissions are shown as the downward-pointing green arrows in Figures 2 and 3. The smaller downward-pointing black arrows indicate the 11% of cost-effective abatement from all of non-forest sectors. In this scenario, the 2020 goal for avoiding deforestation is achieved, but emissions from deforestation (the blue vertical bars) still amount to 5.7 $GtCO_2$ over 2016-2030 for an average of 0.4 $GtCO_2$ per year. These emissions are within the limits of legal deforestation permitted under Brazil's Forest Code. Remaining emissions from other sectors (the black bars) amount to 24 $GtCO_2$. This illustrates the potential for additional emissions reductions from deforestation and other sectors that the country could achieve over and above the NDC targets.

The year-by-year costs of achieving Scenario 1 are shown in Figure 5 . The net present value of the total cost[17] –excluding the cost of the restoration of 12 million ha[18]—is $26.2 billion in 2016 (using a 5% discount rate).

Figure 4 – Meeting Brazil's INDC, estimated cost of emissions reductions in Brazil over 2016-2030 (Scenario 1).



2. Quantifying and valorizing Brazil's emissions reductions beyond the NDC (Scenario 2)

We next consider scenarios where Brazil achieves its NDC goals but also undertakes all mitigation actions that are cost-effective given the estimates value of reductions from the international market. In other words, all emissions reductions are achieved as long as the estimated annual costs per ton of CO_2e are less than or equal to the forecasted carbon price on the international market. We thus consider the possibility that Brazil could exceed its current emissions reduction targets, including the possibility of reducing deforestation to zero across the Amazon[19] and other biomes. This scenario could be feasible while maintaining agricultural production as a modest increase in the current productivity of Brazilian cultivated pasturelands could free up enough land to meet all future demands for meat, crops, wood products and biofuels until at least 2040 (Strasbourg et al. 2014)[20].

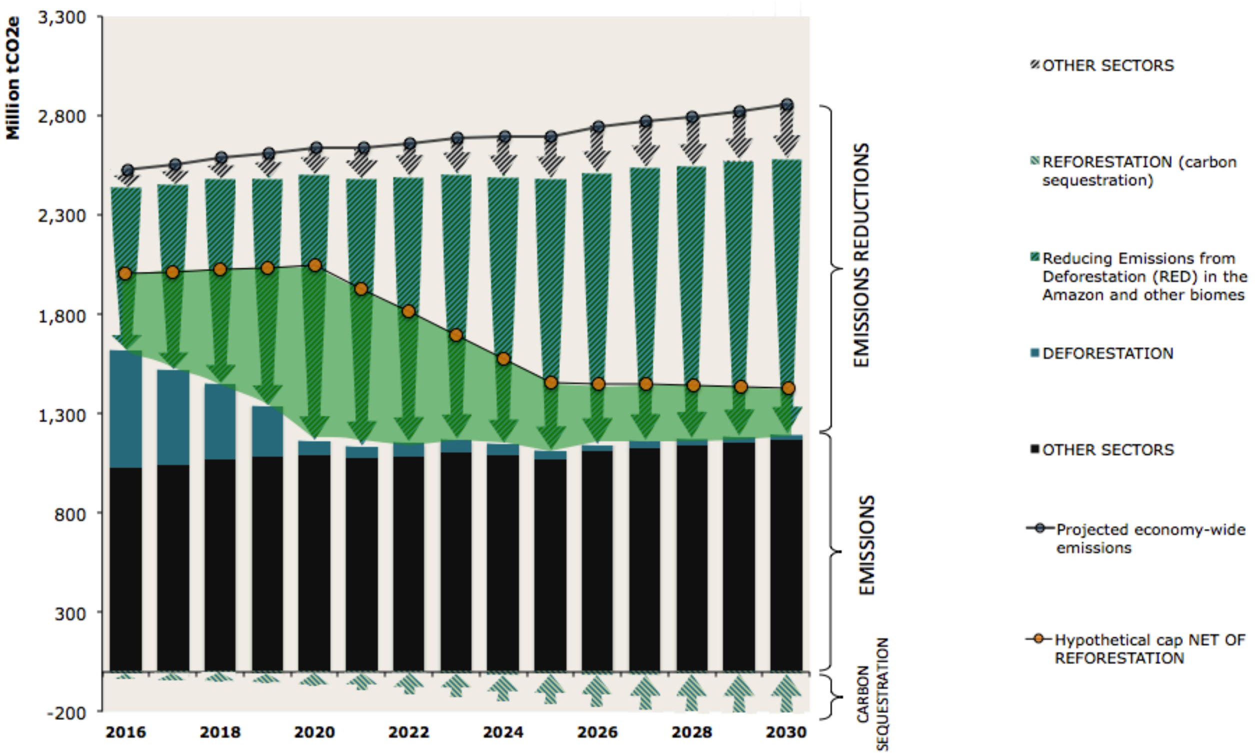
As noted above, in order to quantify the economy-wide surplus we transform the current NDC point targets into a hypothetical economy-wide multi-year budget as depicted in Figure 1. Then, we developed a projection of international carbon prices for Scenarios 2 to 4 that takes into account the climate regime emerging from the Paris Agreement and aviation MBM. Once we have the forecasted carbon prices, we calculate the amount that Brazil could deliver at the forecasted carbon prices.

Brazil's estimated emissions reductions under Scenario 2 are shown in Figure 5. The emissions reductions highlighted with a shaded green area represent Brazil's environmental asset or surplus beyond the INDC. The surplus is a combination of emissions reductions from avoided deforestation, carbon sequestration and abatement from other sectors. In Figure 5 as well as in subsequent figures the hypothetical cap is depicted net of carbon sequestration from reforestation.

[17] Forgone profits from agriculture and cattle ranching and abatement cots from non-forest sectors.
[18] For an estimate of the cost of restoration see Instituto Escolhas (2016) as discussed above.
[19] For example, see: Nepstad, Daniel, Britaldo S. Soares-Filho, Frank Merry, André Lima, Paulo Moutinho, John Carter, Maria Bowman, Andrea Cattaneo, Hermann Rodrigues, Stephan Schwartzman, David G. McGrath, Claudia M. Stickler, Ruben Lubowski, Pedro Piris-Cabezas, Sergio Rivero, Ane Alencar, Oriana Almeida, and Osvaldo Stella. 2009. "The End of Deforestation in the Brazilian Amazon," *Science* 326: 1350-351.
[20] Strassburg, Latawiec, Barioni, Nobre, da Silva, Valentim, Vianna and Assad (2014), "When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil", *Global Environmental Change*, Volume 28, September 2014, Pages 84-97.

Under Scenario 2, Brazil achieves emissions reductions for a total of 23.3 million tons, with a substantial surplus of 6,981 $MtCO_2e$ beyond the multi-year budget or cap and about 5.8 MtCO2e more reductions than under Scenario 1. Cost-effective emissions reductions are still largely from avoided deforestation, which now represent 81% of the total reductions. Compared to scenario 1, total remaining deforestation emissions falls by two thirds to 1.9 $GtCO_2e$ over 2016-2030.

Figure 5 – Estimated emissions reductions across sectors in Brazil over 2016-2030 with abatement costs equal or lower than the forecasted carbon prices for the international market (Scenario 2)



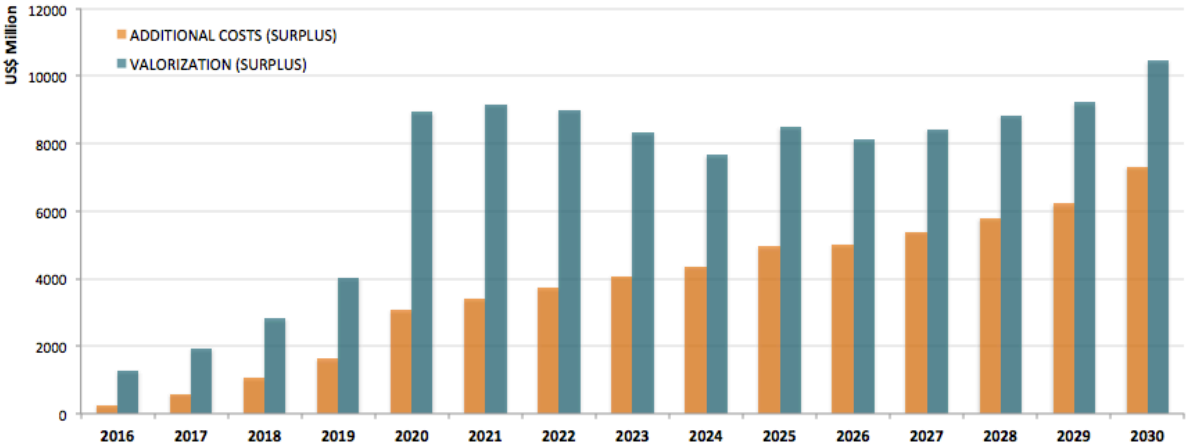
Note: The emissions reductions highlighted with a shaded green area represent Brazil's environmental asset or surplus beyond the INDC (6,981 million tons beyond the multiyear budget or cap). The 2020 voluntary goal for avoiding deforestation is overachieved but emissions from legal deforestation still amount to 1.9 $GtCO_2$ over 2016-2030. Source: EDF analysis based on cost curves from the POLES model; "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

Under Scenario 2, the estimated value of Brazil's surplus reductions beyond the multi-year cap is larger than the total cost of reducing emissions from deforestation and other sectors, generating a net value of $19 billion in 2016 present value over 2016-2030. Compared to scenario 1, total emissions are 26% lower and total emissions reductions overall are about 33% greater, while the net present value of costs is a little more than double. In particular, the net present value of the total mitigation costs[21] –excluding the cost of restoration of 12 million ha[22]—is $53 billion in 2016 (using a 5% discount rate) compared to the estimated cost of $26.2 billion under scenario 1. While costs are significantly higher, all of the reductions are compensated by the value on the international market price. Based on the forecasted carbon prices, the estimated value of this surplus is $72 billion in 2016 present value (using a 5% discount rate). This not only compensates the cost of the surplus reductions (26.8 billion) but all of the costs of the reductions required to meet Brazil's multi-year budget (26.2 billion)[23]. The total annual costs of Brazil's emissions reductions

[21] Forgone profits from agriculture and cattle ranching and abatement costs from non-forest sectors.
[22] For an estimate of the cost of restoration, see Instituto Escolhas (2016) as discussed above.
[23] Excluding the cost of the restoration of 12 million ha.

are compared to the potential value of the surplus in Figure 6. This shows significant potential for a net gain for the country, even in later years where the surplus is smaller (as the NDC is more ambitious) but international carbon prices are higher.

Figure 6 – Estimated additional costs and valorization of emissions reductions below Brazil's hypothetical cap over 2016-2030 (Scenario 2).



Source: EDF analysis based on cost curves from the POLES model; "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

To examine the sensitivity of net gains to our modelled carbon price projections, we run additional scenarios to estimate the minimum "break even" international carbon prices. These would be the prices at which the total net present value of costs of all of Brazil's cost-effective emissions reductions[24] would not exceed the value of the surplus resulting from the lower international carbon prices. We obtain a break-even carbon price of \$6.5/tCO_2 in 2016 rising at 5% per year afterwards to reach \$12.9/tCO_2 in 2030. This is substantially below the projected value of carbon over most of our projection scenario where prices start at \$3.4 in 2016, rise to \$10.3/tCO_2 in 2019, and then reach \$49 by 2030. Alternatively, assuming that carbon prices follow the same path for the first period 2016-2019 as in Figure 2 above, we obtain a break-even carbon price of \$10.5/tCO_2 for 2020 rising at 5% per year afterwards to reach \$16.8/tCO_2 in 2030 or just a third of the 2030 carbon price considered in Scenario 2. This suggests significant potential for Brazil to generate an environmental asset of significant value even with more conservative projections of future carbon prices.

3. Achieving further emissions reductions in the near-term (Scenarios 3 and 4)

As a result of the modeled uncertainty over the future (as reflected in the limited time horizon and risk-premiums added to the discount rate), carbon prices in the first decade are relatively low compared to a case with perfect foresight. In addition to the reductions that have a cost less than or equal to the forecasted carbon price each year, we allow for the fact that, in a situation of uncertainty, additional financial tools and strategies could be developed to create value for emissions reductions with abatement costs higher than the prevailing carbon prices.

In Scenarios 3-4, we consider the case where Brazil could use other financial instruments to valorize, by anticipating the possibility of higher carbon prices prevailing in the future, the additional 1.9 Billion tCO_2 of emissions reductions from deforestation that are not cost-effective under Scenario 2. In particular, we

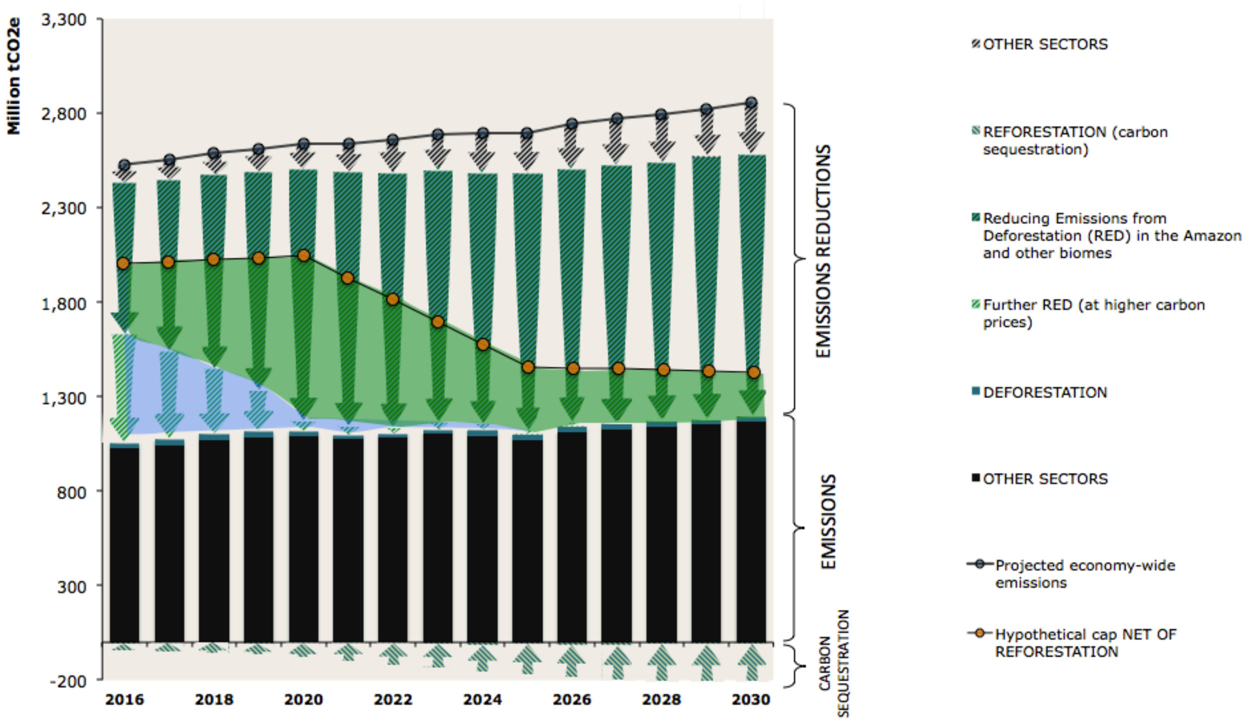
[24] Excluding the cost of the restoration of 12 million ha.

generate two hypothetical scenarios, namely, scenarios 3 and 4, where Brazil is able to monetize the value of its additional emissions reductions from deforestation at 2020-2029 carbon prices and at 2030-2034 carbon prices respectively.

We assume that the demand for additional early action surplus is equal to the amount of additional tons that would actually be demanded under a "risk free" scenario (based on a carbon price forecast that rises at a 5% risk-free interest rate). Brazil could adopt a simple strategy to valorize that asset: save or bank the surplus and use it for future compliance periods when the abatement cost will be higher. Other more sophisticated strategies also exist using financial instruments (e.g. sale of "call" options), as discussed in Golub et al. (2016).

Brazil's estimated emissions reductions and international sales are shown in Figure 7 for both Scenarios 3 and 4. Brazil achieves (net) zero deforestation emissions. Emissions reductions below the hypothetical cap are highlighted with shaded green and blue areas. As in Scenario 2, the green area amounts to 6,981 million tons of emissions reductions beyond the cap. The blue area indicates the 1.9 $GtCO_2$ of additional emissions reductions from avoided deforestation, which are valorized at higher future carbon prices in Scenarios 3-4. In total, almost 40% of the reductions below the hypothetical cap (both green and blue areas) are estimated to come from "early action" in reducing deforestation over 2016-2019.

Figure 7 – Estimated emissions reductions across sectors in Brazil over 2016-2030, with international trading under step-wise development of a global carbon market with declining risk over time (Scenario 3 and 4)



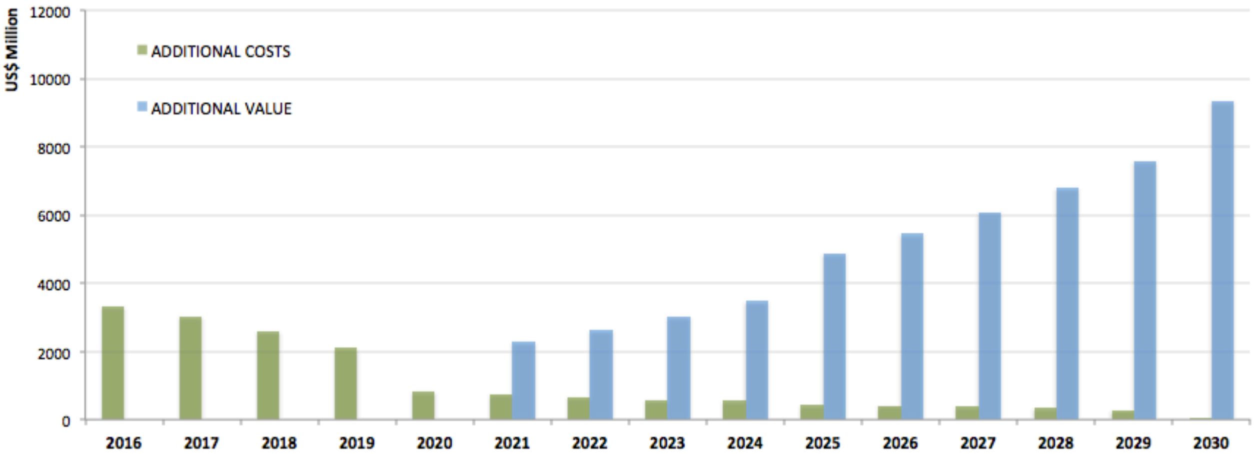
Note: Emissions reductions below the level hypothetical cap are highlighted with shaded green and blue areas. The emissions reductions under the shaded blue area are valorized at higher carbon prices than those forecasted for the year in which the reductions are achieved. Brazil achieves (net) zero deforestation emissions. Source: EDF analysis based on cost curves from the POLES model; "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

Compared to the value of the surplus of $72.0 billion from Scenario 2, Brazil would add a potential value of $30.9 - $53.5 billion[25] under Scenarios 3 and 4, respectively, stemming from the valorization of the

[25] Excluding the cost of the restoration of 12 million ha.

additional 1.9 GtCO2 from further avoided deforestation. Figure 8 illustrates the yearly distribution of the associated estimated costs and the additional value generated under Scenario 3, where the additional surplus is created and valorized with prevailing prices over 2020-2029, rather than those from 2016-2019 as in Scenario 2.

Figure 8 – Additional costs and value from the valorization of the surplus 1.9 GtCO_2 from avoided deforestation with 2020-2029 prices (Scenario 3)



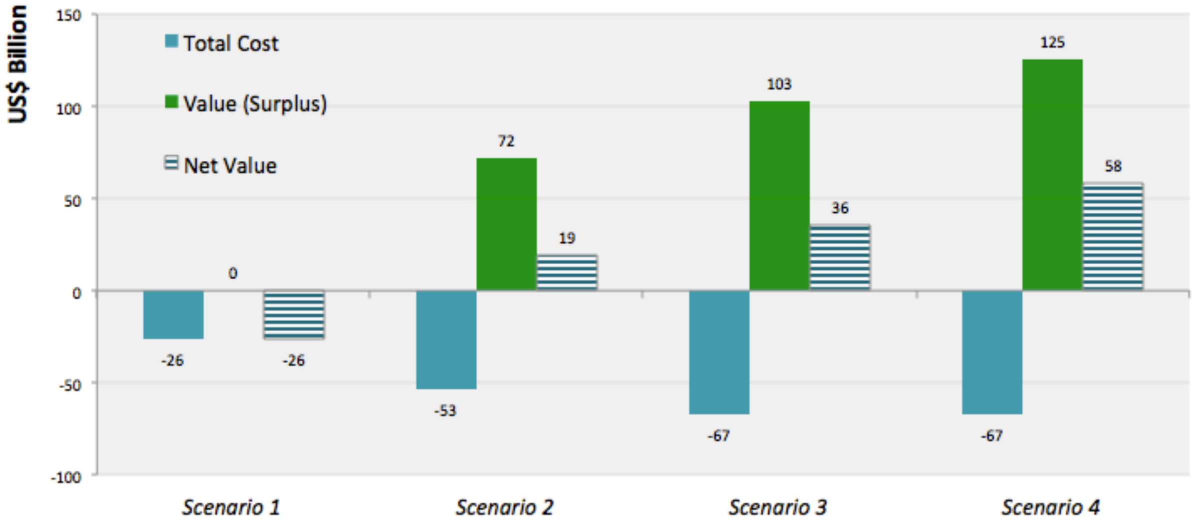
Source: EDF analysis based on cost curves from the POLES model; "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

The total costs of achieving all of Brazil's reductions under Scenarios 3-4 is estimated at $66.6 billion in present value terms in 2016, including an additional $14 billion cost for the added 1.9 billion tons in emissions reductions from avoided deforestation. In summary, the value of the environmental asset would more than cover the costs of achieving all of Brazil's emission reductions and yield an estimated net value valued at $36.3 -$58.9 billion[26] in 2016 present value across Scenarios 3-4.

Figure 9 summarizes the costs all of the emissions reductions, the value of the surplus and the value net of cost under each of the scenarios.

[26] Excluding the cost of the restoration of 12 million ha.

Figure 9 – Estimated costs of emissions reductions, value of surplus and net value[27] over 2016-2030 for Scenarios 1 to 4 (all numbers are net present values in 2016 at 5% interest rate).



Source: EDF analysis based on cost curves from the POLES model; "World Bank Low Carbon Country Case Study: Brazil" (The World Bank: Washington D.C., 2010); and SimBrazil Model from the Federal University of Minas Gerais.

CONCLUSIONS

Brazil could achieve the emissions reductions required to meet its NDC at an estimated cost of around $26 billion over 2016-2030 (in present value terms using a 5% interest rate).

Brazil has the potential to deliver even greater additional emissions reductions while monetizing surplus emissions reductions of significant value. But Brazil would only generate a surplus as long as the country exceeds its aggregate cap across all the sectors. Given the stringency of the goals adopted by Brazil in its INDC, Brazil could only generate its most substantial surplus in the near- to mid-term. Delays in the implementation of policies to deliver surplus emissions reductions would translate in missed opportunities with high opportunity costs for the country.

If Brazil could valorize the emissions reductions beyond the NDC at the forecasted carbon price, its value would more than cover the cost of the whole program resulting in a net value (value of the surplus minus cost of all emissions reductions) for Brazil over 2016-2030 (in 2016 present value) of $19 billion.[28] Most probably the forecasted international carbon prices in the near-term would not be enough to valorize the full potential of Brazil in the near-term. Brazil would not be able to achieve net-zero deforestation for at least another 5 years, losing a mitigation potential of 1.9 $GtCO_2$ along the way. To avoid that, Brazil could recognize the significant option value of realizing these emissions reductions in the anticipation of greater future carbon asset values. If Brazil could valorize the potential additional reductions at a future carbon price, it could generate an additional net value 2016-2035 (in 2016 present value) of $27-40 billion. As a result the total net value of the surplus over 2016-2035 (in 2016 present value) would range between $36 and $59 billion[29]. This surplus could be used for a variety of environmental and economic purposes, including helping to restore the Forest Code environmental debt and engaging Brazil in a deeper transition to clean energy and sustainable agriculture and low-emissions rural development.

[27] Excluding the cost of the restoration of 12 million ha.
[28] Excluding the cost of the restoration of 12 million ha.
[29] Excluding the cost of the restoration of 12 million ha.