Unlocking nature-based solutions in Colombia

TECHNICAL REPORT

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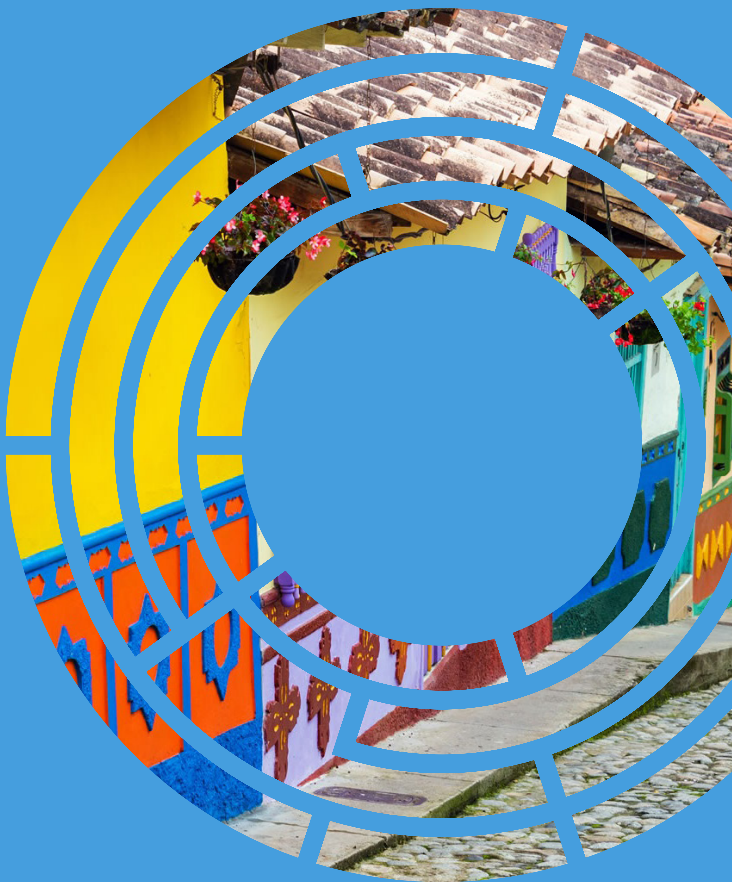

14 September 2022

CLIMATE FOCUS

Acknowledgments

This technical report is one in a series produced by Climate Focus and the Food and Land Use Coalition (FOLU). Since September 2021, Climate Focus and FOLU have been collaborating on a research project around financing strategies for terrestrial nature-based solutions (NbS) at a country and global level. The ultimate objective of the project is to enable public and private decision-makers to prioritize and deploy activities and investments that will unlock the potential of NbS for climate mitigation, adaptation, resilience, biodiversity and beyond. Our current report series includes the publication of country-based assessments in Kenya & Colombia, as well as global analyses focused on the voluntary carbon market. For more information about the project, please see below.

This report has received generous support from the Quadrature Climate Foundation.

Quadrature Climate Foundation

It has been produced in partnership with SYSTEMIQ.

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Climate Focus would like to thank Stefanie Roe (WWF) for contributing time and energy to provide input on the model.

Acronyms

A/R Afforestation and Reforestation

AD Avoided Deforestation

AFOLU Agriculture, Forests and Other Land Uses

AG Agriculture

BAU Business-as-usual

CEMP Cost Effective Mitigation Potential

FAO Food and Agriculture Organization

GHG Greenhouse Gas

IAM Integrated Assessment Model

IDEAM Instituto de Hidrología, Meteorología y Estudios Ambientales

IFM Improved Forest Management

MACC Marginal Abatement Cost Curves

MRV Measuring, Reporting and Verification

NBS Nature-Based Solutions

NDC Nationally Determined Contribution

PA Protected Areas

UNFCCC United Nations Framework Convention on Climate Change

VCM Voluntary Carbon Market

VCS Verified Carbon Standard

WL Wetlands

Introduction

An effective and efficient transition to low-carbon economies will be required over the next three decades to achieve the goals of the Paris Agreement and avoid the worst impacts of a changing climate. In addition to cutting greenhouse gas (GHG) emissions in half each decade, the global economy must also make significant investments in carbon removals to have a high probability of limiting warming to 1.5°C or 2°C by 2100.[1]

Nature-based solutions (NbS) – actions that protect and enhance carbon stored in natural ecosystems and reduce GHG emissions – are essential climate strategies, yet only receive a fraction of global finance. Although the global climate mitigation potential of terrestrial NbS has been estimated at 9-14 $GtCO_2e$ yr[1,2,3] only 3% of public climate mitigation funding is allocated to NbS, compared to 38% to renewable energies alone.[4] At best, the current level of funding for forest protection, restoration, and enhancement only reaches 5% of the estimated total needed to align with the Paris Agreement's 1.5 °C targets,[5] indicating a drastic shortfall in climate finance for forests.

Considering the lack of financing for mitigation in the land sector, it is important that countries like Colombia use climate finance strategically to maximize adaptation and mitigation benefits. Tapping into nature's mitigation potential is particularly relevant for countries that depend on NbS to meet their Nationally Determined Contributions (NDC) under the Paris Agreement. About 59% of Colombia's GHG emissions come from agriculture, forests and other land uses (AFOLU).[6]

Carbon markets provide an opportunity for Colombia to channel finance into sustainable land use. Driven by companies realizing their mitigation targets by increasingly relying on carbon markets to meet global mitigation commitments or offset a portion of their emissions, carbon markets have significantly increased over the last two years.[7,8] Indeed, although there is a lot of uncertainty, some estimates of carbon market demand reach 3-9.5 $GtCO_2e$ by 2050.[9] However, it is unclear whether NbS supply will manage to deliver these amounts considering the sector's current barriers.

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1 Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, H. J. (2017). A roadmap for rapid decarbonization. Science, 355(6331), 1269–1271.

2 Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daioglou, V., et al. (2021). Land-based measures to mitigate climate change: Potential and feasibility by country. Global Change Biology, 27(23), 6025–6058.

3 To illustrate the scale of these numbers: the Climate Action Tracker estimated China's 2021 GHG emissions to be at 14.1 $GtCO_2e$, and the International Energy Agency estimated global transport emissions for 2019 at 8.5 $GtCO_2e$. Tracking Transport 2021. (2021). IEA. Retrieved July 26, 2022, from https://www.iea.org/reports/tracking-transport-2021.

4 Buchner, B., Baysa Naran, & de Aragão Fernandes, P. (2022). Global Landscape of Climate Finance 2021. Climate Policy Initiative (CPI). Retrieved August 1, 2022, from https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2021/.

5 NYDF Assessment Partners. (2021). Taking stock of national climate action for forests. Retrieved August 1, 2022, from https://forestdeclaration.org/resources/taking-stock-of-national-climate-action-for-forests/.

6 IDEAM, Fundación Natura, PNUD, MADS, DNP, & CANCILLERíA. (2021). Tercer Informe Bienal de Actualización de Colombia a la Convención Marco de las Naciones Unidas para el Cambio Climático (CMNUCC). Retrieved from https://unfccc.int/sites/default/files/resource/BUR3%20-%20COLOMBIA.pdf.

7 Verra - Data and Insights VCS Quarterly Update on Q1/2020. (2020). Verra. Retrieved August 1, 2022, from https://verra.org/datainsights/april-2020/.

8 Since 2017, carbon credits' issuance grew from 49 to 300 $MtCO_2e$ in 2021, amounting to a market value of 748 billion in the first eight months of 202. More than 53% of these credits derive from NbS projects, of which 72% comes from developing countries. Donofrio, S., Maguire, P., Zwick, S., & Merry, W. (2020). Voluntary Carbon and the Post-Pandemic Recovery: A Special Climate Week NYC 2020 Installment of Ecosystem Marketplace's State of Voluntary Carbon Markets 2020 Report. Retrieved from https://wecprotects.org/wp-content/uploads/2020/11/EM-Voluntary-Carbon-and-Post-Pandemic-Recovery-2020.pdf.; Verra - Data and Insights VCS Quarterly Update on Q4/2021. (2022). Verra. Retrieved August 1, 2022, from https://verra.org/datainsights/data-and-insights-january-2022/.

9 Trove Research, UCL, Liebreich Associates. (2021). Future Demand, Supply and Prices for Voluntary Carbon Credits – Keeping the Balance. Retrieved from https://trove-research.com/wp-content/uploads/2021/06/Trove-Research-Carbon-Credit-Demand-Supply-and-Prices-1-June-2021.pdf.

To the best of our knowledge, the potential mitigation supply from carbon markets in Colombia covering a wide range of NbS is unknown. Instead, studies tend to focus on global demand, cover a limited set of NbS, and typically disregard other supply constraints other than price. In reality, carbon market investments face barriers across multiple dimensions that go beyond price. Furthermore, there is a lack of spatially explicit information on where the mitigation potential for different NbS activities can be found, which represents an information barrier for both project developers and decision makers.

This technical report addresses these important knowledge gaps and examines the role carbon markets may play in the short and mid-term in Colombia to unlocking NbS mitigation potential. Specifically, the objectives of this report are fourfold:

1. to model what is the projected NBS mitigation potential of carbon markets in Colombia over the 2020-2050 period;
2. to better understand the role different feasibility barriers may play in relation to unlocking carbon markets' full mitigation potential;
3. to identify spatially where the mitigation potential is concentrated in Colombia across different policy-relevant management units (i.e. at a department and biome level); and
4. to determine whether existing project locations are aligned with this mitigation potential.

This technical report accompanies an in-depth country case study for Colombia, which contextualizes in detail the results presented here for policymakers and investors. This technical report also forms part of a series of technical country reports, which currently cover Kenya, US, and Cambodia. Finally, the methodological approach piloted in these countries will be applied analogously at a higher scale in an upcoming global study to better understand how much NbS mitigation potential can be realized from carbon markets.

Methodological approach

To address the research gaps outlined above, we have developed a country-level model that explores how much mitigation potential can be unlocked by the NbS activities of Avoided Deforestation (AD), Afforestation/Reforestation (AR), Agriculture (AG),[10] the conservation and restoration of Wetlands (WL), and Improved Forest Management (IFM), through the assessment of both economic and other country-specific constraints (Figure 1). Specifically, the model accounts for:

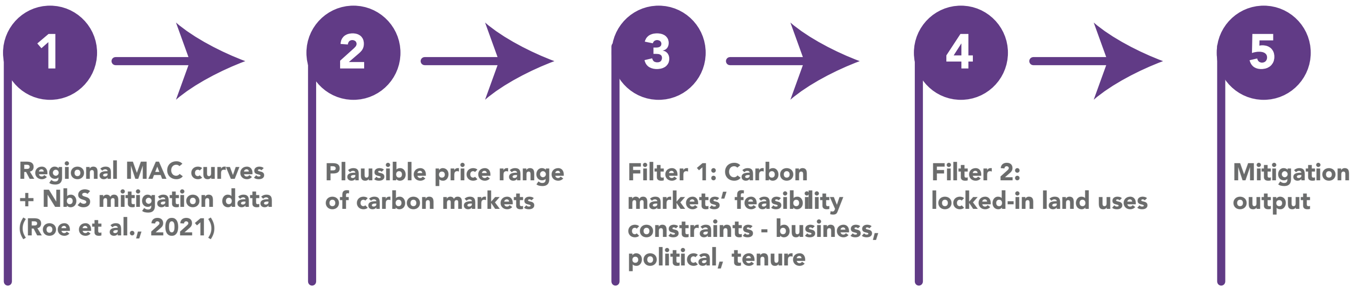
1. the mitigation potentials of the five activities in Colombiaand a wide range of carbon market price scenarios over time,[11]
2. implementation feasibility barriers related to ease of doing business, land tenure, and political factors, and

[10] The "Agriculture" activity includes mitigation potential from activities that reduce emissions and/or remove CO_2 from the atmosphere and store it in the soil and biomass. Specifically, the following activities are considered: Enteric fermentation, manure management, improved rice production, nutrient management, soil carbon sequestration on grasslands, soil carbon sequestration on croplands, agroforestry, and biochar.

[11] Roe, S. et al. (2021).

3. on-the-ground restrictions posed by previously-existing land uses (hereafter referred to as "locked-in land uses"). Specifically, we consider mining concessions, oil and gas concessions, and protected areas.[12] Next, the country level estimates from the model are disaggregated at the department and biome level through the support of secondary, spatially explicit data to determine higher priority areas for carbon market uptake in Colombia. A visual overview of the methodology can be found in **Figure 1**, while a detailed presentation of the model and approach can be found in the **Annex** (Methodology).

Figure 1: Schematic overview of the methodology applied to obtain the NBS mitigation potential from carbon markets in Colombia.



Results and discussion

Under current constraints, carbon markets in Colombia only unlock 33.7- 46.8% of its modelled mitigation potential over three decades (2.2 - 3.1 GtCO_2e of 6.6 GtCO_2e available after 30 years) (**Figure 2**). Carbon markets unlock a moderate 31.2-45.3 MtCO_2e yr-1 in 2023, 66.1-100.6 MtCO_2e yr-1 by 2030 and reach 109.0-134.1 MtCO_2e yr-1by 2050. This represents only 14.2-20.6% of its available mitigation potential (219.6 MtCO_2e yr-1) in 2023 and 49.6-61.1% by 2050.

As observed in Figure 2, there is a rapid increase of carbon-market driven mitigation in the first half of the 2020 decade in relation to historical vintages,[13] followed by a second stabilizing period where its growth reduces to a more moderate trajectory. Finally, towards the end of the period the yearly mitigation starts to level off. These dynamics are determined in part by the regional Marginal Abatement Cost Curves (MACC), which reflect decreasing amounts of mitigation unlocked as prices increase beyond a certain threshold (see **Figure 5**, **Annex**).

In terms of activities, AD dominates carbon markets in Colombia, with 77.1% of total potential, followed by AG (12.3%), A/R (7.1%), IFM (1.9%), and the conservation and restoration of WL (1.6%) (**Figure 3**).

[12] While technically it is possible to develop VCM projects in protected areas in Colombia, numerous barriers exist in practice: first, protected areas are publicly owned land, and bureaucratic procedures may discourage the pursuit of VCM activities; second, there is a generalized perception held by public officials that VCM projects in PAs don't comply with additionality requirements; finally, Colombia may have preference to use these areas to achieve its NDC goals.

[13] The historical vintages are the years in which the emissions reductions associated with the carbon credits issued until 2021 took place. This is used as a proxy for the mitigation potential unlocked per year until 2021. The vintage year of a carbon credit differs from its issuance year, as project developers do not always verify the emission reductions and issue the corresponding carbon credits in the same year that the emission reductions take place.

Figure 2: Carbon markets' mitigation potential for NBS measures in Colombia (AD, AG, A/R, IFM, and the conservation and restoration of WL) for three price scenarios (high, medium, low). Average cost-effective mitigation potential (CEMP) over the 2020-2050 period is showed for reference.[14] For past years vintages are presented, not issuances.[15]

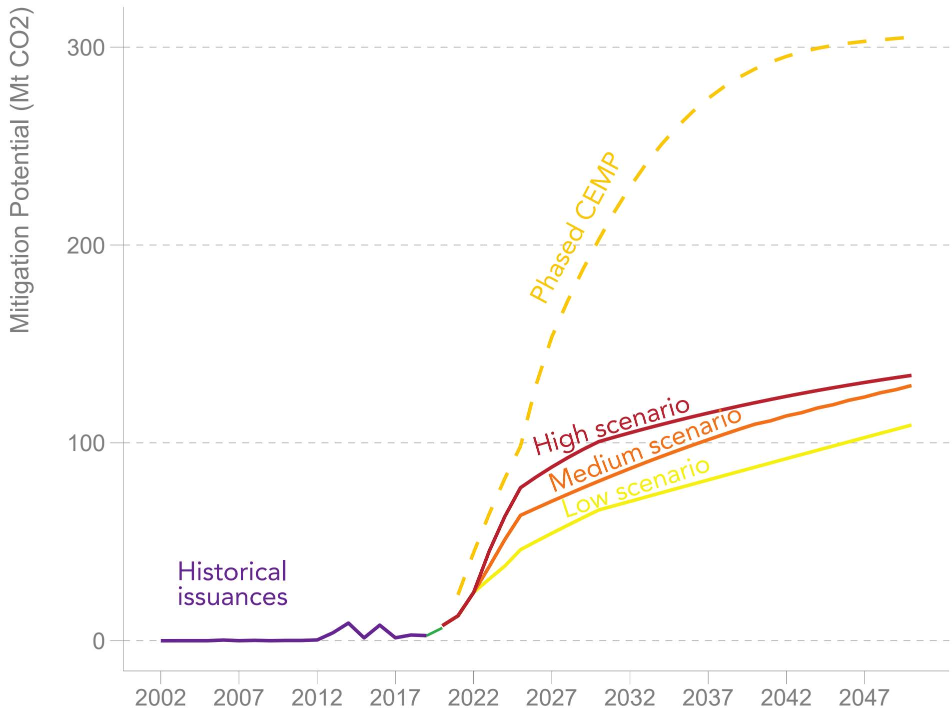
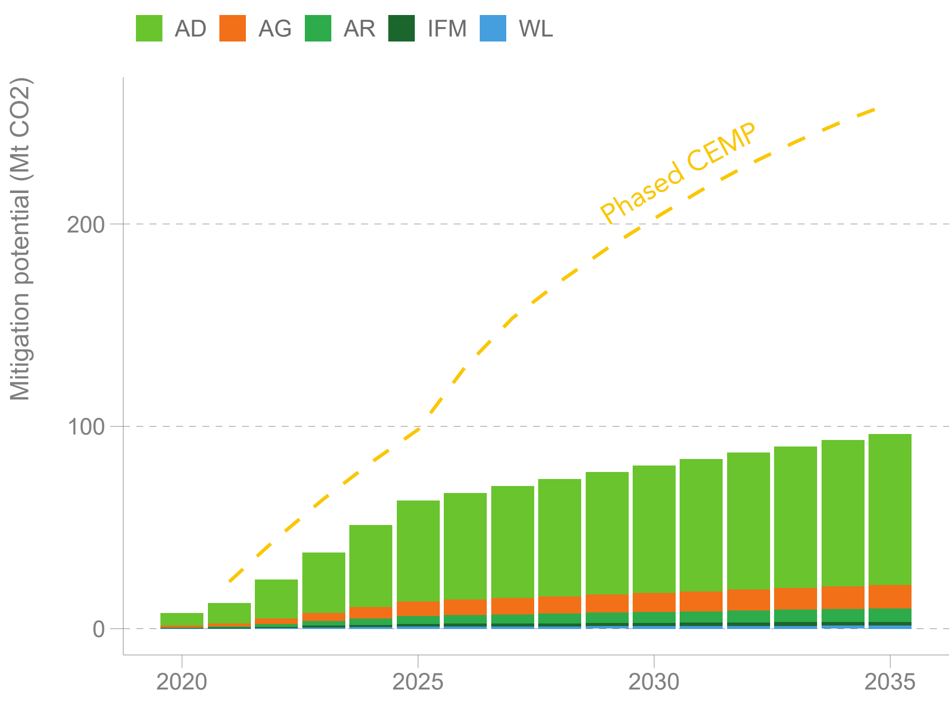


Figure 3: Carbon markets' mitigation potential by NBS measure in Colombia (AD, AG, A/R, IFM, and the conservation and restoration of Wetlands) for a medium price scenario. Average CEMP over the 2020-2050 period is showed for reference.[16]



[14] Roe, S. et al. (2021).

[15] Estimated emission reductions (Estimated ERs, in orange) are calculated as the sum of the estimated annual emission reductions of the 18 projects registered in the voluntary carbon standards VCS and Gold Standard. This figure (6,5 Mt CO_2e) is used in the year 2020 as a bridge between the historical vintages, where data is available until 2019, and the results of the model, which run from 2021 onwards.

[16] Roe, S. et al. (2021).

Our model estimates the carbon market potential for AD in Colombia to reach 63.0 $MtCO_2e$ yr-1 by 2030 under the medium price scenario of USD 40 per tonne (low-high range, 52.0-77.3 $MtCO_2e$ yr-1). Using a combination of secondary datasets, and after filtering out locked-in land uses, we estimate the potential for this activity to be most relevant for the Amazon, the Andes, and the Orinoquia biomes, with 29.2%, 26.8%, and 26.2% of the potential, respectively (see **Figure 4**, **Table 1**). Considering instead a department boundary of intervention, the mitigation potential for AD is led by Guaviare, Antioquia, and Caquetá with 9.3%, 9.1%, and 8.9%, respectively (see **Table 2, Annex**).

Carbon markets' mitigation potential for AG in Colombia reaches 9.3 $MtCO_2e$ yr-1 by 2030 under the medium price scenario (low-high range, 7.3-12.6 $MtCO_2e$ yr-1). The potential for this activity is most relevant for the Andean, Orinoquia, and Caribbean biomes with 50.1%, 29.4%, and 11.7%, respectively (see **Figure 4**). The mitigation potential for AG is led by Vichada, Antioquia, and Meta with 13.1%, 12.4%, and 8.3%, respectively.

Finally, the carbon market potential for A/R in Colombia increases to 5.5 Mt CO_2e yr-1 by 2030 under the medium price scenario (low-high range, 4.4-7.2 $MtCO_2e$ yr-1). The potential for this activity is most relevant for the Andean, Caribbean, and Orinoquia biomes with 51.7%, 19.7%, and 13.4%, respectively (see **Figure 4**). The mitigation potential for A/R is led by Antioquia, Meta, and Caquetá with 13.3%, 8.4%, and 8.0%, respectively.

Accounting for all three activities, the Andes biome shows the highest potential with 45.6%, followed by a similar share for Orinoquia, Caribbean, and Amazonas (17.4%, 16.8%, and 14.7%, respectively). The Pacific biome holds the remaining 5.5%.

We find that a sizable amount of potential cannot be unlocked due to existing locked-in land uses – oil and gas concessions, mining concessions, and protected areas. Specifically, 36.8% of AD mitigation potential overlaps with other land uses and would be hard to target if the areas are subject to concessions. Whether AD activities can be realized in protected areas remains unclear. To be conservative, we consider the additionality of effort in these areas hard to prove.[17] The overlap affects even more strongly the A/R and AG activities (41.9% and 38.5%, respectively).

We lack spatially explicit secondary data of mitigation potential for the IFM and WL activities, which constitute a minor <3.5% of NBS potential in Colombia. For these activities we only provide the results on a country level from our model and don't attempt to disaggregate spatially by biome or department. For IFM, we assume a similar distribution of locked-in land uses as for AD, and, hence, the same percentage of restriction is applied for this activity at the country scale. For WL, we assume an average distribution of locked-in areas from the other three activities.

[17] While technically it is possible to develop VCM projects in protected areas in Colombia, numerous barriers exist in practice: first, protected areas are publicly-owned land, and bureaucratic procedures may discourage the pursuit of VCM activities; second, there is a generalized perception held by public officials that VCM projects in PAs don't comply with additionality requirements; finally, Colombia may have preference to use these areas to achieve its NDC goals.

Figure 4: Distribution of mitigation potential in Colombia for AD[18], A/R[19], and AG.[20] Locked-in land uses such as mining, oil and gas concessions, and protected areas have been removed from the original datasets. The difference between the initial potential and final potential, after accounting for these areas removed, is recorded, and provides the second feasibility filter (%) that is applied to our country-level model estimates. The table below presents the disaggregated potential by biomes, while an analogous disaggregation by department can be found in the ***Annex****.*

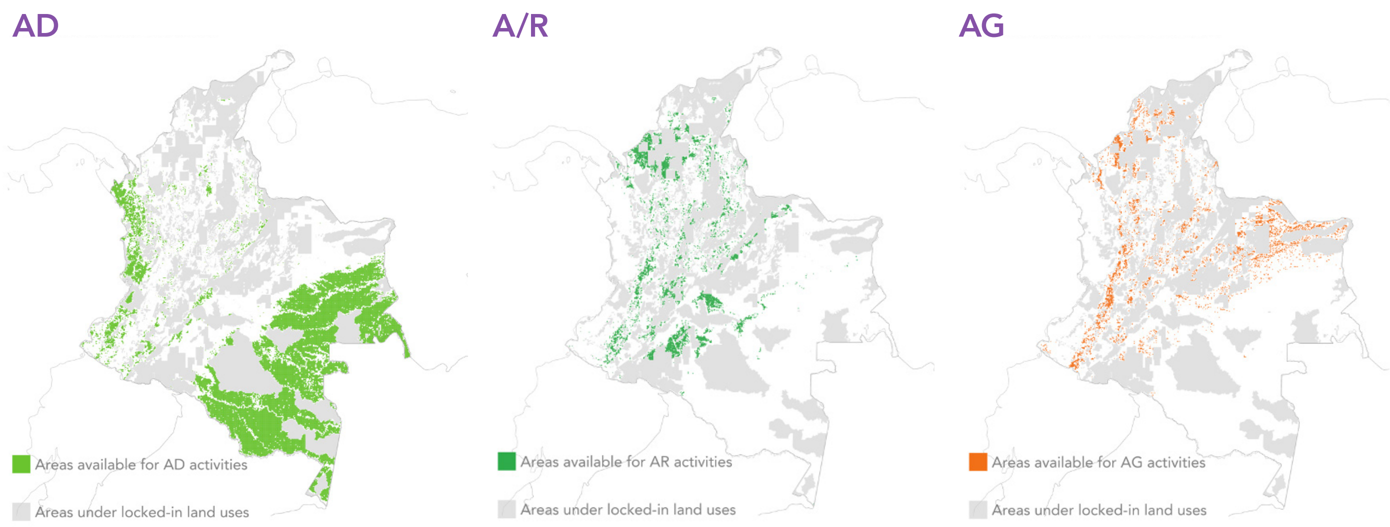


Table 1: Breakdown of NBS mitigation potential by biome for AD, AR, AG. Amount of projects per biome (%) and distribution difference (%) between projects location and total mitigation potential.

Biomes	AD (%)	AR (%)	AG (%)	Total (%)	Projects (%)
Amazon	29.2	10.4	5.5	14.7	15.9
Andes	26.8	51.7	50.1	45.6	36.3
Caribe	9.5	19.7	11.7	16.8	12.4
Orinoquia	26.2	13.4	29.4	17.4	20.4
Pacifico	8.4	4.7	3.3	5.5	15.0

[18] Koh, L. P., Zeng, Y., Sarira, T. V., & Siman, K. (2021). Carbon prospecting in tropical forests for climate change mitigation. *Nature Communications*, *12*(1), 1271.

[19] Cook-Patton, S. C., Leavitt, S. M., Gibbs, D., Harris, N. L., Lister, K., Anderson-Teixeira, K. J., et al. (2020). Mapping carbon accumulation potential from global natural forest regrowth. *Nature*, *585*(7826), 545–550.; Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., et al. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650.

[20] Food and Agriculture Organization (FAO), United Nations. (2022). Global Soil Sequestration Potential (GSOCseq) Map. Retrieved from https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-soil-organic-carbon-sequestration-potential-map-gsocseq/en/.

We find a disproportionately low number of carbon projects in the Andes (36.3%) and Caribbean (12.4%) biomes when compared to their mitigation potential (45.6% and 16.8%, respectively) (see Table 1). In contrast, a larger share of projects is located in the Pacific (15.0%) and Orinoquia (20.4%) biomes in relation to their mitigation potential (5.5% and 20.4%, respectively).

Considering an administrative unit level, we find that nearly two thirds of departments have a disproportionately low number of projects in relation to their mitigation potential (see Table 2), which is particularly problematic for some high potential departments. For instance, Caquetá, Nariño, Guaviare, and Cauca which present, respectively, 8.1%, 5.3%, 5.3%, 4.6% of Colombia's NbS potential, only represent 2.8%, 1.4%, 2.1%, and 1.4%, respectively (Table 2). At the other end of the spectrum, Antioquia, Vichada, and Chocó present a disproportionately larger number of projects (22.4%, 13.3%, 8.4%, respectively) in relation to their department potential (12.4%, 3.3%, and 3.3%, respectively).

Finally, there are more A/R (55.2%) projects in Colombia than AD (43.4%) ones, but the relevant mitigation volumes are provided by the latter. Assessing historic issuances, AD activity completely dominates with 92.5%, while A/R only provides 6.1% of mitigation. Two reasons explain this, firstly mitigation density (tCO_2e ha-1) is > 2.5 times higher for the AD activity, and, secondly, each deforestation project tends to occupy larger spacial boundaries compared to A/R projects.

Conclusions

The results presented here indicate that carbon markets can play an important role but are not a silver bullet: even when measures are taken to facilitate carbon market investments, our results suggest that markets alone are insufficient to fully deliver Colombia's NbS mitigation potential, and that, as a result, it is important to leverage other instruments in parallel. Our study reveals that, to fully leverage carbon market's NbS mitigation potential, it is important to remove barriers for investors and project developers.

This study exemplifies the risks of approaching the supply of NbS mitigation potential from a price-centric perspective alone. Supply studies should attempt to capture, on the one hand, the different political, economic, social, and legal barriers which limit the leverage of NbS mitigation potential via carbon markets. On the other hand, it is important to capture spatial restrictions in the form of locked-in land uses, which outline areas not accessible for carbon markets. The methodological approach presented in this report is a first attempt to reflect more realistically the on-the-ground limitations faced by project developers today.

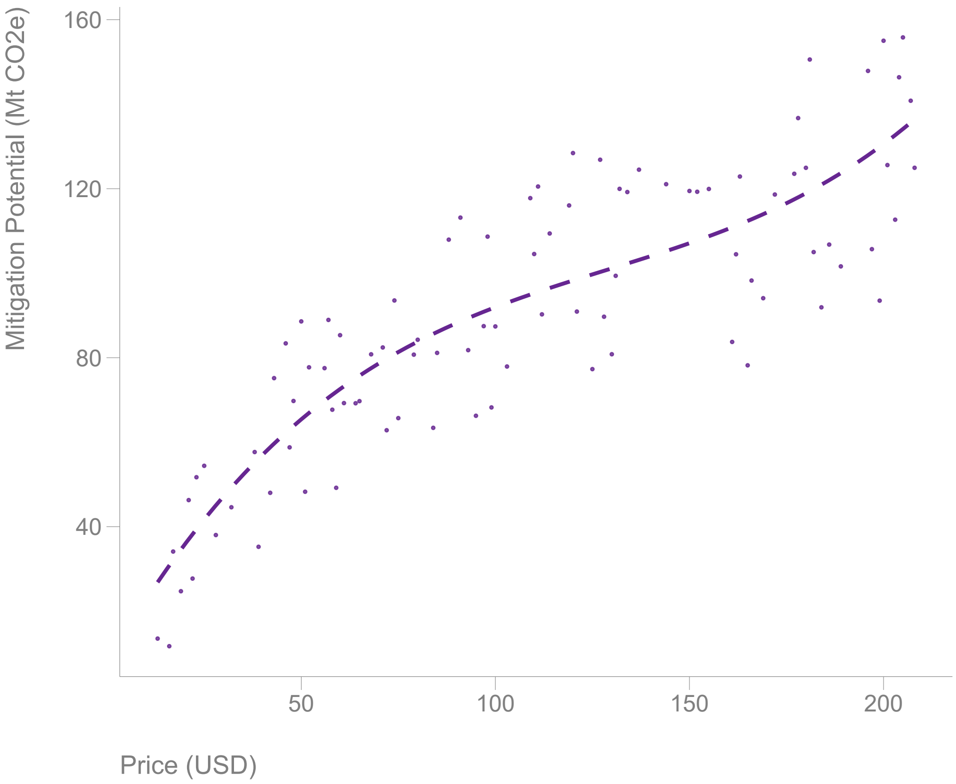
Finally, additional investments are needed to produce high quality local data. An enhanced understanding of local restrictions may be obtained if spatial data becomes available on different types of land ownership (private, public, community, etc.). This data is now not consistently available in Colombia, which has deeply rooted land tenure challenges, but, when available, could further improve our understanding of carbon market limitations on the ground.

Annex

Methodology

To estimate how much mitigation potential can be unlocked by carbon markets, we combined unpublished IPCC regional MACC with the latest country data on NbS mitigation potential from Roe et al. (2021). Specifically, this paper provides available mitigation estimates ("cost-effective mitigation") for 20 different NBS (USD100/tCO_2e). For each of the five activities considered (AD, A/R, AG,[21] the conservation and restoration of WL, and IFM, we fitted a function to the MACC output of MESSAGE-GLOBIOM, an integrated assessment model (IAM). The output of this model provides how much mitigation is unlocked for different prices (see example of Afforestation/Reforestation for Latin America in **Figure 5**). We used the shape of the regional MACC and apply it to the Roe et al. (2021)'s country-level mitigation data estimate (USD100/tCO^2e) to extract how much can be unlocked at lower prices.

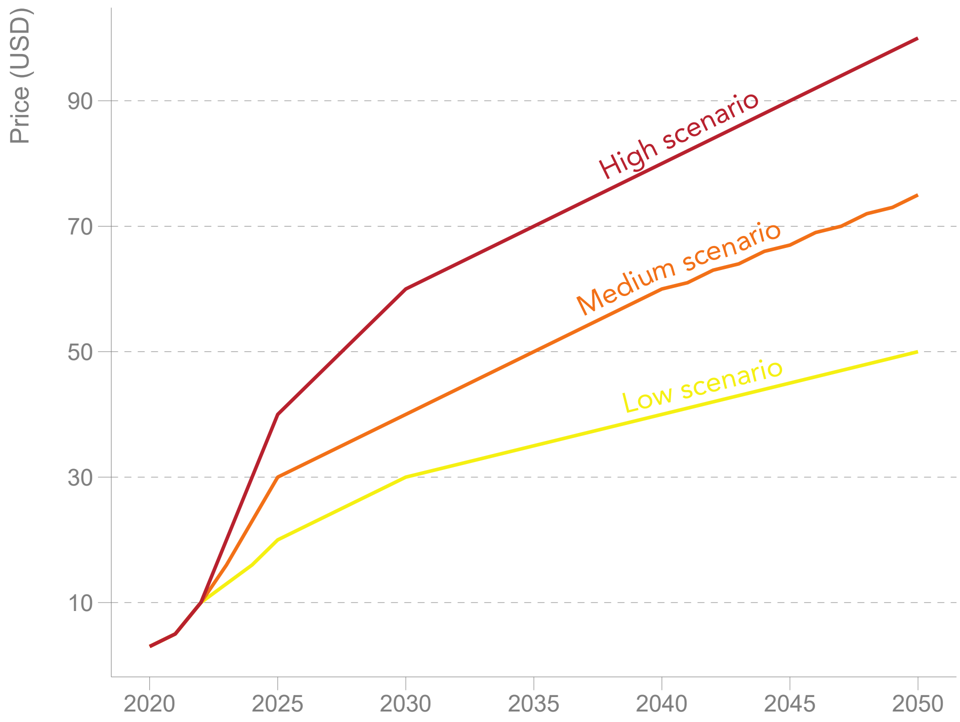
Figure 5: Example of a fitted function for a MACC based on MESSAGE-GLOBIOM's IAM. This particular curve refers to the A/R activity for Latin America.



Next, we considered a wide range of price scenarios (Figure 6). Given the long time-frame considered (until 2050), a simple and transparent scenario-based approach is preferred over modeling specific price forecasts, which is particularly complex in the very uncertain carbon market environment. Combining these wide price projection ranges with the information above, we obtained a first estimate of how much mitigation potential can be unlocked in Colombia for each of the five activities, which considers both available NbS mitigation potential and possible price scenarios.

[21] The Agriculture activity includes mitigation potential from activities that reduce emissions and/or remove CO_2 from the atmosphere and store it in the soil and biomass.

Figure 6: Price projections considered (low, medium, high).



Filter 1: Feasibility factors

In practice, the implementation of NbS projects does not solely consider costs, but numerous other, typically ignored dimensions also act as barriers for the uptake of projects. Political, institutional, social, and technological dimensions are also important. We found there is a significantly positive correlation between Roe et al. (2021)'s NbS country feasibility scores, which includes many of these dimensions, and project uptake across all countries engaged in VCM.[22]

We developed a tailored feasibility score that specifically reflects three distinct carbon market investment and implementation barriers. Specifically, we used the business and investment freedom indexes from the Heritage Foundations as a proxy of "ease of doing business", reflecting the need for countries to remove barriers to external investments. In addition, we considered the same political feasibility factors used in Roe et al. (2021). Political feasibility includes World Bank indicators of Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption.[23] Finally, for land tenure security we used the International Property Rights Index.[24]

We combined the three parameters described above (i.e., ease of doing business, political and land tenure) to calculate a feasibility score for each of the 214 countries in the dataset per year.[25] We used historic data from 2013 to 2020 to estimate how feasibility factors may evolve in the future. For this purpose, we divided the countries into 43 groups of five to six countries each, based on their feasibility scores in year 2013 and calculated the average feasibility factors per year for each group. We then sorted the average group scores from lowest to largest, which were used

[22] We measured project uptake as project*years, i.e., the number of VCM NBS projects a given country times the number of years each project has been running.

[23] The World Bank. (2021). Worldwide Governance Indicators. Retrieved August 18, 2022, from https://info.worldbank.org/governance/wgi/Home/Documents.

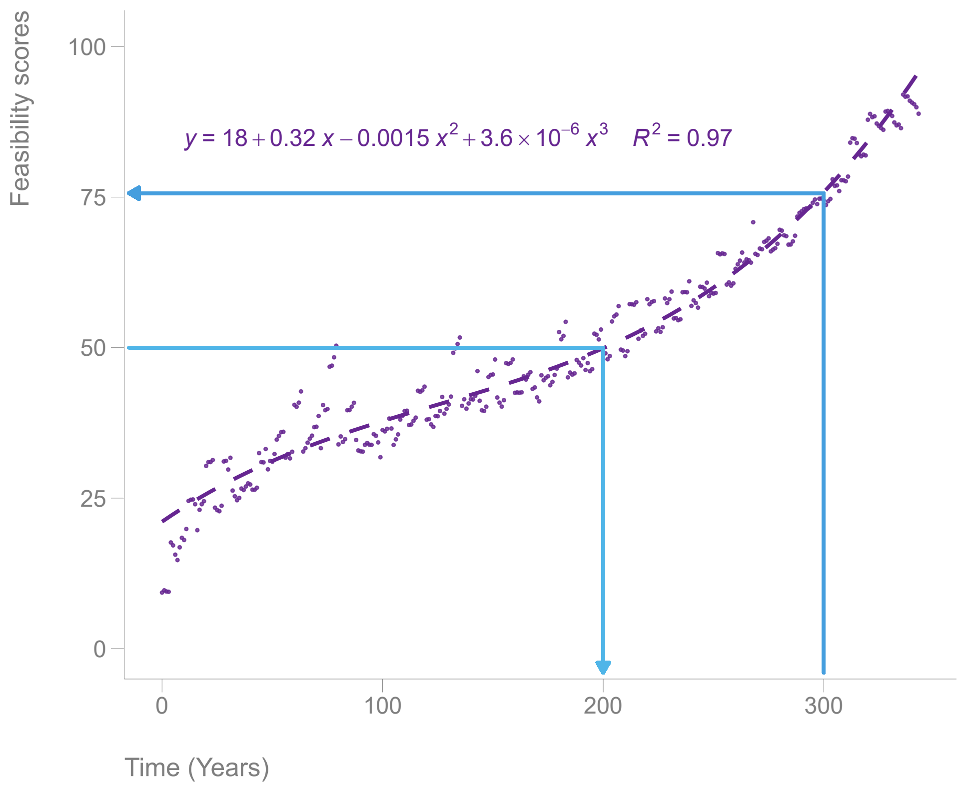
[24] Property Rights Alliance. (2021). International Property Rights Index. Retrieved August 18, 2022, from http://www.internationalpropertyrightsindex.org.

[25] Individual feasibility scores are first normalized (0-100), then averaged across the three variables to obtain a final feasibility score.

to plot a development pathway by putting them alongside each other on a scale of 0 to 343, which is the total number of entries (i.e., 43 groups multiplied by eight years of data, from 2013 to 2020).

Figure 7 **plots how the average feasibility scores of these groups (y axis) change over time (y axis), i.e. the 343 data points.** Based on historic data, as observed, feasibility scores are expected to gradually increase over time, albeit at different rates depending on where a country starts on the development pathway curve.

Figure 7: Modelled evolution of feasibility scores over time. Y axis represents feasibility scores, x axis years. Green lines (with arrows) highlight the process: we have the initial feasibility score for Colombia (63), obtain the initial time value (x axis); then we return x+30 years to the equation to obtain the feasibility factor in 2050 (73).



In practice, we proceeded as follows: we considered the starting feasibility score of a given country, e.g. Colombia (64), and, using the fitted function shown in Figure 7, we obtained the final feasibility score at a x+30 year time (2050), which corresponds to 74. Colombia therefore experiences a growth of 15.5% in their feasibility score over this time period.

The final step is transforming these feasibility scores into percentages, which are applied as a filter to the mitigation potential of each country. This was done by assigning scores from 0 to 100 to each country for every year (i.e., the lowest scoring country receives 0 and the highest 100). Under this assumption the top scoring feasibility country (100%) has no barriers, and no mitigation potential is discounted in the model. In contrast, the worst scoring country receives 0%, i.e. no mitigation is unlocked in this country due to high barriers.

In the case of Colombia, the feasibility filter goes from 75.9% in 2020 to 97.7% in 2050. This means 24.1% and 2.3% are discounted from Colombia's NBS mitigation potential in 2020 and 2050, respectively.

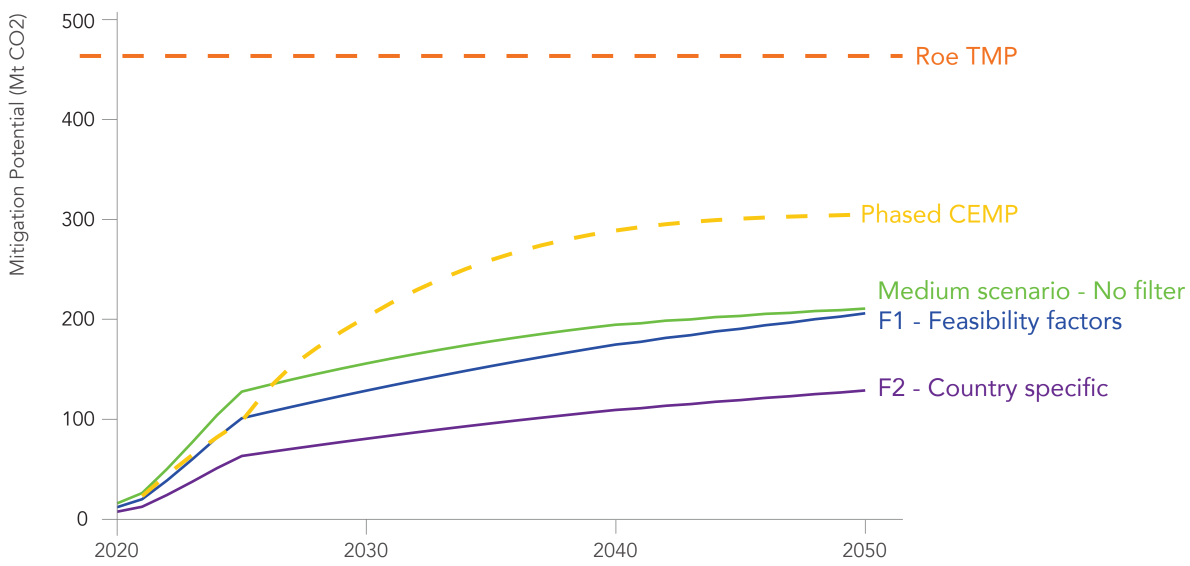
Filter 2: Spatially explicit mitigation potential maps

In a final step, we considered areas where it is very difficult to develop carbon market projects, due to existing on-the-ground limitations. We refered to these as "locked-in land uses". For Colombia, we considered mining concessions, oil and gas concessions, and protected areas, and assumed that investors and project developers would prefer to invest elsewhere in areas with fewer barriers. We used existing spatially explicit maps on mitigation potential per activity for AD, A/R, and AG, and estimated what percentage of the potential falls within these locked-in areas. This percentage is then applied to the country-level model output to provide a conservative estimate on what is realistically available for NBS mitigation via carbon markets. The final maps are also used to highlight where the potential for different activities lies in Colombia (**Figure 4**) and how it compares to the location of existing projects (**Table 1**).

For Avoided Deforestation, data is obtained directly from Koh et al. (2021). These authors address key VCS criteria, including additionality, to model and map investible forest carbon across the tropics; for Afforestation/Reforestation potential we considered carbon accumulation potential from natural forest regrowth in reforestable areas. We used data from Cook-Patton et al. (2020) filtered to include only reforestable areas as defined by Griscom et al. (2017). This map is not specific to carbon markets, but presents overall potential for the activity; finally, for Agriculture potential we use the recently released Global Soil Sequestration Potential (GSOCseq) Map.[26] We used scenario 3 and compared it to business as usual (BAU) scenario. Using a more pessimistic scenario (e.g. scenario 1) would reduce slightly the values presented in the map, but does not affect the distribution of where the potential is. Similar to A/R, this map is not specific to carbon markets, but presents the overall distribution potential for the activity.

All three potential maps are then processed to account for locked-in land uses where leveraging carbon markets is deemed difficult. This provides not only a final map of where the activity may be developed, but also the second feasibility filter (%) that is applied to the country model. After accounting for economic, feasibility, and land tenure barriers, the model then accounts for locked-in land uses by applying a percentage reduction that is informed by these spatially explicit maps.

Figure 8: Visual description of methodological process displaying a medium price scenario (purple). After considering feasibility and locked-in land use constraints the mitigation available is represented by the blue and green lines, respectively.



[26] FAO, 2022

Table 2: Breakdown of NBS mitigation potential by department for AD, AR, AG. Amount of projects per department (%) and distribution difference (%) between projects location and total mitigation potential.

Biomes	Department	AD (%)	AR (%)	AG (%)	Total (%)	Projects (%)
	Amazonas	8.2	0.1	0.1	2.1	1.4
	Antioquia	9.1	13.3	12.4	12.4	22.4
	Arauca	0.5	1.5	1.8	1.3	2.8
	Atlántico	0.0	0.0	0.1	0.0	0.0
	Bogotá	0.1	0.1	0.1	0.1	0.0
	Bolívar	3.7	5.8	3.3	5.2	3.5
	Boyacá	1.3	3.0	3.5	2.7	2.1
	Caldas	1.3	1.8	2.3	1.7	2.1
	Caquetá	8.9	8.0	4.2	8.1	2.8
	Casanare	0.9	1.5	4.8	1.6	2.1
	Cauca	2.9	5.0	4.5	4.6	1.4
	Cesar	0.5	2.1	1.1	1.7	0.0
	Chocó	2.6	3.7	1.2	3.3	8.4
	Córdoba	1.4	6.3	2.8	5.0	4.9
	Cundinamarca	2.4	3.7	4.9	3.5	1.4
	Guainía	8.5	0.0	0.7	2.1	2.8
	Guaviare	9.3	4.1	1.5	5.3	2.1
	Huila	0.8	3.1	2.2	2.5	1.4
	La Guajira	0.1	0.1	0.2	0.1	0.0
	Magdalena	0.2	1.0	1.5	0.8	0.7
	Meta	7.4	8.4	8.3	8.2	9.8
	Nariño	7.4	4.5	4.6	5.3	1.4
	Norte De Santander	1.7	3.6	2.9	3.1	0.0
	Putumayo	1.1	0.7	0.8	0.8	0.7
	Quindío	0.2	0.3	0.6	0.3	0.7
	Risaralda	0.4	0.6	0.9	0.6	0.7
	Santander	2.5	5.3	4.6	4.6	2.8
	Sucre	0.2	0.9	0.9	0.8	0.7
	Tolima	2.1	4.4	3.6	3.9	1.4
	Valle Del Cauca	1.9	4.3	4.5	3.8	4.2
	Vaupés	5.9	0.1	0.2	1.5	2.1
	Vichada	6.2	1.6	13.1	3.3	13.3

Amazon Andes Caribe Orinoquía Pacifico

Limitations

Forecasting carbon markets' potential over a long timeframe for a varied set of NbS is fraught with challenges. The analysis presents the following limitations:

Firstly, the price trajectories defined, MACCs used, and filters (feasibility and locked in land uses) do not capture some additional activity-specific constraints. For instance, our model shows Agriculture as the second activity with most potential; however, important technical measuring, reporting and verification (MRV) barriers need to be overcome for carbon markets to leverage its full potential. A lot of effort is currently placed on solving this barrier, but the outcome is yet unclear. It is also unclear how future changes in carbon market standard rules will affect these estimates: if countries seriously address their deforestation, the AD project activity may flatten eventually over time, in the same way as renewable energy projects are no longer considered by carbon market standards (except for Least Developed Countries). This activity is no longer considered additional to countries' BAU policies.

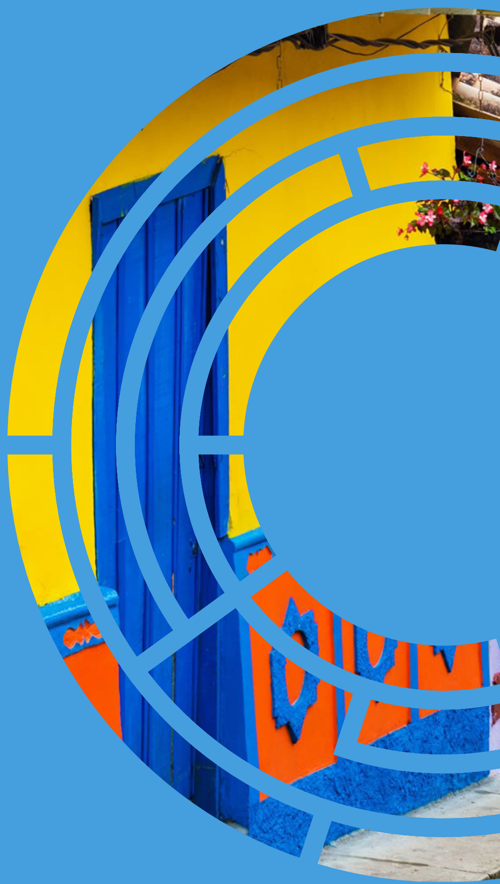
Secondly, our model uses regional MACCs derived from IAMs for 5 different NBS activities. Although the accuracy of estimates may be enhanced by using country-specific information, this assessment only uses the shape of the MAC curve – not its absolute values. It applies the function to very recent country data on NbS-specific mitigation potentials from Roe et al. (2021). Therefore, this approach is not expected to deviate substantially from an approach that gathers country-level costs for different NbS.

Thirdly, mining concessions, oil and gas concessions, and protected areas are used to gauge the percentage of on-the-ground areas where carbon markets cannot tap into. It is not clear whether AD projects can be realized in protected areas. They may fail to pass an additionality test or the government may not approve the development of carbon market projects in these areas. An enhanced understanding of local restrictions may be obtained if spatial data becomes available on different types of ownership (private, public, community, etc.). This data is currently not consistently available in Colombia, which has deeply rooted land tenure challenges, but, when available, could further improve our understanding of carbon market limitations on the ground.

Finally, it is clear that carbon market prices will evolve over time as a function of supply and demand. Regarding the latter, however, there are still a lot of uncertainties regarding how many companies will go beyond net-zero targets. The volume of credits generated by neutrality claims may be even larger than target-year net-zero claims. Hence, until this becomes clearer the uncertainty around demand will be very large over a 30-year forecasting period. Here, we preferred to lay a wide range of price scenarios to gauge the effect under different scenarios. What is clear at the moment is that demand is outpacing supply, and addressing country supply barriers is urgently needed.

Climate Focus is an independent expert in international and national climate law, policies, project design and finance. We have been pioneering carbon markets ever since their inception. We aim to find a creative and unique solution for every single client, ranging from the development of policies to protect the rainforest to structuring greenhouse gas mitigation projects in the energy sector. Our advice is rooted in a profound knowledge of climate change policies, emission trading schemes and project development.

Climate Focus has offices in Amsterdam, Rotterdam, Washington DC, Berlin, and Bogotá. Our core team is complemented by a broad network of in-country and specialized partners.



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