

Future Demand, Supply and Prices for Voluntary Carbon Credits – Keeping the Balance

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Executive summary

This report presents a detailed analysis of the future demand and supply for voluntary carbon credits conducted by Trove Research and University College London.

Currently the voluntary carbon market (VCM) is small with demand around 95MtCO₂e/yr, representing 0.2% of global greenhouse gas emissions. However, our analysis shows that demand is likely to increase significantly, driven by a growing number of corporate Net Zero commitments. This in turn will increase scrutiny that real emissions reductions are being achieved.

As demand for carbon credits increases, the costs of undertaking real emission reduction projects will need to rise as lower cost projects are used up. If the financing of voluntary projects is to genuinely reduce emissions beyond those that would otherwise have occurred, today's average prices of \$3-5/tCO₂e will need to increase to \$20-50/tCO₂e by 2030 and potentially \$100/tCO₂e if governments undertake lower cost projects first. Prices are then expected to keep rising to 2050.

In the modelling, VCM demand scenarios are created to 2050 based on potential future need for offsetting business sector Scope 1 and 2 emissions, Scope 3 emissions for oil companies, and compliance demand from the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Global supply curves are calculated from 2020 to 2050 for four technologies that are likely to make up a substantial part of new voluntary carbon credit projects: forest preservation (REDD+), reforestation, Carbon Capture & Storage and Renewable Energy deployment in Least Developed Countries.

The land-based supply curves use satellite imagery of global land cover at 350mx350m resolution and data on carbon sequestration by trees, coupled with economic analysis of the foregone profits from using the land for agriculture. Alternative land-uses and agricultural land values depend on the most likely crops grown and animals farmed in each country.

The analysis also examines the implication of only allowing projects to generate credits if they contribute to emission reductions in excess of a country's Nationally Determined Contribution (NDCs) under the Paris Agreement. Key insights and recommendations are as follows:

Demand for voluntary carbon credits

- **The Voluntary Carbon Market (VCM) is currently small in relation to anticipated demand.** With demand of 95MtCO₂e/yr in 2020, the VCM currently represents only 0.5% of the reductions pledged in country NDCs by 2030, and 0.2% of the reductions needed to achieve the 1.5C Paris temperature goal pathway in 2030 (differences relative to BAU in 2030).
- With increasing pressure on corporations to show climate action, **VCM demand is expected to grow x5-10 over the next ten years, x8-20 by 2040 and x10-30 by 2050.** With this increase in demand the VCM would account around 5% of the emission

reductions required under country's NDCs in 2030 and 2% of the reductions required to meet the 1.5C Paris goal pathway in 2030.

Future carbon credit prices

- **Current prices in the VCM are unsustainably low (\$3-5/tCO₂e weighted average) and need to increase significantly if they are to have high environmental integrity.** Low prices are in part due to an excess of supply in relation to demand, alongside issues of additionality, with credits able to be created at very low costs. We estimate that without this surplus, prices would be at least \$10/tCO₂e higher.
- With projected increases in VCM demand, **average VCM prices should rise to \$20-50/tCO₂e by 2030 driving real investment in new projects to reduce emissions.** With a further increase in demand by 2040, carbon credit prices would be expected to rise in excess of \$50/tCO₂e.
- **If the tests for additionality in the VCM require projects to be over and above what countries have pledged in their NDC, then carbon credit prices would increase further.** In the extreme case where all Nature Based Solutions (NBS) projects within a country's NDC are assumed to be undertaken by governments and not eligible for the VCM, new VCM projects would be higher in the range \$30 to 100/tCO₂e by 2030 - depending on the level of demand.
- As the cost of using carbon credits rises, **corporate investments in permanently reducing greenhouse gas emissions within their value chain, will become more attractive.**

Role of Nature Based Solutions

- **In the period to 2030 the VCM could be supplied entirely by Nature Based Solutions.** Whilst CCS and supporting renewable energy in LDCs will be important carbon reduction activities in the long term (after 2030), reforestation and REDD+ type projects offer significant supply at lower cost in the short to medium term (up to 2030).

Recommendations

From the modelling and analysis conducted in this project we make five recommendations for the development of the VCM:

1. Price as a measure of environmental integrity

If average prices remain significantly below the forecast levels (\$30-50/tCO₂e in 2030), the credibility of credits in delivering additional emission reductions should be questioned.

There are opportunities for low-cost projects, with favourable combinations of land values and plant growth rates, but some projects in the market today are low-cost because of questionable additionality claims. Genuine low-cost opportunities will run out as demand increases putting upwards pressure on prices.

2. Reducing emissions before the use of the VCM

Reducing greenhouse gas emissions through renewable energy, energy efficiency and non-CO₂ abatement should be prioritised ahead of encouraging companies to use carbon credits

through the voluntary market. This should happen through regulation and publicly-backed financial incentives. In doing so the volume of carbon credits available to the voluntary market would reduce.

3. The importance of Nature Based Solutions (NBS)

On the basis of costs and co-benefits, protecting existing forests and restoring degraded land with above and below ground carbon mass should be prioritised as part of the Voluntary Carbon Market. This is justified on economic grounds, as the costs of these measures are cheaper than the alternatives. High-quality NBS can also provide important additional biodiversity and social benefits.

4. Managing the VCM

Improved and independent regulation of the VCM is needed. In particular, corporate buyers should be encouraged to invest in new, high quality projects. The excess of supply in the VCM continues to suppress carbon credit prices. This is unhelpful for directing corporate capital to the most beneficial projects to reduce carbon emissions. Over time the market will need to move to funding only projects that remove carbon dioxide from the atmosphere, rather than reducing emissions elsewhere, in order to achieve net zero emissions globally.

5. Accounting treatment of carbon credit transactions under the Paris Agreement

The application of Corresponding Adjustments to transactions in the VCM should be carefully considered. Requiring host governments to adjust their national emission inventories through the use of Corresponding Adjustments, could increase voluntary carbon credit prices substantially. This may be justified to retain overall integrity of global carbon transactions, under some types of carbon credit claims.

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1. Introduction

This report presents the results from a detailed analysis of the future market for voluntary carbon credits, conducted by Trove Research and UCL during 2020 and 2021.

The Voluntary Carbon Market (VCM) provides opportunities for companies to fund mitigation action outside their value chain. The VCM also provides a potentially valuable private financing route to help protect and enhance important natural habitats and natural carbon stores, such as forests, wetlands and mangroves, and to support the development of new low carbon technologies.

The scale and dynamics of the VCM, however, have been poorly understood to date. Companies setting climate targets and using carbon credits in their corporate communications, also have little understanding of long-term strategic implications of these commitments.

The purpose of this report is to provide an analytical foundation to enable more informed decisions on future VCM design and corporate decision-making, through a detailed analysis of future demand and supply for carbon credits. The focus of the work is to answer four key questions:

1. How much demand for carbon credits could materialise between now and 2050?
2. Where would the supply come from?
3. How much will it cost to provide this supply?
4. What are the implications of national climate commitments under the Paris architecture on the availability and prices of carbon credits?

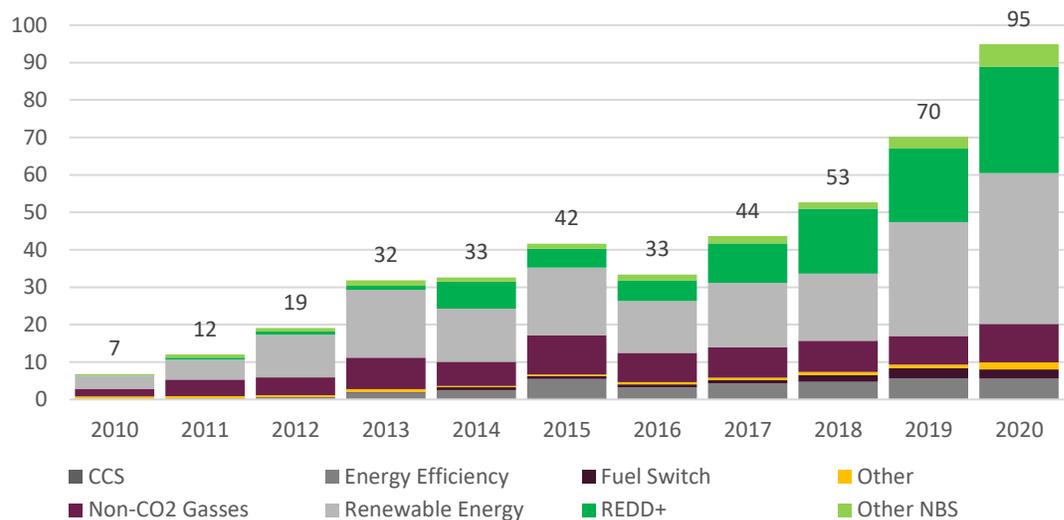
Section 2 describes the current demand for voluntary carbon credits by buying sector and carbon credit type. Section 3 then sets out the methodology for estimating future carbon credit demand. Section 4 describes the methodology for analysing the global supply of voluntary carbon credits. Section 5 introduces potential adjustments the supply of carbon credits to account for country's climate commitments under the Paris Agreement. Section 6 brings the demand and supply modelling together to create insights for future carbon credit prices and policies.

2. Recent demand and prices for voluntary carbon credits

Demand for carbon credits has doubled over the past three to four years

Demand for voluntary carbon credits has been increasing rapidly in recent years, doubling over the last three to four years, reaching 95MtCO₂e in 2020 (Figure 1). Demand has increased for all credit types, but especially Nature Based Solutions.

Figure 1. Demand for voluntarily carbon credits (MtCO₂e)



Source: Trove Intelligence, 2021¹

Carbon credits are used by a wide variety of sectors.

Figure 2 shows the number of carbon credits retired by firms in different sectors in 2019. The source of data is different from the chart above, and not as comprehensive, capturing 70MtCO₂e out of a total of 90MtCO₂e, but gives a good representation by sector.

The financial services sector is the largest user of carbon credits

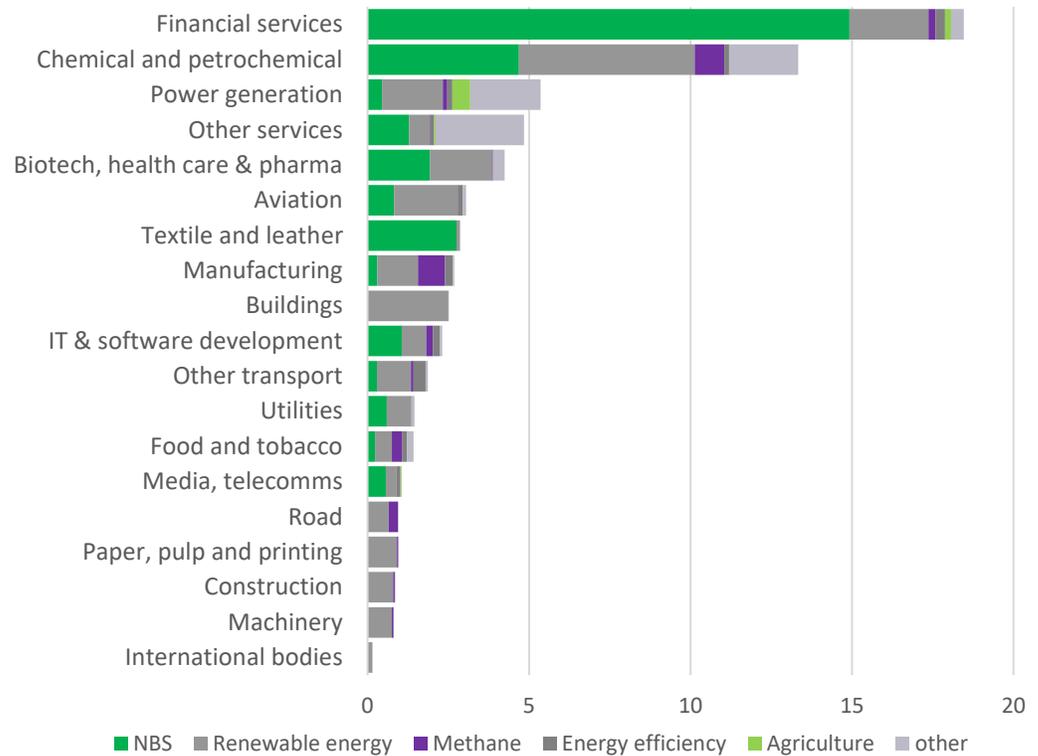
Firms in the financial services sector were the largest users of carbon credits in 2019 accounting for a quarter of all credits retired in the year. This was followed by chemicals and petrochemicals (including oil and gas) at 20%. All other sectors account for less than 10% of carbon credit retirements.

Most sectors use a range of carbon credit types, but financial services have been a major user of Nature Based Solutions (NBS). Half of all NBS credits were used by financial services.

Other sectors tend to prefer credits linked to their industry sector. For example, textiles and leather sector makes nearly exclusive use of NBS credits due to associations with textile supply chain, and the buildings sector, credits from energy efficiency.

¹ www.trove-intelligence.com

Figure 2. Demand for voluntarily carbon credits by sector 2019 (MtcO₂e) (total volume 70MtcO₂e)



Source: Trove Intelligence analysis, 2021, CDP 2020. “Chemical and Petrochem” includes oil and gas companies

Prices for voluntary carbon credits vary considerably according to the project type, its age (vintage), the size of the transaction and the standard (eg Verra, Gold Standard, CAR or ACR) to which it is accredited. Prices can range from under \$1/tCO₂e for older projects with fewer verifiable co-benefits, to over \$20/tCO₂e for projects with unique features and specific co-benefits, such as biodiversity and support for indigenous people.

Figure 3 shows a summary of average prices in 2019 for credits projects in renewable energy, REDD+/forestry & land use, non-CO₂ gases/methane, energy efficiency and other NBS/waste disposal. Pricing data is drawn from Ecosystem Marketplace and demand data from Trove Research analysis of demand in 2019. Figure 4 shows average prices transacted in 2019 by vintage.

From these data the weighted average price of transacted voluntary carbon credits in 2019 was around **\$2.6-3.0/tCO₂e**. More recent data suggests average prices in 2020 are likely to have risen as customers have become more selective in their choice of credits preferring those with more definitive attributes. We estimate that the weighted average price in 2020 is in the **\$4-5/tCO₂e** range. As noted above, this average masks some projects that transact at much higher levels, as well as those with lower quality attributes at lower prices.

There is significant variation in credit prices. We estimate a weighted average price in 2020 of \$4-5/tCO₂e.

Figure 3 Voluntary carbon credit prices and demand 2019 by project type (average of wholesale and retail prices)

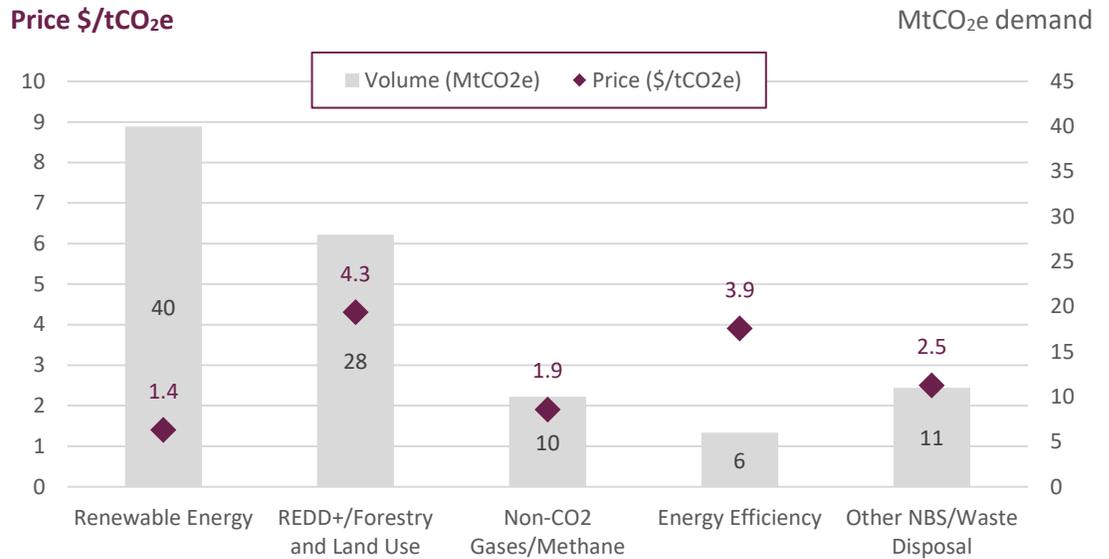
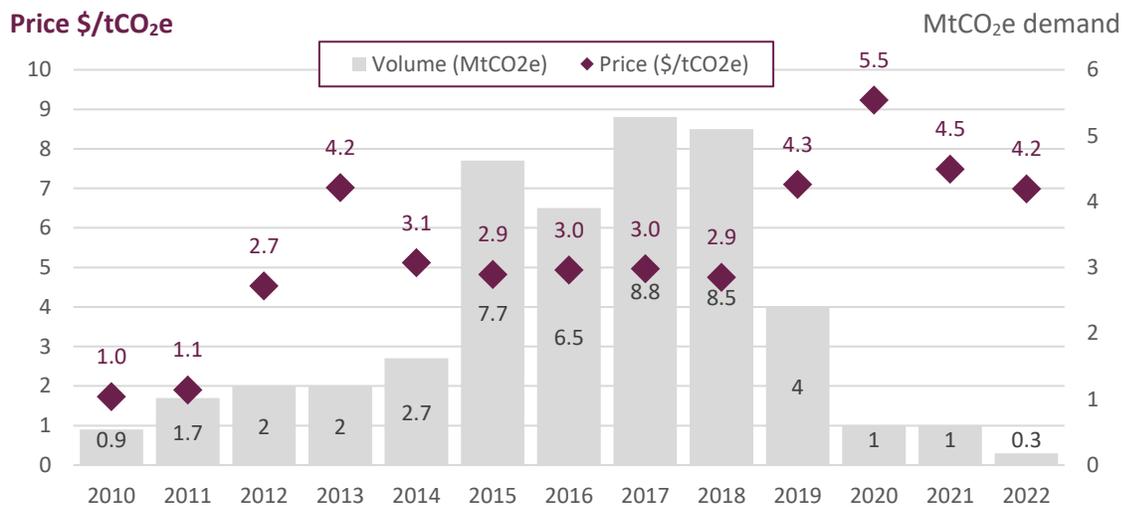


Figure 4 Voluntary carbon credit prices and demand 2019 by vintage (average of wholesale and retail prices)



source: Ecosystem Marketplace 2020². Trove intelligence³

² Ecosystem Marketplace, December 2020, State of the Voluntary Carbon Markets 2020, Second Instalment Featuring Core Carbon and Additional Attributes, Offset Prices Volumes and Insights.

³ <https://trove-intelligence.com/>

3. Future demand for voluntary carbon credits

3.1 Background

Companies in the SBTI database use more than 26 different terms to explain their climate ambition

Forecasting future demand for voluntary carbon credits first needs to take account of how carbon credits are used in the context of corporate climate commitments. Firms use carbon credits in a variety of ways and against several types of claims. Our analysis of 350 firms in the SBTI database shows 26 different terms used to describe climate targets of these companies.

We separate these into three general categories (1) Carbon Neutral (2) Net Zero/Science based (3) Beyond Carbon Neutral. Carbon Neutral describes the intention to offset corporate emissions in the short term through the combination of emission reduction measures and the purchase of carbon credits, but with the emphasis on the use of carbon credits given the short-term nature of the claim. Net Zero/Science Based refer to longer term commitments with a greater emphasis on emission reduction activities in line with science-based emission reduction pathways, and the use of carbon credits to offset residual emissions. “Beyond Carbon Neutral” refers to the use of carbon credits to offset more emissions than the company is currently creating or has created historically.

Table 1 Terms used to describe climate targets in the SBTI database (sample 350 firms)

Carbon Neutral	Net Zero/Science Based	Beyond Carbon Neutral
Carbon Neutral Product/Service	Net Zero Emissions	Carbon Positive
Climate Neutral	Net Zero GHG Emissions	Carbon Negative
CO ₂ Zero	Net Zero Impact on Climate	Carbon Minus
Zero CO ₂	Net Zero Carbon	Climate Positive
Zero Carbon	Net Zero CO ₂	Net Positive
Zero Carbon Emissions		
Effectively Zero CO ₂ Emissions		
Zero Emissions		
Zero GHG Emissions		
Virtually Zero GHG Emissions		
Substantially Zero GHG Emissions		
Fossil-free		
Emission-free Delivery		
Zero Environmental Footprint		
Zero Environmental Impact		

Source: SBTI database, November 2020; Trove Research analysis.

Carbon credits are currently being used inconsistently across this range of claims, which creates confusion for stakeholders and the companies themselves. To address this, a number of Civil Society led initiatives and projects are working on guidance to inform when and how carbon credits can be used as part of credible corporate climate commitments. These include:

- Voluntary Carbon Market Integrity initiative (VCMI)

Corporate climate commitments should prioritise emission reductions in their value chain before making claims associated with the use of carbon credits.

- Science Based Targets Initiative (SBTi) ⁴
- Taskforce on Scaling Voluntary Carbon Markets (TSVCM) ⁵
- Oxford Net Zero ⁶
- International Standards Organisation (ISO) ⁷

The consistent guidance emerging from these initiatives is to encourage firms to firstly reduce emissions across their value chain. The ambition is that these targets should be in-line with deep decarbonization targets required to meet the Paris goals of 1.5 to 2C global temperature increase from pre-industrial levels.

Against this background, the use of carbon credits is typically described for two purposes: “*Neutralising*” residual emissions in the latter years of a 2050 Net Zero pathway in line with science-based targets; and “*Compensating*” for un-abatable emissions in the short term.⁸

3.2 Modelling future voluntary carbon credit demand

To forecast future carbon credit demand we separate the market into three separate modules:

1. Economy-wide scope 1 and 2
2. International aviation
3. EU oil company scope 3 emissions

Economy-wide scope 1 and 2 emissions is the largest module and covers the direct and indirect emissions from all sectors of the economy with the exception of international aviation and emissions associated with the combustion of oil and gas sold by European oil and gas companies.

International aviation emissions are covered through the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) implemented through ICAO, the International Civil Aviation Organisation. The scheme more closely resembles a compliance rather than voluntary scheme but it accesses the carbon credit market and is therefore included in our demand model.

EU oil company scope 3 emissions cover emissions from the combustion of oil and gas sold by energy companies. Demand for carbon credits to cover scope 3 emissions from the energy sector is modelled separately because it double-counts scope 1 and 2 emissions from other sectors. This double-counting is intentional as offsetting scope 3 emissions reflects a genuine demand for carbon credits. This may not be optimal in terms of market design or efficacy of the VCM, but the purpose of this analysis is to understand potential future demand for credits, wherever that demand may arise.

⁴ <https://sciencebasedtargets.org/>

⁵ <https://www.iif.com/tsvcm>

⁶ <https://netzeroclimate.org/>

⁷ <https://www.iso.org/home.html>

⁸ <https://sciencebasedtargets.org/resources/legacy/2020/09/foundations-for-net-zero-full-paper.pdf>

3.1 Economy-wide scope 1 and 2

This module takes two approaches to forecasting future carbon credit demand. The first extrapolates recent year's growth rate in VCM retirements (moderated for slowing relative growth in later years). The second uses the global residual emissions in 2050 under 2C and 1.5C pathways as a maximum market size and creates scenarios of the market uptake of offsetting business-related emissions (assuming linear growth to this end year).

Growth rate approach

In the growth rate approach we extrapolate recent years growth rate, assuming the market doubles every four years between 2020 and 2030 (CAGR of 19%/year). From 2030 to 2050 we assume low and high CAGRs of 10% and 15% respectively. These assumptions are illustrative scenarios and not intended to be regarded as forecasts. The compounding of annual growth rates over 30 years can create large estimates of future VCM demand (Table 2). Under the low scenario demand would reach 2,300Mt/yr by 2050 and 8,300Mt/yr under the high scenario.

Table 2. Economy-wide scope 1 and 2 VCM demand based on estimated CAGRs

Year	CAGR over following decade		Demand MtCO ₂ e/yr	
	Low	High	Low	High
2020	19%	19%	90	90
2030	10%	15%	340	510
2040	10%	15%	890	2,100
2050	-	-	2,300	8,300

We analyse the climate commitments of 5,600 companies to estimate their long term need for carbon credits

Residual emissions from company Net Zero commitments

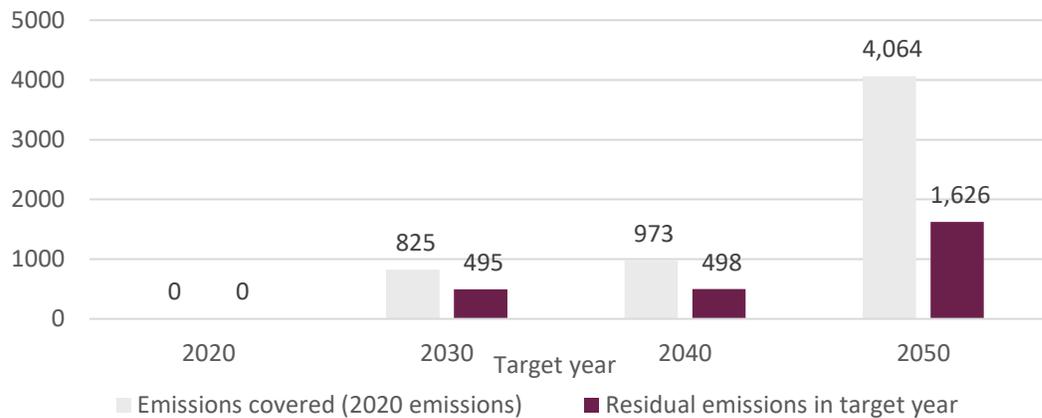
To provide a lower boundary on future VCM demand we have analysed the current climate commitments of 5,600 companies in the CDP and SBTi databases. 368 of these firms have made Net Zero commitments, implying the offsetting of residual emissions after achieving emissions abatement in their supply chains. The majority of emissions covered by these firms have set targets for 2050. These tend to be businesses in the more carbon intensive industries (Figure 5).

Today's carbon footprint of these firms amounts to around 4bntCO₂e, but this could reduce to around 1.6bntCO₂e by 2050 if Paris aligned mitigation targets in these company's supply chains are achieved. This represents the minimum future demand for carbon credits in 2050. If emissions from these firms are higher than the Paris pathways, we assume that demand for carbon credits is still limited by the Paris aligned trajectory.

Demand could be higher in 2050 if more companies adopt Net Zero emission targets, and supply chain emission reductions are less effective than anticipated. Demand in the interim years to 2050 would also be higher than shown if companies "compensate" for residual emissions in preceding years.

Today's carbon footprint of corporate Net Commitments is around 4bntCO_{2e}. This could be reduced to 1.6bntCO_{2e} by 2050 if Paris aligned mitigation targets are achieved.

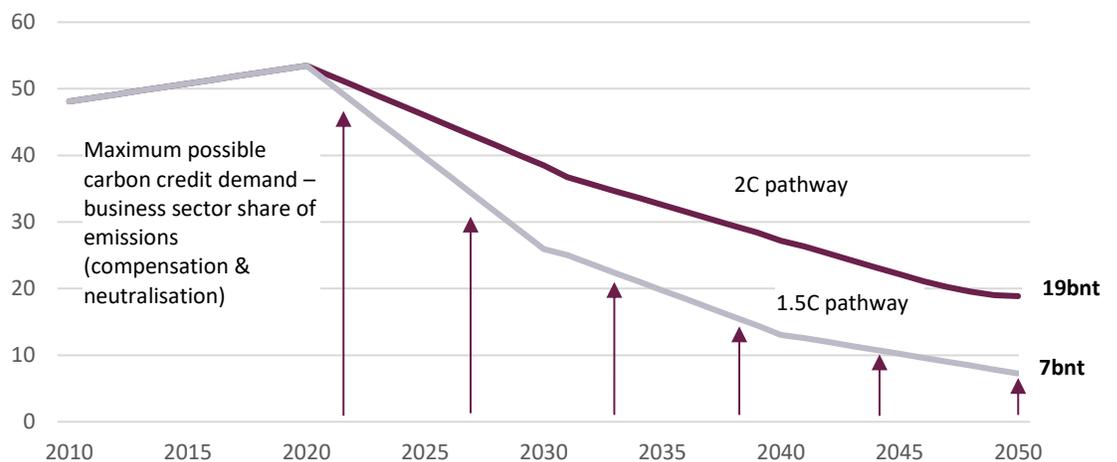
Figure 5. Emissions covered by corporate Net Zero commitments in target years (MtCO_{2e})



Source: Trove Research analysis, CDP and SBTi database

The maximum VCM size in 2050 is determined by global residual emissions in the business sector under Net Zero targets. Based on IPCC projections, global GHG emissions in 2050 would need to be no more 7bnt under a 1.5C target and 19bnt under a 2C target (Figure 6).

Figure 6. Global GHG emissions pathways consistent with Paris Agreement targets (bntCO_{2e})



Source: Climate Action Tracker, 2021. Includes all GHGs.

Carbon credits are most likely to be used by the business sector and much less by the public or domestic sectors. Currently around 11% of global GHG emissions are attributable to the domestic sector and 5% from the public sector.⁹ The business sector therefore would represent 6 - 16bnt of emissions in 2050, with a mean of 11bnt.

However, only a proportion of these emissions would be offset. In our low scenario we assume 10% of these emissions are offset and 33% in the high scenario. These assumptions

⁹ World Greenhouse Gas Emissions: 2016 | World Resources Institute (wri.org)

are illustrative as it is unclear how many firms will set voluntary Net Zero commitments in addition to those that have already done so. On the basis that demand increases linearly from 90Mt in 2020 to this maximum market size in 2050, VCM demand would reach **430-1,300Mt** in 2030, **770-2,500Mt** in 2040, and **1,100-3,630Mt** in 2050.

3.2 International aviation - CORSIA

Carbon credit demand under CORSIA assumes air travel resumes to pre-Covid levels.

The CORSIA scheme is due to start in 2021 with the target of holding international aviation emissions constant at 2019 levels.¹⁰ Our analysis calculates demand for offsets from the CORSIA scheme by projecting international aviation emissions to 2050 and referencing these against the 2019 baseline.¹¹ Prior to the pandemic global aviation emissions grew consistently at an annual average of around 4-5% between 2010 and 2020.¹² However, growth after the pandemic is much less certain, with views ranging from resumption of pre-pandemic growth to a resetting of demand for international travel at a lower level. The model uses low and high growth scenarios, as shown in Table 3.

Table 3. International Aviation Growth Scenarios

Scenario	Description	Cumulative demand for carbon credits 2020 to 2050 (MtCO _{2e})
Low	Growth in international aviation suffers longer term decline. Pre-pandemic growth does not resume until 2025, and then follows ICAO Trend Report growth rates	4,000
High	Growth in international aviation resumes at the pre-pandemic rate in 2022 and ICAO Trends Report. ¹³	9,600

3.3 European Oil Company Scope 3 Emissions

All major international oil companies based in Europe have set long term climate goals. BP, Shell, Total and Repsol have thus far pledged net zero commitments across scope 1 and 2 emissions, as well as net zero across all scope 3 emissions by 2050. Analysis of these companies' plans shows they intend to use a varying mix of efficiency improvements, switching to lower carbon products and offsetting residual emissions towards 2050.

The companies differ in the weighting they give to these three techniques. Shell, for example, expects to rely heavily on the use of offsets, whereas BP intends to make more structural changes to the mix of energy products it sells.

This level of climate commitment is currently focussed in Europe. In our model, we do not assume any scope 3 offsetting demand from oil companies outside Europe. To date, oil companies based outside Europe have shown little appetite to set long term climate goals,

¹⁰ The base year for the scheme has been revised from the average of 2019 and 2020, to 2019 alone, in light of the collapse in international air travel due the Covid pandemic in 2020.

¹¹ External sources are drawn on, for example, Environmental Defence Fund, 2020, Covid-19, International Aviation and Climate Change: How Airlines Proposed Re-write of ICAO Rules would Undermine CORSIA.

¹² <https://ourworldindata.org/co2-emissions-from-aviation>

¹³ https://www.icao.int/environmental-protection/Pages/ClimateChange_Trends.aspx

We assume European oil companies offset 50% of their residual scope 3 emissions by 2050

especially in relation to Net Zero. One exception is Petrochina which has declared a Net Zero ambition by 2050, but has released few details on how this target will be achieved. For this reason we exclude it from the carbon credit demand projections.

As with aviation, we create low and high scenarios for future carbon credit demand from the oil and gas sector. In our high scenario, we assume BP, Shell, Total, Eni, Equinor and Repsol maintain the same output of energy products each year, defined on an energy content basis, but reduce the carbon intensity of their products by 50% by 2050. Residual emissions are offset. This demand is maximised in 2050 but increases linearly from 2020 to 2050.

In 2020 scope 3 emissions from these companies were around 1,240MtCO₂e/yr. Assuming changes in product mix deliver half of the net zero commitment (BP's 2050 climate target), annual carbon credit demand in 2050 would be 620Mt/yr. In the low scenario we assume half this demand for carbon credits by 2050, ie 310MtCO₂e/yr.

3.4 Summary

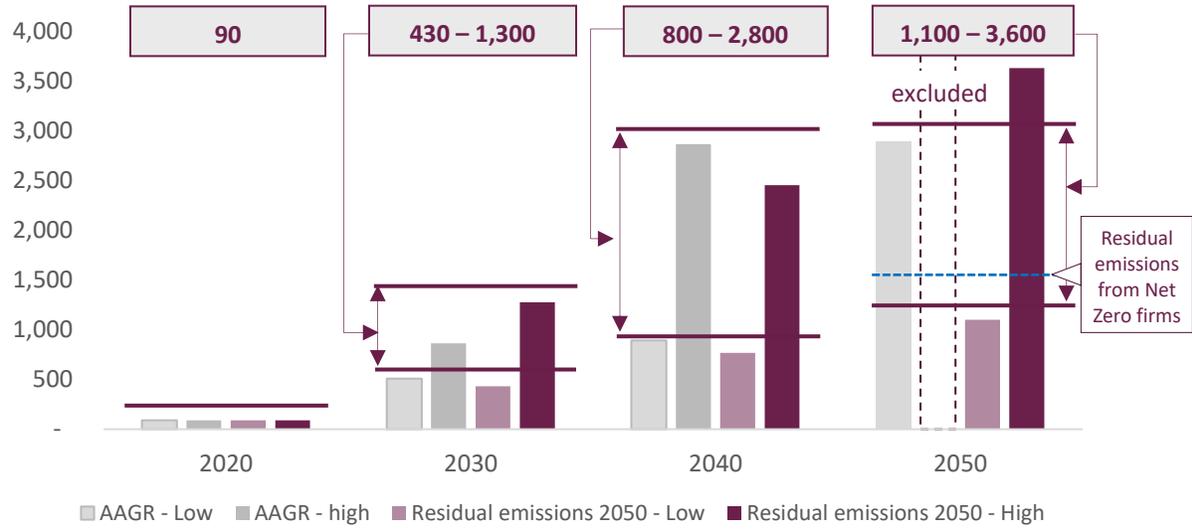
Figure 7 aggregates the low and high scenarios from both modelling approaches. The high CAGR scenario of 9,600Mt in 2050 would cover nearly all residual business emissions globally. This is highly unlikely and therefore excluded from our central range. The ranges shown illustrate a potential demand of 340-1,300Mt by 2030 and 800-2,800Mt by 2040, and 1,100-3,600Mt by 2050.

The contribution of the main sectors within each VCM demand scenario are shown in Table 4. On the basis of the approach and assumptions described above, some 60 - 70% of demand for carbon credits would come from Economy-wide scope 1 and 2 sectors. Scope 3 emissions from the EU oil & gas sector and CORSIA would typically each make up 15-20% of the global demand for carbon credits between 2020 and 2050.

Table 4. Summary VCM demand scenarios by broad sector (MtCO₂e/yr)

	2020	2030	2040	2050
EU oil & gas scope 3	-	100 - 200	200 - 410	310 - 620
CORSIA	-	60 - 150	160 - 400	270 - 640
Economy-wide scope 1 and 2	90	270 - 950	440 - 1,990	520 - 2,340
Total	90	430 - 1,300	800 - 2,800	1,100 - 3,600

Figure 7. VCM future demand scenarios (MtCO₂e/yr)



4. The future supply of voluntary carbon credits

4.1 Overview

We model the future supply of carbon credits that could be made available to the voluntary carbon market, and their associated costs, from 2020 to 2050

The Trove Research Global Carbon Credit Supply (GCCS) model projects the potential future supply of carbon credits that could be made available to the voluntary carbon market, and their associated costs, from 2020 to 2050. The supply model consists of three general project types that are likely to comprise the majority of new carbon credit projects in the near term: Nature Based Solutions (NBS) (comprising forest restoration and avoided deforestation), Negative Emission Technologies (including Carbon Capture & Storage, and Bioenergy with CCS), and Renewable Energy in Least Developed Countries (Table 5).

Only 1(i) and 2(ii) remove carbon dioxide from the atmosphere (although the effectiveness of BECCs in the long term is disputed), whereas 1(ii) Avoided deforestation and forest degradation, 2(i) CCS and 3. Renewable Energy, reduce the collective rate of emissions into the atmosphere. This distinction is relevant in the context of corporate Net Zero emission pathways where removals are prioritised once all feasible mitigation activity has been undertaken.

Table 5. Supply technologies assessed in the model

Project type	Net Zero classification	
	Reduction	Removal
1. Nature based Solutions		
(i) Forest restoration		✓
(ii) Avoided deforestation (REDD+)	✓	
2. Negative emission technologies		
(i) Carbon capture & storage (CCS)	✓	
(ii) Bioenergy with CCS (BECCs)		✓
3 Renewable Energy in Least Developed Countries.	✓	

The model presents average annual supply capacity and costs from 2020 to 2050. For simplicity it can be assumed that the rate of emission reduction and sequestration grows linearly over time, hence the annual average emissions reduction can be approximated as that in 2035. Figure 8 summarises the structure of the GCCS model, highlighting approaches to volume and cost calculations.

The analysis of carbon credit availability and costs in this section does not judge the additionality of individual projects or project types. The modelling assumes that the processes for approving voluntary carbon projects are robust and adhere to high quality principles of additionality and holistic environmental benefits.

Figure 8. Global Carbon Credit Supply (GCCS) Model structure

		Supply volume calculations	Cost calculations
Nature based Solutions model	Forest and other ecosystem restoration	Difference between BAU where no restoration takes place and previously published carbon uptake estimates. Five land cover classes for each country.	Value of land derived from forecast crop prices and yields. Supplemented with project monitoring and management costs obtained from interviews with project developers.
	Reducing Emissions from Deforestation and Forest Degradation (REDD+)	Difference between BAU rate of deforestation and targets in New York Declaration of Forests (no deforestation after 2030)	
Negative emission technologies	Carbon Capture & Storage Model (CCS)	Published data and expert interviews to forecast CCS capacity to 2050.	Published data and expert interviews to forecast CCS costs to 2050.
	Bioenergy Carbon Capture & Storage Model (BECCS)	Energy crop yields and projected technological advancements that increase the capacity of BECCS. Capacity capped by capacity in CCS model.	CCS costs from CCS model, crop costs from land-use sub-model
Renewable energy in Least Developed Countries		IEA growth models for renewable energy in LDCs and calculated carbon reductions achieved in each country.	Incremental RE costs from public funding programmes to support RE in LDCs in Africa.

4.2 Forest and other ecosystem restoration

The Trove Research GCCS model assesses the potential for carbon uptake from ecosystem restoration in four steps:

1. Land availability
2. Carbon uptake of available land
3. Country allocation
4. Unit cost calculations

(i) Land availability

Land availability for forest restoration is determined for every 350 m² of earth’s ice-free land using Copernicus Land Cover satellite data for the years 2015-2019.¹⁴ Urban land, crop land, intact forest and naturally low tree density areas (deserts, savanna, and steppe) are excluded, as well as high-latitude boreal forests due to albedo effects.

We define five land cover types available for forest restoration:

- Grassland
- Shrubland

The model assesses each 350x350m of global land cover

¹⁴ Buchhorn, M. et al. Copernicus Global Land Service: Land Cover 100m: Version 3 Globe 2015-2019: Product User Manual. Copernicus Glob. L. Oper. 1–93 (2020)

3% of the earth's ice-free land is biophysically available for forest restoration

- Open (degraded) forest
- Closed (degraded) forest
- Wetlands (mangroves¹⁵ other wetlands)

Globally, 3% of the earth's ice-free land is biophysically available for forest restoration (3.9 million km²).

(ii) Carbon uptake of land available

To estimate the cumulative carbon uptake by 2050, we use annual carbon uptake rates for each 350 m² grid cell available. These are based on 13,112 on-the-ground measurements of aboveground carbon stocks.¹⁶ These are then adjusted to include belowground biomass, scaled to initial biomass and aggregated over the next 30 years.

Above-ground biomass (AGB) carbon is scaled by biome-specific root-to-shoot ratios to represent above and below-ground carbon.¹⁷ Since a grid cell with a high initial biomass in 2019 will not sequester as much carbon in the future as a similar grid cell with lower existing biomass, carbon uptake estimates are scaled depending on the initial 2019 biomass.

If the initial AGB is less than the total amount of carbon sequestered from restoration until 2050, the original carbon sequestration rate is applied (ref 16). If the initial AGB is greater than the total amount of carbon sequestered from restoration until 2050 and the initial AGB is less than 100 tC ha⁻¹ the carbon sequestration rate is reduced by 50%.

If the initial AGB is greater than the total amount of carbon sequestered from restoration until 2050 and the initial AGB is greater than or equal to 100 tC ha⁻¹, but less than 200 tC ha⁻¹, the carbon sequestration rate is linearly reduced by 50% to 100%.

Finally, any grid cell where initial AGB is greater than 200 tC ha⁻¹ has been excluded from this analysis because biomass is considered to be near its maximum with no further room for further carbon uptake. This provides the carbon sequestration potentials for every available area of land for forest restoration.

(iii) Country allocation

Carbon uptakes for each 350 m² are then summed for 206 countries, to produce the total carbon uptake potential for each country (Figure 9). Brazil, China, Colombia, Indonesia, and India account for 50% of the world's biophysical restoration potential.

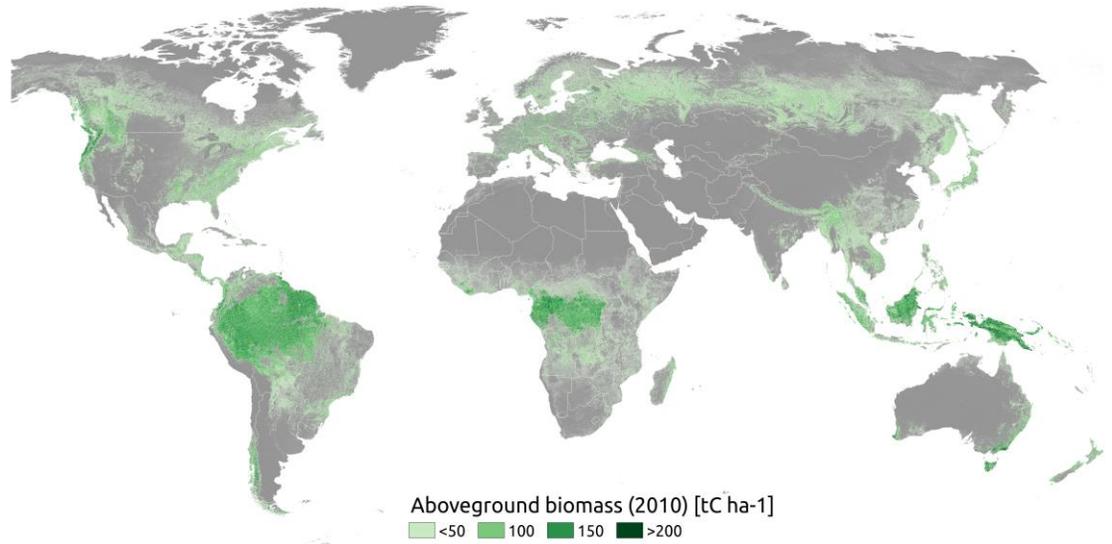
¹⁵ Simard, M. et al. Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nat. Geosci.* 12, 40–45 (2019)

¹⁶ Cook-Patton, S. C. et al. Mapping carbon accumulation potential from global natural forest regrowth. *Nature* 585, 545–550 (2020)

¹⁷ Mokany, K., Raison, R. J. & Prokushkin, A. S. Critical analysis of root: Shoot ratios in terrestrial biomes. *Glob. Chang. Biol.* 12, 84–96 (2006)

Figure 9. Aboveground biomass (2010) (tC ha⁻¹)

Brazil, China, Colombia, Indonesia, and India account for 50% of the world's biophysical restoration potential



Source. Spawn et al. All data layers are resampled to a common grid cell size of 350m x 350m at the equator¹⁸

(iv) Unit cost calculations

The GCCS model calculates the cost per tonne of CO₂ sequestered in above ground biomass (mostly trees) for each 350m² cell of global land cover by comparing the value of the land converted to trees with the next most valuable use, agriculture, this is the opportunity cost. We also factor in estimated carbon project validation, management and monitoring costs to conduct the necessary processes to create and calculate the carbon credits. The calculation is as follows:

$$\begin{array}{rcl}
 \text{Restoration cost for} & = & \text{Opportunity cost of land} & + & \text{Project validation,} \\
 \text{each land use type} & & (\$/\text{ha}) & & \text{management \&} \\
 (\$/\text{tCO}_2) & & & & \text{monitoring (\$/yr)} \\
 & & & & \\
 & & \hline
 & & \text{Sequestration rate (tCO}_2/\text{ha)}
 \end{array}$$

The opportunity cost of the land is dependent on the land use type, its geographical location and value of the alternative land use. Land can be used for crops and raising livestock. The model assesses the opportunity cost of land areas separately for crops and livestock where spatial maps indicate there is no overlap of land use. However, where the maps indicate that the land could be used for growing crops or raising livestock, the model calculates the simple average opportunity cost per ha from both land uses.

¹⁸ Spawn et al, 2020, Harmonised global maps of above and belowground biomass carbon density in the year 2010.

The IMPACT model projects commodity prices of 60 agricultural products covering 159 countries

Crop land values

The potential crops grown in each grid cell are based on local soil and environmental conditions. The expected revenues are based on the productivity yield per ha of land for each land-use type, multiplied by the wholesale price of that commodity in local currency. Productivity and commodity price forecasts are based on the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), produced by International Food and Agriculture Research Institute (IFPRI).¹⁹

The IMPACT model is a sophisticated forecasting tool projecting the prices of 60 agricultural products covering 159 countries. Agricultural production is specified by models of land supply, allocation of land to irrigated and rainfed crops, and determination of yields. Production is modeled at a subnational level, including 320 regions, called food production units (FPUs). FPU's are defined to link to the water models and correspond to water basins within national boundaries—154 basins (that is, Nile, Amazon, and so forth) and the 159 countries.

The model is a widely used reference for creating future commodity price scenarios, simulating national and international markets, solving for production, demand, and prices that equate supply and demand across the globe. The core model takes into account multiple factors affecting future agricultural prices including: climate change (earth system models); hydrology and water basin management; crop growth rates; value chains (eg sugar, oils, livestock); land use and cropping patterns; and nutrition and health (eg future meat consumption).

In the Trove Research GCCS model, future commodity prices are based on a moderate GDP and population growth IPCC scenario (Shared Socio-economic Pathway, SSP2-45) in the IMPACT model. Modelled commodity yields, however, are not impacted by climate change in this scenario.²⁰ Table 6 shows the agricultural products used in the model.

Table 6. Main land-use types and animal land used in the GCCS model

Commodity			
Lamb	Yams	Sunflower	Sugar
Beef	Other Roots	Sunflower Oil	Groundnut
Barley	Beans	Sunflower Meal	Groundnut Oil
Maize	Chickpeas	Palm Fruit Oil	Groundnut meal
Millet	Cowpeas	Palm Kernel Oil	Rapeseed
Rice	Lentils	Palm Kernel Meal	Rapeseed Oil
Sorghum	Pigeon peas	Other Oils	Rapeseed Meal
Wheat	Other Pulses	Cacao	Soybean
Other Cereals	Banana	Coffee	Soybean Oil
Cassava	Plantain	Cotton	Soybean Meal
Potato	Tropical Fruit	Tea	
Sweet Potato	Temperate Fruit	Vegetables	

¹⁹ Robinson, S. et al. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3. SSRN Electron. J. (2016)

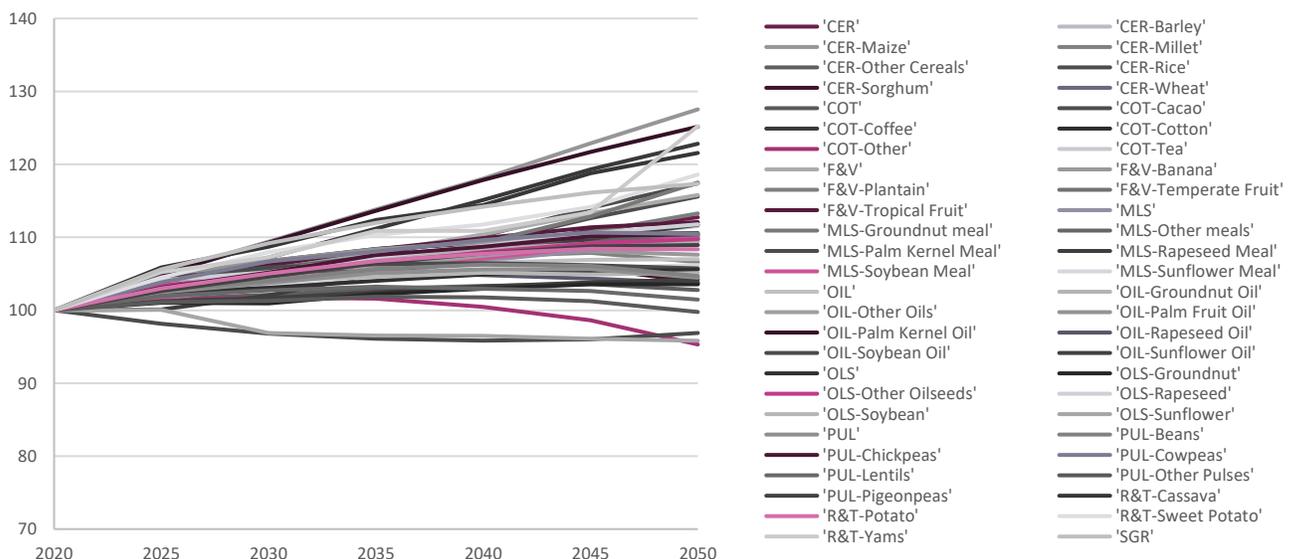
²⁰ Research Institute (IFPRI), I. F.P. Beyond a middle-income Africa: Transforming African economies for sustained growth with rising employment and incomes. (2015)

IMPACT forecast commodity prices have been calibrated off the most recent world commodity prices

The IMPACT model commodity price forecasts reference off 2005 prices, hence 2020 prices are effectively a 15-year forecasts from 2005 to 2020, expressed in \$2005 prices. Trove Research analysis of agricultural commodity prices published by the World Bank in 2020 shows that, on average, prices are 16% higher than the \$2005 IMPACT prices in 2020. Data published by the FAO show commodity prices are 21% higher. To adjust for this, all commodity price forecasts in 2020 from the IMPACT model are inflated by 18% (the average difference between the World Bank & FAO prices and the IMPACT model forecasts for 2020). All prices presented in the GCCS model are shown in \$2020.

Figure 10 shows the relative changes in agricultural commodity prices from 2020 to 2050 in the IMPACT model and used in the GCCS. These show some commodities increasing in price by 30% in real terms, as demand growth outstrips land availability and increases in productivity, for example maize, palm kernel oil, coffee, cassava and yams.

Figure 10. Relative changes in agricultural commodity prices used in the GCCS model



Source: IFRI, Impact Model

Livestock land values

Land values for livestock are modelled through a dedicated livestock model.

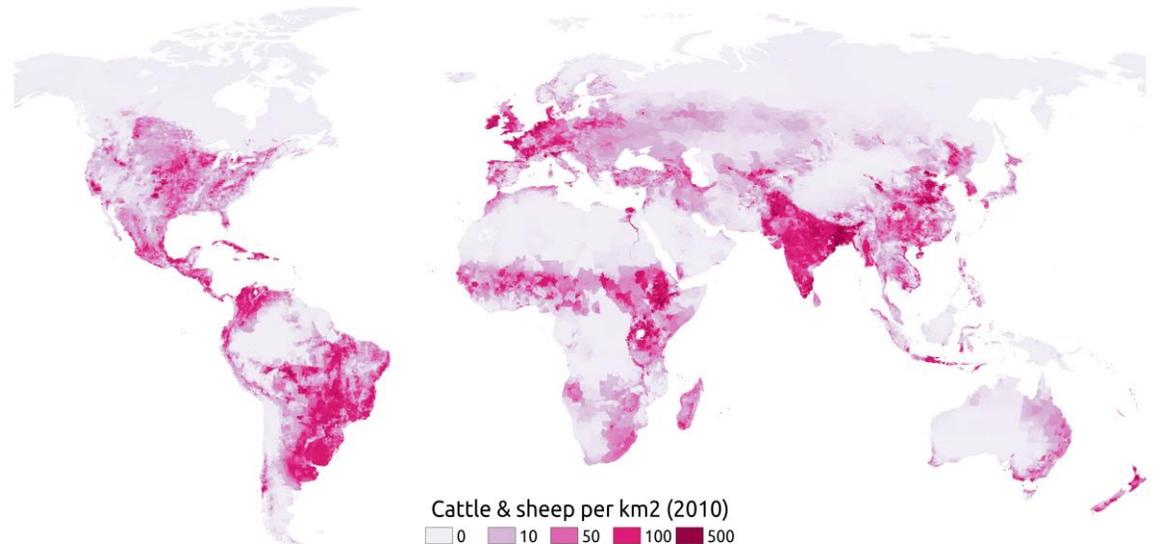
The value of land used to raise livestock is modelled separately from crops, using independent models of livestock coverage at 1 km resolution from the ‘Gridded Livestock of the World v2’. ²¹ In our model we focus on cattle and sheep, selecting grid cells of between 0.1 to 20 cows and 0.1 to 30 sheep used for pasture.

We convert number of animals per area into produced meat per area (t ha⁻¹) using output from the IMPACT model under the SSP2-45 scenario, and convert this to production value per area (USD ha⁻¹) using the equilibrium-price estimates from the same model. The value of beef and lamb are taken from the IMPACT model (cattle, \$3703/t, sheep \$4314/t). We assume a 20% profit margin to arrive at the opportunity cost for each livestock, and then aggregate

²¹ Robinson, T. P. et al. Mapping the Global Distribution of Livestock. PLoS One 9, e96084 (2014)

both cattle and sheep layers to arrive at a gridded global opportunity cost layer for restoring grassland. We then extract the median opportunity cost (USD ha) for each land cover type in each of the 206 countries. Figure 11 shows the distribution of farm animals across the world, used in the model.

Figure 11. Cattle and Sheep density per km²



Carbon credit project costs

The additional cost incorporated in to the GCCS is the validation, verification and on-going monitoring needed to sell carbon credits. These costs vary considerably by project, depending on the type of project, local conditions and, most importantly, the scale of the project. There are significant economies of scale, especially for land-based projects such as forest restoration and REDD - larger projects have lower per unit costs.

The GCCS model assumes an average restoration projects size of 72,000tCO₂/yr, from land restoration project data in the Verra VCS database. For these projects we assume an average project validation, management and monitoring cost of USD 40,000 per project per year. This is based on interviews with project developers and from an independent analysis of the costs of REDD+ projects in South America.²² We scale this to a cost per ha for validation, verification and monitoring costs.

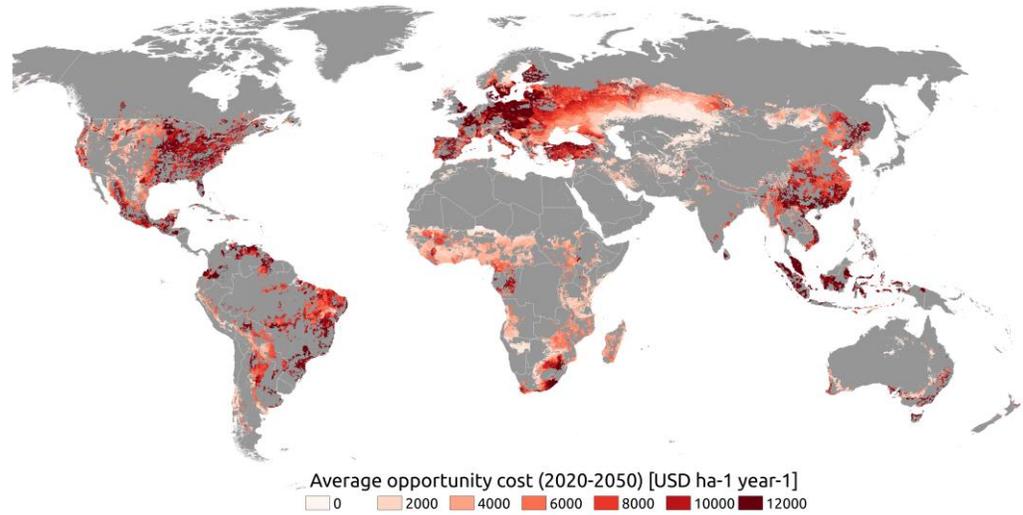
Combined restoration opportunity costs

The combined opportunity cost at 350 x 350m² cells on land that can be practically converted to tree cover is shown in Figure 12. This highlights the higher costs in countries with higher land productivity rates, such as Europe, North America and China, and parts of Brazil and South Africa.

The GCCS model builds in costs for carbon credit project monitoring and verification

²² Rendon, O. et al. Reducing Emissions from Deforestation and Forest Degradation (REDD+): Transaction Costs of Six Peruvian Projects. Ecol. Soc. 18, 17 (2013)

Figure 12. Average opportunity cost over the period 2020-2050 at 350x 350m (\$/ha/yr)



Source: Trove Research calculations

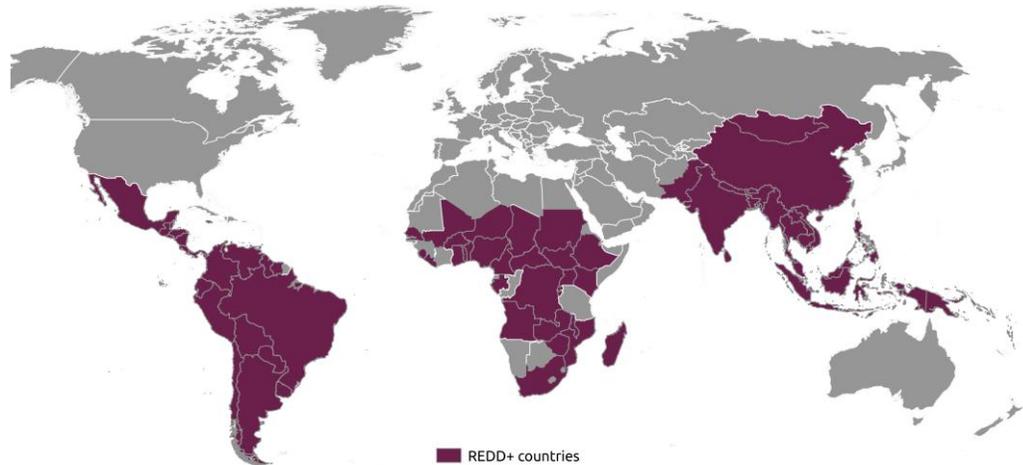
4.3 REDD+

Calculating the available supply of REDD+ carbon credits

The REDD+ module covers 71 countries

The calculation of the carbon credit supply from REDD+ projects is limited to 71 countries that already participate in REDD+ with existing projects (Figure 13). The maximum potential for REDD+ is the difference between linearly reducing deforestation to zero from 2020 to 2030 (consistent with the New York Declaration on ending deforestation by 2030), and business as usual deforestation from 2020 to 2050 described below. The difference between a successful REDD+ implementation and a baseline deforestation rate for each country is the maximum potential contribution by REDD+.

Figure 13. REDD countries included in the GCCS



Brazil, Indonesia and Democratic Republic of Congo make up 50% of the REDD+ potential between 2020 and 2050

We create a baseline deforestation up to 2050 using a peer-reviewed population-driven deforestation model that was specifically designed for estimating REDD+ baselines.²³ The model is based on the empirical relationship between a country's forest cover and its population pressure with regard to the available forest area, where deforestation is shown to *decline* when a country's population increases. This is due to scarcity of material (eg wood), which leads to reforestation, and increases in agricultural productivity and urbanization.

The relationship is as follows:

$$PP_{t,i} = POP_{t,i} / FA_i$$

$$FC_{t,i}^* = -3.109 + 0.621 \ln(PP_{t,i})$$

$$FC_{t,i} = FC_{pot1} + e^{FC_{t,i}^*}$$

Here *POP* is the population of a country *i* and time *t*, *FA* is the total forest area of that country, *PP* is the population pressure of the available forest area, *FC_{pot}* is the potential forest cover in percent,²⁴ and *FC* is the projected forest cover. As with the restoration modelling we use central assumptions on population and GDP growth, Socio-economic Scenario Pathway (SSP2-45) population projection and FAO forest area per country.^{25, 26}

In the scenario where REDD+ is successfully implemented we decrease deforestation rates linearly to zero by 2030 in agreement with multiple countries' pledges to end deforestation by 2030 via the New York Declaration on Forests.

We convert deforested areas to carbon emissions using 2005-2019 CO₂ emissions per unit area (tCO₂ ha⁻¹) for each country.²⁷ We assume that forests continue to act as a carbon sink in the tropics, and that this sink is removed if these forests were deforested. Therefore, these forgone CO₂ removals are added to the deforestation emissions of the baseline.²⁸ Overall, Brazil, Indonesia and Democratic Republic of Congo make up 50% of the REDD+ potential between 2020 and 2050.

Projected REDD+ CO₂ benefits - the difference between baseline emissions and achieving zero deforestation by 2030 - are shown for six key countries in Figure 14 (Brazil, Democratic Republic of the Congo, Indonesia, Colombia, Zambia and Thailand). In Brazil, Colombia, Indonesia, and Thailand population is projected to steeply increase until 2050, causing at first deforestation and an increased potential for avoided deforestation emissions. According to the population-driven deforestation model referenced above, further increases in population

²³ Köthke, M., Leischner, B. & Elsasser, P. Uniform global deforestation patterns — An empirical analysis. *For. Policy Econ.* 28, 23–37 (2013)

²⁴ Hengl, T. et al. Global mapping of potential natural vegetation: an assessment of machine learning algorithms for estimating land potential. *PeerJ* 6, e5457 (2018)

²⁵ Kc, S. & Lutz, W. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Glob. Environ. Change* 42, 181-192 (2017)

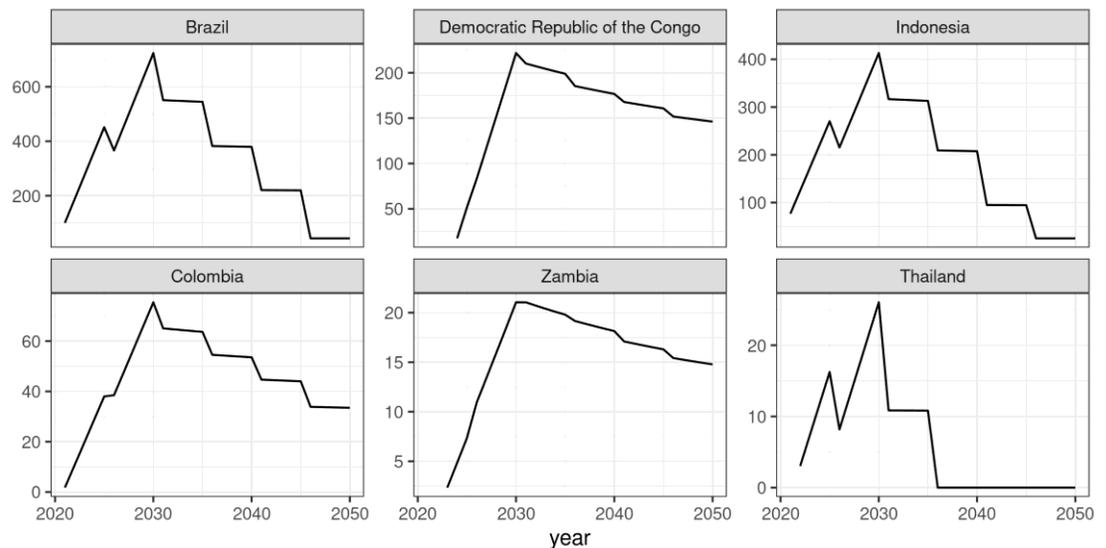
²⁶ Food and Agriculture Organization of the United Nations (FAO). FAOSTAT – Land use data. <http://www.fao.org/faostat/en/#data/RL/visualise> (2019)

²⁷ Zarin, D. J. et al. Can carbon emissions from tropical deforestation drop by 50% in 5 years? *Glob. Change Biol.* 22, 1336-1347 (2016)

²⁸ Hubau, W. et al. Asynchronous carbon sink saturation in African and Amazonian tropical forests. *Nature* 579, 80–87 (2020)

then result in a decline in the deforestation rate under the baseline scenario and therefore a decline in the potential for additional avoided deforestation emissions. In Thailand, for example, the end of deforestation under the baseline scenario is projected to occur in the mid-2030s, after which no additional reductions in deforestation emissions are possible. In the Democratic Republic of Congo and Zambia there is a slower shift from high deforestation rates towards a decline in deforestation due to population pressure, resulting in more deforestation in the baseline scenario and a more prolonged CO₂ benefit from REDD+.

Figure 14. Modelled REDD+ CO₂ benefit (difference between baseline emissions and achieving zero deforestation by 2030) - example countries (2020-2050, MtCO₂/yr)



REDD+ Unit costs

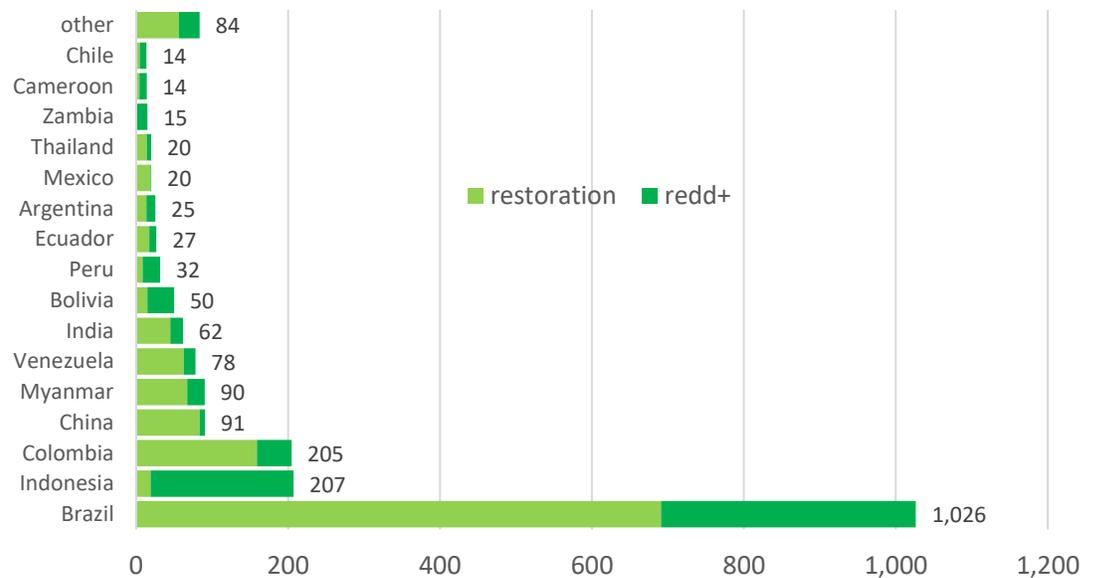
REDD+ costs are the sum of the forgone profits from converting the forest and the REDD+ project management and monitoring costs.

The cost of REDD+ is the sum of the forgone profits from converting the forest to crop land or pasture and the REDD+ project management and monitoring costs. We calculate the opportunity cost of land as for restoration, as the conversion of forest for agriculture is the most common cause for deforestation. The average opportunity cost is determined for each country for each year up to 2050 by multiplying by the annual average foregone profits from agriculture by the forecast REDD+ land area.

REDD+ project costs are assumed to be USD 40,000 per year, based on the aforementioned data from six South American projects. The average REDD+ project size is assumed to be 860,000 tCO₂/yr, based on our analysis of 59 REDD+ projects in the Verra VCS database. These project costs are small, at around USD 0.05/tCO₂ avoided.

Combined Restoration and REDD carbon credit supply curve

Figure 15 shows the potential for REDD+ and restoration activities in the top 16 countries. Potentials are largely a function of land area within each country and historical rates of deforestation. Brazil represents 50% of the world's potential for REDD+ and restoration, followed by Indonesia and Colombia at around 10%.

Figure 15 Restoration and REDD+ potential by country (MtCO₂/yr, average 2020-2050)

Over 2020-2505 there is considerably more potential for land restoration than REDD+.

Figure 16 shows the global combined supply curves for restoration and REDD+ for the average year in the period 2020-2050. These curves include all potential carbon emission reductions and removals from Nature Based Solutions, covering developing and developed countries. No allowance is made in these charts for plans countries have made to restore forests or reduce deforestation through planned activities. The curve also only represents the value of carbon emissions reduced and excludes other ecosystem benefits such as biodiversity preservation.

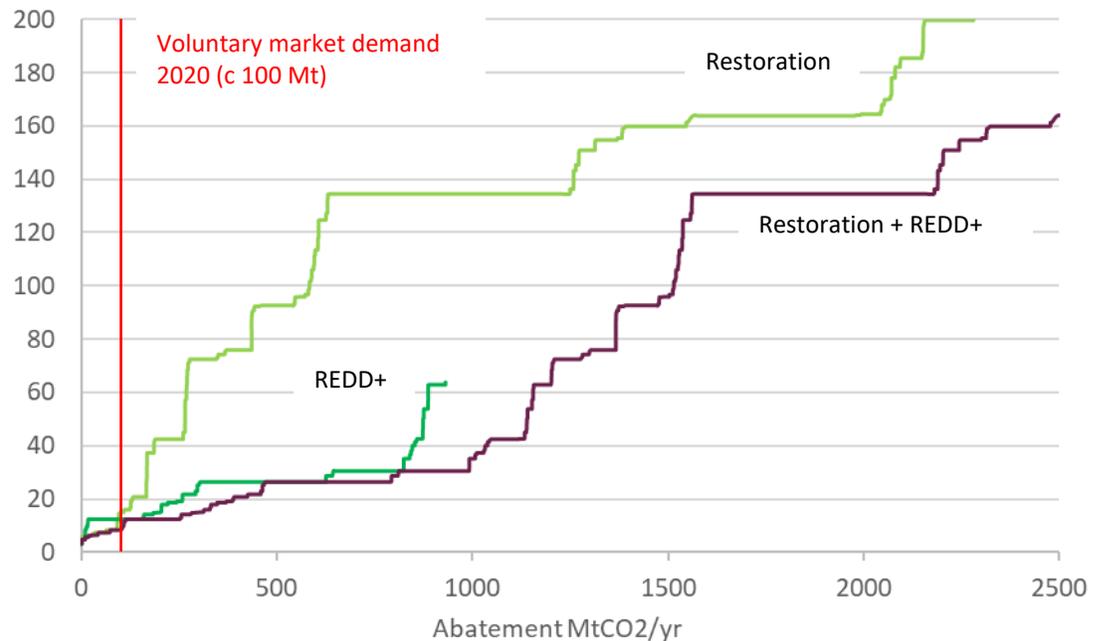
Figure 16 shows that Nature Based Solutions have the potential to reduce and remove up to 2,500MtCO₂/yr on average between 2020 and 2050, representing around 7% of world CO₂ emissions (from fossil fuels and cement processing).²⁹ However, a little over half of this volume (1,400MtCO₂/yr) is available at a cost of over \$50/tCO₂ (\$2020 prices).

Over the period 2020 to 2050 there is considerably more potential for land restoration to absorb CO₂ than for REDD+ to reduce emissions. REDD+ could reduce emissions by just under the 1,000MtCO₂/yr, compared to the potential for restoration to absorb up to 2,200MtCO₂/yr on average over the period.

The lower potential contribution from REDD+ is intuitive, as greater efforts to reduce baseline rates of deforestation should reduce the potential for avoiding this form of emissions release. Restoration of land to grow trees, on the other hand, can cover much larger land areas (cumulative past deforested areas).

²⁹ <https://ourworldindata.org/co2-emissions>

Figure 16. Global annual average sequestration supply curve 2020-2050 (\$/tCO₂) (2020 prices)



Source: Trove Research Global Carbon Credit Supply model

4.4 Carbon Capture & Storage

Carbon Capture & Storage is a key technology in efforts to reduce global CO₂ emissions, and many independent scenarios assume substantial use of CCS by 2050 if Paris temperature goals are to be achieved. CCS technology, however, is still at a relatively early stage of development, and CCS projects take several years to come to fruition.

Creating an abatement supply curve for CCS that represents an average carbon reduction potential between 2020 and 2050, therefore needs to take *the rate of deployment of CCS*, as well as its long term technical and economic potential.

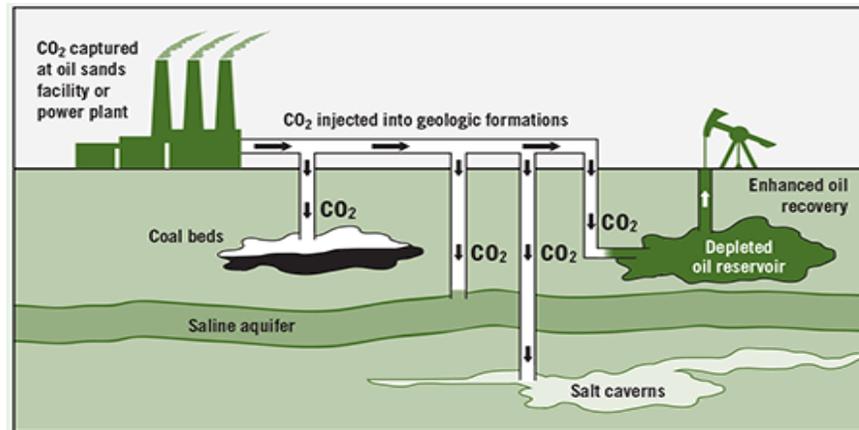
A key challenge in producing a supply curve for CCS is the number of permutations that can be deployed. The cost per tonne of CO₂ reduced depends on seven key variables:

1. Size of the plant
2. CO₂ concentration of the waste gas (the higher the concentration, the more cost effective its removal)
3. Fuel source (fossil or biological)
4. CO₂ capture technology (pre-combustion, post-combustion and oxyfuel)
5. Transport distance to the point of storage
6. Method of transport (pipeline, shipping vessel, tank)
7. Type of long-term storage (oil well, salt cavern, aquifer)

The costs and performance efficiencies of each stage in the CCS process are also changing as technology improves and operating experience expands. Figure 17 shows the structure and options for CCS processes.

The CCS supply curve is based on likely future CCS deployment rates, rather than theoretical potential.

Figure 17. Carbon Capture & Storage process



Given these uncertainties the GCCS model takes a simplified approach to building the CCS supply curve, based on:

- (i) Projected CCS capacity that could realistically be built by 2035 (mid-year of 2020-2050)
- (ii) Generalised unit costs and cost reductions that could be expected between 2020 and 2035.

Future CCS capacity

Current commercial-scale CCS plants in operation and in development can capture and permanently store around 40MtCO₂ per year.³⁰ These are shown in Table 7.

Table 7. Current CCS capacity in operation and in development

Country	Project	Capacity (MtCO ₂ per year)
UK	Net Zero Teesside (in development)	3.4
Norway	Northern lights (in development)	2.7
Netherlands	Rotterdam (in development)	2.5
Italy	Adriatic blue (in development)	2
China	China Hueng (in development)	1.6
Canada	Quest (in development)	1.8
US	Multiple	26
Total		40

Unlike other carbon credit sectors where capacity can be deployed relatively quickly (the impact of REDD is immediate) CCS capacity that could be built by 2035 is a function of the policy environment and willingness to pay, not limitations of geological storage capacity or technology. There is a considerable capacity to store CO₂ in geological formations, in excess of annual rates of greenhouse gas emissions. According to research funded by the Oil and Gas Climate Initiative (OGCI) global theoretical CO₂ storage capacity in saline aquifers and oil and

³⁰ Global CCS Institute (GCI). Global status of CCS. *Glob. CCS Inst.* 40 (2019)

gas basis amounts to around 12,200 bntCO₂. This is 350 times the current annual global CO₂ emissions from fossil fuels.³¹

Global theoretical CCS capacity is 350 times current global CO₂ emissions, but only a fraction of this will be used.

The limitation on accessing this capacity is due to the location of the emissions source and the sinks, as well as the nature of the exhaust stream. The large combustion plants producing the CO₂, such as power stations, may not be located near the oil and gas basis or aquifers.

The GCCS model estimates sequestration potential based on IEA scenarios of power sector coal and gas capacity that could be deployed with CCS by 2050, using the World Energy Outlook 2020. We assume that 30% of fossil fired stations are fitted with CCS technology by this time.³² The GCCS model uses the average year between 20202 and 2050, which in a linearly increasing market is 2035.

Two scenarios are considered in the IEA World Energy Outlook: the Stated Policies Scenario (SPS) which reflects the current trajectory of the world energy system, and Sustainable Development Scenario (SDS) which is aligned with the Paris temperature goals of less and 2°C warming. These scenarios are similar to those in the IEA 2021 World Energy Outlook. The SPS scenario has considerably higher fossil sector CO₂ emissions in 2050 than the SDS. Applying CCS capacity to 30% of fossil power sector emissions results in installed CCS capacity by 2035 of 300MtCO₂/yr in the SDS scenario and 1,650MtCO₂/yr in the SPS scenario Table 8.

We estimate global installed CCS capacity of 300MtCO₂ by 2035. This is x8 current CCS capacity.

Table 8. CCS deployment scenarios by 2050 and 2035) MtCO₂/yr)

	CO ₂ emissions from coal and gas power stations in 2050	CCS capacity in 2050	CCS capacity in 2035
IEA Stated Policies Scenario (SPS)	11,200	3,300	1,650 (x40 current capacity)
IEA Sustainable Development Scenario (SDS)	2,000	600	300 (x8 current capacity)

There are still considerable uncertainties around the rate of deployment of CCS for a range of technical, environmental and economic reasons. We therefore take a conservative approach to projections about the capacity potential by 2035, and use the lower range of these estimates at 300MtCO₂/yr. This is still eight times the current installed global CCS capacity including all Enhanced Oil Recovery facilities.

Future CCS costs

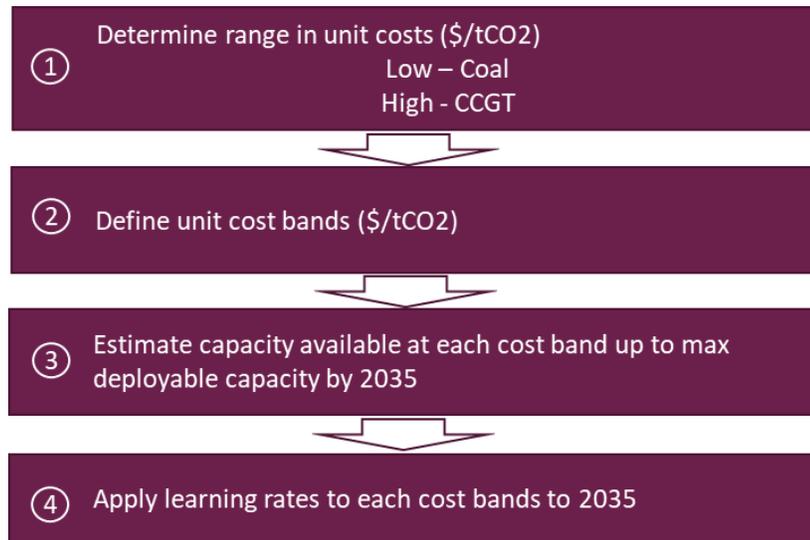
Given the number of factors affecting CCS plants, the cost per tonne of CO₂ removed can vary widely. Ideally the CCS abatement supply curve would be built up from discrete analyses of potential CCS capacity based on type of plant, fuel source, geology, transport distance, capture technology etc. However, as noted above, the number of permutations make this approach unfeasible.

³¹ Global CCS Institute (GCI). Global Storage Resource Assessment – 2019 Update. (2020). Note: over 97% of this capacity is “undiscovered”.

³² Koelbl, B. S., van den Broek, M. A., Faaij, A. P. C. & van Vuuren, D. P. Uncertainty in Carbon Capture and Storage (CCS) deployment projections: a cross-model comparison exercise. *Clim. Change* **123**, 461–476 (2014).

The GCCS simplifies the problem by taking the range in CCS costs observed today, dividing into cost bands, estimating the capacity available at each cost band (up to the maximum capacity deployable by 2035) and finally applying learning rates to these costs to 2035. The process is summarised in Figure 18.

Figure 18. Abatement supply curve methodology for CCS



1. Unit costs

Most CCS plants to date have been used for Enhanced Oil Recovery (EOR), or coal or natural gas power plants (Combined Cycle Gas Turbines, or CCGT) in demonstration projects. Experiences of these projects give a range of cost estimates. The GCCS model focuses on CCS projects applied to power sector facilities (coal and CCGT) where additional carbon finance is needed to make the projects viable.

CCS applied to EOR is not included in the model as it is already widely deployed and largely cost effective. We also do not include CCS for industrial uses, eg cement and iron and steel, as these projects are still in their infancy and likely to be more costly than those applied to power stations.

Key studies analysing the cost of CCS in the power sector are summarised in Table 9. In the GCCS model we take the Global CCS Institute figures as the basis for CCS costs in 2020, with the lowest at \$56/tCO₂ and the highest at \$125/tCO₂ in 2020. These ranges reflect the potential application of CCS to both coal and CCGT power plants.

2. Unit cost bands

In the GCCS model, unit costs are divided into bands to six discrete cost bands between the lowest (\$56t/CO₂) and highest costs (\$125t/CO₂).

Table 9. Power station CCS unit costs in 2020 (USD2020/tCO₂)

Source	Coal	CCGT
Global CCS Institute ³³	56	125
An Assessment of CCS costs, barriers and potential – Budinis et al ³⁴	41 - 62	52 – 100
European Technology Platform for Fossil Fuel Power Plants ³⁵	80 (FOAK) 55 (NOAK)	89 (FOAK) 43 (NOAK)

Note: FOAL = First Of A Kind; NOAK = Nth Of A Kind (ie after learning affects absorbed)

3. Capacity available at each cost band

The capacity available at each cost band is estimated based on Trove Research’s assessment of the likely share of CCS plants applied to coal and CCGT plants in the period 2020 to 2035. We expect most of the potential for CCS plants to be applied to coal plants because of their lower cost, but with some residual capacity available at CCGT plants due the proximity to geological carbon sinks.

4. Learning rates to 2035

Finally, a learning rate effect is applied to take account of technical improvements and gains in efficiency over time. Most efficiency improvements are expected to be in the CO₂ capture phase of the CCS process, as transport and sequestration technologies are considered relatively mature.

Learning rates are applied over time, using decadal averages, rather than the cumulative installed capacity. The GCCS model assumes the learning rates shown in Table 10, based on forecasts of the costs of retrofitting CCS to coal fired power stations in China up to 2050. ³⁶

Table 10. Annual learning rates assumed for CSS

Decade	Annual learning rate
2020-2030	3%
2030-2040	2%
2040-2050	1%

³³ Global CCS Institute (Irlam et al), 2017, Global Costs of Carbon Capture and Storage

³⁴ Budinis, S., Krevor, S., Dowell, N., Brandon, N. & Hawkes, A. An assessment of CCS costs, barriers and potential. *Energy Strateg. Rev.* 22, 61–81 (2018).

³⁵ European Technology Platform for Emission Fossil Fuel Power Plants, 2011, Post Demonstration Costs in the EU, The Costs of CO₂ Capture, Transport and Storage.

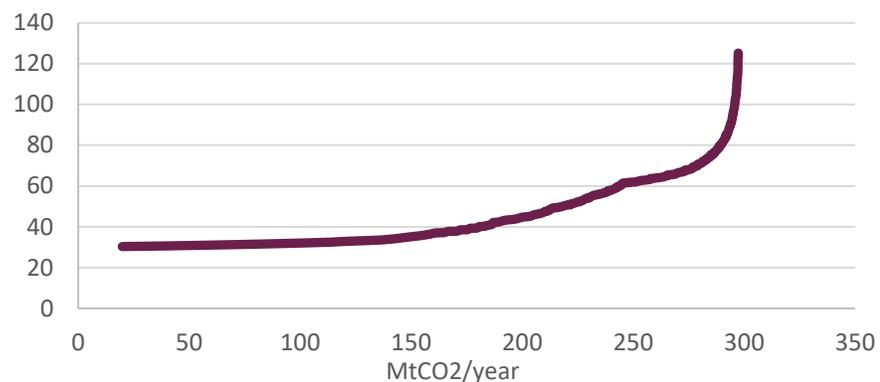
³⁶ Guo, J.-X. & Huang, C. Feasible roadmap for CCS retrofit of coal-based power plants to reduce Chinese carbon emissions by 2050. *Appl. Energy* **259**, 114112 (2020)

By 2035 we expect 160MtCO₂/yr to be removed at under \$40/tCO₂, but costs increase at higher deployment rates

The GCCS presents costs expected in 2035, as the average year between 2020 and 2050. The combined CCS supply curve is shown in Figure 19. Figures are expressed in \$2020.

We expect that by 2035 160MtCO₂/yr will be able to be removed from waste gas streams at a cost of less than \$40/tCO₂ in \$2020 prices. 160MtCO₂/yr is four times the currently installed CCS capacity, but represents only 0.3% of global greenhouse gas emissions. However, at higher rates of deployment costs start to rise, as power plants further away from appropriate sources of storage need to be used. To reach the maximum deployable capacity in 2035 of 300 MtCO₂/yr costs would need to rise to over \$100/tCO₂.

Figure 19. CCS global annual sequestration potential in 2035 (2020-2050) (2020\$/tCO₂)



4.5 Bioenergy with CCS (BECCS)

The concept behind the BECCS process is to remove CO₂ from the atmosphere through plants and permanently store the gas underground, whilst generating heat and power. BECCS makes use of the same geological storage capacity as CCS applied to fossil-fired combustion plants, but with the fuel coming from biological rather than fossil sources. The process is illustrated in Figure 20.

However, growing crops for energy use requires the existing biomass to be removed before the energy crops can be planted, thereby incurring a carbon debt. We account for this in the model by subtracting the initial biomass carbon (based on the adjusted above ground biomass map used for scaling the carbon uptake from restoration) from the first year of CO₂ uptake from bioenergy crops.

BECCS (supply volume)

The BECCS module is bounded by the CCS capacity projected in the CCS module but incorporates additional analysis to calculate the carbon absorbed by the energy crops used in the power plant. This is based on a global bioenergy crop yield map covering five key bioenergy crops (miscanthus, switchgrass, eucalypt, poplar and willow).³⁷ Atmospheric CO₂

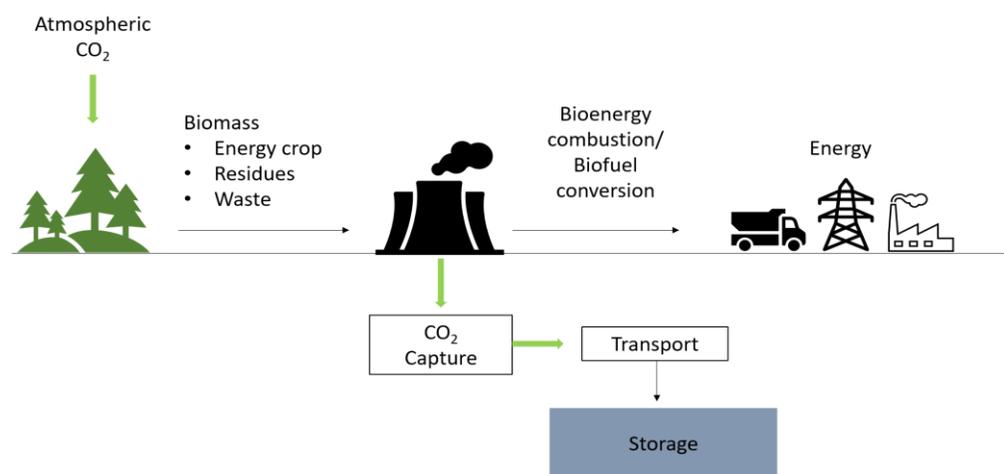
BECCS capacity is bounded by the deployable CCS capacity in 2035

³⁷ Li, W., Ciais, P., Makowski, D. & Peng, S. A global yield dataset for major lignocellulosic bioenergy crops based on field measurements. *Sci. Data* **5**, 180169 (2018)

absorption is calculated from the carbon taken up by the plants for each land cover type in each country.

However, growing crops for energy use requires the existing biomass to be removed before the energy crops can be planted, thereby incurring a carbon debt. We account for this in the model by subtracting the initial biomass carbon (based on the adjusted above ground biomass map used for scaling the carbon uptake from restoration) from the first year of CO₂ uptake from bioenergy crops.

Figure 20. The BECCS process



Projected BECCS costs

The bioenergy production cost component is separated into land rent, agriculture inputs and labour costs. For the land rent, we assume the same costs as for forest restoration. Agriculture costs, such as from fertilizer input and transport of crops to power plants are implicitly included in the production cost.

The production cost of switchgrass in the UK (95 USD ha⁻¹ year⁻¹³⁸) is scaled by the labour cost in the agriculture sector of a country relative to the UK⁽³¹⁾. Labour costs are only available for 30 countries, we therefore grouped each country into "High income", "Upper middle income", and "Lower middle income" countries as defined by the World Bank^{39 40} and used the averages for other countries in the same income group. For "Low income" countries we use the 80% of the minimum labour cost of the "Lower middle income" group.

³⁸ Perrin, R. & Harlow, S. The Economics of Switchgrass for Biofuel – Farm Energy. <https://farm-energy.extension.org/the-economics-of-switchgrass-for-biofuel/> (2019)

³⁹ International Labour Organization (ILO). Labour costs. *ILOSTAT* <https://ilostat.ilo.org/topics/labour-costs/> (2017)

⁴⁰ Serajuddin, U. & Hamadeh, N. New World Bank country classifications by income level: 2020-2021. <https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2020-2021> (2020)

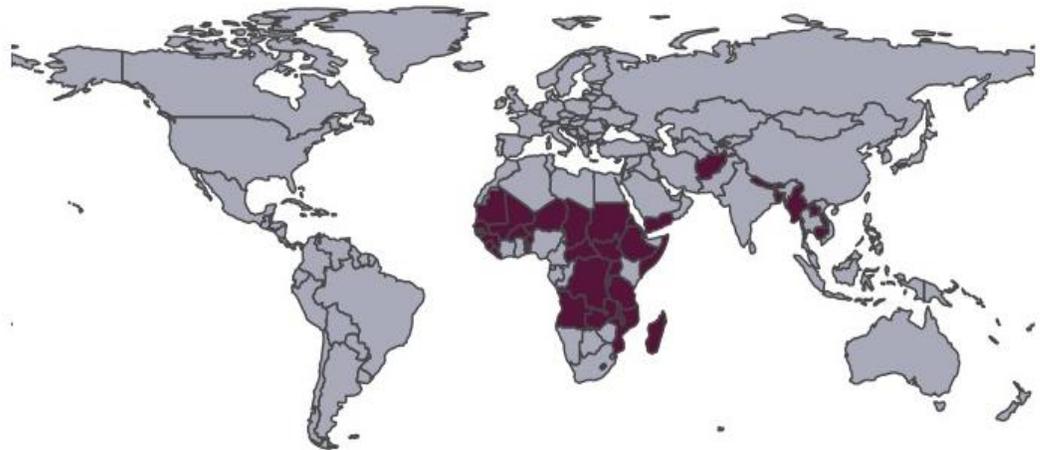
4.6 Renewable energy in Least Developed Countries

The two main voluntary carbon credit standard setting bodies (Verra and Gold Standard) have put in place restrictions to only allow carbon credits to be generated from renewable energy projects in Least Developed Countries (LDCs). This is because the cost of renewable energy projects has reduced to the point that the main renewable energy technologies of wind, solar and hydro power are assumed to be cost effective in all but LDCs, and therefore do not need the additional finance from the sale of carbon credits to be viable. These core renewable technologies have also benefited from strong government support. The two main US voluntary market registries, Climate Action reserve and America Carbon Registry, already exclude wind and solar projects.

Verra and Gold Standard only allow new renewable energy projects from LDCs

In the case of LDCs the development of renewable energy projects could still be eligible for the creation of carbon credits. The UN defines 46 countries as Least Developed Figure 21. Collectively whilst these countries account for 12% of world population, they account for less than 2% of world GDP and 1% of world trade. In 2020 LDCs emitted around 380MtCO₂ from fossil fuel consumption, accounting for around 1% of world primary energy consumption and CO₂ emissions. This is expected to grow to around 5.3% by 2050 (WEO,2020).

Figure 21. UN Least Developed Countries



Source: United Nations.⁴¹

Many of these countries currently rely on traditional biomass (wood) or fossil fuel (coal, gas or diesel) for their energy. Renewable energy projects in these countries could potentially displace this increase in fossil fuel demand and be eligible for producing carbon credits, providing they pass additionality tests contained in the standards and methodologies.

⁴¹ <https://unstats.un.org/unsd/methodology/m49/>

Carbon credit supply

Future carbon credit supply potential from renewable energy in these countries is modelled by forecasting increases in renewable output for these countries and assuming displacement of existing grid-based power at present day levels of carbon intensity.

Future renewable output is based on IEA World Energy Outlook projections Stated Policies (STEPS) and Sustainable Development Scenario (SDS) for Developed Countries, from which the LDC proportion is estimated based on shares of GDP.

The model suggests under the Stated Policies Scenario, by 2035, around 200MtCO₂/yr of carbon credits could be provided by renewable energy projects in LDCs. Under the SDS, with more rapid build out of renewable energy capacity, LDCs could provide up to 400 MtCO₂/yr of carbon credits.

Unit costs of renewable energy carbon credits

The prices transacted for voluntary carbon credits for renewable projects are currently unrealistically low. In 2019 the Ecosystem Marketplace survey showed average prices for carbon credits sold from renewable energy projects to be \$1.4/tCO₂.⁴² This price is insufficient to justify that the project would not have gone ahead without the sale of the carbon credit. The GCCS model takes a more fundamental approach to determining the cost of a carbon credit from renewable energy projects in LDCs.

The cost of a carbon credit should represent the additional finance required to enable a project that reduces emissions (compared to the counterfactual) to be financially viable. Least Developed Countries have particularly challenging problems when financing and building renewable energy projects. These stem as much from political and institutional risks, as from the basic economics of the project. Renewable energy projects (even small scale or rural projects) typically last for 20 years or more but have relatively high upfront capital requirements. Developers need long-term payment assurance, and in Least Developed Countries these assurances are more difficult to attain due to weaker political and institutional structures.

The extra cost required to support renewable energy projects in LDCs are often associated with managing these counter-party risks, for example by under-writing off-taker risk or helping build institutional capacity to support the regulations around the project.

The GCCS model uses data from the UK government funded Renewable Energy Performance Platform (REPP) which supports renewable energy projects in Africa, where almost all LDCs

The GCCS model uses data from government funded programmes that support renewable projects in LDCs to estimate carbon credit costs.

The GCCS model assumes the voluntary market finances 100% of the costs of supporting renewable energy projects in LDCs.

⁴² <https://share.hsforms.com/1ICNqRm4gSRGccSuyRZF-dg1yp8f>

are located.⁴³ In the period 2020 to 2023, the programme aims to disperse £100m finance to enable the construction of small-scale renewable energy projects in Africa (mostly solar).

The REPP aims to provide support for renewable energy projects at an average cost of **£26/tCO₂ (\$36/tCO₂)**. These figures include all disbursements and administrative overheads.

The GCCS model uses \$36/tCO₂ as a central figure and assumes a spread around this mid-value as shown in Table 11. The model assumes this price remains constant over the period.

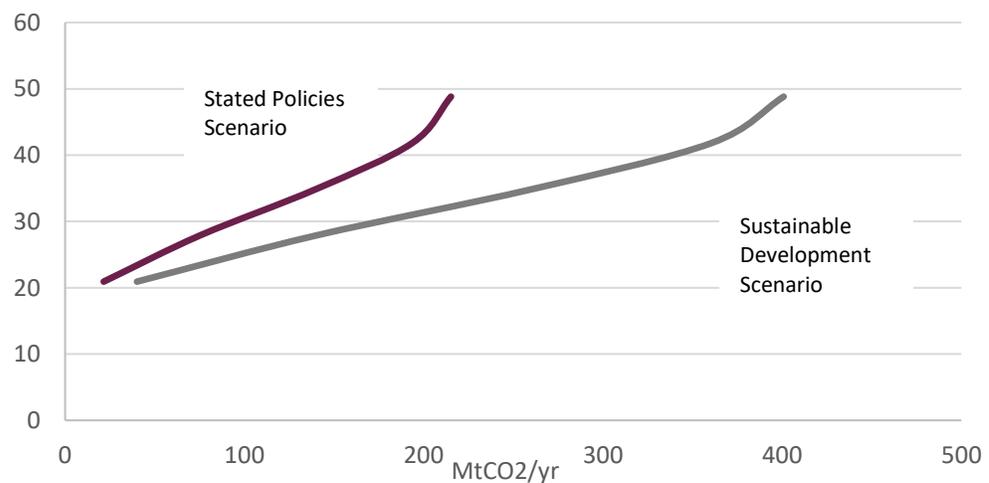
Table 11. Cost curve assumptions for renewable energy in LDCs

Proportion of renewable energy capacity growth in LDCs	\$/tCO ₂
10%	21
25%	28
30%	36
25%	42
10%	48

As renewable energy technology costs come down further and LDCs become more developed and more attractive places to undertake projects, the assumed carbon credits costs may also reduce. However, if project costs fall sufficiently and become cost effective, they would fail additionality tests and be rendered ineligible for carbon credit generation.

Combining the cost assumptions and the capacity modelling for LDCs we derive a carbon credit supply curve for renewable energy in LDCs in the representative year of 2035 (Figure 22). In the GCCS model we use the Stated Policies Scenario (SPS) to represent the supply from RE in LDCs, as we consider this to be the more likely development pathway for renewable energy in these countries.

Figure 22. Carbon credit supply curves for renewable projects in LDCs in 2035 (\$/tCO₂, \$2020 prices)



⁴³ <https://repp.energy/>

5. Adjusting Carbon Credit Supply Volume for NDCs

5.1 Agriculture, forestry and land-use in NDCs

Under the Paris Agreement, each country is required set out their plans for reducing greenhouse gas emissions to achieve the temperature goal of below a 2C warming from pre-industrial levels. These plans are referred to as Nationally Determined Contributions (NDCs).

The Voluntary Carbon Market needs to operate within these national commitments and ensure that the carbon credits being created and used by buyers to “offset” their emissions remain “additional”. This means reducing emissions beyond those which would have otherwise occurred. However, once an NDC is set by a country it is argued that it has made a commitment to achieve these emission reductions, and any activity within that country to reduce emissions cannot claim to be additional to that country’s efforts. Others argue that all emission reduction activities within a country are beneficial and should be counted as additional, irrespective of the country’s commitment to its NDC. A review of these issues was published by Trove Research in December 2020.⁴⁴

One way of viewing this challenge is to only allow projects to be eligible for generating carbon credits if they are additional to the emission reduction commitments in a country’s NDC. Under this approach all emission reduction activity within a county’s NDC would be counted towards the host government, not for the sale for another use.

We have assessed the implications for the Voluntary Carbon Market of applying such an approach, using the GCCS model together with an independent analysis of contribution of the Agriculture, Forestry and Land Use (AFOLU) land use to NDCs under the Paris Agreement.⁴⁵ In this analysis, the share of NDCs from the AFOLU sectors is deducted from the GCCS modelled carbon sequestration volumes. The model assumes countries start with the lowest cost reductions first, on the basis that governments will prioritise large scale, programmatic initiatives. Because of their scale these initiatives will tend to have lower costs. Any sale of carbon credits would then occur from higher cost projects that are in excess of that country’s NDC.

42 countries are included in this analysis, accounting for 66% of the total share of available reductions and removals from the land use and forestry sector. This is shown in Figure 23.

Several countries have pledged higher emission reductions via AFOLU than the volume we calculate is available through restoration, REDD+ and BECCS. These include Australia, Brazil, Canada, Indonesia, Angola, Madagascar and Central African Republic. This is because these countries include sources of AFOLU carbon sequestration in their NDCs other than REDD+ and restoration which are covered by the GCCS model. These additional abatement measures

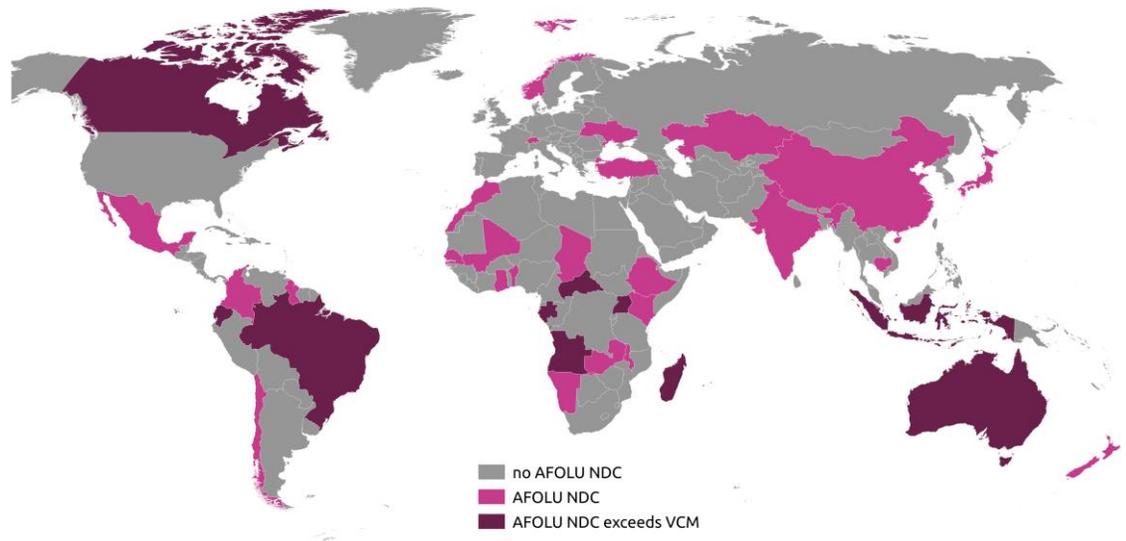
We run a scenario to assess the implications of removing carbon credit capacity from all projects within NDCs

⁴⁴ <https://globalcarbonoffsets.com/wp-content/uploads/2021/01/VCM-and-Article-6-interaction-6-Jan-2021-1.pdf>

⁴⁵ Grassi, G. et al. The key role of forests in meeting climate targets requires science for credible mitigation. *Nat. Clim. Chang.* **7**, 220–226 (2017)

may include agricultural practices such as reduced fertilizer use. Countries where the AFOLU NDC commitment is greater than the carbon reduction potential calculated through the GCCS model are treated as having zero residual emission reduction potential, as all their emission reductions are allocated to their NDC.

Figure 23. Countries with assessed AFOLU NDCs included in the model



Note: Countries where NDCs exceed available carbon supply from restoration and REDD in darker colour.

5.2 Adjusting cost curves for NDCs

The accounting treatment of voluntary carbon credit transactions under the Paris Agreement is subject to ongoing debate. The central issue relates to whether the use of carbon credits for voluntary purposes should require an adjustment in the host country's national emissions inventory – known as a Corresponding Adjustment (CA). Increasing emissions reported in the host country's inventory by the volume of the carbon credits used in the voluntary market prevents the emission reductions from being claimed twice (once by the host country and once by the buyer of the credit).

Applying Corresponding Adjustments would increase the cost of projects available to the voluntary market

Applying Corresponding Adjustments means the host country has the same abatement gap to achieve once the credit has been for use by an entity other than the host country. This could be for compliance, for example, under the international airline offsetting scheme, CORSIA, or in the voluntary market.

Assuming the least-cost abatement measures are undertaken first by the host government, applying Corresponding Adjustments would move the country along its abatement cost curve. This is illustrated in Figure 24 which shows a stylized abatement cost curve for a host country at a particular point in time. If project “6” is undertaken as a VCM project and used elsewhere to offset emissions, a Corresponding Adjustment of amount X would be added to the host country emissions inventory in order to retain the same emissions abatement effort for the host country. As lower cost projects are undertaken first, the marginal cost of

abatement as a result of the CA (project 10) would be at a higher cost than without the CA (project 8). The effect of the CA is to move the equilibrium price from P to P^{CA} .

From a modelling point of view, adding emissions to the NDC target through Corresponding Adjustments, has the same effect on price outcomes as removing the projects from the abatement cost curve and holding the NDC target constant. This is shown in Figure 25.

Figure 24 Effect of Corresponding Adjustments on marginal abatement cost of host country

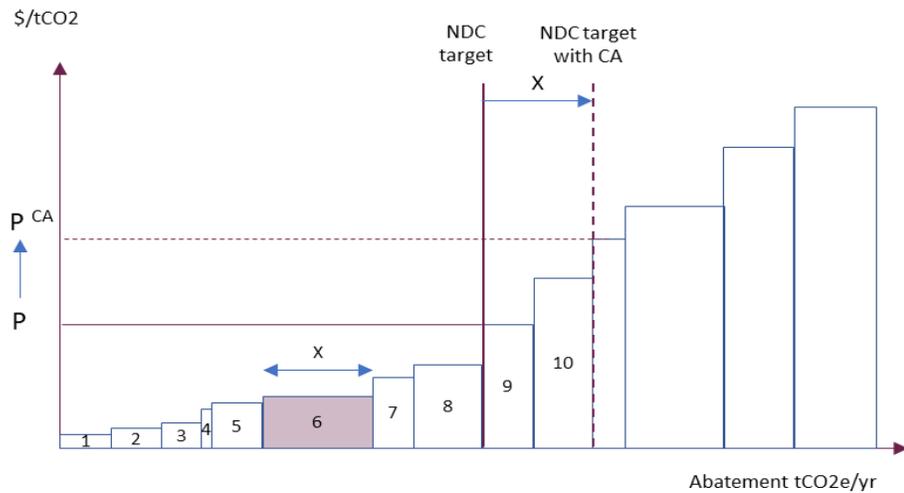
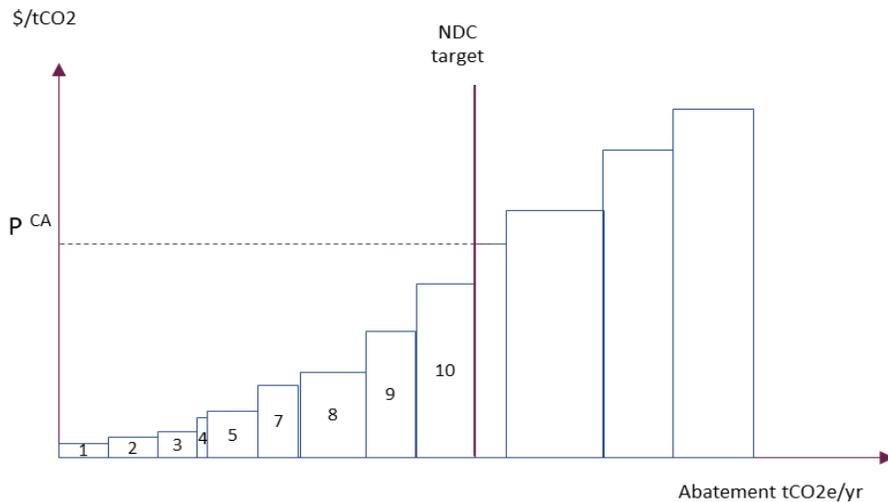


Figure 25 Removing project “6” from the abatement cost curve



This simplified approach assumes NDCs are static, whereas the Paris Agreement requires countries to set more ambitious targets every five years. In this case, a privately-funded, voluntary project would contribute to *future* public spending in meeting its future NDC target.

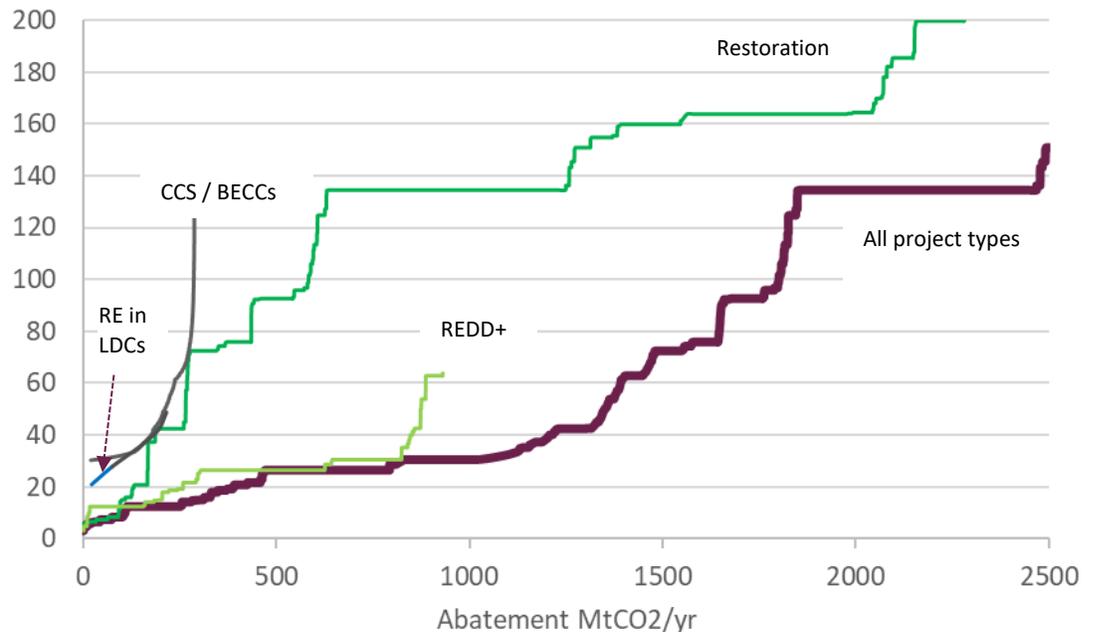
6. Global voluntary carbon credit prices and policy implications

6.1 Voluntary carbon market contribution to the Paris Agreement

The carbon credit supply potential described in the previous sections shows the volume of credits that can be supplied globally at different carbon prices for each of the four types of abatement: restoration, REDD, CCS/BECCs and Renewable Energy in LDCs. The combined curves are shown in Figure 26.

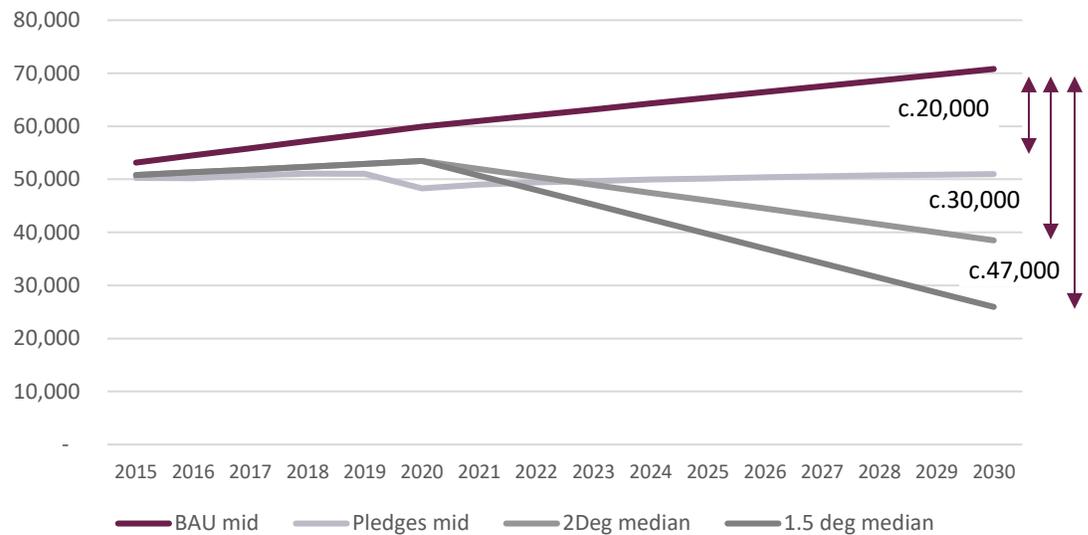
In Figure 26 abatement of 1000MtCO₂e/yr represents around 5% of the emission reductions pledged in countries' Paris NDCs in 2030, but only 2% of the abatement that would be needed in 2030 consistent with the Paris goal of 1.5C warming. Abatement of 2000MtCO₂e/yr would represent 10% of the Paris NDC pledges in 2030, and 4% of abatement needed in 2030 to be aligned with the 1.5C Paris warming goal.

Figure 26. Global carbon credit supply curve (excluding NDC adjustments) – Average over period 2020-2050 (\$/tCO₂e, 2020 prices)



Source: Global Carbon Credit Supply model

Figure 27 shows the global emissions abatement required in 2030 relative to BAU under the Paris pledges as of September 2020.

Figure 27 Emission gaps for NDCs as of September 2020 (MtCO₂e/yr)

Source: Climate Action Tracker ⁴⁶

The curves assume that all the carbon reduction potential from these project types is available to the voluntary carbon market. This means that the voluntary carbon market is responsible for providing all the necessary finance to enable the projects to go ahead. In practice some projects will be financed by other sources and would therefore not be eligible as voluntary carbon projects – they would not be “additional”. For example, this could apply to large-scale REDD or restoration projects under government sponsored programmes, country to country Internationally Traded Mitigation Options under the Paris Agreement, CCS/BECCs plants in receipt of government subsidies or RE projects financed through international development.

Hence it may be that all projects covered by a country’s NDC could be deemed ineligible for the generation of carbon credits, because they could be seen to be contributing to that countries NDCs and not in addition to it.

Figure 28 shows the effect on the aggregate carbon credit supply curve of deducting the modelled capacity of nature-based solutions (restoration and REDD+) from a country’s NDCs. As noted in the previous section we only adjust carbon credit projects falling within the restoration and REDD parts of a country’s NDC, due to limitations on the breakdown of other project types included in NDCs. Figure 28 focusses on the price range under \$100/tCO₂e.

Figure 28 shows that, without adjusting for NDCs:

- If demand in the voluntary carbon market increased fivefold to 500MtCO₂e/yr, prices would need to rise to \$25/tCO₂e (2020 prices). ⁴⁷ 500MtCO₂e/yr represents only 2.5% of

⁴⁶ <https://climateactiontracker.org/global/cat-emissions-gaps/>

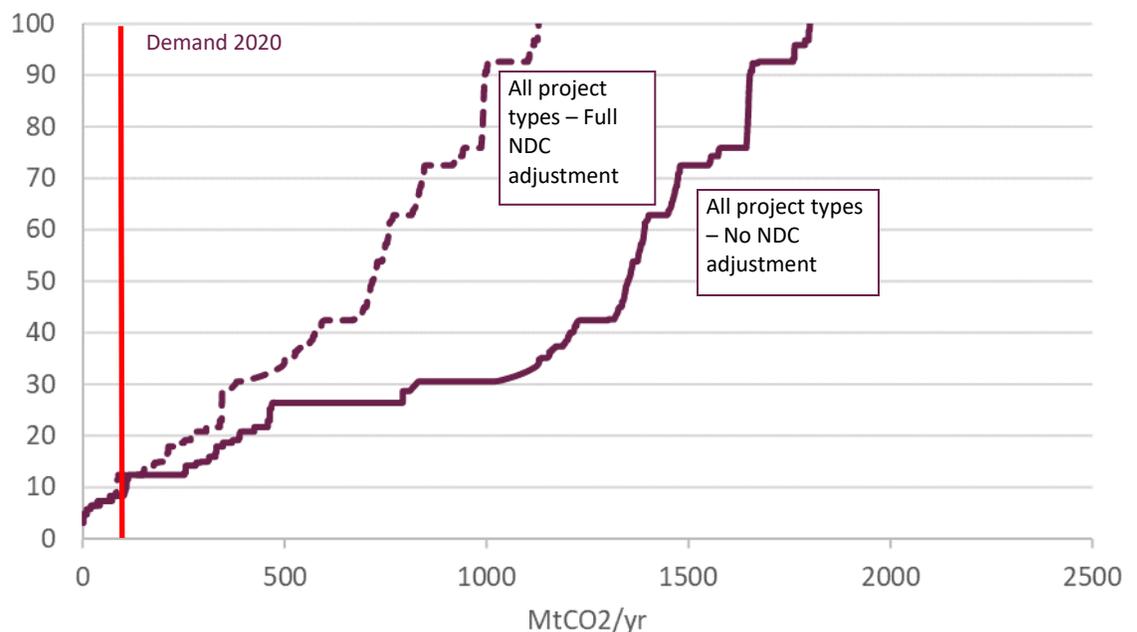
⁴⁷ Annual demand for voluntary carbon credits in 2020 was around 95Mt/CO₂

the emission reductions required in the NDCs made under the Paris Agreement in 2030, or only 1.1% of the emission reductions required to meet the Paris 1.5C goal in 2030.

- If voluntary carbon market demand increases tenfold to around 1000MtCO₂e/yr prices would need to rise to \$30/tCO₂e to meet this demand.

However, if voluntary market credits are only eligible for projects that are in addition to NDC commitment levels, then to deliver an additional 500MtCO₂e/yr would require a carbon price of around \$30/tCO₂e, and to meet a demand of 1000MtCO₂e/yr would require a carbon price of around \$80-100/tCO₂e.

Figure 28. Global carbon credit supply curve (including NDC adjustments) – Average over period 2020-2050 (\$/tCO₂e, 2020 prices)



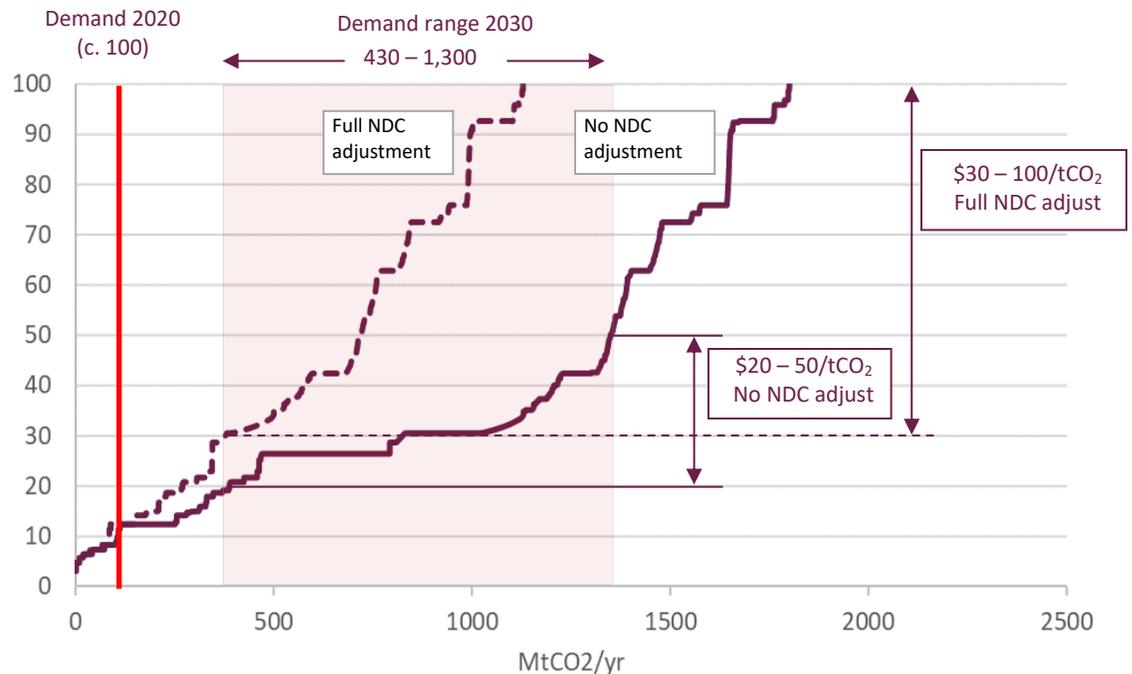
Source: Global Carbon Credit Supply model

6.2 Carbon credit prices needed to meet future voluntary carbon market demand

Demand for carbon credits in the voluntary market is expected to rise as more companies commit to emission reduction targets and make use of carbon credits to meet their goals. Section 3 described the Global Carbon Credit Demand model and presented scenarios for future carbon credit demand to 2050.

Figure 29 maps the demand onto the supply curves to show the carbon prices that would be needed in the voluntary market to deliver sufficient volume of credits to meet this demand. In this figure only the demand forecast range for 2030 is shown (430 – 1,300MtCO₂/yr) as 2040 and 2050 forecasts intersect with the supply curve at higher prices. As noted in section 3 these demand ranges assume no price response, whereas in practice voluntary carbon demand would be muted if credit prices rise significantly.

Figure 29. Global voluntary carbon credit price projections – average over period 2020-2050 (\$/tCO₂, 2020 prices)



Source: Global Carbon Credit Supply model

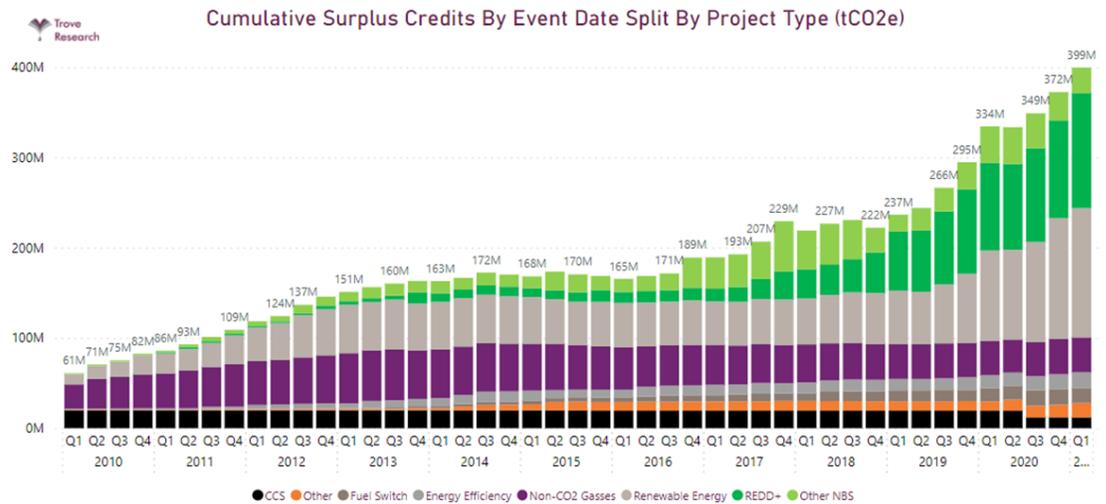
The modelling shows that at the levels of demand that could be expected in 2030 (x 10 to x20 current demand), carbon prices will need to rise significantly to incentivize the necessary investment in land restoration, REDD+, CCS/BECCs, and RE in LDCs.

By 2030 carbon prices would need to reach \$20 to \$50/tCO₂, assuming VCM projects could claim carbon credits whilst contributing to host country NDC targets. These emission reductions will need to come primarily from restoration and REDD+ up to \$30/tCO₂, but thereafter CCS and RE in LDCs would make a larger contribution.

If the tests for additionality in the VCM require projects to be over and above what countries have pledged in their NDC, then carbon credit prices would need to be even higher and in the range of **\$30 to 100/tCO₂**.

6.3 Price impact of the credit surplus

The volume of surplus credits has been building in the voluntary carbon market for several years. At the end of Q1 2021 the surplus - excluding CDM credits that have not been converted into VCM registries - stood at nearly 400MtCO₂e (Figure 30). This is around four times the demand in 2020.

Figure 30 Voluntary carbon market surplus from Q1 2010 to Q1 2021

Source: www.trove-intelligence.com

This surplus weighs down on VCM prices as buyers are able to source credits from a large range of existing projects with minimal incremental cost of delivery. If all of this surplus were ineligible for the VCM it would have a material impact on credit prices, with proceeds from the sale of carbon credits flowing to new projects, driving further emission reductions. **We estimate that removal of the surplus would add \$10/tCO₂ to average price of a carbon credit at today's level of demand.**⁴⁸

6.4 Policy implications

These price projections have important implications for how the voluntary carbon market evolves.

(i) Price as a measure of environmental integrity

Prices of carbon credits today, at an average price of \$4-5/tCO₂ for forestry related projects and \$1-2/tCO₂ for renewable energy projects, are unsustainably low.⁴⁹ There are opportunities for low-cost projects, with favourable combinations of land values and plant growth rates, but these opportunities are limited.

If prices remain below the forecast levels (\$30-50/tCO₂), questions should be raised about the credibility of the credits in delivering emission reductions that are genuinely additional to what would have otherwise occurred.

The Trove Research modelling shows that landowners and project developers require these levels of compensation to be incentivized to forego the economic benefits of converting land into agriculture and either reducing rates of deforestation or restoring forests. Similar levels

⁴⁸ VCM demand was around 100Mt/yr in 2020. On the basis of Figure 25 the average price of a credit at this level of demand should be around \$10-15/tCO₂. Current prices are in the \$4-5t/CO₂ range, partly due to excess supply. Without the surplus, prices should increase by c.\$10 to \$10-15/tCO₂.

⁴⁹ Ecosystem Market Place, Sept 2020, State and Trends of the Voluntary Carbon Market 2020.

of compensation are also required to develop CCS projects at scale and over-come the barriers to developing renewable energy projects in LDCs.

Persistent prices in the VCM below these levels would suggest the carbon credits sale is not the critical factor in financing the project, questioning the additionality criteria.

(ii) The importance of Nature Based Solutions

The VCM could be supplied entirely by Nature Based Solutions for the next 10 years.

Reforestation and REDD+ type projects offer significant supply at lower cost in the short to medium term. Nature Based Solutions could supply the VCM entirely up to a four-fold growth from current levels of demand, if these projects are allowed to help host countries achieve their NDCs (400Mt/yr compared to 90Mt/yr in 2020). The VCM could then grow eight-fold and be supplied by Nature Based Solutions before CCS would be justified in financed solely through the VCM at \$30/tCO₂.

(iii) Accounting treatment of carbon credit transactions under the Paris Agreement

Section 5 described how applying Corresponding Adjustments to voluntary market transfers would raise the cost of the projects available to the voluntary market. From Figure 29 our analysis shows that where all NBS projects contained within country's NDC are subject to CAs, **this would add up to \$50/tCO₂ to the price of a carbon credit by 2030.** This is an extreme case however. If Corresponding Adjustments are used for voluntary market transactions, they would only likely be applied to select projects.

(iv) Managing the surplus of credits from older projects

Trove Research report published in January 2021 (The Global Voluntary Carbon Market – Dealing with the Problem of Historic Credits) highlighted the issue with the build-up of surplus older credits in the voluntary carbon market, typically with lower environmental integrity than newer credits.⁵⁰

The analysis in this report shows how this overhang of un-used credits is weighing down on prices and limiting new investment. If this surplus was removed carbon credit prices would rise from an average of around \$5/tCO₂ to upwards of \$20t/CO₂.

6.4 Caveats and qualifications

The modelling of the future demand and supply of carbon credits in this report makes a number of assumptions and simplifications. These are outlined below together with their implications.

Demand forecasting

Modelling the future demand for voluntary carbon credits carries a large degree of uncertainty as in theory demand could cover all of the world's corporate emissions. We have used various approaches to estimating future carbon credit demand from scope 1 and 2

⁵⁰ <https://trove-research.com/research-and-insight/the-global-voluntary-carbon-market-dealing-with-the-problem-of-historic-credits-dec-2020/>

emissions, based on the most recent guidance on how carbon credits could be used as part of credible corporate climate commitments.

These estimates are static projections and assume companies are insensitive to the price of carbon credits. This is clearly a simplification as firms' willingness to acquire carbon credits in significant volumes at higher prices has not yet been tested.

Supply side modelling

Our supply side model focuses on the two main removal technologies of potential use in the VCM (reforestation, CCS/BECCS) and two key reduction technologies (REDD+ and renewable energy in LDCs). The removal technologies were chosen because of their importance in the context of achieving Net Zero targets and the Paris Agreement, noting a balance of anthropogenic sources and sinks of greenhouse gases. Initiatives such as the Science Based Targets Initiative prioritises removal technologies for "neutralizing" residual emissions, after a company has undertaken all it can to reduce its own emissions.

Reduction technologies of REDD+ and renewable energy in LDCs were chosen because these credits are being sold and look set to be in the future. Additionally, reducing deforestation is essential to meeting Net Zero targets and preserving forests is important for reasons other than climate change. Renewable energy is a key technology to fight climate change with the main standard setting bodies (Verra and Gold Standard) only allowing renewables in LDCs going forward.

Other reduction technologies could add to the potential supply outside these four key technologies. These include energy efficiency measures, such as clean cook stoves, or projects to reduce methane emissions and other non-CO₂ gases. However, these typically do not remove carbon dioxide from the atmosphere and energy efficiency measures may struggle to achieve the higher quality standards being discussed in various forums such as the TSVM. More technical assumptions and simplifications in the supply side modelling are explained in the previous section.

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