Interactive tool on the impact of carbon dioxide removal approaches on the Sustainable Development Goals in Latin America and Caribbean countries

User instructions

UNITED NATIONS
ECLAC

C2G
Carnegie Climate Governance Initiative

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CARNEGIE COUNCIL for Ethics in International Affairs

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ACRONYMS

The following acronyms are used throughout the tool and this manual:

AGB: Above Ground Biomass growth rates
BECCS: Bioenergy with Carbon Capture and Storage
CAPEX: Capital Expenditures
CCS: Carbon Capture and Storage
CDR: Carbon Dioxide Removal
CO_2: carbon dioxide
DM: dry mass
GDP: Gross Domestic Product
GHG: Greenhouse Gas Emissions
ha: hectares
ktdm: kilo tons of dry mass
LAC: Latin America and the Caribbean
LCOE: Levelized Cost of Energy
MM: Millions
NDC: Nationally Determined Contribution
O&M: Operation and Maintenance
OPEX: Operating Expenditures
SDG: Sustainable Development Goals
ton: tons
USD: US dollars

BACKGROUND

A study titled "Current understanding of the potential impact of Carbon Dioxide Removal approaches on the Sustainable Development Goals in selected countries in Latin America and the Caribbean"[1] , was performed at request made in late 2020 by the Economic Commission for Latin America and the Caribbean (ECLAC) and the Carnegie Climate Governance Initiative (C2G),to the Fundación Torcuato Di Tella.

That report synthesized the best understandings of potential implications of the adoption of nature-based and technical options for carbon dioxide removal (CDR), aiming to complement direct greenhouse gas emissions (GHG) reductions. The findings were based on the assessment of the available scientific, technical and socio-economic literature and the economic, social and environmental implications of the implementation of CDR technological options. The implications are to be examined against the achievement of the Sustainable Development Goals (SDGs) and the contribution to climate mitigation that the implementation of CDR approaches may have in Argentina and Colombia, and, in general terms, in Latin America and the Caribbean (LAC).

In general, and with rare exceptions, a significant knowledge and empirical development gap of CDR was identified in LAC countries:

- LAC countries efforts on climate change mitigation are heavily focused on emissions reduction and replacement of fossil fuels, and only in a largely incipient manner carbon removal efforts are being considered

[1] Samaniego, Schmidt, Carlino and others, "Current understanding of the potential impact of Carbon Dioxide Removal approaches on the SDGs in selected countries in Latin America and the Caribbean. Final Report", Carnegie Climate Governance Initiative (C2G)/ Economic Commission for Latin America and the Caribbean (ECLAC), March 2021.

- Deployment of large-scale CDR approaches would be expected to have physical side-effects and socio-economic or governance implications affecting in different ways the delivery of SDGs
- The broader implications of CDR technologies in contributing to delivering or hindering sustainable development efforts are so far insufficiently explored and understood, predominantly from a planning perspective
- LAC countries face a persistent finance gap, the decision on the potential development of those options would require accurate abatement costs information and careful consideration of implementation risks in order to avoid misallocation of scarce resources
- A comprehensive research and technical development effort for each technology should be undertaken

Finally, the reference study recommended supporting informed decision-making in relation to potential CDR options large-scale implementations that would be applicable in LAC, deepening research and planning, through (among others) the development of comprehensive evaluation models at the national and sectoral level.

I. INTRODUCTION

The objective of this manual is to develop a tool for four (4) CDR approaches, the most relevant to the LAC region/context (according to the mentioned study finalized in January 2021), that would allow to calculate potential economic, social and environmental impacts (positive and/or negative) that these CDR approaches could have in a specific country, in particular on key indicators including:

- Investment
- Employment
- GDP (Gross Domestic Product)
- Greenhouse gases (GHG) emissions

In addition, the positive and negative, direct and indirect impacts in relation to the achievement of each of the SDGs.

The four CDR approaches developed in the tool are:

- Enhancing soil carbon content with biochar: Biomass burning under low-O_2 conditions (pyrolysis) yields charcoal "biochar", then added to the soil to enhance soil carbon levels
- Mangroves Restoration: Restoration of coastal mangrove ecosystems resulting in long-term storage of carbon in biomass
- Afforestation and reforestation: Forest planting and reforestation resulting in long-term storage of carbon in above- and below-ground biomass
- Bioenergy with carbon capture and storage (BECCS): Burning biomass for energy generation and capturing and permanently storing the resulting CO_2

- In addition, there is the possibility of including a new CDR for results comparison purposes with the other technological alternatives.

This document represents a guideline with an explanation of the interactive tool and instructions for the proper use of it.

II. TOOL STRUCTURE

This tool is structured in 12 main spreadsheets. The first one "Intro" summarizes the content of the remaining 11 sheets and contains access links to each of those sheets:

- Results Panel
  - Summary results panel with comparative graphs and tables that allow to easily view the projected scenarios by CDR and prioritize their impact.
- SDG Impacts
  - For a selected CDR, summarizes direct and indirect, both positive and negative impacts from CDR deployment in each of the 17 SDGs.
- Biochar Control Panel
  - Panel in which different data and assumptions necessary to build the scenarios of Biochar deployment are entered.
  - Includes general assumptions on biochar application area, technical and socio-economic assumptions.
- Detailed Biochar Scenarios
  - Spreadsheet with detailed projection to year 2050 for each scenario of Biochar deployment according to the assumptions defined in the Control Panel.
- Mangroves Control Panel
  - Panel in which different data and assumptions necessary to build the scenarios of Mangrove restoration deployment are entered.

- Includes general assumptions on mangrove restoration area, technical and socio-economic assumptions.

- Detailed Mangroves Scenarios
  - Spreadsheet with detailed projection to year 2050 for each scenario of Mangroves Restoration deployment according to the assumptions defined in the Control Panel.
- Reforestation Control Panel
  - Panel in which different data and assumptions necessary to build the scenarios of Reforestation deployment are entered.
  - Includes general assumptions on reforestation area, technical and socio-economic assumptions.
- Detailed Reforestation Scenarios
  - Spreadsheet with detailed projection to year 2050 for each scenario of Reforestation deployment according to the assumptions defined in the Control Panel.
- BECCS Control Panel
  - Panel in which different data and assumptions necessary to build the scenarios of BECCS deployment are entered.
  - Includes general assumptions on BECCS generation, technical and socio-economic assumptions.
- Detailed BECCS Scenarios
  - Spreadsheet with detailed projection to year 2050 for each scenario of BECCS deployment according to the assumptions defined in the Control Panel.
- Additional CDR
  - Spreadsheet with basic assumptions for the projection to year 2050 by scenarios for the deployment of a new CDR.

For each of the CDR technologies, the model allows to simulate three deployment scenarios: baseline scenario and two scenarios with a higher degree of technology adoption.

The detailed scenario sheets are 100% automated, based on the assumptions of the respective control panel sheets, and do not require entering any data in them.

III. COLOUR CODE OF CELLS

The model respects a colour coding of cells to facilitate its interpretation and to enter only in the required cells the data and assumptions necessary to obtain results, as follows:

Cell Colour Code:

	Cells to enter data and assumptions by the user
	Intermediate calculation cells
	Main result cells
	Cells with key indicators

With the exception of the cells where data and assumptions are to be entered, the rest of the cells should not be modified, and no information is required.

IV. RESULTS PANEL

The Results Panel shows comparative results of the projected scenarios of CDR technologies deployment for a given country.

It is mainly made up of four sections:

(i) Comparative graphs with key metrics by scenario and CDR technology;

(ii) Comparative table with key metrics by scenario and CDR technology;

(iii) Consolidated results of a set of CDR technologies deployment for a given country;

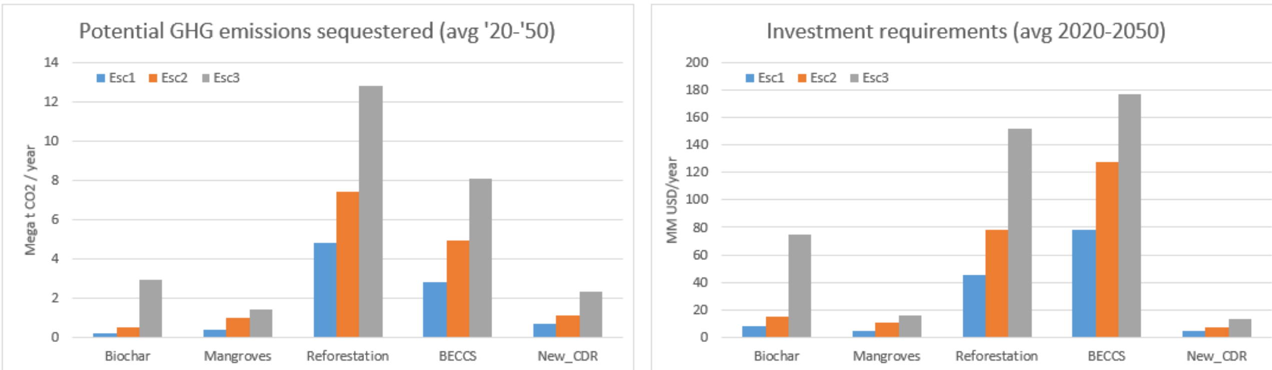
(iv) Projections of CDR deployment by scenario.

A. Comparative graphs with key metrics by scenario and CDR technology

The first section of the Results Panel shows graphs that compare the results for the three scenarios of the CDR technologies, for certain key variables:

- Potential GHG emissions sequestered (2020-2050 average)
- Investment Requirements (average 2020-2050)
- Cost per ton CO_2eq seq
- Employment generated (number of direct jobs created / Mega ton CO_2e seq)
- Contribution to GDP (in Δ Million USD GDP / Mega t CO_2 seq)

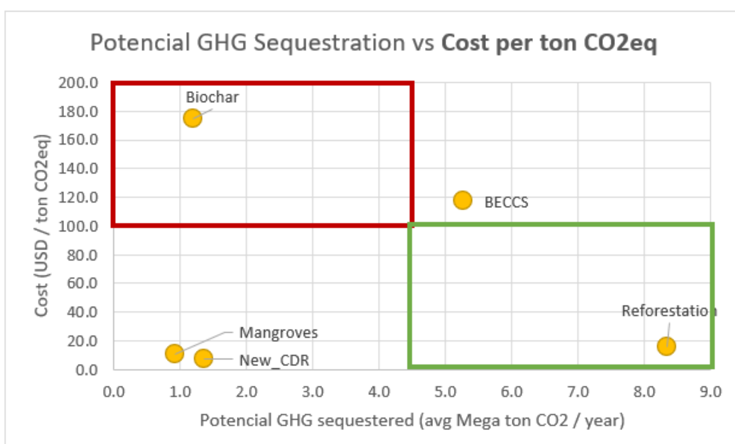
Figure 1
Comparative graphs with key metrics by scenario and CDR technology



Source: Own elaboration

Certain crossovers of variables are also displayed considering the average values of the three scenarios for each CDR. Following, an illustrative example of the cross comparison between Potential GHG sequestered vs Cost per ton CO2eq seq. The quadrants with the best and worst combinations are highlighted in green and red respectively.

Figure 2
Potential GHG sequestered vs Cost per ton CO2eq seq



Source: Own elaboration
Note: Average values of all 3 Scenarios by CDR

B. Comparative table with key metrics by scenario and CDR technology

The comparative tables contain greater detail of the main metrics by scenario and CDR technology that are shown in the comparative graphs described above.

Figure 3
Comparative table with key metrics by scenario and CDR technology

		Potential GHG emissions (sequestered)	Investment requirements	Cost	Net changes in employment created	Contribution to GDP	Net changes in employment created	Contribution to GDP
	Scenarios Deployment	Mega t CO2 / year	MM USD/year	USD / t CO2	# jobs created / Mega t CO2 seq	Δ MMUSD GDP / Mega t CO2 seq	# direct jobs created per year	Δ MMUSD GDP per year
Biochar	Sce1 25% Area / Pellet 10% BC	0.2 (avg.) 0.4 (2050)	7.6 (avg.) 228 (total 2020-2050)	185.8	120 (direct) 60 (indirect)	186	24 avg.	37 avg.
	Sce2 50% Area / Pellet 10% BC	0.5 (avg.) 0.8 (2050)	15.2 (avg.) 457 (total 2020-2050)	185.8	120 (direct) 60 (indirect)	186	60 avg.	93 avg.
	Sce3 60% Area / Pellet 50% BC	2.9 (avg.) 4.8 (2050)	74.8 (avg.) 2244 (total 2020-2050)	151.6	98 (direct) 49 (indirect)	152	284 avg.	441 avg.
Mangroves	Sce1 - Annual Restoration Rate 0.2%	0.4 (avg.) 0.8 (2050)	4.5 (avg.) 136 (total 2020-2050)	11.2	66 (direct) - (indirect)	67	26 avg.	27 avg.
	Sce1 - Annual Restoration Rate 0.5%	0.99 (avg.) 2.01 (2050)	10.7 (avg.) 321 (total 2020-2050)	10.9	68 (direct) - (indirect)	65	67 avg.	64 avg.
	Sce1 - Annual Restoration Rate 0.7%	1.4 (avg.) 2.9 (2050)	15.4 (avg.) 461 (total 2020-2050)	10.9	69 (direct) - (indirect)	66	97 avg.	92 avg.

Source: Own elaboration

The values shown in the table arise from the detailed simulation of each scenario of each CDR, and feed the comparative graphs previously described.

1. Consolidated results of a set of CDR technologies deployment for a given country

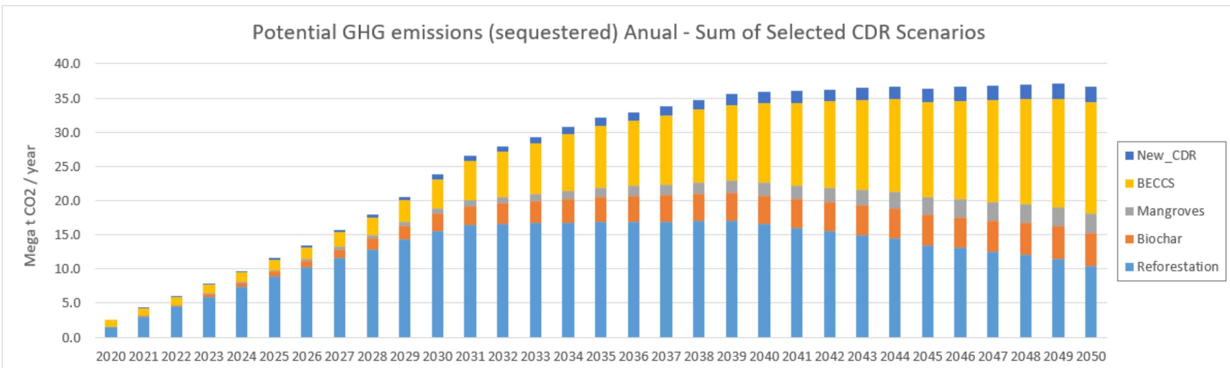
The model allows to show consolidated results at the country level for the sum of selected scenarios for each CDR. The desired scenario must be selected for each CDR in cells D46 to D50. The graphs show the consolidated 2020-2050 evolution of the following variables:

- Potential GHG emissions removed
- Investment Requirements (Annual and Accumulated)
- Carbon Removal as % of Nationally Determined Contribution (NDC) by year 2030
- Contribution to GDP
- Employment generated

Note: The country's NDC goal to 2030 must be entered (cell F47) to obtain these results.

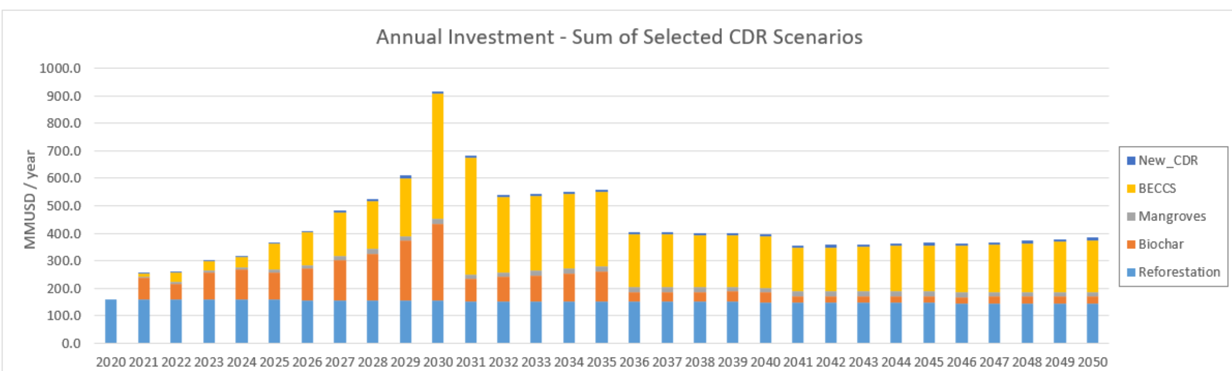
Figure 4
Consolidated GHG Emissions removed - Total Country

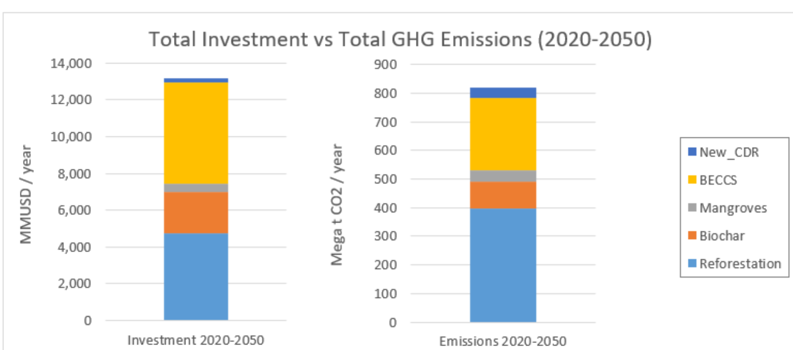
Select Scenario per CDR			
Biochar	Scenario 3	Enter NDC @2030 Goal	
Mangroves	Scenario 3	300	MtCO2eq/year
Reforestation	Scenario 3		
BECCS	Scenario 3		
New_CDR	Scenario 2		



Source: Own elaboration

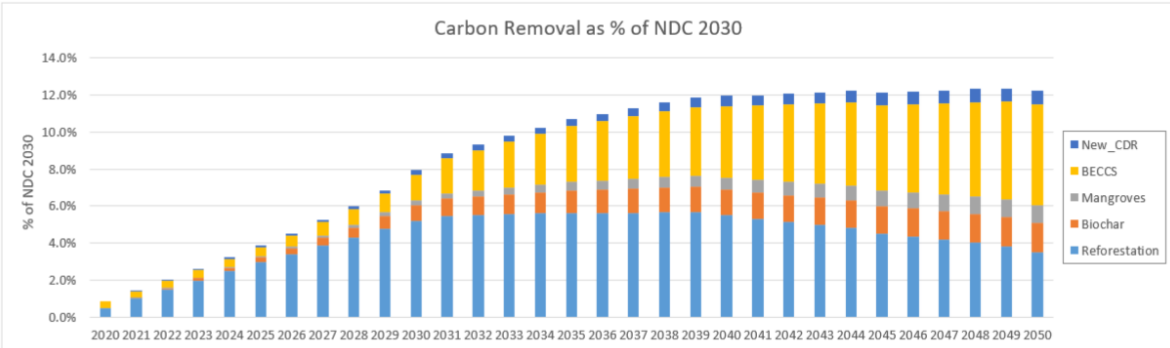
Figure 5
Consolidated Investment Requirements - Total Country





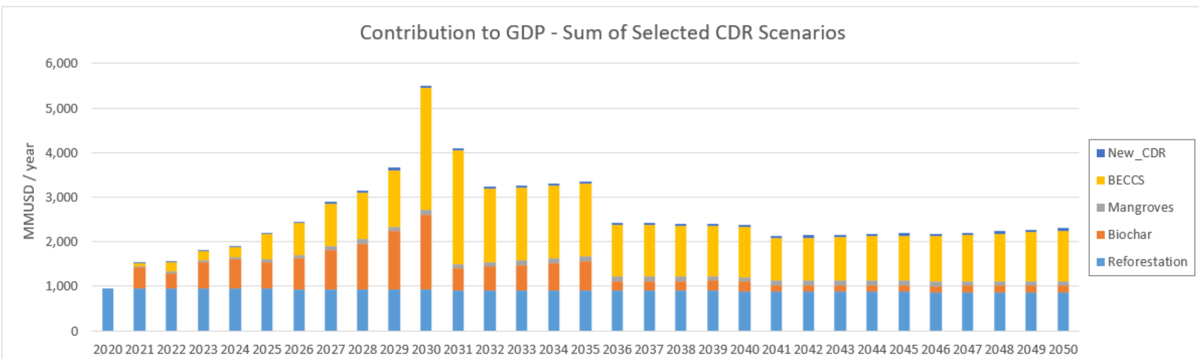
Source: Own elaboration

Figure 6
Consolidated Carbon Removal as % of NDC 2030 - Total Country



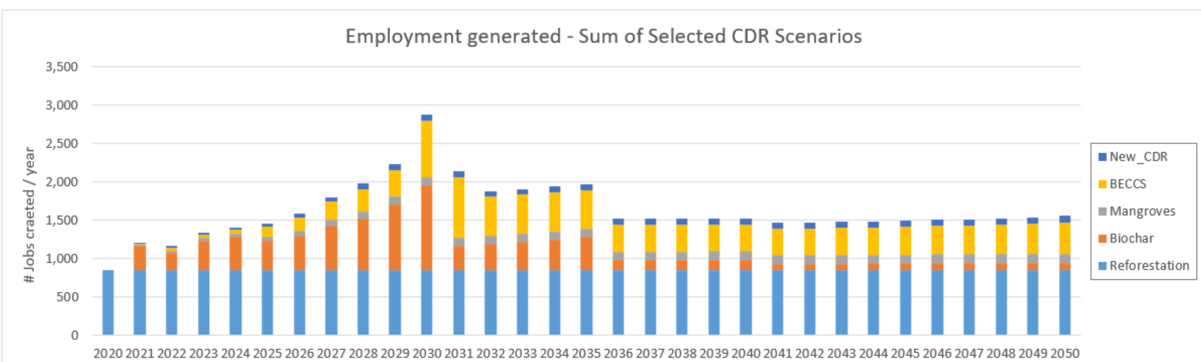
Source: Own elaboration

Figure 7
Consolidated Annual Contribution to GDP - Total Country



Source: Own elaboration

Figure 8
Consolidated Annual Employment Generated - Total Country

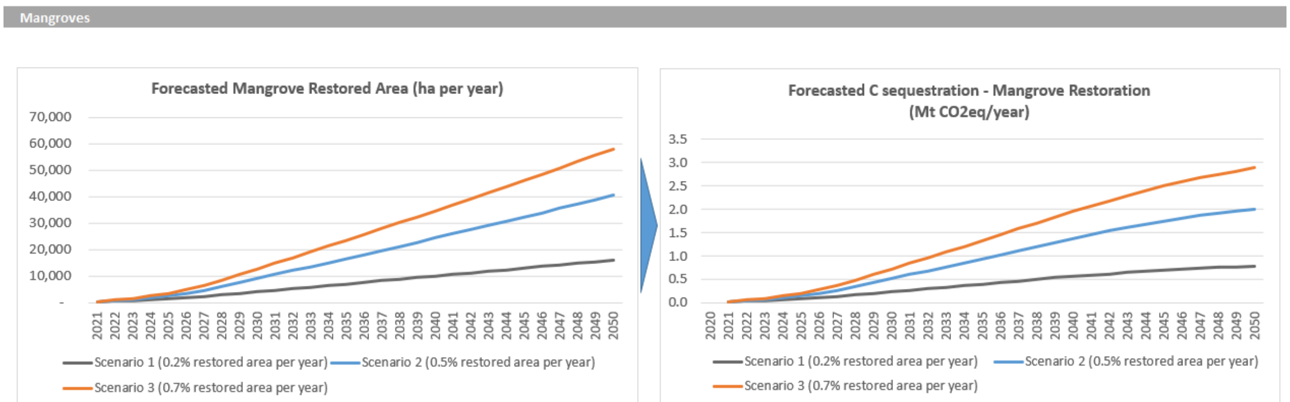


Source: Own elaboration

2. Projections of CDR deployment by scenario

The last section of the Results Panel shows details of the 2020-2050 annual evolution for the three scenarios for certain key variables of the forecast of each CDR technology. An example of modeling forecasts for mangrove restoration deployment, as follows.

Figure 9
Forecasts of Mangrove Restoration deployment by scenario



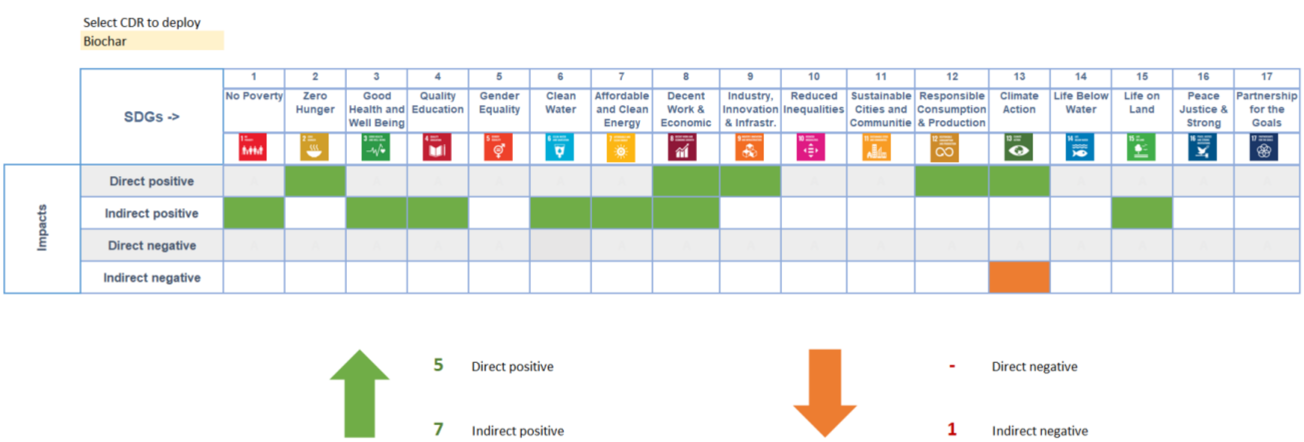
Source: Own elaboration

V. IMPACT ON SDGS

In the sheet "Impact on SDGs", the model allows to select a CDR technology in cell C7 and automatically shows a double-entry table with direct and indirect impacts, both positive and negative, in each of the 17 SDGs defined by the United Nations, resulting from the implementation of the selected CDR.

The number of SDGs impacted by type of impact are summarized below the table.

Figure 10
Impact on the SDGs from CDR deployment



Source: Own elaboration

VI. CONTROL PANEL - BIOCHAR

The Biochar Control Panel is divided into three main sections: 1) Selection of crops and projection of planted area; 2) Dosage and composition of Biochar; and 3) Investment, Employment and GDP Impact.

A. Selection of crops and projection of planted area

The model is designed to differentiate among the following types of crops: fruit trees, vegetables, other intensive crops and extensive crops.

For each of the crops, the initial area sown in 2020, the historical growth rate of the area sown of the crop (in % per year) and the growth trend to be simulated in the period 2020-2050 (based on historical growth), must be entered. The options for the growth trend are: stable, smoothed and accelerated. The resulting 2050 projected area is displayed on the screen for easy calibration.

Then, it must be indicated for each crop, if the scenario considers the application of biochar or not, and the percentage of the total projected area to which biochar will be applied. This desired percentage is reached by the year 2050, after a gradual growth in the percentage of biochar application.

Figure 11
Assumptions input for selection of crops and projection of planted area

Crop Selection and Cultivated Area Projection								
	Cultivated Area ha Initial 2020	Growth Rate % annual 2010-2020	Trend Growth 2020-2050	Cultivated Area ha Projection 2050	Biochar Applies? Yes / No	Biochar Application Area (Proyection 2050) % total area per crop		
						Sce 1	Sce 2	Sce 3
Fruit Tree	1,000,000	3.0%	Suaviza	1,914,284	Yes	25%	50%	60%
Vegetables	1,000,000	3.0%	Acelera	3,230,837	No	0%	0%	0%
Other Intensive Crops	1,000,000	3.0%	Estable	2,427,262	No	0%	0%	0%
Other Extensive Crops	35,000,000	1.0%	Estable	47,174,712	No	0%	0%	0%

Source: Own elaboration

B. Biochar Dosage and Composition

Regarding the technical assumptions, firstly, the dose of fertilizer in the form of pellets to be applied must be defined (in tons per hectare per year). The use of "pure" biochar presents some challenges such as the immobilization of nutrients and even negative alterations in the soil microflora, depending on the type of biochar and the texture of the soil. Therefore, biochar is also applied "enriched" in combination with compost pellets, added mineral fertilizer (urea or ammonium nitrate) and enriched with bacteria, such as trichomonads.

Once the dosage has been defined, assumptions must be entered for the pellets composition. The application of biochar in Europe is being carried out in 10% mixtures, with 85% pelleted compost and 5% mineral fertilizers (urea, ammonium nitrate, etc.). The Fraction considered as sequestration is defined by IPCC[2] in its equation 4A.1 and depends on two factors: the C content of the biochar (Fcp) and the fraction of biochar that remains in the soil after 100 years (Fpermp). Therefore, the increase in soil carbon from applying biochar results from multiplying the incorporated mass of biochar by the C content and the permanence factor.

Figure 12
Input of technical assumptions on Biochar Dosage and Composition

Biochar composition and Dose
(Note: in case of not having detailed customized information, use the predefined parameters according to the results presented)

	Units	Sce 1	Sce 2	Sce 3
Organic-mineral fertilizer Annual Dose in Tons/ha/year (Pellet X% BC)	tn/ha/year Pellet	5.0	5.0	5.0
Biochar proportion in pellet mix (%)	%	10%	10%	50%
Biochar Carbon Content (%) - Fcp	%	70%	70%	70%
Fraction immobilized x 100 years - Fperm	%	65%	65%	65%

Source: Own elaboration

[2] IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

C. Investment, Employment and GDP Impact

In terms of investment, biochar plant size assumptions (in tons per year of installed capacity) and investment (CAPEX) per plant must be entered first.[3] The model allows to define efficiencies in capital costs for the long term, being the options: No (= no cost efficiencies), Low (10%) and High (40%). For example, if "Low (10%)" is chosen, it indicates that by the year 2050 the investment costs will represent 90% of the original amount by the year 2020.

Regarding costs, the assumptions to be defined include: biomass costs for pellets to be applied on land (in USD per ton of firewood and waste), operation and maintenance costs of the biochar plant (in USD per ton produced) and costs of applying biochar pellets on land (in USD per hectare of crops planted).

In relation to employment, the number of direct jobs generated per hectare of biochar application area must first be indicated. Then, the ratio between indirect jobs to direct jobs created must be entered (e.g. 3x means that 3 indirect jobs are created for each direct job created).[4]

Finally, the Investment to GDP multiplier must be defined, the options being 4x, 6x or the flexibility of entering the country's historical data to obtain the customized multiplier.

Figure 13
Input assumptions for Investment, Employment and GDP Impact for Biochar

Investment, Employment and GDP Contribution			
Plant Size	ton-year / plant	1,000	
CAPEX per plant	USD / plant	1,000,000	
Long-term CAPEX Efficency	% savings by 2050	Low (10%)	Esc1 y Esc2
	% savings by 2050	High (40%)	Esc3
Biomass cost (wood feedstock) for biochar pr	USD/ ton BM	30	
Biomass cost waste for pellets	USD/ ton BM	0	
Cost O&M for biochar plant	USD/ ton biochar	80	
Biochar Land application costs	USD / ha	30	
Direct Jobs created	# jobs/MMUSD	4.0	
Indirect Jobs created	ratio ind / dir	0.5	
Multiplier Investment to GDP	x times	6.0	

Source: Own elaboration

For the calculation of the customized multiplier of Investment to GDP (which is optional), historical data of Investment in Equipment and Machinery (or similar) and GDP must be entered, in 2020 constant millions of dollars (or near date and / or adjusted to achieve that basis). The model is programmed to perform an analysis of both variables and generate an average multiplier based on a series of predefined examples.

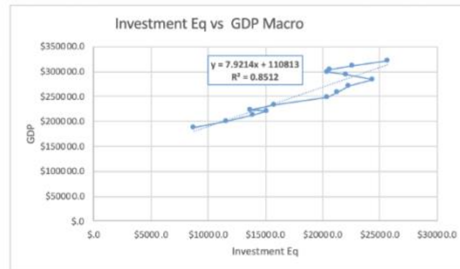
3. Biochar plant CAPEX assumptions based on interviews with sectoral experts and industry stakeholders.
4. In the absence of information on these variables, the values used in the study completed in 2021 can be used as a proxy.

Figure 14: Auxiliary Customized Calculation of Investment to GDP Multiplier (Optional)

Auxiliary Custom Calculation of Investment to GDP Multiplier (Optional)

Instructions: Enter historical series of Investment and GDP in constant currency and select "custom" in the drop-down list of the assumption "Investment to GDP multiplier"

	Investment Equipment	GDP
year	Million USD constant	Million USD constant
2000		
2001		
2002		
2003		
2004		
2005	$8.795	$187.671
2006	$11.625	$200.276
2007	$13.902	$213.771
2008	$15.143	$220.790
2009	$13.714	$223.306
2010	$15.853	$233.343
2011	$20.506	$249.556
2012	$21.328	$259.320
2013	$22.354	$272.633
2014	$24.411	$284.899
2015	$22.143	$293.321
2016	$20.403	$299.443
2017	$20.688	$303.514
2018	$22.623	$311.148
2019	$25.765	$321.292
2020		



	Avg CAPEX	Avg GDP	
	Million USD constant	Million USD constan	Multiplier
Eg. 1	10	66	6.6
Eg. 2	20	133	6.6
Eg. 3	100	664	6.6
Eg. 4	200	1326	6.6
			6.6 avg multiplier

Source: Own elaboration

VII. CONTROL PANEL - MANGROVES

The Mangrove Restoration Control Panel is divided into three main sections: 1) Projection of the mangrove area to be restored; 2) Technical assumptions; and 3) Investment, Employment and GDP Impact.

A. Projection of the mangrove area to be restored

For the projection of the mangrove area to be restored, it must be entered the initial mangrove area in the country in year 2020 (cell E8) and the restoration rates in annual percentage for the scenario (E12 to G12). Another assumption to enter is the share of shrub-scrub in the total mangrove area.

he results of projected area to 2050 by scenario are shown in cells E13 to G13.

Figure 15
Input assumptions for projection of the mangrove area to be restored

Forecasted Mangrove restoration area					
Initial Mangroves Area - 2020		ha	290,000		
Shrub-scrub share		% total area	20%		
			Sce 1	Sce 2	Sce 3
Restoration Rate	% annual	2021-2050	0.2%	0.5%	0.7%
Mangroves Area	ha	Forecast 2050	306,046	330,425	348,071

Source: Own elaboration

B. Technical Assumptions

In order to quantify C sequestration and GHG removal, the first step is to estimate biomass growth rates of mangrove plantations. Above Ground Biomass (AGB) growth rates were adopted from Bernal et al study (2017).[5] The authors, differentiates growth rate between mangrove trees and smaller mangrove shrub-scrub and also differentiate growth rates from first 20 years from following 30 years.

Palacios Peñaranda et al (2019)[6] estimated that AGB accounts for only 17% of total carbon stock in mangroves when considering Below Ground Biomass, Leaf Litter, Fallen Wood and Soil Sediments. This factor was also considered in carbon sequestration projections. A conservative factor of 70% was applied to biomass growth rates due to restoration plantations on previously eroded / damaged mangroves land.

The model allows using these predefined technical assumption values, or entering custom values for the particular country and / or modifying them between scenarios.

Figure 16
Input of Technical Assumptions for Mangrove Restoration

Technical Assumptions
(Note: in case of not having detailed customized information, use the predefined parameters according to the results presented)

	Units	Sce 1	Sce 2	Sce 3
Above Ground Biomass (AGB) rate (Years 0-20) - Tree	t CO2e / ha / y	16.1	16.1	16.1
Above Ground Biomass (AGB) rate (Years 21-50)- Tree	t CO2e / ha / y	7.4	7.4	7.4
Above Ground Biomass (AGB) rate (Years 0-20) - Shrub-scrub	t CO2e / ha / y	4.4	4.4	4.4
Above Ground Biomass (AGB) rate (Years 21-50) - Shrub-scrub	t CO2e / ha / y	1.4	1.4	1.4
AGB share over Total Carbon stock in mangroves	%	17%	17%	17%
Biomass Growth Factor on Erosioned Mangroves Land	%	70%	70%	70%

Source: Own elaboration

In case of not having detailed information to customize these technical assumptions to the specific country, predefined parameters should be considered according to the results presented in the example spreadsheet.

C. Investment, Employment and GDP Impact

In terms of investment and restoration costs, assumptions per hectare must be entered for each scenario. The model allows defining efficiencies in capital costs for the long term, being the options: No (= no cost efficiencies), Low (10%) and Moderate (20%). For example, if "Low (10%)" is chosen, this indicates that in 2050 the investment costs will represent 90% of the original amount in 2020.

In relation to employment, the number of direct and indirect jobs generated per thousand hectares of reforested area must be indicated. [7]

Finally, the Investment to GDP multiplier must be defined, the options being 4x, 6x or the flexibility of entering the country's historical data to obtain the customized multiplier.

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5. Bernal B., Sidman, G. and Pearson, T. (2017). Assessment of mangrove ecosystems in Colombia and their potential for emissions reductions and restauration. Winrock International. 29 pp.
6. Palacios Peñaranda, M., Cantera Kintz, J., Peña Salamanca, E. (2019). Carbon stocks in mangrove forests of the Colombian Pacific, Estuarine, Coastal and Shelf Science, Volume 227, 2019, 106299, ISSN 0272-7714, https://doi.org/10.1016/j.ecss.2019.106299.
7. In the absence of information on these variables, the values used in the study completed in 2021 can be used as a proxy.

Figure 17
Assumptions for Investment, employment and GDP. Mangrove Restoration

Investment, Employment and GDP Contribution				
		Sce 1	Sce 2	Sce 3
Restoration costs (unitary)	USD/ha	9,000	9,000	9,000
Long-term CAPEX Efficency	% savings by 2050	Low (10%)	Moderate (20%)	Moderate (20%)
Direct Jobs created	# jobs/ha	0.05	0.05	0.05
Indirect Jobs created	# jobs/ha	0.0	0.0	0.0
Multiplier Investment to GDP	x times	6.0	6.0	6.0

Source: Own elaboration

VIII. CONTROL PANEL – REFORESTATION

The Reforestation Control Panel is divided into three main sections:

(v) Projection of the area to be reforested;

(vi) Technical assumptions

(vii) Investment, Employment and GDP Impact.

A. Projection of the area to be reforested

For the different scenarios, the new area to be reforested per year must be defined, in this example 20 thousand hectares per year in Scenario 1. Then the different combinations of regions / provinces and plant species to be reforested must be selected, for which the initial area reforested in year 2020 must be entered. The model calculates the participation of each region and species combination in the total reforested area and will assume these % shares to be constant in the 2021-2050 simulation period, when distributing the new area to be reforested annually.

Additionally, a maximum limit of the area to be reforested can be defined at the country level (depending on the natural characteristics of the soil), and the model will react by alerting in the event that this limit is exceeded with the assumptions entered.

Figure 18
Input assumptions for Projection of the area to be reforested

Reforestation Area Estimation						
Maximum Potential Area for Reforestation		ha	5,000,000			
				Reforestation Area 2050 (ha)		
State / Region	Species	Initial Reforested Area (ha)	% Area / Total Area	Sce 1	Sce 2	Sce 3
Region 1	Species A	25,000	4%	50,833	70,208	115,417
Region 2	Species A	150,000	25%	305,000	421,250	692,500
Region 3	Species A	60,000	10%	122,000	168,500	277,000
Other Regions	Species A	40,000	7%	81,333	112,333	184,667
Region 1	Species B	15,000	3%	30,500	42,125	69,250
Region 2	Species B	70,000	12%	142,333	196,583	323,167
Region 3	Species B	60,000	10%	122,000	168,500	277,000
Other Regions	Species B	25,000	4%	50,833	70,208	115,417
Region 1	Species C	40,000	7%	81,333	112,333	184,667
Region 2	Species C	30,000	5%	61,000	84,250	138,500
Region 3	Species C	40,000	7%	81,333	112,333	184,667
Other Regions	Species C	7,000	1%	14,233	19,658	32,317
Region 1	Species D	25,000	4%	50,833	70,208	115,417
Region 2	Species D	5,000	1%	10,167	14,042	23,083
Region 3	Species D	5,000	1%	10,167	14,042	23,083
Other Regions	Species D	3,000	1%	6,100	8,425	13,850
Total		600,000	100%	1,220,000	1,685,000	2,770,000
			Sce 1	Sce 2	Sce 3	
New Annual Reforested Area - Total Count		ha/year	20,000	35,000	70,000	

Source: Own elaboration

B. Technical Assumptions

The annual growth of the reforested area is calculated based on the yield rates (m3 / ha / year) and the density values (dry mass tons / m3) for each species.

The balance or net carbon capture was calculated as the difference between the annual growth captures and the annual extraction emissions. The fixation data correspond to the initial surface (2020) fixing carbon at the corresponding growth rate for each species / region to which the annual increase is added (cumulative until 2050).

The annual emission data correspond to the initial implanted area (2020) divided by the cutting shift, to which is added from the shift, the area implanted from 2021 onwards. That is, with a 10-year shift, the total area of the species / region considered emits one tenth of the biomass (ktdm = kilo tons of dry matter) which is the area that is ready for use. Once the years corresponding to the shift of what was implanted at the initial year have elapsed, it will begin to emit the entire surface implanted that arrives in turn that year.

Figure 19
Input of Technical Assumptions for Reforestation deployment

Technical Assumptions

(Note: in case of not having detailed customized information, use the predefined parameters according to the results presented)

	Pruning shifts	Density	Yield	Annual Growth
	years	ton DM/m3	m3/ha/year	tn DM/ha year
Species A	20	0.40	20	8.0
Species B	12	0.65	30	19.5
Species C	11	0.35	28	9.8
Species D	20	0.45	18	8.1
Species E				-

	Sce 1	Sce 2	Sce 3
Yield Drop Factor	No	Low	Moderate

Convertion Factor DM to CO2	ton dry mass / ton CO2eq	1.83

Source: Own elaboration

The tool also contemplates a yield reduction factor due to extending the reforested area towards the productive yield frontiers, for cases of high levels of annual reforestation in relation to the potential maximum limit to be reforested. The options are "No" (no performance impact), "Low" (Performance drops gradually by up to 10pp from 2030 onwards) and Medium" (Performance drops gradually by up to from 2025 onwards).

The biomass values were converted to carbon and then to CO_2. In this CO_2 balance estimate, emissions from intermediate treatments of plantations (pruning and thinning) are not included, neither are emissions / removals of products originating from afforestation considered.

C. Investment, Employment and GDP Impact

In terms of investment and costs, assumptions for Investment (CAPEX) per hectare in year 0 and Operating costs (OPEX) per hectare for the next four years must be entered, for each scenario. In addition, the model allows to define efficiencies in capital costs for the long term, being the options: No (= no cost efficiencies), Low (10%) and Moderate (20%). For example, if "Low (10%)" is chosen, it indicates that by the year 2050 the investment costs will represent 90% of the original amount by the year 2020.

In relation to employment, the number of direct jobs generated per thousand hectares of reforested area must first be indicated. Then the ratio between indirect jobs to direct jobs created must be entered (e.g. 3x means that 3 indirect jobs are created for each direct job created). [8]

Finally, the Investment to GDP multiplier must be defined, the options being 4x, 6x or the flexibility of entering the country's historical data to obtain the customized multiplier.

[8]. In the absence of information on these variables, the values used in the study completed in 2021 can be used as a proxy.

Figure 20
Input assumptions for Investment, Employment and GDP Impact for Reforestation

Investment, Employment and GDP Contribution				
		Sce 1	Sce 2	Sce 3
Reforestation CAPEX Year 0 (unitary)	USD/ha	1,100	1,100	1,100
Reforestation OPEX - Year 1 (unitary)	USD/ha	372	372	372
Reforestation OPEX - Year 2 (unitary)	USD/ha	372	372	372
Reforestation OPEX - Year 3 (unitary)	USD/ha	237	237	237
Reforestation OPEX - Year 4 (unitary)	USD/ha	203	203	203
Long-term CAPEX Efficency	% savings by 2050	No	Low (10%)	Moderate (20%)
Direct Jobs created	# jobs/'000ha	20	16	12
Indirect Jobs created	ratio ind / dir	3	3	3
Multiplier Investment to GDP	x times	custom	6.0	6.0

Source: Own elaboration

IX. CONTROL PANEL - BECCS

The BECCS Control Panel is divided into three main sections:

(viii) Energy Matrix Projection

(ix) Technical assumptions

(x) Investment, Employment and GDP Impact.

A. Energy Matrix Projection

In the first place, the initial total country power generation data for the year 2020 in GWh and the growth rate of the total country generation must be entered, to be used in the projection.

Then, for each scenario and for the years of the 2020-2050 simulation period, the weight % of each generation source in the total national power generation must be completed. The power generation sources contemplated are: hydroelectric, fossil thermal, coal thermal, nuclear, wind, bioenergy without CCS (BIO_NOCCS = BE), bioenergy with CCS (BIO_CCS = BECCS) and photovoltaic solar.

Figure 21
Input assumptions for Energy matrix projections for BECCS deployment

Power Generation Matrix Projections						
Inicial Generation - year 2020	GWh	62.818				
Generation Annual Growth	% annual	2%				
Scenario 1 - Power Generation Matrix Evolution		2020	2021	2022	2023	2.024
GEN_Hydro	%	78,2%	78,2%	77,7%	77,3%	76,8%
GEN_Thermalfossil	%	10,7%	10,7%	10,7%	10,7%	10,7%
GEN_Thermalcoal	%	8,4%	8,4%	8,6%	8,7%	8,9%
GEN_Nuclaer	%					
GEN_Wind	%	1,4%	1,4%	1,5%	1,7%	1,9%
GEN_BioEnergy_NOCCS	%	1,0%	1,0%	1,1%	1,1%	1,2%
GEN_BioEnergy_CCS	%	0,0%	0,0%	0,0%	0,0%	0,0%
GEN_SolarPV	%	0,3%	0,3%	0,4%	0,5%	0,6%
		100%	*100%*	*100%*	*100%*	*100%*
Scenario 2 - Power Generation Matrix Evolution		2020	2021	2022	2023	2.024
GEN_Hydro	%	78,2%	78,2%	77,7%	77,3%	76,8%
GEN_Thermalfossil	%	10,7%	10,7%	10,7%	10,7%	10,7%
GEN_Thermalcoal	%	8,4%	8,4%	8,6%	8,7%	8,9%
GEN_Nuclear	%					
GEN_Wind	%	1,4%	1,4%	1,5%	1,7%	1,9%
GEN_BioEnergy_NOCCS	%	1,0%	1,0%	1,1%	1,1%	1,2%
GEN_BioEnergy_CCS	%	0,0%	0,0%	0,0%	0,0%	0,0%
GEN_SolarPV	%	0,3%	0,3%	0,4%	0,5%	0,6%
		100%	*100%*	*100%*	*100%*	*100%*

Source: Own elaboration

B. Technical Assumptions

Among the technical assumptions required, is the average capacity utilization factor for each source of power generation. By this way, the installed capacities per source will be estimated, based on the power generation per source and its capacity utilization factor.

In the logic of the model is automated the calculation of emissions by power generation source - mainly those related to combustion such as fossil thermal, coal thermal and bioenergy-, and the emissions intensity for the entire country power generation matrix.

To calculate the removed emissions attributable to BE + BECCS, the following components are considered:

- Net emissions from Bio_NOCCS+Bio_CCS generation:
  - Carbon fixed in biomass feedstock used for power generation
  - Other lifecycle emissions from transport and processing of feedstock and energy
  - Post-combustion capture in CCS phase (the assumption of % post-combustion capture must be entered in the control panel, for example 60%)
- Avoided Emissions by Substitution of Other Sources of Power Generation

Figure 22
Input of Technical Assumptions for BECCS deployment

Technical Assumptions			
(Note: in case of not having detailed customized information, use the predefined parameters according to the results presented)			
Average Capacity Factor			
GEN_Hydro	%	48%	
GEN_Thermalfossil	%	16%	
GEN_Thermalcoal	%	43%	
GEN_Nuclaer	%	82%	
GEN_Wind	%	33%	
GEN_BioEnergy_NOCCS	%	56%	
GEN_BioEnergy_CCS	%	56%	
GEN_SolarPV	%	17%	
Other technical parameters			
Lifecycle emissions	%	16%	Other lifecycle emissions from transport a
Post Combustion Capture	%	60%	Capture in CCS phase of BECCS

Source: Own elaboration

C. Investment, Employment and GDP Impact

In terms of BECCS investment and deployment costs, it must be entered investment assumptions (CAPEX in USD per KW of installed capacity),[9] fixed (in USD / KW of installed capacity per year) and variable (USD per MWh generated) operation and maintenance costs, and fuel costs (USD per equivalent MWh generated) each scenario. The model allows to define efficiencies in capital costs for the long term, being the options: No (= no cost efficiencies), Low (10%) and High (40%). For example, if "High (40%)" is chosen, this indicates that in 2050 the investment costs will represent 60% of the original amount in 2020.

With this data, the levelized cost of energy LCOE is calculated, which is a measure of the average net present cost of generating electricity for a generation plant during its lifetime. The model allows to choose between different cost estimation methodologies:

- CAPEX: simple division of the initial CAPEX over the total generation in its lifetime
- LCOE (discounted only CAPEX): similar to the previous one, dividing by the present value of the lifetime generation at a certain discount rate
- LCOE (discounted both CAPEX + OPEX): similar to the previous one, but includes lifetime operating costs (OPEX) also discounted to present value at the discount rate

In order to obtain the cost per ton of CO_2eq removed, LCOE is divided by the intensity of reduced emissions attributable to the generation of BE (Bioenergy without CCS) and BECCS (Bioenergy with CCS).

9. Adapted from Langholtz et al (2020) "The Economic Accessibility of CO_2 Sequestration through Bioenergy with Carbon Capture and Storage (BECCS) in the US"

In relation to employment, the number of permanent direct jobs generated for each MW of installed capacity must be indicated, as well as jobs generated in the construction of the BECCS facilities.[10]

Finally, the Investment to GDP multiplier must be defined, the options being 4x, 6x or the flexibility of entering the country's historical data to obtain the customized multiplier.

Figure 23
Input assumptions for Investment, Employment and GDP Impact of BECCS

Investment, Employment and GDP Contribution				
				Source:
CAPEX	USD/kW	4,000		Adapted from Lar
Fixed O&M	USD/kWe/y	100		
Variable O&M	USD/MWh	90		
Fuel costs	USD/MWhe	35		
Discount Rate	% annual	10%		
Cost estimation		LCOE (discounted CAPEX+OPEX)		
		Sce 1	Sce 2	Sce 3
Long-term CAPEX Efficency	% savings by 2050	No	Low (10%)	High (40%)
Permanent Jobs created	# jobs/MW	1.2	1.2	1.2
Construccion Jobs created	# jobs/MW	4.0	4.0	4.0
Investment to GDP multiplier	x times	6.0	6.0	6.0

Source: Own elaboration

[10]. In the absence of information on these variables, the values used in the study completed in 2021 can be used as a proxy.

X. ADDITIONAL CDR

The model provides, for comparative purposes, the possibility to add the results of the deployment of a new CDR not included among the four CDRs modelled in the tool and described above.

First, the name of the new CDR must be entered in cell C4. This name will be the one displayed in the graphs of the Results Panel.

Assumptions can be entered for up to three deployment scenarios for the new CDR. For each of these scenarios, projections to 2050 of the following variables must be completed:

- Potential Annual Sequestered GHG Emissions (in Mega ton CO_2e / year)
- Annual Investment for CDR deployment (in Millions of USD / year)
- Annual OPEX of the CDR (in Millions of USD / year)
- Direct jobs generated (in number of employees created per year)
- Indirect jobs generated (in number of employees created per year)

Figure 24
Entry projections for new CDR

Add CDR

CDR Name	New_CDR
Input cells - code colour	

SCENARIO 1

		2020	2021	2022	2023	2024
Potential GHG emissions sequestered	Mega t CO2e / y	0.0	0.0	0.1	0.1	0.1
Annual Investment in CDR	MM USD / y		3	3	3	3
OPEX Annual in CDR	MM USD / y		0.3	0.3	0.3	0.3
Direct jobs created	# jobs		15	15	15	15
Indirect jobs created	# jobs		15	15	15	15
% NDC 2030	%	0.0%	0.0%	0.0%	0.0%	0.0%
Cost per ton CO2eq	USD / t CO2 seq	7.3				
Direct jobs per ton CO2eq	jobs / Mega t CO2 seq	39.0				
Indirect jobs per ton CO2eq	jobs / Mega t CO2 seq	39.0				

Source: Own elaboration

Also, the desired GDP Investment multiplier (among the available options) should be entered in cell F49.

The model will automatically calculate all the necessary metrics to complete the comparative charts and tables in the Results Panel.

XI. SCOPES

The tool that has been developed enables to assess the economic, social and environmental implications of the deployment of different CDR approaches, in particular the effects on:

- Employment
- Investment
- GDP
- GHG Emissions

This tool aims to facilitate the planning and decision process in LAC countries for the implementation of a number of CDR technological options, under different scenarios of mitigation ambition.

The sensitivity analyses, which can also be performed, allows for the understanding of the effects of large-scale deployment in the short, medium and-long term horizons in order to prioritize national efforts, according to the level of maturity and cost efficiency of each CDR option.

Therefore, the tool may contribute to informed decision-making relative to policies and measures towards climate action and SDGs achievement, the implementation of current Nationally Determined Contributions (NDC) and the design of subsequent NDC.