Current understanding of the potential impacts of Carbon Dioxide Removal approaches on the SDGs in selected countries in Latin America and the Caribbean

Final Report

Joseluis Samaniego
Kai-Uwe Schmidt
Hernán Carlino
Luciano Caratori
Micaela Carlino
Agustín Gogorza
Alfonso Rodríguez Vagaría
Gabriel Vázquez Amábile

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Current understanding of the potential impact of Carbon Dioxide Removal approaches on SDGs in selected countries in Latin America and the Caribbean. Final Report.

This document was produced under the coordination of Joseluis Samianego, of the Economic Commission for Latin America and the Caribbean (ECLAC) and Kai-Uwe Schmidt, of the Carnegie Climate Governance Initiative (C2G). Hernán Carlino, Luciano Caratori, Micaela Carlino, Agustín Gogorza, Alfonso Rodríguez Vagaría and Gabriel Vázquez Amábile, from the Torcuato Di Tella Foundation participated in its elaboration. The authors thank the following people for their comments, suggestions, revisions and contributions to the document: Estefani Rondón, José Javier Gómez and Jimy Ferrer, from ECLAC, Nicholas Harrison, Alia Hassan and Michael Thompson, from C2G.

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AFOLU: Agriculture, Forestry and Other Land Use
AR: Afforestation and Reforestation
BAU: Business as Usual
BE: Bioenergy
BECCS: Bioenergy with Carbon Capture and Storage
C2G: Carnegie Climate Governance Initiative
CAGR: Compound Annual Growth Rate
CAPEX: Capital Expenditures
CBD: Convention on Biological Diversity
CCS: Carbon Capture and Storage
CDR: Carbon Dioxide Removal
CO2: Carbon Dioxide
DACCS: Direct Air Carbon Dioxide Capture and Storage [1]
ECLAC: Economic Commission for Latin America and the Caribbean
EW: Enhanced Weathering
GDP: Gross Domestic Product
GHG: Greenhouse Gases
GW: GigaWatts
GWh: GigaWatts hours
ha: hectares
IPCC: Intergovernmental Panel on Climate Change
LAC: Latin American and the Caribbean
LCOE: Levelized Cost of Energy
LUC: Land Use Change
LULUCF: Land use, land-use change, and forestry
MM: Millions
B: Billion
MW: MegaWatts
MSW: Municipal Solid Waste
NDC: Nationally Determined Contributions
NET: Negative Emissions Technologies
OPEX: Operational Expenditures
O&M: Operation and Maintenance
SDG: Sustainable Development Goals
t: tons
tCO2eq: tons of carbon dioxide equivalent
TORs: Terms of Reference
TWh: TeraWatts hours
UN: United Nations
UNEP: United Nations Environment Programme

[1] Also known as direct air capture and storage (DACS)

PART I – OVERVIEW

I. Introduction

1. Background

This is the final report of the study "Current understanding of the potential impact of Carbon Dioxide Removal (CDR) approaches on Sustainable Development Goals (SDGs) in selected countries in Latin America and the Caribbean".

The objective of this study is to identify and select four Carbon Dioxide Removal (CDR) approaches that may be the most relevant to the LAC region/context, and conduct, when possible, an analysis on the potential economic, social and environmental impacts (positive and/or negative) that the introduction of those CDR approaches could have, in terms of a set of key indicators: Employment; GDP (Gross Domestic Product); costs; greenhouse gases (GHG) emissions removal; and, the achievement of specific SDGs.

The analysis is focused primarily in two selected LAC countries: Argentina and Colombia; however, references to the broader Latin America and Caribbean perspective and opportunities are made in a number of cases.

This analysis aims to help identify knowledge gaps and where possible formulate generic recommendations/options for consideration by governments in the region to eventually incentivize and effectively govern the incorporation of relevant CDR approaches in national climate change strategies that aim to contribute to the achievement of the SDGs, implement the Nationally Determined Contributions (NDCs) and, additionally, inform green recovery plans, when applicable.

The results of this study could be used to help showcase the need to undertake further research efforts in order to reduce potential knowledge gaps, as well as making a contribution to support governments in the region taking informed decisions on assigning resources to further explore and inquire about these options and subsequently assess the convenience of the adoption of these approaches and gauge their potential in adding up to long-term climate mitigation efforts and sustainable development national strategies and plans, in the context of the national long-term strategies and climate policies.

In line with the above-mentioned objectives, the study comprises three main phases; the outcomes of each of those phases are being presented in this report:

- *I. Current status of knowledge and development – A deep dive review:*

  Firstly, identify and characterize the current status of knowledge on a set of Carbon Dioxide Removal (CDR) approaches and on the range of their impacts, indicating the level of availability of scientific and technical knowledge and information at the country level, potentially ranging from "not-known / not understood" to indicating increasing levels of qualitative and/or quantitative information, as well as of progress made in the discussion, planning and initial pilot implementation of those more relevant options.

- *II. Carbon Dioxide Removal (CDR) analysis:*

  Analyze and compare the application of each relevant CDR approach in order to assess its sequestration capacity (mitigation potential[2]) and the resulting impact factors of the adoption of these technologies in the selected countries.

- *III. Analysis on the potential economic, social and environmental implications of the adoption of the technologies under consideration:*

  A comparative analysis on the potential economic, social and environmental impacts (positive and/or negative) that these CDR approaches could have, in particular on a set of key indicators including: employment, GDP (Gross Domestic Product), costs, greenhouse gases (GHG) emissions with respect to their BAU scenarios in the selected countries and, in addition, assess these approaches against the SDGs.

According to the TORs, the analysis is to be focused in the selected CDR approaches and the selected countries within the Latin America and the Caribbean region.

A brief analysis of the background for the adoption of these technologies in the context of the international climate regime is included in order to acknowledge potential implications of the overall understanding of the limitations that these technologies may contend with, in conjunction with the contributions that may be yielded through its implementation.

2. Categories of CDR approaches

In the analysis undertaken, the definitions for each CDR technology adopted was initially based on those employed in the report "Carbon Removal and Solar Geoengineering: Potential implications for delivery of the Sustainable Development Goals" (C2G Report, 2018)[3], complying

[2] According to the IPCC SR15 Glossary, "Carbon Dioxide Removal methods refer to processes that remove CO2 from the atmosphere by either increasing biological sinks of CO2 or using chemical processes to directly bind CO2. CDR is classified as a special type of mitigation." https://www.ipcc.ch/sr15/chapter/glossary/

[3] C2G (2018). Honegger, M.; Derwent, H.; Harrison, N.; Michaelowa, A. and Schäfer, S. Carbon Removal and Solar Geoengineering: Potential implications for delivery of the Sustainable Development Goals. C2G2 Report. May 2018.

with the specifications included in the ToRs. In this regard, the aim is aligning the analysis with previous research activities undertaken by the Carnegie Climate Governance Initiative (C2G), as well as with thematically related initiatives lead by ECLAC.

The IPCC SR15 has indicated that the efficacy and feasibility of many existing Carbon Removal technologies remains highly uncertain and different concerns have been raised that large-scale deployment could result in significant physical, socio-economic or political consequences. Hence this report aims to assess the knowledge gap in the selected countries, by making a first attempt towards an in-depth review of the existing body of knowledge on large-scale CDR technologies at the national level and then identifying potential implications that Carbon Removal could have in terms of mitigation potential and economic and social impacts against the SDGs.

For the purpose of the study, then, the same classification, description and structure, for the CDR approaches as C2G applied in its 2018 report was followed:

- Afforestation and reforestation: Planting of forests and reforestation that result 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 CO2
- Enhancing soil carbon content with biochar: Biomass burning under low-oxygen conditions (pyrolysis) yields charcoal "biochar" which is then added to the soil to enhance soil carbon levels.
- Enhanced weathering or ocean alkalinisation: Enhancing natural weathering of rocks by extracting, grinding and dispersing carbon binding minerals on land or by adding alkaline minerals to the ocean to enhance oceanic carbon uptake.
- Direct air carbon dioxide capture and storage: Chemical process by which CO2 is captured directly from the ambient air, with subsequent storage
- Ocean fertilization: Fertilizing ocean ecosystems with nutrients to accelerate phytoplankton growth, which partly sinks to the seabed thus moving carbon from the atmosphere to the seabed.

While the analysis done is in conformity with the definitions adopted, we also have considered the terms included in the Glossary of the IPCC Global Warming of 1.5°C report, that asserts that the notion of Carbon Dioxide Removal methods refers to processes that remove CO2 from the atmosphere by either increasing biological sinks of CO2 or using chemical processes to directly bind CO2. The definition specifically states that "Anthropogenic activities **removing CO2 from the atmosphere and durably storing it** in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage,but excludes natural CO2 uptake not directly caused by human activities" (IPCC, 2018: Annex I: Glossary).

We thus considered on the one hand the categories of land-based CDR approaches covered by the IPCC (see Table 1), to verify the compatibility of both categorizations, including in addition

DACCS and ocean fertilization in the set of technological options that were to be examined, given the sustained interest in this last category and included in the C2G report (2018).

Table 1: CDR Approaches covered by IPCC

Option	Potentials [a]	Cost [a]	Required land [b]	Required water [b]	Impact on nutrients [b]	Impact on albedo [b]	Saturation and permanence [a]
	$GtCO_2\,y^{-1}$	$\$\,tCO_2^{-1}$	$Mha\,GtCO_2^{-1}$	$km^3\,GtCO_2^{-1}$	$Mt\,N, P, K\,y^{-1}$	No units	No units
BECCS	0.5–5	100–200	31–58	60	Variable	Variable; depends on source of biofuel (higher albedo for crops than for forests) and on land management (e.g., no-till farming for crops)	Long-term governance of storage; limits on rates of bioenergy production and carbon sequestration
Afforestation & reforestation	0.5–3.6	5–50	80	92	0.5	Negative, or reduced GHG benefit where not negative	Saturation of forests; vulnerable to disturbance; post-AR forest management essential
Enhanced weathering	2–4	50–200	3	0.4	0	0	Saturation of soil; residence time from months to geological timescale
Biochar	0.3–2	30–120	16–100	0	N: 8.2, P: 2.7, K: 19.1	0.08–0.12	Mean residence times between decades to centuries, depending on soil type, management and environmental conditions
Soil carbon sequestration	2.3–5	0–100	0	0	N: 21.8, P: 5.5, K: 4.1	0	Soil sinks saturate and can reverse if poor management practices resume

Source: IPCC SR 1.5ºC, Chapter 3, pag. 270.
a: assessed ranges by Fuss et al. (2018), see Figures in Section 4.3.7 for full literature range;
b: based on the 2100 estimate for mean potentials by Smith et al. (2015). Note that biophysical impacts of land-based CDR options besides albedo changes (ex:, through changes in evapotranspiration related to irrigation or land cover/use type) are not displayed.

In turn, the Convention on Biological Diversity (CBD) defined carbon sequestration as "the process of increasing the carbon content of a reservoir/pool other than the atmosphere".[4] The CBD classifies the CDR techniques and examines their additional impacts relevant to biodiversity, including ocean fertilization; enhanced weathering (ocean and land); terrestrial ecosystem management; biomass; direct air capture and carbon storage (ocean and subsurface). To avoid ambiguities, the CBD sustains that it is advisable to recognize that carbon sequestration necessarily involves two steps (CBD, 2012):

[4] Provisionally defined at the tenth meeting of the Conference of the Parties to the CBD. See Footnote to CBD decision X/33, paragraph 8(w).

- i) removal of CO_2 from the atmosphere; and
- ii) long-term storage of the captured carbon, taking it out of circulation for a **climatically-significant** period.

Other UN agencies, such as the United Nations Environment Programme (UNEP), typify the diverse techniques and technology options for carbon elimination according to the following scheme:

- Natural (afforestation and reforestation; biochar; soil carbon sequestration; and other land use and wetlands).
- Combined (bioenergy with carbon capture and storage).
- Technological (accelerated weathering; direct air capture; ocean alkalinity enhancement; CO_2 to durable carbon).

Ecosystem-based approaches such as afforestation, reforestation or the enhancement of soil carbon are already utilized as climate change mitigation activities, and are, certainly at the current scales, not regarded as CDR approaches.

A range of other methods may also be included as greenhouse gas removal methods, in particular some related to the use of particular building materials and transformation of existing industrial processes. These methods or techniques, however, are not being considered in this analysis.

3. Selected Countries in LAC

This report comprises the current information and understanding of the impact and implications of CDR approaches on Argentina and Colombia. The initial decision on the two countries to be analysed was based on different elements:

- the overall national circumstances,
- the fact that both countries have a persistent and still strong deforestation and forest degradation process ongoing, even if in each case due to different conditions and even in spite of the efforts made to revert those processes,
- the significant emphasis placed in both cases in developing extractive policies, including the production and consumption of coal in one case and shale gas in the other, as well as continual or increasing mining activities,
- the relevance of agriculture and livestock production with its concomitant GHG emissions, and,
- more generally, the difficulties in avoiding trends towards a reinforced reliance on primary production and commoditization of exports.

Conversely, the actual national resource endowment and natural capital assests available vis a vis increasingly astringent carbon budgets, water scarcity and revalorization of ecosystem services, unlocks multiple opportunities for climate mitigation, carbon sequestration and restoration of degraded ecosystems as well as ecosystem services supply.[5]

In addition to the exploratory exhaustive review being made in Argentina and Colombia, an abbreviated literature review in other Latin American and the Caribbean countries is also included in this report, with a focus in those areas and countries where research and knowledge on CDR technologies seems to be most developed or, in some cases, experimental initiatives have already been attempted. The purpose of this complementary analysis is to provide a broader landscape on the status and trends in long-term CDR options in the region.

4. Activities undertaken

Activities undertaken throughout the study included:

- Extensive review of the body of research in selected countries and, summarily, at the regional level.
- Desk review of documentary evidence on governmental visions, strategies, plans, programmes considering these technology options and of initiatives or projects aiming at the introduction of CDR technologies
- Assessment and grading of current status of knowledge, planning and implementation gaps in selected countries
- Technical and economic modeling for the estimation of scenarios-based impacts according to historic trends and governmental policies and plans
- Environmental and economic impact analysis of the implementation of selected CDR approaches
- Preliminary recommendations for policy makers on the potential benefits and implications of the introduction of CDR approaches and eventually of large-scale deployment

[5] Also, as established in the Terms of Reference of the present study.

II. Methodological approach

In the first phase, the methodology to review documentary evidence and the available body of research for this study comprised three steps:

i. Information search:

- Identifying knowledge and technical pieces (peer-reviewed online academic journals and books, conference papers, theses and dissertations, preprints, abstracts, technical reports, and other scholarly literature, like court opinions and patents) by searching through the web search engine Google Scholar. The search engine indexes articles from most of the recognized database sources like Elsevier, Scielo, Wiley, NCBI, Science, Nature, MDPI, Springer, Research Gate, among others.
- Academic research was also broadened by reviewing the "cited by/citing articles" feature and "recommended articles" feature in the databases and references of the most relevant articles found related to CDR approaches in Latin America and the Caribbean.
- Reviewing other databases from local research entities like institutional repository "Conicet Digital" of CONICET from Argentina and of local universities like the institutional digital repository of the University of Buenos Aires (UBA) as well as the National University of Colombia (UNAL), among others similar sites.
- Defining keywords as input for the search engines. Those keywords included the titles of the CDR approaches plus the name of the different countries of Latin America and the Caribbean.
- Reviewing and syntethizing main conclusions of knowledge and technical pieces identified through the search.
- Reviewing official journals of the Government of Argentina and Colombia (*Boletin Oficial* and *Diario Oficial* respectively) that encompass the laws, decrees, acts, and most pertinent documents and public announcements of the Executive Power, Congress, and government agencies of such countries.
- Reviewing plans and programmes on the websites of the relevant Ministries (i.e. Ministry of Environment or Ministry of Agriculture, Foreign Affairs) and their dependences for the different countries of Latin America and the Caribbean

ii. Analysis of collated material:

- Analysing all the identified laws, plans, programmes, academic pieces of knowledge and initiatives and projects and obtaining key findings for each CDR approach for each selected country

iii. Metrics

- Defining a grading methodology developed during the study to establish the current status of knowledge, development and commitment under certain assessment dimensions and scales

In the second and third phases, the impact analysis comprised four main steps:

i. Compilation of historical statistics for macro and CDR specific variables

- Identifying key macroeconomic variables for Argentina and Colombia and gathering historical statistics
- Identifying specific key variables in terms of CDR implementation for Argentina and Colombia and compiling historical statistics

ii. Scenario definition and impacts linkages

- For each CDR approach selected, according to results of the assessment of knowledge, planning and implementation gaps, 3 scenarios were defined:
    - baseline scenario based on BAU trends
    - scenario 1 including CDR technology in a moderate manner
    - scenario 2 including CDR technology in an ambitous manner
- Identification of main linkages between macroeconomic and specific variables for CDR impact assessment

iii. Assessment of impacts

- Running simulations among macro and intrasectorial variables for each scenario of each CDR approachbeing examined
- Estimating high level long-term impacts of CDR deployment on key chosen variables (Grenhouse emissions, GDP, Employment, others)
- Estimating costs and investments needed for the different CDR deployment scenarios
- Analyze and compare the application of each relevant CDR approach in order to assess its mitigation potential and impact economic factors for the application of these technologies on the selected countries.

iv. Elucidation of key findings

- Contribution to the achievement of the SDGs
- Recommendations for policy makers on the potential benefits and implications of the introduction of CDR approaches and eventually of large-scale deployment

III. Key Findings of the study

As an outcome of the assessment done throughout the study, key findings in this report are organized as follows:

1. Context
2. Assessment of knowledge, planning and implementation gaps and selection of CDR approaches for impact analysis
3. Impact analysis of CDR approaches on key variables
4. Recommendations for potential research and deployment based on impacts on SDGs

1. Context

These references to the context in which the outcomes of the report should be broadly considered provide a very succinct characterization of major contextual elements from a scientific perspective which might define the border conditions for the integration of those outcomes into a climate policy stance.

The study recalls that, from a global perspective:

- **The Paris Agreement specifies that the long-term temperature goal should be achieved by means of reaching a balance between anthropogenic emissions of greenhouse gases by sources and removals by sinks**, in the second half of this century.
- Further, **there is a growing agreement in the recent body of literature and research that most scenarios to meet the Paris Agreement include negative emissions technologies**. Notwithstanding that, higher near-term emission reductions should decrease the need for a high scale of deployment of those negative emissions technology options, reinforcing the rationale for a global imperative for urgent and deep decarbonization in order to minimize future reliance on CDR options and their potential associated risks.
- **In the IPCC AR5 it was stated that CDR plays a major role in many mitigation scenarios while underscoring that delay in additional mitigation action to 2030 will imply a larger reliance on CDR in the long-term**. Furthermore, the IPCC indicated that **"most terrestrial CDR techniques would require large-scale land-use changes and could involve local and regional risks, while maritime CDR may involve significant transboundary risks for ocean ecosystems."** [6]
- In addition, the IPCC further asserts that **"CDR plays a major role in many mitigation scenarios"** and **"several CDR techniques could potentially reduce atmospheric**

[6] IPCC (2014a). Technical Summary, page 60.

greenhouse gas (GHG) levels. However, there are biogeochemical, technical and societal limitations that to, varying degrees, make it difficult to provide quantitative estimates of the potential for CDR." [7]

- More specifically, the IPCC AR5 had already made an introduction to carbon dioxide removal methods and discussed the potential effects of those methods on the Carbon Cycle (IPCC, 2013). The non-exhaustive list of methods then included: enhanced biological production and storage on land, enhanced biological production and storage in ocean, accelerated weathering and others of a chemical nature (direct air-capture with storage).[8]
- **According to research done at the global level, CDR options can generate positive and negative local and regional impacts on various SDGs,** via physical, social, economic, and political channels.
- Hence, **it is necessary to assess the possible environmental, economic, and societal impacts of technological innovations that might be aiming for public support** and funding in research, development, and market implementation and **ensure that the objectives of the SDGs are safeguarded in the possible implementation of those technologies.**
- **Since those previous findings made by the IPCC, research has steadily advanced.** Protracted climate action and persistent increase in GHG emissions led to diverse initiatives to consider -from a scientific and technical perspective- carbon dioxide removal technologies with an increasing level of interest.
- **The adoption of the Paris Agreement and its entry into force, as well as the intensified exploration of plausible scenarios related to zero carbon futures increased the interest in CDR approaches.**
- **The IPCC Special Report on Global Warming of 1.5 ºC provided scientific basis to the examination of CDR technological options** -being part of a possible additional menu of negative emission technologies- and exploring the potential for expansion of already widely examined mitigation actions, primarily as a set of nature based -and technical- approaches to be applied.
- **In this context, CDR options may, a priori, be looked at as complementary means to achieve the goals embraced in the Paris Agreement and securing the SDGs.** Those emission pathways consistent with a 1.5 ºC limit require reduced emissions at global scale in addition to near-term carbon dioxide removal.
- Lingering political aversion to the large-scale utilization of CDR approaches would be assuaged by heightened ambition in the elaboration and subsequent concrete implementation of NDCs demonstrating that effective mitigation action is taking place, as well by increased perception of the need to exhaust the understanding of the diversity of technical options and their possibilities.

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[7] IPCC (2014b). AR5 Synthesis Report, page 89.
[8] IPCC (2013). See Chapter 6.5, pp. 546-555.

- Hence, to minimize future CDR reliance, the imperative for rapid and deep decarbonization remains a pillar of the international climate regime global mandate.
- In the 1.5 ºC report, the SPM underscores that “All pathways that limit global warming to 1.5˚C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 GtCO2 over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5˚C following a peak.”[9]
- The SPM then highlights that “The longer the delay in reducing CO2 emissions towards zero, the larger the likelihood of exceeding 1.5˚C, and the heavier the implied reliance on net negative emissions after mid-century to return warming to 1.5˚C” making the need for exploring the CDR options more inexorable.
- In addition, the IPCC warns that most current and potential CDR measures could have significant impacts on land, energy, water or nutrients if deployed at large scale.[10]
- Hence, it is necessary to ensure that the potential environmental, economic, and societal impacts of those technological innovations aiming for public support and funding in research, development, and market implementation are aligned with the respective objectives of the SDGs and have been carefully assessed in order to determine the technical, economic and environmental feasibility of each of the different options.
- Some of the approaches being categorized as CDR are also commonly understood as part of Nature based options. Hence the boundaries -semantic, conceptual, operative, and in particular, political- between absorption and mitigation reckoning may be a source of contention in the political arena, or merely a controversial issue, when these options are being introduced as part of planned climate action implementation efforts.
- There is a growing understanding that the implications of the social, environmental and economic implications of utilizing these CDR technology options would primarily be contingent on the quality of a governance regime, including issues related to legitimacy, capacity and relevance, in the context of the international climate architecture.
- However, the IPCC also acknowledges that the existing governance mechanisms to address an array of complex issues (governance, constraints, accounting, monitoring) are still scarce or insufficient (IPCC, 2018).
- A number of views and interpretations suggest that the need to start deployment of CDR in the 2020s in order to meet the global climate targets, comprising in particular the 2ºC and 1.5ºC thresholds, might imply the admission of a partial failure of present policy approaches at the national level and, more importantly, the inability of the international climate regime to achieve the agreed Paris Agreement global goals. It is possible to progressively demonstrate that this is not the case and that CDR approaches

[9] IPCC (2018). SPM, page 17.
[10] IPCC (2018). SPM, page 17.

are valid, efficient -in a case specific context- and consistent with current mitigation objectives.

2. Assessment of knowledge, planning and implementation gaps

As the different technological options to be explored are at different stages of development (in some cases at the theoretical or merely experimental stage) and a number of LAC countries typically face a climate finance and budgetary 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 and negative impacts on the Sustainable Development Goals.

LAC countries efforts on climate change mitigation are appropriately primarily focused on emissions reduction and complete replacement of fossil fuels consumption, and only in a largely incipient manner carbon removal efforts are being considered, with diverse degrees of theoretical and practical advance, in scientific knowledge, planning and ensuing implementation of those technological options.

In general, and with rare exemptions, a significant knowledge and empirical development gap has been identified in relation with the appraisal of the feasibility and convenience of the implementation of CDR approaches in LAC countries.

The body of research on the effectiveness and potential implications of some of the CDR options is a new and, in many cases, nascent exploratory field.

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.

Significant gaps in knowledge mean that a comprehensive research and technical development effort for each technology should be undertaken, if it is decided that these options -or some of them- should be part of the national climate policy.

Deployment of large-scale CDR approaches assessed in this study would be expected to have physical side-effects and socio-economic or governance implications, affecting in different ways the delivery of SDGs; effects can either reinforce accomplishment of or hinder achieving the SDGs.

Physical side-effects identified in particular relate to: land-use alternative uses and food security; water quality and availability; health; energy; economic productivity; infrastructure needs; and biodiversity. Socio-economic or political implications include: economic and cultural impacts; opportunity costs; significant financial requirements; and political consistency among sectors.

Afforestation and reforestation and enhancing soil carbon content with biochar are the most explored CDR approaches in the scientific and academic field in LAC.

Afforestation and reforestation, in addition, is supported by an array of laws, regulations and national plans and programmes both in Argentina and Colombia as in the other LAC countries. Furthermore, several large-scale projects have been identified for Afforestation and reforestation in Argentina and Colombia and other LAC countries. For example, large scale forest restoration plans are being planned and implemented, among others.

A number of countries, including Argentina have developed policies and plans promoting the use of wood from sustainably managed forests for industry and construction (which represent long-term carbon storage alternatives) and their other related projects. Brazil and Chile have been traditionally active in this field.

Argentina and Colombia are countries with intensive use of land for agriculture. Even though a nascent field of research in LAC countries, enhancing soils carbon content and technologies that include the use of biochar as soil enhancer as well as enhanced weathering should be worth analyzing deeper in order to quantify its potential impacts and risks.

There is a good basis of research and initiatives/projects on the bioenergy side of the BECCS equation, however there is no integral research on BECCS, per se. Incipient but rapidly increasing installed capacity of biomass and biogas power generation plants and biofuels production plants is being observed. Nonetheless, the focus is primarily on the BE side.[11]

Biofuels applied to power generation in non-grid connected areas (distributed generation) could have a potential for BECCS development in LAC countries, although there are no relevant knowledge, commitment nor implementation efforts identified to the date of the elaboration of this report.

Brazil leads CCS research capabilities in Latin American and Caribbean, mainly focusing in geological storage in salt caverns in ultra-deep water.

According to the IPCC 1.5 special report, given the DACCS technology's early stage of development (see also McLaren, 2012; NRC, 2015a; Nemet et al., 2018) and a limited number of empirical demonstrations (Holmes et al., 2013; Rau et al., 2013; Agee et al., 2016), deploying the technology at scale seems to still be a considerable challenge, though both optimistic (Lackner et al., 2012) and pessimistic outlooks co-exist (Pritchard et al., 2015).

Worlwide there are several DACCS plants (mainly pilot plants) with a combined capacity of less than 10,000 tons of CO2 per year. Locations include Europe, US and Canada, but none of them is

[11] BE refers to BioEnergy only, not including CCS phases of BECCS

located in Latin America. The first large-scale DACCS plant (1 million-ton CO2/ year capacity) is expected to start the construction phase in US Permian basin although not before 2022.

In a transition to net-zero emissions, the CO2 resulting from producing synthetic fuels would increasingly need to be captured through bioenergy sources or from the atmosphere to avoid delayed emissions from fossil-based CO2, when the fuel is combusted. Direct air capture is one of a short number of technological options available to remove CO2 directly from the atmosphere. Carbon removal is expected to play a key role in the transition to a net-zero energy system in which the amount of CO2 released into the atmosphere is equivalent to the amount being removed. According to European Commission, DACCS cost needs to drop by at least an order of magnitude with respect to its value today for this option to become financially and economically feasible.

As the technology has yet to be demonstrated at large scale and in different locations, the expected cost of direct air capture is uncertain. For this reason, direct air capture needs to be demonstrated at a relevant scale, to reduce uncertainties regarding future deployment potential and costs, and to ensure that these technologies can be available to support the transition to net-zero emissions and beyond.

Regarding ocean fertilization, only small-scale field experiments and theoretical modelling have been conducted (ex:, McLaren, 2012). Fuss et al. (2018) consider the potential to be extremely limited given the available evidence and existing barriers. The greatest theoretical potential for this practice is the Southern Ocean, posing challenges for monitoring and governance (Robinson et al.,2014).

Carbon removal options include nature-based solutions (ex: afforestation, reforestation, restoration of costal and marine habitats), measures to enhance naturally occurring processes (ex: land management approaches to increase the carbon content in soil, biochar) and other technology-based solutions such as bioenergy with carbon capture and storage (BECCS).

In the near term, large-scale demonstration of CDR technologies such as DACCS and ocean fertilization will require targeted government support, including through grants, tax credits and subsidies and public procurement of CO2 offsets. The CDR potentials that can be realized are constrained by the lack or insufficiency of policy portfolios incentivising large-scale CDR (Peters and Geden, 2017). Near-term opportunities could be supported through modifying a number of existing policy mechanisms (Lomax et al., 2015). Social impacts of large-scale CDR deployment (Buck, 2016) require policies taking these effects into account and alleviating the negative effects that may result from the planned interventions.

Assessment of knowledge, planning and implementation gaps in Argentina and Colombia

The review of knowledge, planning and implementation gaps is undertaken with the ultimate aim of assessing the CDR technologies against the SDGs and contribute to enable the discussion on whether the CDR technologies can be instrumental to delivering the SDGs by 2030.

To that end, our own methodological approach was applied, building upon the C2G methodology [Honegger, et al 2018], and considering three different dimensions: i) scientific and technical knowledge, ii) mainstreaming in government planning, and iii) advances in implementation, to determine the current status of knowledge, adoption in planning and empirical application of the selected CDR approaches in the chosen countries.

For each of those assessment dimensions, a scale was created reflecting increasing degrees of knowledge, planning and implementation. To facilitate graphic perception, a colour was assigned to those different degrees in the scales:

Table 2: Scales by assessment dimension

Assessment dimension	Scale	Colour
Scientific and Technical Knowledge	Not known / not understood	Orange
	Research underway NOT directly/partially related to the CDR tech	Grey
	Up to 10 relevant knowledge pieces identified	Light green
	More than 10 relevant knowledge pieces identified	Green
Mainstreaming in Government planning	No legislation, plan or programme identified	Orange
	Gvmt action identified NOT directly/partially related to the CDR tech	Grey
	Gvmt legislation, plan, programme identified but NOT executed yet	Light green
	Gvmt legislation, plan, programme identified and executed / in execution	Green
Implementation of initiatives and projects	No initiatives / no projects identified	Orange
	Initiatives / Projects identified NOT directly/partially related to the CDR tech	Grey
	Small-scale initiatives / project executed and/or large-scale project planned	Light green
	Large-scale projects completed / in operation	Green

The following table depict the scoring for each CDR approach and each of the assessment dimensions for Argentina and Colombia respectively, with its supportive summarized evidence for such scoring, based on the detailed review of the current status of knowledge, planning and implementation (collated in the following sections)[12].

[12] For further detail and references on the knowledge pieces please proceed to section "III. Current status of knowledge and development – A detailed review"

Table 3: Argentina - Current Status of Knowledge and Development -Scoring Methodology

CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
Afforestation and reforestation	*Scientific and Technical Knowledge*	●	• Fourteen pieces of knowledge identified that evaluate the impact of reforestation on fauna, soil nutrients and the ecosystem
	Mainstreaming in Government planning	●	• Extensive track record of legal frameworks related to forestry development and conservation (Laws 12,103/1934; 13,273/1947; 24,688/1996; 25,080/1998; 26,331/2017) • Relevant national plans identified: 2017's National Action Plan for Forests and Climate Change, 2018's National Plan for the Restoration of Native Forests (18,000 ha), and ForestAr 2030 plan (2 million ha) • Deforestation rate still at 150,000 ha per year levels (reduced from 600,000 ha per year)
	Implementation of initiatives and projects	●	• Ongoing large projects identified: Santo Domingo sustainability project (since 2007 seeks to capture 600,000 CO_2 tons by 2020 in 3,400 ha), Las Yungas (REDD+ project 1.85 million-ton CO_2 in 10 years in 62,000 ha) and 23 reforestation projects approved under the ForestAr 2030 plan, which will restore 1,720 hectares of native forests (and targets to increase to 20,000 ha by 2023) • Even though there are plans and programs in execution, the incentives and promotion actions (i.e. financing, subsidies) are insufficient for broader implementation

Bioenergy with carbon capture and storage (BECCS)	*Scientific and Technical Knowledge*		• Nine articles have been identified analysing the potential of biomass power generation in Argentina and feasibility of specific biofuels and biogas plants • Eight pieces of academic literature have been identified related to power generation from MSW and industrial / agriculture effluents in Argentina, assessing technology/process challenges, environmental impacts and economic feasibility • No academic article was identified approaching BECCS integrally in Argentina
	Mainstreaming in Government planning		• Committed to renewable energy and biofuels through legislation, incentives and national programs (Renovar, Probiomasa) including a minimum blend of 7% for biodiesel in diesel oil for power generation, • 2005's National Strategy for Urban Solid Waste Management (ENGIRSU) and 2016's PROBIOGAS program • There is no specific Government plan or program promoting BECCS as an integral CDR approach
	Implementation of initiatives and projects		• All identified projects are focused on BE, but none of them has reported a CCS phase, therefore there are no integral BECCS projects planned, under construction nor in operation in Argentina • Nearly 240 MW of installed capacity have been awarded among 69 biomass, biogas and biogas landfill projects in Renovar auctions • Small scale biogas projects are being developed (Renovar projects, CEAMSE project, RyVERI project and PROBIOGAS projects)
Enhancing soil carbon content with biochar	*Scientific and Technical Knowledge*		• Academic research on "biochar as soil enhancer" subject is still incipient in Argentina.
	Mainstreaming in Government planning		• No explicit mention to biochar as soil enhancer was identified in Argentinean policies and development plans. However, there are

			some incipient efforts to evaluate the direct effect of biochar on soil carbon.
	Implementation of initiatives and projects	● (orange)	• No specific initiatives or small / large-scale projects identified but some interest shown by private actors to migrate to biochar production.
Enhanced weathering or Ocean alkalinization	*Scientific and Technical Knowledge*	● (grey)	• Multiple scientific entities (including CONICET, Naval Hydrography Service, Argentine Institute of Oceanography, Institute of Marine and Coastal Research, Institute of Coastal Geology) and universities are actively conducting various investigations on oceans behaviour and characterization in Argentine waters. Most relevant academic literature cover the dynamics of CO2 in South Atlantic seas and the effects of ocean acidification in the ocean ecosystems • However, no specific academic literature was identified related to Enhanced weathering or Ocean alkalinization
	Mainstreaming in Government planning	● (grey)	• Creation of the National System of Marine Protected • There are no specific national plans or programmes related to Enhanced weathering or Ocean alkalinization
	Implementation of initiatives and projects	● (orange)	• No specific initiatives or small / large-scale projects identified
Direct air capture and storage	*Scientific and Technical Knowledge*	● (orange)	• No academic literature was identified related to DACS • A workshop on the DAC topic was held by the National University of Cuyo in Mendoza, Argentina in October 2018
	Mainstreaming in Government planning	● (orange)	• No specific legislation, government plans / programmes nor academic literature was identified in Argentina
	Implementation of initiatives and projects	● (green)	• In 2018 a DAC project was announced in Mendoza province with technology from US-based company Global Thermostat and an estimated investment of 4 million dollars. However, as for October 2020, no progress has been reported

Ocean fertilization	*Scientific and Technical Knowledge*		• *Idem Ocean Alkalinization*. There are no specific national plans or programs related to ocean fertilization.
	Mainstreaming in Government planning		• *Idem Ocean Alkalinization*. Indirect academic research on oceans behaviour and characterization and CO2 dynamics, but no specific article on Ocean fertilization
	Implementation of initiatives and projects		• *Idem Ocean Alkalinization*. No specific initiatives or small / large-scale projects identified

Source: own elaboration on the basis of review of information and rating

Table 4: Colombia - Current Status of Knowledge and Development -Scoring Methodology

CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
Afforestation and reforestation	*Scientific and Technical Knowledge*	●	• Fifteen pieces of knowledge identified covering the territory assessment with information on deforested / reforested areas and carbon capture analysis by different species of trees, among other topics
	Mainstreaming in Government planning	●	• As part of the government's commitment to climate change, various national plans were developed: 2000's National Forest Development Plan (restoration of 245,000 ha, establishment of 271,000 ha protective forests and 332,000 ha protective/producing forests); 2004's Support Program for the National Environmental System (20,472 ha) and 2015's National Plan for Ecological Restoration, Rehabilitation, Restoration and Recovery of Disturbed Areas. • Colombia has set ambitious goals to curb deforestation, including reducing the annual loss of natural forests to 155,000 ha or less by 2022 and 100,000 ha or less by 2025 (from current levels of 220,000 ha per year).
	Implementation of initiatives and projects	●	• Various programs and projects are being carried out, including Celsia from Grupo Argos with the aim of planting 10 million trees in 10 years; two projects (Tumacoco and La Pedregoza) from Tree Nation platform that already offset more than 400,000 tons of CO_2; and the Biocarbono Fund in strategic collaboration with the World Bank
Bioenergy with carbon capture	*Scientific and Technical Knowledge*	●	• Eleven academic articles have been identified covering biomass power generation and biofuel production in Colombia

CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
and storage (BECCS)			• Four pieces of knowledge were identified regarding other biomass power generation covering the following topics: energy potential of agriculture, agroindustry, livestock, and slaughterhouse biomass wastes; government incentives for waste energy; comparison of operating annual cost under some types of biogas produced from poultry, bovine and porcine manure, and solid urban organic waste; municipal solid waste as a source of electric power generation. • None academic articles were identified approaching BECCS integrally in Colombia
	Mainstreaming in Government planning	●	• Laws N° 1,715/2014 and N° 1,955/2019, regulated the integration of non-conventional renewable energy to the national energy system; promoted investigation on the subject; granted fiscal incentives and approved a national plan that included a goal to produce 8 to 10% of Colombia's energy from renewable energy sources • "National Policy for Comprehensive Solid Waste Management by 2030" (2016) • No specific Government plan or program promoting BECCS as an integral CDR approach was identified in Colombia
	Implementation of initiatives and projects	●	• All identified projects are focused on BE, but none of them has reported a CCS phase, therefore there are no integral BECCS projects planned, under construction nor in operation in Colombia • Biomass-fed power generation installed capacity is mostly represented by bagasse CHP and currently represents 0.8% over Colombia's installed capacity (140 MW), after an increase of 50 MW (+54%, at a CAGR of 9%) between 2015 and 2020.

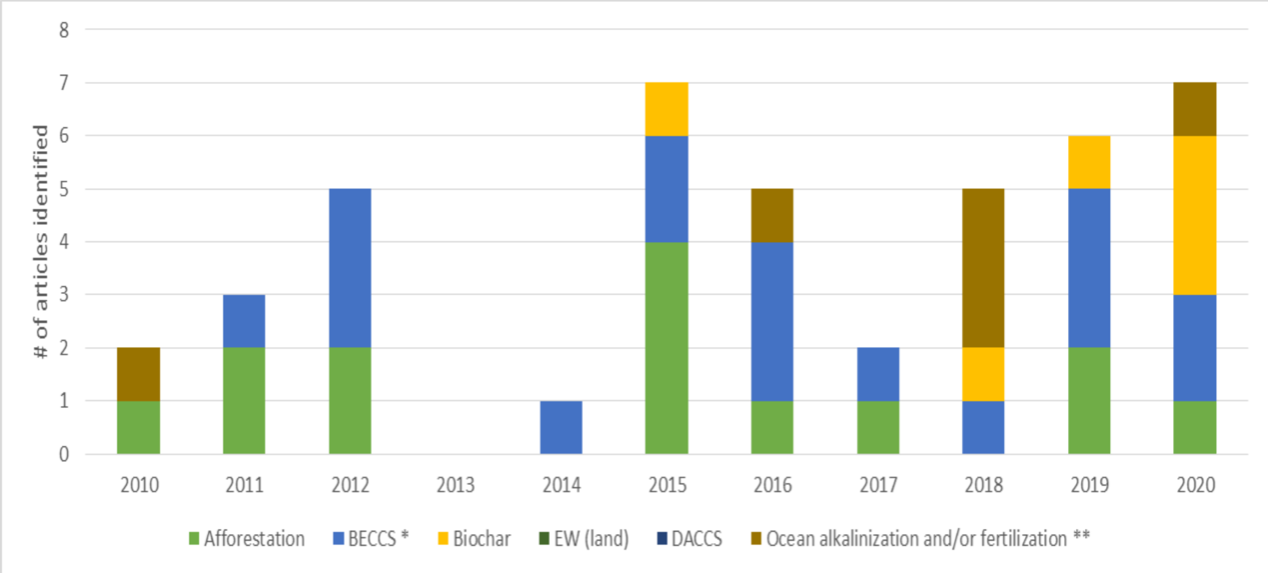
CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
			• Despite no bioenergy project was awarded in Colombia's first two renewable energy auctions, there are a few small-scale biomass projects under study
Enhancing soil carbon content with biochar	*Scientific and Technical Knowledge*		• Nine academic articles and research initiatives have been identified related to biochar as soil carbon content enhancer in Colombia. All of them mentioned positive preliminary results for biochar on small scale (laboratory) tests.
	Mainstreaming in Government planning		• Even though not mentioning biochar explicitly, there is a national program launched in 2015 called "Colombia Siembra" which main goal was to expand by one million the hectares sown in the country, aiming to increase the area and the yields destined to the production and strengthen technological development
	Implementation of initiatives and projects		• No large-scale projects have been identified related to biochar as soil enhancer in Colombia. • However, many experimental / laboratory projects and test were performed, as detailed in the literature review
Enhanced weathering or Ocean alkalinization	*Scientific and Technical Knowledge*		• Four academic articles have been identified in Colombia related to ocean characterization and effects of climate change on it. However, no specific academic literature was identified related to Enhanced weathering or Ocean alkalinization
	Mainstreaming in Government planning		• Since beginning of 2000 decade, Colombia has instrumented its National Policy of the Ocean and Coastal Spaces and the Colombian Ocean Commission (CCO). • There are no specific national plans or programs related to Enhanced weathering or Ocean alkalinization

CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
	Implementation of initiatives and projects	●	• No specific initiatives or small / large-scale projects identified
Direct air capture and storage	*Scientific and Technical Knowledge*	●	• No academic literature was identified related to DACS
	Mainstreaming in Government planning	●	• No specific legislation, government plans / programs nor academic literature was identified in Colombia
	Implementation of initiatives and projects	●	• No specific initiatives or small / large-scale projects identified
Ocean fertilization	*Scientific and Technical Knowledge*	●	• *Idem Ocean Alkalinization*. There are no specific national plans or programs related to ocean fertilization.
	Mainstreaming in Government planning	●	• *Idem Ocean Alkalinization*. Indirect academic research on oceans behaviour and characterization and CO2 dynamics, but no specific article on Ocean fertilization
	Implementation of initiatives and projects	●	• *Idem Ocean Alkalinization*. No specific initiatives or small / large-scale projects identified

Source: own elaboration on the basis of review of information and rating

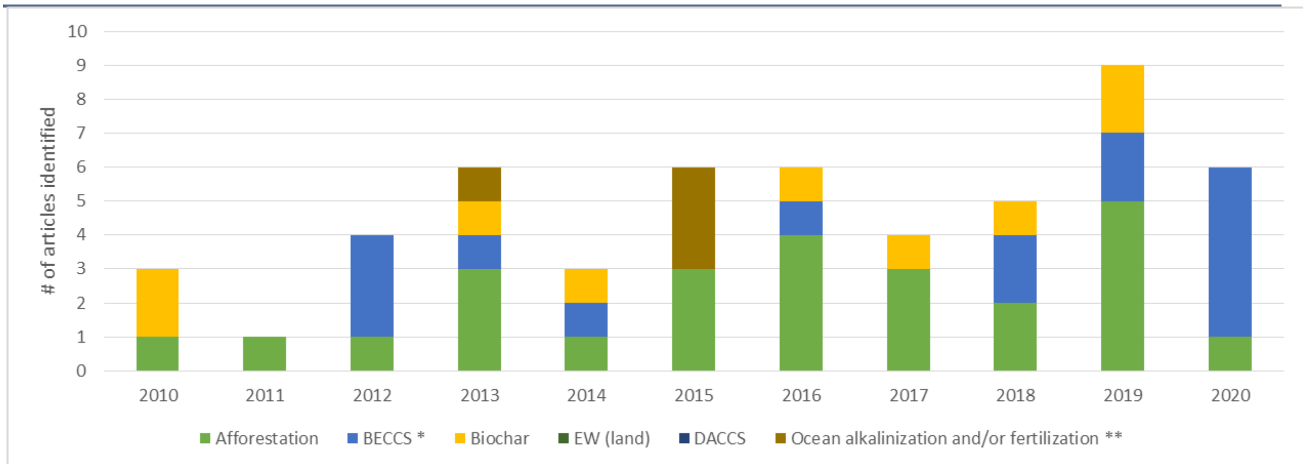
Additionally, an analysis on the chronology of the pieces of knowledge or articles identified for each CDR approach was performed. In the last three years (2018-2020 period) the highest number of academic articles was developed when considering the entire 2010-2020 period for both Argentina and Colombia.

Figure 1: Chronology of pieces of knowledge identified in Argentina (2010-2020 period)



*Note: * Only BE but no integral BECCS research identified. ** Indirect academic research on oceans behaviour and characterization and CO2 dynamics, but no specific article on Ocean alkalinization or Ocean fertilization.*
Source: Own elaboration

Figure 2: Chronology of pieces of knowledge identified in Colombia (2010-2020 period)



*Note: * Only BE but no integral BECCS research identified. ** Indirect academic research on oceans behaviour and characterization and CO2 dynamics, but no specific article on Ocean alkalinization or Ocean fertilization. Afforestation includes 10 relevant knowledge pieces of Mangroves in Colombia during the 2010-2020 period.*
Source: Own elaboration

Based on the analysis on the current status of knowledge, planning and implementation of CDR approaches in LAC countries and, specifically, in Argentina and Colombia, the following four CDR approaches were selected to further deep-dive in terms of impact analysis:

- Afforestation and reforestation
- Bioenergy with carbon capture and storage (BECCS)
- Enhancing soil carbon content with biochar
- Enhanced weathering (land)

3. Impact Analysis of CDR Implementation

For each country and CDR approach, technical scenarios estimates were completed according to the following definitions:

- Afforestation and reforestation
    - Baseline scenario according to historic trends
    - Scenario 1 (Sc1) resulting from the annual increase of commercial forest plantations according to the countries' NDCs and plans
    - Scenario 2 (Sc2) of Maximum potential area suitable for forestlands in Argentina and Colombia, based if possible, on "site quality" criteria (soil, topography and climate), regardless of any economic benefit associated with afforestation and reforestation activities
- Mangroves
    - Baseline scenario of null or marginal incremental mangrove restoration in Colombia
    - Sc.1 resulting from a mangrove restoration plan of 0.2% of total mangrove area annually (16,000 total restored hectares by year 2050)
    - Sc.2 resulting from a mangrove restoration plan of 0.7% of mangrove area annually (58,000 total restored hectares by year 2050) (Maximum mangrove restoration area according to Bernal et al 2017)
- BECCS
    - Baseline scenario, based on official Energy Scenarios in Argentina (SGE, 2019) for the period 2019-2030, extended to 2050 / Plan Energético Nacional Colombia 2020- 2050 (UPME, 2019).
    - Sc1, an enhanced biomass/biogas power generation scenario, with low CCS adoption
    - Sc2, an enhanced biomass/biogas power generation scenario, with high CCS adoption
- Enhancing soil carbon content and enhancing soil carbon content with biochar
    - Baseline scenario: no biochar applied
    - Sc1, an enhanced soil carbon content scenario, with low biochar applied
    - Sc2, an enhanced soil carbon content scenario, with high biochar applied

Uncertainties surrounding enhanced weathering (land) are still large. The broader implications of Enhanced weathering (land) technologies for delivering sustainable development are insufficiently understood at this time and thus, was not feasible to perform the impact analysis done for the rest of CDR technologies in Argentina and Colombia. The technology is untested at scale, not exhibiting enough quantitative and qualitative information, presenting a limitation for impact analysis.

Impact analysis - Argentina and Colombia

This section summarizes the estimation of the impacts of the large-scale deployment for the selected CDR approaches in Argentina and Colombia, according to the scenarios determined for each of them.

Several linkages among macro and intrasectorial variables for each CDR approach and country were identified, estimating long-term impacts of CDR deployment on key variables contributing to the achievement of the SDGs (Grenhouse emissions, GDP, Employment, others), based on the technical scenario forecasting the aforementioned. Costs and investments needed for the different CDR deployment scenarios were also quantified.

Argentina impacts

- Adopting a deep decarbonization pathway in Argentina requires deepening efforts in key sectors by launching transitions primarily but not only in the energy, transport and the Agriculture Forestry and Other Land Use (AFOLU) sectors. In this context, afforestation and reforestation constitutes a core mitigation strategy to reduce net emissions and ensure removal at a large scale. It is estimated that afforestation could remove an average of over 15 Mega tons of CO2e per year during the 2020-2050 period in a plausible scenario of a maximum of 80 thousand hectares planted per year. The consideration and implementation of the Afforestation and Reforestation option is consistent with decarbonization pathways envisaged by national climate policies.
- Afforestation and reforestation present the lowest cost per ton sequestred (about 6 USD per ton CO2e) and the largest emissions removal for Argentina, and should be prioritized in the near term. Despite its low cost per ton of CO2e, the Afforestation scenarios elaborated estimate investments in the 60-100 million dollars per year and provide a significant source of direct primary employment. Larger investments and effects in employment and GDP than estimated might be possible if the wood industrial value chain is significantly developed downstream
- Changes in livestock production practices, in particular those related to increasing soil carbon stocks can provide additional means to increasing mitigation ambition in the short to medium term.
- Similarly, changes in current but evolving agricultural practices (and thus technically and culturally feasible) can contribute to incremental emission reductions.

- The application of biochar on soils could sequester up to 2.5 Mega tons of CO2e per year by 2050, only considering fruit trees. Further expansion to other intensive crops and later to extensive crops might be an upside to explore with further research efforts and pilot projects. Moreover, biochar deployment exhibits the second lowest cost per ton sequestered after Afforestation.
- There is uncertainty about the feasibility of timely upscaling of BECCS. CCS is largely absent from the Argentinean Nationally Determined Contributions and lowly ranked in investment priorities. It is estimated that BECCS could sequester up to 2.0 Mega tons of CO2e per year by 2050 with over 1,300 MW of additional installed capacity
- BECCS deployment in the mid-term implies large investments in capital intensive industrial facilities, and therefore exhibits high multiplier in terms of GDP and employment. However, BECCS is still an inmature technology in Argentina with the largest cost per ton sequestered (240 to 260 USD/ ton CO2e)

Table 2: Impact of CDR deployment on key variables – Argentina

		Potential GHG emissions (sequestered)	Avg Investment requirements	Cost	Net changes in employment created	Contribution to GDP
		Mega t CO2 /yr	MM USD/yr	USD / t CO2	# jobs created/ Mega t CO2 seq	Δ MMUSD GDP / Mega t CO2 seq
Afforestation	Baseline	5.6 (avg) 7.7 (2050)	29 (avg)	5.1	73 direct 117 indirect	22
	Sc1	10.3 (avg) 11.3 (2050)	59 (avg)	5.6	80 direct 127 indirect	24
	Sc2	15.9 (avg) 14.4 (2050)	100 (avg)	6.1	85 direct 136 indirect	26
BECCS	Baseline	No CCS adoption in baseline scenario, only bioenergy				
	Sc1	0.1 (avg) 0.3 (2050)	35 (avg)	256.5	733 permanent 258 constr.	1,075
	Sc2	0.7 (avg) 2.0 (2050)	163 (avg)	239	1,037 permanent 360 constr.	1,000
Biochar	Baseline	No biochar deployment in baseline scenario				
	Sc1	0.1 (avg) 0.2 (2050)	3 (avg)	25.4	102 industrial	110
	Sc2	1.5 (avg) 2.5 (2050)	30 (avg)	19.3	77 industrial	84

Source: Own elaboration

Colombia impacts

- In Colombia, controlling deforestation is key for lowering its emissions. Further, given the need to produce additional food and biomass by intensifying agriculture and cattle production, halting deforestation emerges as an imperative to facilitate the adoption of a deep decarbonization and long-term sustainable food production.

- Afforestation also presents in Colombia the largest GHG emissions potential, with an average of over 13 Mega ton of CO_2e per year in the 2020-2050 period
- Colombia is one of the world's top 20 countries in terms of mangrove covered area, with nearly 300,000 ha of mangrove trees in both the Pacific and Caribbean Coasts. Mangroves are well known for its high capacity to capture carbon stock per unit of land compared with terrestrial forests. It is expected that mangrove restoration at an 0.7% annual rate (equivalent to 58 thousand ha restored in the next 30 years) could sequester up to 3 Mega ton of CO_2e per year, with relatively low investments and costs per ton of CO_2
- Effects in employment and GDP contribution of afforestation and mangrove restoration interventions might be underestimated if other indirect economic activities derived from its value chain and ecosystem respectively were also considered (not included in the figures below) beyond primary plantations activities.
- Only considering deployment in fruit tree plantations, Biochar application on Colombian soil could sequester up to 5 Mega tons of CO_2e per year by 2050. As mentioned in Argentina, further expansion to other intensive crops and later to extensive crops might be an upside to explore with further research and pilots in Colombia. Although higher than Afforestation and Mangrove restoration, Biochar application cost per ton is expected to remain below 25 USD/ton CO_2e
- Over 1,100 MW of BECCS installed capacity are forecasted for Colombia by 2050 in a high adoption scenario, potentially sequestering nearly 5 Mega tons of CO_2e per year. BECCS is constrained by sustainable bioenergy potentials and availability of safe storage for CO_2. Similar to Argentina, in Colombia there is also uncertainty about the feasibility of timely upscaling of BECCS. CCS is largely absent from the Colombian Nationally Determined Contributions and lowly ranked in investment priorities. BECCS competes with other land-based CDR approaches and mitigation measures for resources
- Larger investments requirements like capital intensive BECCS deployment and Biochar production plants generate larger effects in employment craetion and GDP contribution. Although significantly lower than in Argentina, BECCS present the highest CDR cost per ton sequested in Colombia at an estimate of about 70 USD per ton CO_2e

Table 3: Impact of CDR deployment on key variables – Colombia

		**Potential GHG emissions (sequestered)**	**Avg Investment requirements**	**Cost**	**Net changes in employment created**	**Contribution to GDP**
		Mega t CO_2 / yr	MM USD/yr	USD / t CO_2	# jobs created / Mega t CO_2 seq	Δ MMUSD GDP / Mega t CO_2 seq
Afforestation	Baseline	4.7 (avg) 6.3 (2050)	48 (avg)	9.7	76 direct 122 indirect	62
	Sc1	7.5 (avg) 8.1 (2050)	78 (avg)	10.1	74 direct 118 indirect	65
	Sc2	13.4 (avg) 12.0 (2050)	144 (avg)	10.5	66 direct 106 indirect	67
	Baseline	Null or marginal mangrove restoration in Colombia				

Mangrove restoration	Sc1	0.4 (avg) 0.8 (2050)	5 (avg)	11.1	65 direct	69
	Sc2	1.4 (avg) 2.9 (2050)	15 (avg)	10.9	69 direct	68
BECCS	Baseline	No CCS adoption in baseline scenario, only bioenergy				
	Sc1	0.1 (avg) 0.4 (2050)	12 (avg)	72.9	271 permanent 104 construction	453
	Sc2	2.1 (avg) 4.7 (2050)	146 (avg)	69.2	259 permanent 101 construction	429
Biochar	Baseline	No biochar deployment in baseline scenario				
	Sc1	0.3 (avg) 0.4 (2050)	7 (avg)	25.0	100 industrial	161
	Sc2	3.1 (avg) 4.8 (2050)	58 (avg)	18.0	72 industrial	116

Source: Own elaboration

Contribution to the achievement of the SDGs

The review of knowledge, planning and implementation gaps and impact estimates were undertaken with the ultimate aim of assessing the CDR approaches against the SDGs. In this chapter we summarise the potential implications that deployment of CDR technologies could have for reaching each of the seventeen SDGs.

The body of research on the effectiveness and potential implications of some of the CDR approaches is a new and, in many cases, exploratory field. The broader implications of CDR technologies for delivering sustainable development are insufficiently understood, particularly in LAC countries. Nevertheless, an initial effort was done to elucidate the impact of Carbon Dioxide Removal (CDR) approaches on the SDGs in selected countries in Latin America and the Caribbean (LAC).

The potential implications identified for the SDGs are likely to differ strongly depending on the assumed scale of intervention, as well as the main hypothesis considered in terms of scenarios and contexts in which they would be deployed.

As stated earlier, it is important to note that while this report endeavours to present a balanced, impartial and evidence-based view of potential implications, significant gaps in knowledge mean that even if a comprehensive research for each technology is undertaken, in some cases those implications may not be gauged with optimal accuracy.

The technologies assessed in LAC are untested at scale and substantially more expensive than ongoing efforts to reduce CO2 emissions. However, positive effects for non-climate related SDG delivery beyond climate action are also likely. Achieving beneficial outcomes and avoiding social and environmental harm requires more research and policy-specific impact assessments that take local conditions into account.

Implmentation of large-scale CDR approaches assessed in this study would be expected to have physical side-effects and socio-economic or political implications eventually affecting the delivery of SDGs.

Physical side-effects in particular relate to: land-use alternative uses and food security; water quality and availability; health; energy; economic productivity; infrastructure needs; and biodiversity. Socio-economic or political implications include: economic and cultural impacts; opportunity costs; significant financial requirements; political consistency among sectors.

According to the assessment performed throughout the study, it is expected that in LAC countries large scale deployment of CDR approaches would affect the delivery of SDGs in the following manner:

- **Afforestation** could positively affect delivery of more than half of all SDGs (at least 10 out of 17 SDGs). The estimates identify potential direct positive impacts regarding delivery of SDG 8 (Decent work and economic growth), SDG 9 (Industry, innovation and infrastructure) and SDG 13 (Climate action) and potential indirect positive impacts regarding SDG 1 (No poverty), SDG 3 (Good health and well-being), SDG 4 (Quality education), SDG 5 (Gender equality), SDG 7 (Affordable and clean energy), SDG 12 (Responsible production and consumption) and SDG 15 (Life on land). On the other hand, there are a number of risks in particular those associated with the delivery of SDG 6 (Clean water and sanitation). Further risks are also identified for other SDGs including SDG 2 (Zero hunger), SDG 3 (Good health and well-being), and SDG 15 (Life on land).

- **BECCS** could positively affect delivery of more than one third of all SDGs (at least 7 out of 17 SDGs). The estimates identify potential direct positive impacts regarding delivery of SDG 7 (Affordable and clean energy), SDG 8 (Decent work and economic growth), SDG 9 (Industry, innovation and infrastructure) and SDG 13 (Climate action) and potential indirect positive impacts regarding SDG 3 (Good health and well- being), SDG 4 (Quality education) and SDG 11 (Sustainable cities and communities). On the other hand, there are some indirect risks in particular regarding delivery of SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 3 (Good health and well-being), SDG 4 (Quality education), SDG 6 Clean water and sanitation). SDG 13 (Climate action) and SDG 15 (Life on land).

- **Enhancing soil content** with biochar could positively affect the delivery of almost two thirds of all SDGs (at least 11 out of 17 SDGs). The estimates identify potential direct positive impacts regarding delivery of SDG 2 (Zero hunger), SDG 8 (Decent work and economic growth), SDG 9 (Industry, innovation and infrastructure), SDG 12 (Responsible production and consumption) and SDG 13 (Climate action) and potential indirect positive impacts regarding SDG 1 (No poverty), SDG 3 (Good health and well-being), SDG 4 (Quality education), SDG 6 Clean water and sanitation). SDG 7 (Affordable and clean energy), and SDG 15 (Life on land). On the other hand, there are some indirect risks in particular regarding delivery of SDG 13 (Climate action).

*Table 4: Potential Impacts on SDGs in LAC countries**

Afforestation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Direct positive								8	9				13				
Indirect positive	1		3	4	5		7	8				12			15		
Direct negative						6											
Indirect negative		2	3												15		

BECCS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Direct positive							7	8	9				13				
Indirect positive			3	4				8			11						
Direct negative																	
Indirect negative	1	2	3			6							13		15		

Enhancing soil	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Direct positive		2						8	9			12	13				
Indirect positive	1		3	4		6	7	8							15		
Direct negative																	
Indirect negative													13				

Source: Own elaboration

** This analysis on potential impacts of CDR deployment on SDGs is applicable for LAC countries in general and does not distinguish any particular country*

The above assessment of impact of large-scale deployment of CDR technologies in LAC towards the achievement of SDGs is based on the positive and negative impacts, constraints and risks of each CDR approach, as a result of the detailed analysis undertaken (Part II of the study) that is summarized in the following table:

*Table 5: Potential Constraints, impacts and risks of CDR approaches in LAC countries **

	Afforestation	BECCS	Biochar
Key constraints	• Land competition with other purposes (ex: crop planted area for food production) • Water and nutrients requirements • Lack of financing for long-term investments • Development of the value chain downstream: wood manufacturing and pulp and paper industry are CAPEX intensive activities	• Land availability/ competition • Biomass feedstock availability • CO2 storage availability (technical feasibility) and CO2 storage infrastructure investment (economic feasibility) • CO2 transportation infrastructure • Poor knowledge and development of CCS phase (and therefore related technological challenges)	• Availability of biomass for biochar production (competition with other uses of biomass) • Logistic constrains: Trade-off distance from raw material (biomass) vs distance to plantations where to be applied • Technological challenges for the development, construction and operation of biochar plants in Argentina • Lack of long-term financing alternatives for biochar plant CAPEX

Key positive impacts	• Proven and known technology / practices (for implantation and maintenance), and know how developed along the years in the country makes it feasible with higher probability than other undeveloped CDR approaches, that will be extended in the following years • Women are critical to ensuring the sustainability of forests and forestry (full contributions of women to forestry have not been realized yet) • Reduction of poverty levels due to job creation, economic development and health improvement • Economic development and growth • Direct and indirects jobs for forestry and wood extraction • Potential direct and indirect jobs in wood manufacturing and pulp and paper industries • Potential development of wood related industries: construction and furniture (value-added products and responsible production and consumption) • Affordable and clean energy provision taking advantage of forestry residues	• Clean energy supply that increases power autonomy and security in the energy supply • Direct and permanent jobs generated in BECCS plants operation. • Jobs created for BECCS plants constructions and Indirects jobs related • Health improvement related to clean energy and forestry requirements • Know how and technical capabilities to be developed • Potential development of related industries	• Enhanced soil properties and therefore increasing yields (responsible production and consumption). Potential increase in fruit tree yields (to be confirmed by further research), expanding food supply • Technological know how for the development, construction and operation of biochar plants • Long-term C sequestration in soil • Lower N2O and CH4 emmisions • Higher soil water balance • Potential expansion for biochar application on other crops beyond intensive crops as fruit trees (ex: vegetables, legumes and tubers) • Biochar pyrolysis is an exotermic process which can be utilized for power generation • Other valuable co-products including wood flavoring and adhesives can also be obtained as a byproduct of biochar (Czernik and Bridgwater, 2004) • Direct and permanent jobs generated in biochar plants operation. • Jobs created for biochar plants constructions. • Jobs created for biochar application in plantations. Indirects jobs related

Key negative impacts and risks	• Impacts on food supply and land tenure • Bioversity (depending on the species to be planted) • NOX emissions from nitrogen fertilizers • Changes in evapotranspiration, albedo and cloud cover • Water scarcity	• Supply chain and land-use change (LUC) emissions • Water scarcity • Soil depletion • Pollution due to fertiliser use • Risk of CO2 leaks during transportation and/or storage • Impacts on food supply and land tenure • In case of wood biomass, lost C sequestration of harvested forest • Impact on country's power generation cost curve (in case of large-scale adoption and significant share in the power generation matrix due to higher costs per MWh than other sources - ex: hydro-)	• Logistics costs and environmental impacts of raw material and biochar transportation • Lower albedo and radiative forcing

Source: Own elaboration

** This analysis on potential constraints, impacts and risks of CDR deployment is applicable for LAC countries in general and does not differentiate any particular country*

IV. Limitations of the analysis

The impact analysis faces certain challenges that might have effectslevel of confidence in terms of its accuracy and level of confidence:

- Large-scale CDR deployments are a novel field of research and project implementation in Argentina, Colombia and the other Latin America countries (and, to certain extent, globally).
- Despite some knowledge gained in the technical aspects of CDR approaches, the understanding of their large-scale deployment impacts in the economy and at the societal level is at least scarce; moreover, the quantification of the magnitude of those impacts is still largely incipient.
- In the case of DACCS and Ocean fertilization, the knowledge gap was deemed so significant that it was preferred not to model the potential impacts given the scarce basis of information available or its incipient condition.
- Impact analysis is estimated based on
    - historical statistics with their level of accuracy depending on data collection (not always on an annual basis) and levels of informality in the Argentine and Colombian economies
    - long-term scenario definitions that inherently present uncertainties
- Over the long-term, new breakthrough technologies not yet fully developed today would significantly impact scenarios conceived for this study.
- Investment and operating costs may see significant decreases, as each technology is massively deployed.
- Comparison between countries can be affected by differences in statistical bases.
- Accurate assessment of relative risk between different technologies is not yet possible, but should also be weighed against the risks that alternative options, including following current trajectories, would pose to successfully delivering the SDG.
- The relative level of potential effects identified may also be a function of the current extent or level of maturity of the literature available, plans and projects assessed throughout the report.
- There are large uncertainties resulting from knowledge gaps, from the complexity of the ecosystems involved and due to interactions between different combinations of options implemented.

Some CDR approaches covered in this study (like DACCS, Enhanced weathering, Ocean Alkalinization and Ocean Fertilization) were not examined in terms of deep-dive impact analysis due to lack of information for accurate modelling.

In the near term, large-scale demonstration of such CDR technologies will require targeted government support. In conclusion, the CDR potentials that can be realized are constrained by the lack or insufficiency of policy portfolios incentivising large-scale CDR (Peters and Geden, 2017), acknowledging that to elaborate those policies the rationale for these policies need to be clear and accepted. Near-term opportunities could be supported through modifying existing policy mechanisms (Lomax et al., 2015)

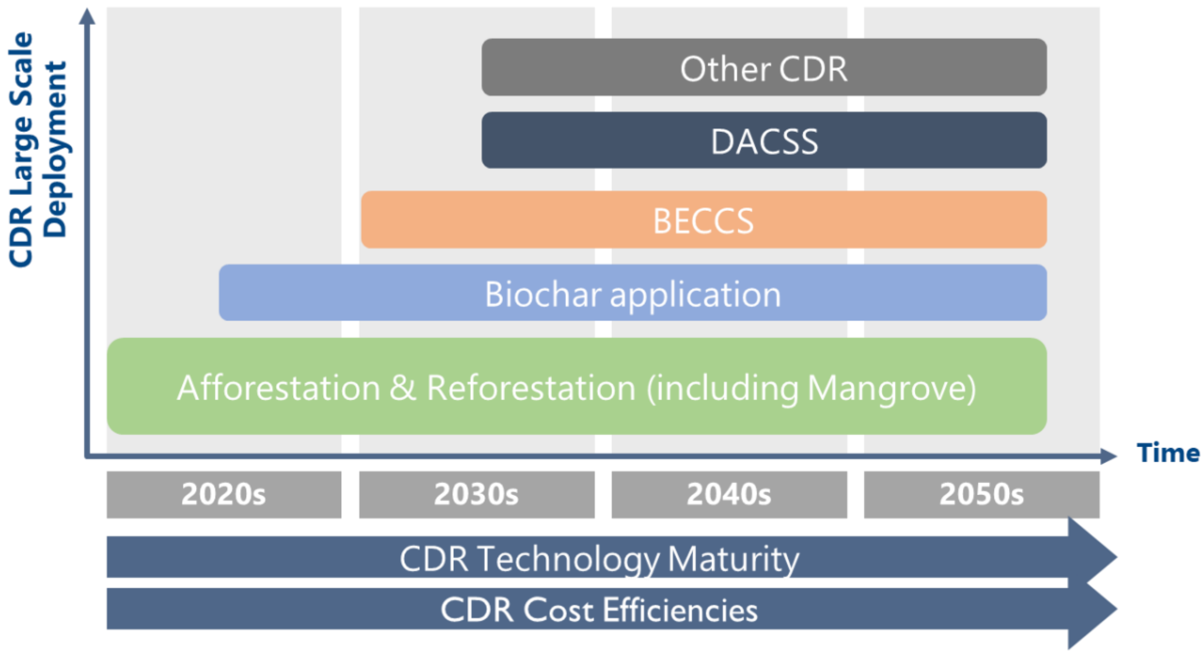
V. Recommendations

The following recommendations aim to enable better informed decision-making on the potential deployment of applicable large-scale CDR approaches in Latin America and the Caribbean.

- **Given the complexities and remaining uncertainties** associated with some of the CDR approaches analyzed, **progress is required at least in:**
    - elaboration of integrated assessment models at the national and sectoral level
    - cost-benefit analysis
    - risk analysis
    - intensification of ongoing scientific and technical research
    - multiple pilot projects
- LAC countries might face a persistent finance gap (accentuated by the pandemics). The decision on the potential CDR development would **require accurate abatement costs information and careful consideration and assessment of implementation risks.**
- Overall assessment of the **technical and economic feasibility of the CDR approaches** should be embedded in the framework to be provided by **long-term strategies elaborated by LAC countries, including next generation of NDCs.**
- **Collaborative platforms and programmes of work and a common requirement for additional international climate finance** to address the need for additional resources.
- The potential for **coalescing robust finance flows in the context of Article 6** might contribute to finance the required long-term transitions in LAC countries.
- **More transdisciplinary and geographically diverse research is required** on the linkages of large scale CDR deployment and the delivery of the Sustainable Development Goals, which may include development of common assessment principles or metrics.
- **Integrated policy impact assessments are needed** to understand potential policy designs to mobilize CDR and what implications they would have for delivery of the SDGs.
- **Afforestation and reforestation present the largest potential of carbon dioxide removal and the current lowest abatement cost in selected LAC countries and therefore should be prioritized in large-scale CDR deployment in the near and mid-term.**
- **Mangrove restoration also present a large carbon sequestration potential that could be achieved in the near and mid-term** in several countries: Brazil, Colombia, Venezuela, Ecuador, Surinam, Guyana, French Guiana and Peru.
- **Argentina and Colombia** are countries with intensive use of land for agriculture and relevant activities in this area; **further assessment might allow to improve knowledge on how CDR options reinforce synergies with existing efforts to mitigate climate change and enhance sustainable agricultural practices.**
- Eventhough a nascent field of research in LAC countries, **enhancing soils carbon content and technologies that include the use of biochar as a soil enhancer, as well as enhanced weathering, could be worth analyzing deeper in a site and activity-specific manner** in order to quantify its potential impacts and risks at the field level.

- There is a good basis of research and initiatives/projects on the bioenergy side of the BECCS equation, however there is no integral research on BECCS, per se. Incipient but rapidly increasing installed capacity of biomass and biogas power generation plants and biofuels production plants is being observed. Nonetheless, the focus is primarily on BE.
- **Biofuels applied to power generation in non-grid connected areas (distributed generation) could have a potential for BECCS development in LAC countries**, although relevant knowledge, stakeholder commitment and implementation efforts -identified at this point in time- are scarce.
- **Efforts on large-scale CDR deployment options in the short, medium and long terms should be prioritized according to maturity and costs efficiencies.**
- **Research and demonstration pilots (ex: DACCS, BECCS and other CDR approaches) should start well before the suggested large-scale deployment phase in order to achieve technology development and cost reduction. In the near term, large-scale demonstration of such CDR approaches will require targeted government support.**
- Latin American and Caribbean governments could **play an active role in the shaping, and guiding of the research, development and deployment of DACCS, BECCS and other CDR approaches, nationally, regionally and internationally**.

Figure 3: Suggested Phasing of CDR Large-Scale Deployment in LAC countries



Source: *Own elaboration*

We also suggest further research for particularly ambiguous consequences of the six CDR approaches deployment (assessed in the research, planning and implementation gap section):

- Afforestation and restoration
    - Updated forest inventory by province/department and by species
    - Analysis of potential impact on biodiversity arising from increased afforestation and restoration deployment
    - Analysis of potential impact on land use change arising from increased afforestation and restoration deployment
    - Analysis of water requirements arising from increased afforestation and restoration deployment
    - Long-term Wood Industrialization development plan for potential value-added realization from increased afforestation and restoration deployment
    - Innovation and Technology Transfer strategies and policies in biorefineries and nanotechnology topics
    - Promotion of wood construction and its impact on the traditional construction sector
    - International insertion of SMEs related to the wood and furniture value chain
    - Further analysis on bioenergy technologies for power generation from municipal solid waste (MSW), industrial and agriculture effluents, such as poultry and cattle residues
    - Gender equality in forestry chain employment
    - Schemes for long-term financing of afforestation/restoration projects
    - Quantification of effectiveness of incentives and tax-exemptions for development of afforestation/restoration projects
- BECCS
    - Analysis and prioritization of potential locations for new BECCS plants
    - Screening and analysis of relevant technologies and processes for BECCS plants
    - Determination of optimal scale of BECCS plants
    - Further analysis on externalities of bioenergy projects with dry biomass and biogas
    - Analysis of potential impact on land use change arising from large-scale BECCS deployment
    - Analysis of potential impact on biodiversity arising from large-scale BECCS deployment
    - Analysis of long-term impact in electricity prices resulting from changes in power generation matrix in scenarios of large-scale BECCS deployment
    - Plans and schemes for jobs retention from outplacement of thermal and coal plants
    - Risk assessment study and risk mitigation plan for large-scale BECCS deployment (particular focus on captured CO2 transportation and storage phases)

  - Analysis of materials and technologies preventing CO2 leaks
  - Schemes for long-term financing of BECCS projects
  - Quantification of effectiveness of incentives and tax-exemptions for development of BECCS projects
  - Innovative strategies for oriented bidding rounds for BECCS projects awarding
- Biochar
  - Analysis and prioritization of potential locations for biochar plants
  - Screening and Analysis of relevant technologies and process for biochar production
  - Determination of optimal scale of biochar plants and analysis on its modularization
  - Analysis and prioritization of potential areas for biochar application per crop and region (including both intensive and extensive crops)
  - Determination of optimal dose and composition of biochar pellets for each crop type and each region where to be applied
  - Analysis of logistics requirements and logistics costs of biochar deployment
  - Analysis of potential power generation from biochar plants (from exothermic pyrolysis process) and industrial micro grids
  - Procedures for safety production and handling of biochar
  - Procedures for correct biochar application on soil
  - Analysis of impact on employment and local communities related to biochar application on plantations
  - Analysis of impact on crops yields from biochar application by main crops and regions
  - Analysis of impact on soil nutrients, PH and other relevant soil properties from biochar application by main crops and regions
  - Analysis of other potential uses of biochar beyond agriculture (e.g remediation of effluents, remediation of contaminated soils etc)
  - Schemes for long-term financing of biochar projects
  - Quantification of effectiveness of incentives and tax-exemptions for development of biochar projects
- Enhanced weathering land
  - Analysis and prioritization of potential areas for enhanced weathering (land) application per crop and region (including both intensive and extensive crops)
  - Analysis of availability of silicate minerals for enhanced weathering deployment
  - Analysis of processes and technologies for mining, grinding and spreading rocks on a large-scale
  - Determination of optimal dose, composition and size of grains of powder of silicate minerals for each crop type and each region where to be applied
  - Analysis of logistics requirements and logistics costs of silicate minerals for deployment
  - Procedures for correct silicate minerals application on soil

- Analysis of impact on employment and local communities related to enhanced weathering on plantations
- Analysis of impact on crops yields from enhanced weathering by main crops and regions
- Analysis of impact on soil nutrients, PH and other relevant soil properties from enhanced weathering by main crops and regions
- Analysis of impact on fertilizers offset
- Schemes for long-term financing of enhanced weathering projects
- Quantification of effectiveness of incentives and tax-exemptions for development of enhanced weathering projects

⊃ DACCS

- Screening, analysis and prioritization of processes and technologies for DACCS facilities
- Determination of optimal scale of DACCS plants and analysis on feasibility of its modularization
- Techno-economic feasibility analysis of DACCS plants adapted to local country conditions
- Analysis of requirements, availability and supply chain of key materials (like sorbents) for large-scale DACCS deployment
- Technical research on optimal sorbent composition and properties
- Analysis of requirements and availability of energy (power) for large-scale DACCS deployment
- Analysis and prioritization of potential locations for DACCS plants
- Risk assessment study and risk mitigation plan for large-scale DACCS deployment (particular focus on captured CO2 transportation and storage phases)
- Analysis of materials and technologies preventing CO2 leaks
- Schemes for long-term financing of DACCS projects
- Quantification of effectiveness of incentives and tax-exemptions for development of DACCS projects

⊃ Ocean fertilization

- Analysis and prioritization of potential areas for Ocean fertilization
- Technical research on optimal silicate mineral composition and properties
- Assessment of impacts from increased mining industry value chain activity
- Determination of optimal silicate mineral dose per km2
- Analysis of logistics requirements and logistics costs for Ocean fertilization
- Analysis and selection of optimal techniques for adding fertilization to the ocean
- Quantification of carbon sequestration adapted to local conditions / selected ocean areas from large-scale Ocean fertilization deployment
- Impact assessment on marine ecosystem and risk mitigation plan (ex: possible biogeochemical side effects; seafloor ecosystems effects)

- Monitoring schemes of any large-scale fertilization activity
- Schemes for long-term financing of Ocean fertilization projects
- Quantification of effectiveness of incentives and tax-exemptions for development of Ocean fertilization projects

- Ocean alkalinization
  - Schemes for long-term financing of Ocean alkalinization projects
  - Analysis and prioritization of potential areas for Ocean alkalinization
  - Technical research on optimal alkaline substances composition and properties
  - Assessment of impacts from increased mining industry value chain activity
  - Determination of optimal alkaline substances dose per km2
  - Analysis of logistics requirements and logistics costs for Ocean alkalinization
  - Analysis and selection of optimal techniques for adding alkalinity to the ocean (ex: spreading finely ground alkaline substances over the open ocean, depositing alkaline sand or gravel on beaches or coastal seabeds, and reacting seawater with alkaline minerals inside specialized fuel cells before releasing it back into the ocean; others)
  - Quantification of carbon sequestration adapted to local conditions / selected ocean areas from large-scale Ocean alkalinization deployment
  - Explore feasibility of Co-production of hydrogen
  - Monitoring schemes of any large-scale alkalinization activity
  - Impact assessment on marine ecosystem and risk mitigation plan (ex: possible biogeochemical side effects; seafloor ecosystems effects; surface pH; trace heavy metals)
  - Schemes for long-term financing of Ocean alkalinization projects
  - Quantification of effectiveness of incentives and tax-exemptions for development of Ocean alkalinization projects

PART II – ANALYSIS

I. Current status of knowledge and development

This section aims to assess in detail the current status of knowledge and development for the six CDR approaches in Argentina and Colombia and succinctly identifies developments related to those same approaches in other Latin American and Caribbean countries.

For each selected country, there is an introduction of national commitments germane to climate change mitigation, according to the specifications contained in the Nationally Determined Contributions (NDCs) and pursuant to the sustainable development goals achievement, including the results described in each country's Voluntary National Reports.

For each CDR approach, the analysis is performed considering three main thematic axes to evaluate the degree of progress of the technologies in the countries under assessment:

- *Alignment with Government Vision and Commitment*: regulatory assessment, including ministerial resolutions, national plans, specific programmes, incentives, tax exemptions and any other policies and policy instruments that reflect government´s vision, commitment and priorities related to adoption of CDR approaches.
- *Degree of Scientific Development / Academic Literature Review*: Analysis of the most relevant research and academic documents related to the CDR approaches in the country, including a brief description of the purpose of the research, methodology, results, impacts and risks and conclusions (when applicable and / or available).
- *Initiatives and Development of Projects*: Identification and analysis of initiatives and projects adopting any of the CDR approaches in the country under study, with focus in large scale projects

The review of knowledge, planning and implementation gaps is undertaken with the ultimate aim of assessing the CDR technologies against the SDGs and contribute to enable the discussion on whether the CDR technologies can be instrumental to delivering the SDGs by 2030.

To that end, our own methodological approach was applied, building upon the C2G methodology [Honegger, et al 2018], and considering the three different dimensions to determine the current status of knowledge, adoption in planning and empirical application of the selected CDR approaches in the chosen countries.

1. Argentina

Argentina submitted its Nationally Determined Contribution (NDC), against which the country will report its progress under the UN Framework Convention on Climate Change (UNFCCC) and the Paris Agreement.

Argentina has presented its first Nationally Determined Contribution (NDC) in October 2015. As from the achievements reached during the twenty first session of the Conference of the Parties (COP 21), the Paris Agreement, the country decided to make a first effort of revision of its NDC, submitting the ratification document in September 2016.

According to the NDC, Argentina shall not exceed a net emission of 483 million tons of carbon dioxide equivalent (tCO2eq) by 2030. The goal shall be achieved through several means of implementation throughout the economy, focusing on energy, agriculture, forests, transport, industry and the waste sector. As a result of the NDC revision submitted in 2016, Argentina improved its contribution by planning unconditional mitigation measures that manage to lower their target from 570 to 483 million tCO2eq in 2030. The difference of 87 million tCO2eq- between the original contribution and the reviewed one results from two main aspects. Firstly, the change to the 2006 IPCC methodology allows for the improvement of the inventory quality by avoiding the overestimation of the agricultural emissions, giving a difference of 79 million tCO2eq. Secondly, the revision of more than 50 unconditional measures and the incorporation of new ambitious measures to the national contribution imply 8 million tCO2eq of additional reduction. Argentina has also calculated the impact of conditional measures, which if jointly implemented could bring emissions to 369 million tCO2eq by 2030.

The share of Argentina in GHG global emissions in 2014 was 0.7%, while Argentina’s reviewed mitigation contribution accounts for 2.8% over the total amount of unconditional reductions informed by the UNFCCC Parties, showing a strong commitment towards the emission reduction goal.

The Argentinean National Climate Change Cabinet (GNCC, for its Spanish acronym), created by Presidential Decree in 2016, is chaired and coordinated at a high political level by the head of the ministerial cabinet, and brings together representatives of approximately 12 ministries and government secretariats.

The National Adaptation and Climate Change Mitigation Plan was published and approved recently in November 2019, by the Resolution 447/2019 of the Secretariat of Government for the Environment and Sustainable Development. The Plan included at least three main mitigation measures related to the CDR approaches reviewed in this study:

- *Increase in afforestation:* Proposes a growth from 1.4 million forested hectares to 2.0 million hectares within a decade. This would reduce emissions by 18.1 million tons.

- *Crop rotation:* It points to an increase in the area cultivated with cereals (wheat, corn), and a reduction in the area occupied with oilseeds (soybeans, sunflower), starting in 2020. The estimate is that this would make it possible to cut emissions by 4.3 million tons.
- *Bioenergy:* The objective is to foster biomass for energy generation, both thermal and not connected to the grid. Emissions would be lowered by 3.4 million tons.

According to the Voluntary National Report (2020) on SDGs, “Argentina assumes the 2030 Agenda after a sustained commitment to the provisions of the Millennium Summit. In 2003, President Kirchner resumed the Millennium Development Goals (MDGs) as part of his government agenda, establishing the National Council for the Coordination of Social Policies (CNCPS) as a focal point, having participated since 2013 in dialogues and consultations on the post 2015 Agenda and the Sustainable Development Goals (SDGs). In September 2015, during Cristina Fernández's presidency, Argentina made a commitment to the 2030 Agenda. In December 2015, the Macri Government continued with the CNCPS as the governing and coordinating body.”

In 2016, Argentina formed the National Inter-institutional Commission for the Implementation and Follow-up of the SDGs, led by the CNCPS. The former, established a progress monitoring matrix, which includes indicators, public policies and budgetary investment linked to the SDG goals.

In 2020, the political, economic and social context differs from that of the presentation of the first National Voluntary Report. In 2017, Argentina had started a political cycle of neoliberal reinstatement. In December 2019, a new government assumed with focus on state leadership, and social justice, but in a scenario of social vulnerabilities and economic weaknesses conditioned by unsustainable external debt. The new government reaffirmed its adherence to the 2030 Agenda by focusing on the Argentina Against Hunger Program. To which was added the combat to the pandemic of COVID-19.

Argentina implemented early mandatory preventive social isolation measures to prevent the spread of COVID19; construction of 12 Modular Emergency Hospitals began and a special fund was created to acquire equipment and supplies from laboratories and hospitals. It provided support for workers and the real economy. In the post-pandemic world, Argentina must strengthen its productive apparatus and continue eliminating inherited and aggravated social inequalities by COVID-19. Getting Argentina back on its feet will require restoring priorities so that, starting with the inequities, it reaches everyone. Achieving the objectives set by the 2030 Agenda remains a challenge and a horizon for the country.

The following tables depict the scoring for each CDR approach and each of the assessment dimensions for Argentina, with its supportive summarized evidence for such scoring, based on the detailed review of the current status of knowledge, planning and implementation.

Table 6: Argentina - Current Status of Knowledge and Development -Scoring Methodology

CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
Afforestation and reforestation	*Scientific and Technical Knowledge*	●	• Fourteen pieces of knowledge identified that evaluate the impact of reforestation on fauna, soil nutrients and the ecosystem
	Mainstreaming in Government planning	●	• Extensive track record of legal frameworks related to forestry development and conservation (Laws 12,103/1934; 13,273/1947; 24,688/1996; 25,080/1998; 26,331/2017) • Relevant national plans identified: 2017's National Action Plan for Forests and Climate Change, 2018's National Plan for the Restoration of Native Forests (18,000 ha), and ForestAr 2030 plan (2 million ha) • Deforestation rate still at 150,000 ha per year levels (reduced from 600,000 ha per year)
	Implementation of initiatives and projects	●	• Ongoing large projects identified: Santo Domingo sustainability project (since 2007 seeks to capture 600,000 CO2 tons by 2020 in 3,400 ha), Las Yungas (REDD+ project 1.85 million-ton CO2 in 10 years in 62,000 ha) and 23 reforestation projects approved under the ForestAr 2030 plan, which will restore 1,720 hectares of native forests (and targets to increase to 20,000 ha by 2023) • Even though there are plans and programs in execution, the incentives and promotion actions (i.e. financing, subsidies) are insufficient for broader implementation

Bioenergy with carbon capture and storage (BECCS)	*Scientific and Technical Knowledge*		• Nine articles have been identified analysing the potential of biomass power generation in Argentina and feasibility of specific biofuels and biogas plants • Eight pieces of academic literature have been identified related to power generation from MSW and industrial / agriculture effluents in Argentina, assessing technology/process challenges, environmental impacts and economic feasibility • No academic article was identified approaching BECCS integrally in Argentina
	Mainstreaming in Government planning		• Committed to renewable energy and biofuels through legislation, incentives and national programs (Renovar, Probiomasa) including a minimum blend of 7% for biodiesel in diesel oil for power generation, • 2005's National Strategy for Urban Solid Waste Management (ENGIRSU) and 2016's PROBIOGAS program • There is no specific Government plan or program promoting BECCS as an integral CDR approach
	Implementation of initiatives and projects		• All identified projects are focused on BE, but none of them has reported a CCS phase, therefore there are no integral BECCS projects planned, under construction nor in operation in Argentina • Nearly 240 MW of installed capacity have been awarded among 69 biomass, biogas and biogas landfill projects in Renovar auctions • Small scale biogas projects are being developed (Renovar projects, CEAMSE project, RyVERI project and PROBIOGAS projects)
Enhancing soil carbon content with biochar	*Scientific and Technical Knowledge*		• Academic research on "biochar as soil enhancer" subject is still incipient in Argentina.
	Mainstreaming in Government planning		• No explicit mention to biochar as soil enhancer was identified in Argentinean policies and development plans. However, there are some incipient efforts to evaluate the direct effect of biochar on soil carbon.

	Implementation of initiatives and projects		• No specific initiatives or small / large-scale projects identified but some interest shown by private actors to migrate to biochar production.
Enhanced weathering or Ocean alkalinization	*Scientific and Technical Knowledge*		• Multiple scientific entities (including CONICET, Naval Hydrography Service, Argentine Institute of Oceanography, Institute of Marine and Coastal Research, Institute of Coastal Geology) and universities are actively conducting various investigations on oceans behaviour and characterization in Argentine waters. Most relevant academic literature cover the dynamics of CO_2 in South Atlantic seas and the effects of ocean acidification in the ocean ecosystems • However, no specific academic literature was identified related to Enhanced weathering or Ocean alkalinization
	Mainstreaming in Government planning		• Creation of the National System of Marine Protected • There are no specific national plans or programmes related to Enhanced weathering or Ocean alkalinization
	Implementation of initiatives and projects		• No specific initiatives or small / large-scale projects identified
Direct air carbon dioxide capture and storage	*Scientific and Technical Knowledge*		• No academic literature was identified related to DACCS • However, some articles were identified analysing the CO_2 capture properties of Li_4SiO_4 and CO_2 reactivity with Mg_2NiH_4, but with no specific mention to DACCS • A workshop on the DACCS topic was held by the National University of Cuyo in Mendoza, Argentina in October 2018
	Mainstreaming in Government planning		• No specific legislation, government plans / programmes nor academic literature was identified in Argentina
	Implementation of initiatives and projects		• In 2018 a DACCS project was announced in Mendoza province with technology from US-based company Global Thermostat and an estimated investment of 4 million dollars. However, as for October 2020, no progress has been reported

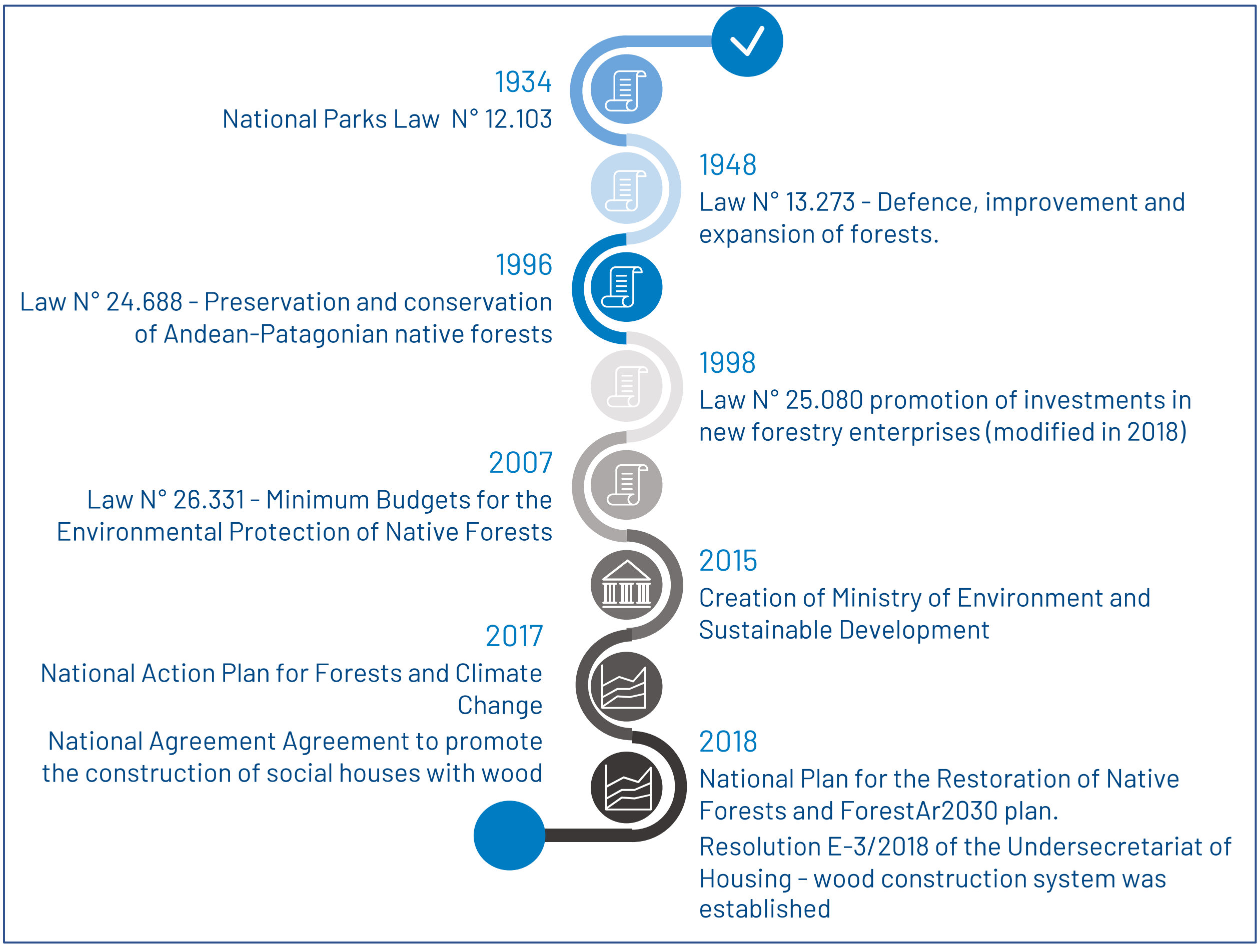
Ocean fertilization	*Scientific and Technical Knowledge*		• *Idem Ocean Alkalinization*. There are no specific national plans or programs related to ocean fertilization.
	Mainstreaming in Government planning		• *Idem Ocean Alkalinization*. Indirect academic research on oceans behaviour and characterization and CO2 dynamics, but no specific article on Ocean fertilization
	Implementation of initiatives and projects		• *Idem Ocean Alkalinization*. No specific initiatives or small / large-scale projects identified

Source: Own elaboration on the basis of review of information and rating

Afforestation and reforestation

The following figure summarizes in a timeline, regulations, plans and programmes related to afforestation and forest restoration CDR approaches implemented in Argentina, that are developed in a detailed manner in the following sections.

Figure 4: Afforestation and reforestation related regulations, plans and programmes implemented in Argentina - Timeline



Source: own elaboration

<u>Alignment with Government Vision and Commitment</u>

Argentina has an extensive track record of legal frameworks related to forestry, which shows its long-term commitment with afforestation and forest restoration.

National Parks Law (N° 12.103), sanctioned in 1934, created the Directorate of National Parks and created the Nahuel Huapi and Iguazu National Parks. This law seeks to ensure the attention and conservation of forests, and in general for the existing and future development of forest wealth in parks and reserves. Law N° 13.273, from 1948, fosters the defence, improvement and expansion of forests. It also created a fund for afforestation and reforestation, among other expenditures. In 1996 the Law N° 24.688 declared of national interest the preservation and conservation of Andean-Patagonian native forests and their reforestation with the same species.

In 1998, Law N° 25.080 was enacted, establishing a regime for the promotion of investments in new forestry enterprises and in the extensions of existing forests. In December 2018, the mentioned Law was modified, creating the National Fund for Cultivated Forests.

More recently, Law N° 26.331 of "Minimum Budgets for the Environmental Protection of Native Forests", or "Native Forest Law" was sanctioned in 2007, in order to regulate and manage native forests use. Its objectives are to reduce deforestation in Argentina, the conservation of native forests, the regulation and responsible management of forest use, and the promotion of sustainable forest management. The law determines categories of conservation of the forests, creates a trust fund for the conservation and promotion of forests responsible management under a model ecosystem services payment, and establishes enforcement authorities whose mandate is to prepare data to monitor the state of conservation of native forests, in coordination with the provinces.

The Ministry of Environment and Sustainable Development was created in year 2015, and is in charge of coordinating national government policies on environmental matters, establishing strategic planning of policies and programs. Is responsible of the promotion, dissemination, and development of activities to contribute in its scope, integrating with various state agencies, as well as compliance with the right to a healthy environment guaranteed by the Argentine Constitution. The Ministry is organized in secretariats: Secretariat of Environmental Control and Monitoring, Secretariat of Climate Change, Sustainable Development and Innovation, Secretariat of Environmental Policy in Natural Resources and Administration of National Parks.

With the aim of reinforcing the leadership position, proactivity and commitment to climate change, during 2017, the country began developing action plans on climate change to organize the implementation of the NDC. The most relevant national plans regarding afforestation and forests restoration are the following:

- 2017's National Action Plan for Forests and Climate Change,
- 2018's National Plan for the Restoration of Native Forests, and
- ForestAr2030 plan.

The **National Action Plan for Forests and Climate Change** is a public policy instrument and an operational management tool whose general objective is to reduce emissions and increase GHG capture in the sector, through the strengthening of the sustainable management of native forests. The Plan has been developed and prepared by the Ministry of the Environment and Sustainable Development (MAyDS) through the National Directorate of Climate Change (DNCC), in conjunction with the National Directorate of Forests (DNB), and with the support of the United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation (UNREDD) Argentina. Seven native forest areas are defined: Selva Misionera, Yungas (Tucumano-Bolivian jungle), Chaqueño Park, Andean Patagonian Forest, Espinal, Monte y Delta, and Islands of the Parana River.

Then National Action Plan comprises ten strategic axes, covered of five structural strategic axes: 1) governance strengthening, 2) strengthening of local communities, 3) management strengthening, 4) control and monitoring capacities, 5) recognition of the importance of native forests for society and knowledge management; and 5 strategic operational axes (actions that represent direct interventions on native forests and that, therefore, allow quantifying the reductions of GHG): 6) land use planning, 7) forests sustainable management, 8) productive landscapes conservation, 9) restoration and recovery and 10) forest fire prevention.

In particular, the restoration and recovery axes seek to promote the restoration of degraded forests and the recovery of deforested areas, through intervention actions coordinated with the different local actors, to reduce the vulnerability to climate change of local communities that depend on them and for the recovery of productive capacity and ecosystem services. The related mitigation measure, which accounts for the reduction of emissions (operational axes), is the restoration and recovery of native forests. For example, in the Parque Chaqueño region, the objectives are the restoration and / or forest recovery of 63,000 ha and recover the degraded forest structure in silvopastoral systems and / or restore degraded forests around cattle ranches. The recovery of degraded forests within a 5 km radius of a cattle ranch allows the capture of 0.005 MtCO2 eq / year, while the recovery of the forest structure to reach a MBGI system is equivalent to 0.00009 MtCO2eq / ha. It aims to restore degraded forests and areas without native forests.

The **National Plan for the Restoration of Native Forests** proposes a series of activities to directly and indirectly promote the restoration of degraded native forests and thus, simultaneously, undertake the recovery of biodiversity and in some cases the ecosystem productive capacity, and proceed to recapture carbon emissions caused by degradation processes. The Plan also proposes to develop a program for a first six-year period (2018-2023) in order to reach the goal of 18,000 hectares of restored native forest by 2023. It establishes six priority areas for restoration:

- Yungas and piedmont forest: Province of Jujuy, 2,734,437 ha.
- Yungas-Dry Chaco Corridor: Province of Salta, 6,175,698 ha.
- Sali-Dulce Basin: Provinces of Tucumán, Catamarca and Santiago del Estero, 2,922,289 ha.
- Monte y Espinal: Provinces of Mendoza, San Luis, Córdoba and La Pampa, 5,000,000 ha.
- Andean-Patagonian Forest: Provinces of Neuquén, Rio Negro, Chubut, Santa Cruz and Tierra del Fuego, 6,486,075 ha.
- Missionary Forest: Province of Misiones, 825,958 ha.

The **ForestAr 2030 plan** is a multisector platform that aims to conserve and expand the Argentine forest heritage and the activation of a forest economy that promotes social, economic and environmental development. Led by the Government Secretariat for the Environment and Sustainable Development, it is also promoted by the Ministry of Agriculture, Livestock and Fisheries and the Ministries of Production and Labour, Health and Social Development, Education, Culture and Science and Technology, with the collaboration of The Nature Conservancy Argentina (TNC). Private and non-governmental organizations also join this initiative. The plan is based on the ability of native and cultivated forests to provide natural solutions to mitigate climate change. The platform will facilitate Argentina's compliance with the national commitments undertaken under the Paris Agreement and with the Sustainable Development Goals of the 2030 Agenda, through the value chains linked to forests. The expected aim for 2030 is to increase the planted forest area to 2 million hectares; attract 7 million dollars in investments that will allow industrialization of different regions of the country; create 187 thousand quality jobs; value native forests by expanding sustainable management and recognition of the ecosystem services they provide to communities; increase the value added to the forestry-industrial chain relying on permanent policies of research, development and innovation; contribute to the adaptation and mitigation of climate change, contribute significantly to the fulfilment of the unconditional objective of the NDC not to exceed the net emissions of 483 MtCO2eq in 2030, through the reduction of emissions and increased HGH capture due to sustainable management of native forests, forestation and the entire associated value chain.

The plan has seven thematic axes: 1) Native Forests, 2) Forestation, 3) Pulp and Paper, 4) Wood and Furniture, 5) Wood Construction, 6) Thermal Energy, and 7) Innovation.

Within the Native Forests axis (1), the objectives for 2030 are to sustainably manage the native forests of Argentina, so that they become a source of development for the related communities, incorporating themselves in the productive value chains in a competitive way. Thus, their vulnerability to climate change and that of the communities that depend on the forest ecosystems will be reduced. Also pursues the reduction of deforestation and forest degradation by increasing the restoration and recovery of native forests (and with it associated GHG). Through a set of additional measures, a total reduction of 81 MtCO2 eq could be achieved by 2030. It Is expected to formalize employment correlated with forestry production with the socioeconomic benefits that this entails for the entire community. This axis is coordinated by the Government Secretariat for the Environment and Sustainable Development (SGAyDS) and The Nature Conservancy (TNC).

The Forestation axis (2) aims to increase forested area, providing forest bio economy value chains with competitive, environmentally sustainable and socially responsible goods, while also providing environmental services, in particular, in mitigation and adaptation to climate change. The goals are to increase the forested area up to 2 million hectares (50% growth) and to mitigate climate change. It is expected that 64,000 direct annual forest jobs will be created with investments over 150 million dollars annually in reforesting, management and protection (1,500 million dollars in 10 years).

ForestAr 2030 plan also covers the "Wood and Furniture" and "Wood Construction" axes. Wood furniture and wood construction are relevant as both value-added products and long-term carbon storage alternatives. The following figure summarizes the objectives, goals, impacts and critical factors of these two axes.

Figure 5: "Wood and Furniture" and "Wood Construction" axes of ForestAr 2030 plan

ForestAr 2030 Plan – Furniture and wood axis

Objective Transform the wood and furniture industry into a reliable supplier of competitive goods, environmentally sustainable and socially responsible for an industry with high added value, generator of quality employment, focused on both the domestic and international markets.

Goals

•Position Argentina among the world top 30 exporters of design furniture (currently ranked 74)

• Increase productivity index above 60%

•Increase labor formality to national average

Impact

•Employment: 100,000 direct and indirect jobs in the next 10 years (45,000 direct, 55,000 indirect based on estimates)

•Exports: USD 400 million in 2030

• Increase wood-demand by 2030 to 5 million of m3 (10 million m3 raw)

Critical factors

•Promote the quality improvement through technological updating, continuous process improvement, incorporation of design with a focus on both national and international markets in articulation with INTI and quality institutions

•Strengthen the export capabilities of wood block and furniture SMEs

•Expand business and labor formality

•Promote the productive reconversion of low productivity units through diversification to new products and markets

ForestAr Plan 2030 – Construction with wood axis

Objective Expand the wood construction industry to provide quality, reliable, safe and sustainable housing, commercial and institutional solutions, in line with the concept of smart construction and international standards

Goals

•Installed capacity to build 30,000 wood homes annually

• Technological capabilities to build between 5 to 10 tall buildings

• Technological capabilities to provide quick and quality solutions for the improvement of housing conditions in residential, commercial, industrial and institutional sectors

Critical Factors

•Governance: Continuity of the meetings of the Advisory Commission and Wood Construction Commission for monitoring the progress of the Strategic Plan

•Quality: Improve construction quality with implementation of voluntary wood structural labeling, mandatory technical regulation of market use for structural wood, updating of technical regulations

Impact

•Investment: 100 million USD on industrial wood-construction

•Employment: Creation of at least 12,000 direct jobs linked to wood construction

•SMEs: Improvement and creation of dozens of wood- related SMEs

•Export: although the relevant market will be internally, the scale of certain investments will increase exports

Source: ForestAr 2030 plan.

Also related to wood construction, the Government -through several of its Ministries- signed an Agreement in year 2017 to promote the construction of social houses with wood. The agreement, a 10 years term, was also signed by representatives of the construction and wood industry unions; real estate chambers, logging federations and banking associations. In addition, it establishes that at least 10% of social housing financed by the State through the Undersecretariat of Housing and Urban Development will be built with wood and also provides training in this type of construction to the provincial housing institutes.

Another relevant legislation was the Resolution E-3/2018 of the Undersecretariat of Housing, in which the wood construction system was established as traditional construction, and therefore the Certificate of Technical Aptitude (CAT) is no longer required for presentation in social housing plans.

Degree of Scientific Development / Academic Literature Review

An exhaustive search was undergone in order to identify scientific articles on the subject, Main relevant papers are summarized with their main findings:

- Ianni, E., et al. 2010. Applying the Ecosystem Approach to Select Priority Areas for Forest Landscape Restoration in the Yungas, Northwestern Argentina. Environmental Management 46, 748–760.

This paper proposes a method to select forest restoration priority areas consistently with the key principles of the Ecosystem Approach (EA) and the Forest Landscape Restoration (FLR) framework. This study represented the first attempt to apply EA principles to forest restoration at landscape scale in the Yungas region. The benefits obtained by the application of the method were twofold: on one hand, researchers and local actors were forced to conceive the Yungas as a complex net of rights rather than as a sum of personal interests. On the other hand, the participatory multicriteria approach provided a structured process for collective decision-making in an area where it has never been implemented.

- Falasca S. et al. 2011. Forestations with paradise (Melia Azedarach L.) as a mitigating climate change species in Argentina. III International Congress on climate change and sustainable development. CONICET.

The objective of the work was to zoning the Argentine agroclimatic aptitude, in order to reforest degraded areas and contribute to carbon sequestration and obtaining oil (biodiesel and bioinsecticide). Since its potential as an invasive weed was proven, it is not recommended afforestation in the traditional agriculture zone, unless it is land to be restored. Under humid climate conditions, afforestation is recommended in those lands that need restoration (perennial species), as cultural work is reduced and contributes to soil improvement, and at the same time produces industrial oil for biodiesel and / or bioinsecticid.

- Falasca S. et al. 2011. The introduction of the cultivation of oil carob (Pngamia pinnata) promising species to deal with climate change. III International Congress on climate change and sustainable development. CONICET.

The species Pongamia pinnata, known as oil carob, a legume native which can sequester 2-3 t CO_2 / ha in 2 years life. By virtue of the aforementioned qualities and its resistance to drought, it is emerging as an alternative crop for Argentina, which could even replace soybeans as a biodiesel input in some sectors of the country. The objective of this work was to delimit the area suitable for the cultivation of this species, emphasizing marginal lands. The superposition of the layers containing information on the spatial variability of the agroclimatic indices allowed to obtain the agroclimatic aptitude map for its possible introduction in the country.

- Lopez Lauenstein D. et al. 2012. Differences in drought responses of seedlings of Prosopis chilensis, P. flexuosa and interspecific hybrids: implications for reforestation in arid zones. Ecología Austral 22:43-52.

The objectives of this study were (1) to determine the differential response in growth and survival of seedlings of P. flexuosa, P. chilensis and interspecific hybrids under controlled water stress conditions, and (2) to determine the influence of an imposed treatment of drought hardening in the greenhouse on the plant's performance in the field. In controlled water stress conditions, P. flexuosa showed less growth under control treatment (no stress), however under stress treatment was the least affected by water strain. By contrast, P. chilensis was the most susceptible to drought stress, response that could be enhanced by hardening treatment before planting. The hybrid was similar to P. chilensis (under stress treatment and control treatment), but showed grate survival rate, similar to P. flexuosa. Both P. chilensis and hybrids showed a positive effect of hardening, but in P. flexuosa only this effect was observed at the driest site.

- Berthrong, S T et al. "Soil C and N changes with afforestation of grasslands across gradients of precipitation and plantation age"; Ecological Applications 22(1), 2012.

The purpose of this study was to test how labile and bulk pools of soil organic carbon (SOC) and total soil nitrogen (TN) is modified with afforestation across a rainfall gradient of 600–1500 mm in the Rio de la Plata grasslands of Argentina and Uruguay. The sites were all former grasslands implanted with Eucalyptus spp. Overall, it found that afforestation increased (up to 1012 kg Cha1yr1) or decreased (as much as 1294 kg Cha1yr1) SOC pools in this region and that these changes were significantly related to mean annual precipitation (MAP). Drier sites gained, and wetter sites lost, SOC and TN (r21/40.59, P1/40.003; and r2 1/40.57, P1/40.004, respectively). Labile C and N in microbial biomass and extractable soil pools followed similar patterns to bulk SOC and TN. Interestingly, drier sites gained more SOC and TN as vegetation species aged, while losses reversed as vegetation species aged in wet sites, suggesting that, in addition to precipitation, the age of trees is a critical driver of changes in soil organic matter with afforestation. This new evidence implies that longer intervals between harvests for plantations could improve SOC storage, ameliorating the negative trends found in humid sites. The results suggest that the value of afforestation as a carbon sequestration tool should be considered in the context of precipitation and age of the forest.

- Garay Schiebelbein, M M. "Carbon sequestering and vertical pattern of chemical properties in forested molisols with Pinus radiata"; Doctoral thesis in Agronomy, Universidad Nacional del Sur, 2015.

Afforestation on grassland lands could significantly alter the properties of soils, degrading them. The objective of the work was to explain the magnitude of the modifications occurred in the soil as a result of the replacement of natural vegetation by conifers, and evaluate both the CO_2 sequestration capacity and the potential risk of environmental pollution derived from the implementation of this practice in the Ventania area (Province of Buenos Aires). Treatments included six mature Pinus radiata (TB) stands and adjacent areas with natural vegetation (baseline; TP). The study concluded that the change in land use created conflicting environmental effects, incompatible with the principles of sustainability. The adoption of a recommended practice to reduce the concentration of atmospheric CO_2, through afforestation, showed high efficiency for this purpose. However, afforestation with P. radiata in grassland lands drastically affected the quality of the soils and even generated a potential risk of pollution of biological origin capable of transcending the limits of the stands.

- Barrionuevo S. A. et al. 2015. Estimating the CO_2 fixed by a stand of Pinus halepensis (Miller) in Santiago del Estero, Argentina. Foresta Veracruzana 17(1):27-32.

In this paper the importance of forest plantations as alternatives for mitigation is introduced. The CO_2 fixed by the aerial biomass of an approximately forty-year old stand of Pinus halepensis was estimated. Extracting methods in situ together with allometric equations allowed to determine that the stand fixed 5 tons of CO_2 per ha.

- Arzuaga S. A. 2016. Carbon and Nitrogen stocks and stratification ratios in oxisols under forest systems. Ciencia y Suelo (ARGENTINA) 34(1): 13-20.

The objective of this study was to assess the effect of deforestation and subsequent conifer reforestation on carbon stocks and nitrogen stock, and their stratification ratios in Oxisols. Lower values for soil organic carbon and total nitrogen content, as well as their respective stock decline, were indicative of soil degradation in the pine plantation. The carbon stratification ratios were higher in the subtropical rainforest (>2) which indicated enhanced soil quality. Carbon accumulation rate in the forest soil was - 0.86 Mg C ha^{-1} $year^{-1}$, which revealed soil carbon loss. Removal of the subtropical rainforest and subsequent conifer reforestation reduced SC and SN by 28% and 51%, respectively

- De Paz, M et al. "Review of revegetation experiences for the purpose of restoration in forests of Argentina"; Ecología Austral, 29:194-207; August 2019.

A bibliographic review was carried out in order to ascertain the current status of revegetation interventions for restoration purposes and the most used techniques in the different forests of Argentina´s ecoregions. It was concluded that of 137 projects, which cover the period 1957-2015, little published information is recorded (50% of the experiences). At the regional level, the largest intervened area was in the Dry Chaco, the Andean-Patagonian Forest and the Jungle. The most used source of financing was the State (83%), followed by NGOs (12.1%), private (9.6%) and, lastly, international funds (7%). Most of the revegetation experiences were carried out through planting native species (89.9%) and with closures against herbivores (50%). The two techniques that generated a positive effect on the survival of the seedlings were the use of irrigation and exclosures against herbivores.

- Araujo, P I et al, "A shady business: pine afforestation alters the primary controls on litter decomposition along a precipitation gradient in Patagonia". Argentina Journal of Ecology, 103, 1408–1420, 2015.

Researchers concluded that concurrent changes in plant cover in natural vegetation NV with increasing mean annual precipitation (MAP) resulted in reduced incident solar radiation at the soil surface and decreased the relative importance of photodegradation as a control on surface mass loss. These changes eclipsed direct effects of water availability, litter quality and soil nutrients. In contrast, increased shade and recalcitrant litter with afforestation in PP sites combined such that photodegradation was entirely eliminated as a control and biotic decomposition was much reduced. While afforestation projects are promoted as a strategy to mitigate increased atmospheric carbon dioxide due to human activity, the results highlight that primary controls of litter decomposition were substantially altered with unexpected consequences for the C balance of these ecosystems.

- Hess, L J T et al. "Pine afforestation alters rhizosphere effects and soil nutrient turnover across a precipitation gradient in Patagonia, Argentina"; Springer International Publishing Switzerland 2017.

Researchers investigated the effects of exotic planting of Pinus ponderosa on Carbon (C) and Nitrogen (N) cycling in the rhizosphere along a precipitation gradient in Patagonia, Argentina. They measured C mineralization, microbial biomass-C, and soil enzyme activity in rhizosphere and bulk soil collected from pine plantations and native vegetation. Rhizosphere effects were calculated as the percent difference between paired rhizosphere and bulk soil samples. In afforested sites, they found enhanced rhizosphere effects for C mineralization and microbial biomass relative to native vegetation, but not for enzymatic activity. The absolute values of all evaluated variables were significantly reduced in pine plantations compared to native vegetation. We also observed strong correlations between enzymatic activity, and soil organic matter and microbial biomass. For both pine and native trees species, rhizosphere effects for N-degrading enzymes were positively correlated with precipitation. They concluded that Pine afforestation reduced overall N turn over and microbial activity in these ecosystems. Data suggest that these reductions may be driven by reductions in soil organic C pools. Additionally, ecosystem water availability may directly or indirectly regulate the magnitude of rhizosphere effects on N cycling independent of plant species. The negative impacts of afforestation on N cycling should be considered in evaluating the long-term potential for C sequestration in these human modified ecosystems.

- Sione S M, et al. "Carbon fraction in the biomass of Prosopis Affinis sprengel (fabaceae) in a native espinal forest Argentina". Rev. Facultad de Agronomía UBA, 39 (1): 6-15, 2019

The aim of this study was to determine the C fraction in the biomass components of the ñandubay tree (Prosopis affinis), and its variation by diameter class, in a native forest of Espinal (Entre Ríos, Argentina). The results obtained provide precision to the estimation of C and CO2 emissions stored from deforestation and degradation of the Espinal native forests. The C fraction was analysed in the components of the above-ground biomass (trunks, T; large branches, LB; and small branches+leaves+flowers+fruits, SBLFF), on 30 types of five different diameter classes. The mean value of the C fraction was 0.474 ± 0,023. Considering the biomass partitioned by component, and the C fraction of each, the weighted average C fraction was 0,472 ± 0,013. The C fraction of T showed significant statistical differences ($p<0,05$) between diameter classes; the highest values were found in individuals with trunk diameters larger than 20 cm. The values obtained in this study are lower than the default value suggested by the Intergovernmental Panel on Climate Change (IPCC) (0,50).

- Marquez, J A et al. "Stream macroinvertebrate communities change with grassland afforestation in central Argentina"; Limnologica 53, 17-25, 2015.

The aim of this study was to analyse the effect of pine plantations on benthic invertebrate communities in mountain grassland streams. Additionally, researchers assessed if the hydrological period modifies the effect of afforestation on stream invertebrates. Changes in light intensity, hydrology and coarse organic matter inputs produced by afforestation alter fluvial habitats and consequently the composition and trophic structure of invertebrate communities in grassland streams of Córdoba mountains. Three headwater streams draining grasslands (reference streams) and three draining plantations of Pinus elliottii were selected in a mountain watershed of Córdoba province. Hydrologic and physicochemical variables were registered and benthic invertebrate samples were collected in each stream at two different hydrological periods. Total invertebrate abundance, richness and diversity were reduced in afforested streams as well as the number of indicator taxa. In addition, invertebrate functional structure (i.e. taxonomic richness and total and relative abundance of functional feeding groups, FFG) showed differences between streams with different riparian vegetation and between hydrological periods. Total abundance of all FFGs was lower in afforested streams and scrapers' relative abundance was higher in grassland streams at the low water period. In addition, in most FFGs richness was diminished in afforested streams.

- Vargas G. G. 2020. Effects of reforestation with species from genus Prosopis in the biodiversity of Epigeal arthropods: Comparison of environments with different conditions natural and anthropic recovery for the Monte Central, Mendoza. Thesis to qualify for the degree of Resource Engineer Natural Renewable. Faculty of Agricultural Sciences, Universidad Nacional de Cuyo.

The objective of this Thesis was to determine if reforestation with specimens Arboreal Prosopis, influences the diversity and composition of arthropods that live on the ground locally, under the canopy and intercanopy and on a regional scale comparing it with other communities present in the ecoregion, among them Larrea divaricata, fields that have been burned and Prosopis forests preserved. The results suggest that the reestablishment of environments by reforestation with Prosopis flexuosa and Prosopis chilensis plays an important role in the composition or structuring of soil-dwelling arthropod communities, although the same results have not been obtained for the numerical variables of biodiversity.

Another relevant articles from earlier than the recent ten-year period defined are the following:

- Nuñez, M A et al. "Afforestation causes changes in post-fire regeneration in native shrubland communities of north-western Patagonia, Argentina". Journal of Vegetation Science 18: 827-834, 2007.

The article surveyed four sites in Chall–Huaco valley, located in northwest Patagonia. Each site was a vegetation mosaic composed of an unburned Pinus ponderosa plantation, a plantation burned in 1996, and an unburned matorral and a matorral burned by the same fire. This study shows that plantations of exotic conifers affect native vegetation even after they have been removed, as in this case by fire. The cover of all vascular plant species was recorded. Researchers found that fire had different effects on native matorral and pine plantations. Five years after fire, plantations came to be dominated by herbs and exotic species, showing differences in floristic composition. In contrast, matorral communities remained very similar to unburned matorral in terms of species richness, proportion of woody species, and herb species and proportion of exotics. Also, pine plantations were primarily colonized by seedlings, while matorrals were primarily colonized by re-sprouting. In conclusion matorrals are highly fire resilient communities, and the practice of establishing plantations on matorrals produces a strong reduction in the capacity of matorral to return to its original state. The elimination of shrubs owing to the effect of plantations can hinder regeneration of native ecosystems. Burned plantations may slowly develop into ecosystems similar to the native ones, or they may produce a new ecosystem dominated by exotic herbs.

Initiatives and Projects Development

In Argentina, numerous projects are being conducted, some of them are developed by the government and others by non-governmental organizations and private funds.

Since 2007, Novartis Argentina in association with GMF Latin America has carried out the "**Santo Domingo**" sustainability project. With an initial investment of 16 million dollars, it is a unique project due to its triple economic, social and environmental impact. It is located on a 3,400-hectare property located in Ituzaingó, Corrientes province, 24% of that surface is covered by reserves of native forests, grasslands, riparian corridors and natural water springs. Since 2007, more than 3.5 million trees of 20 different species have been planted. As part of its initial objectives, it seeks to capture 600 thousand tons of carbon by 2020 and four billion tons by 2040. Regarding the socioeconomic impact, the benefits are observed in local communities, since it generates, indirectly, the creation of employment. This project in terms of sustainability is positioned as a sustainable development plan in accordance with the objectives established by the United Nations Global Compact.

Another project, carried out by Latin American GMF, targets the reduction of emissions resulting from deforestation and forest degradation in the native forest of **Las Yungas** in north-western Argentina. With an investment of 8.3 million dollars, it comprises an area of 62,000 hectares in the provinces of Jujuy and Salta. With an expected duration of 20 years, an initial investment phase of 10 years, it seeks to mitigate 1.85M tn CO_2 in 10 years (3.3 tn CO_2 / ha / year). In terms of the Sustainable Development Goals of the United Nations, this project seeks to meet at least 10 of the 17 goals: life and land, climate action, responsible consumption and production, clean water and sanitation, no poverty, gender equality, decent work and economic growth, partnerships for de goals, reduced inequalities and sustainable cities and communities.

Tree nation is carrying out a reforestation project in the Yungas jungle in the province of Tucuman. This project started in 2002, with an environmental and social strategy. The aim was to conserve and restore the forest in order to recover the richness of the ecosystem. Since the beginning of the project they have planted approximately 100 000 trees of which 70 000 are concentrated in an area of 300 hectares. The aims of the project are: recover the upper layer of the forest, improving the quality of the ecosystem services, enhance the value of the native forest; quantify and maximize the carbon sequestration of the native forest; identify the richness of the present biodiversity, in particular of endemic and endangered species; involve the local community promoting social development.

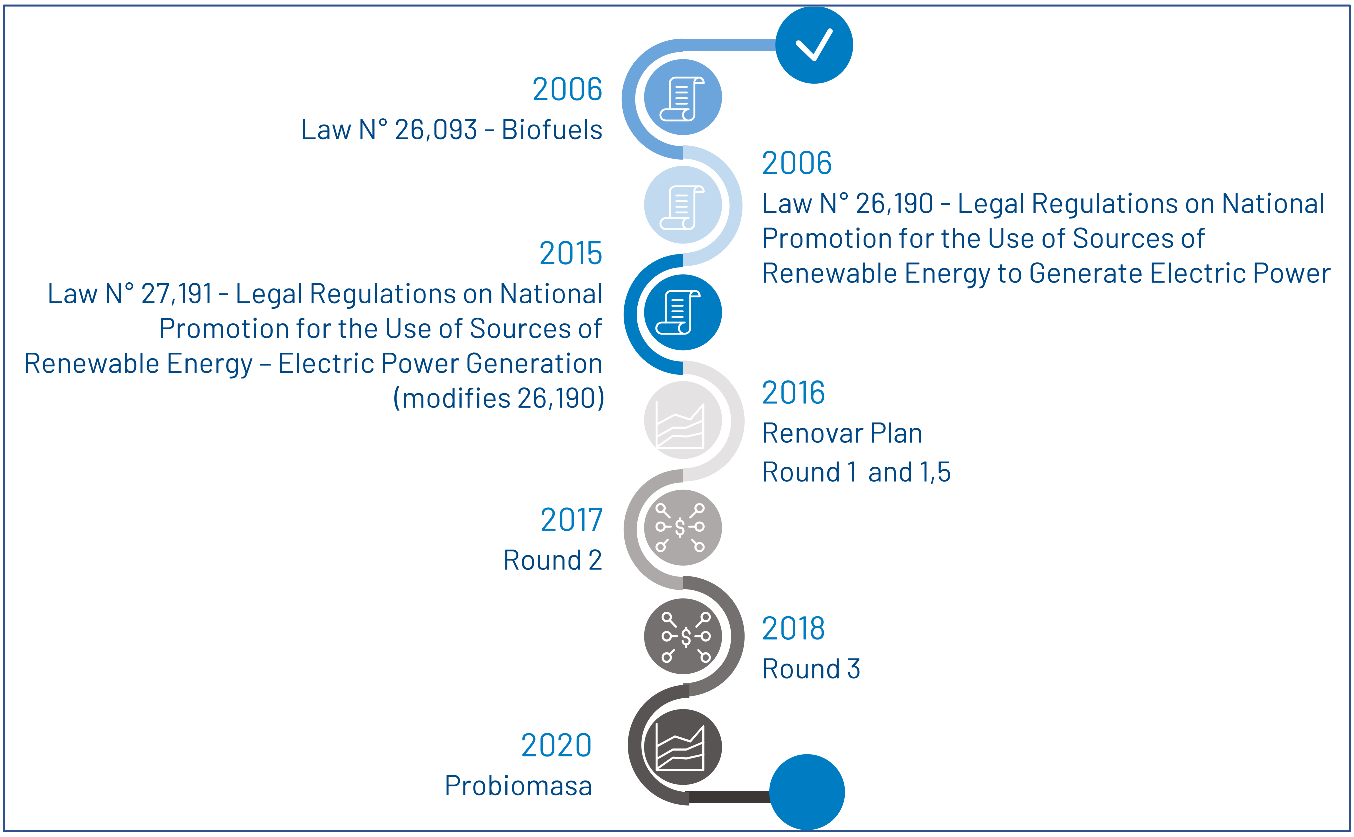
Under the umbrella of ForestAr 2030 plan, 23 reforestation projects were approved, which will handle 1,720 hectares of native forests in northern and southern parts of the country, as part of the plan to recover 20 thousand hectares up to the year 2023. The winners of the 23 projects were located in three places: the Salí Dulce Basin (Tucumán, Catamarca, Santiago del Estero), Monte and Espinal (Mendoza and San Luis) and Andean Forest Patagonian (Neuquén, Río Negro, Chubut, Santa Cruz, Tierra del Fuego), which are added to the eight experiences of restoration that are in force in Chaco, Jujuy, Mendoza, Misiones, San Luis, Santiago del Estero, Buenos Aires and Chubut. The initiative, which estimates to create 5 thousand jobs in the coming years, has an investment over 30 million Argentinean pesos from the Program National Forest of Native Forests, managed together with the United Nations Program for the Development (UNDP). What follows is a new call, for the second half of the year, destined to the Northwest and Northeast of the country.

Regarding the wood construction based on sustainable managed forests, in June 2019, a new industrialized wooden-housing factory was inaugurated in the Posadas Industrial Park. It was materialized through the creation of a partnership between seven SMEs nucleated under the Association of Forest Producers and Industries of Misiones and NE of Corrientes (APICOFOM) with a 10 million dollars investment. The factory is equipped with German technology by the technological provider Weinmann, and will be capable of producing up to 8,000 houses annually, increasing the total national capacity of industrialized wood-housing from 3,000/4,000 to 12,000 houses per year.

Bioenergy with carbon capture and storage (BECCS)

The following figure summarizes in a timeline, regulations, plans and programmes related to BECCS CDR approaches implemented in Argentina, that are developed in a detailed manner in the following sections.

Figure 6: BECCS related regulations, plans and programmes implemented in Argentina - Timeline



Source: own elaboration

Alignment with Government Vision and Commitment

The country has set a legal framework that regulates and promotes bioenergy as a renewable energy source according to the following laws and programmes.

The biofuels Law N° 26,093 passed in 2006, states that biofuels are bioethanol, biodiesel and biogas, which are produced from raw materials of agricultural, agro-industrial or organic waste origin, and determines that quality requirements will be established by the enforcement authority. The law aims to promote and control sustainable production and use of biofuels, as it establishes the requirements and conditions necessary for the authorization of the biofuel production and mixing plants and the requirements and selection criteria for the presentation of projects.

In 2006, the Law N° 26,190 "Legal Regulations on National Promotion for the Use of Sources of Renewable Energy to Generate Electric Power" was sanctioned. It declared of public interest the generation of electric power from renewable energy sources, in order to supply the electricity public service and to conduct research, develop technology and manufacture equipment. Established sources of renewable energy are non-fossil sources of renewable energy suitable to be used in a sustainable way in the short-, medium- and long- term: wind energy, solar thermal energy, solar photovoltaic energy, geothermic energy, tidal energy, energy from ocean currents, hydraulic energy, biomass, landfill gas, treatment plant gas, biogas and biofuels.

In 2015, the previous law was modified by Law N° 27,191 "Legal Regulations on National Promotion for the Use of Sources of Renewable Energy – Electric Power Generation". Established the creation of the Trust Fund for the Development of Renewable Energies (FODER). Promoted incentives and benefits for those who generate energy from renewable sources. Sets a goal to reach a contribution of renewable energy sources equal to 20 % of total national consumption of electric power by end of 2025.

In 2016 the Renovar plan was launched. The objective of the RenovAr program is to reach 10,000 MW by 2025. The Program is designed to achieve several objectives simultaneously: assign contracts in a transparent and competitive way; minimize the long-term cost to be paid by consumers; respect the legal mandate of technological and geographic diversification; and, establish incentives for the development of the national industry of renewable generation equipment. It is carried out through periodic public tenders. There have been 3 award rounds.

- Round 1: 29 projects with 1,142 MW total capacity were awarded (mainly solar and wind power projects), out of which 15 MW correspond to biomass and 9 MW to biogas. The reduction of CO_2 emissions is expected to reach 2 million tons CO_2 / year.
- Round 1.5: 30 projects with 1,281 MW total capacity were awarded (mainly solar and wind power projects). There were no projects awarded related to biomass or biogas.

- Round 2: 88 projects with 2,043 MW total capacity were awarded (mainly solar and wind power projects), out of which 143 MW to biomass, 56 MW to biogas and 13 MW to landfill biogas.
- Round 3: 38 projects with 259 MW total capacity were awarded (mainly solar and wind power projects), out of which 8.5 for biomass, 13 MW for biogas, 5 MW biogas from landfill.

The Ministry of Agriculture has a program called Probiomasa to encourage energy production with biogas and biomass through renewable energy tenders. This program ended in June 2020 but discussions are ongoing for an extension that would focus on agricultural and agro industrial waste. Its objectives are to convert a total of 1,889,153 tons of waste per year (estimated in 2016), reaching a total of 12,515,637 tons of waste by 2030, into useful by-products for power generation; mobilize investments, estimated at 3,216 million to install 200 electric MW and 200 thermal MW in 2016 and approximately 25.7 billion pesos to install 1,325 electric MW and 1,325 thermal MW in 2030. The estimated emission reductions would reach: 1.2 million tCO2e / year in 2016 and 8.3 million tCO2e / year in 2030.

In conclusion, there are some regulatory precedents to mandating fuel and energy resources that have resulted in current and planned installed capacity of thermoelectric generation from bioenergy sources that could include CCS in the future. Although not focused on CCUS —as in the case of other government programmes referred in this document— PROBIOMASA serves both as a regulatory precedent to be considered for future regulations potentially promoting BECCS. The programme is also relevant as one of the initiatives that catalysed the addition of Bioenergy-powered generation both on-grid and off-grid in Argentina. Additionally, PROBIOMASA results serve as a basis for bioenergy power generation potential assessment for the scenarios to be included in next phases, and thus, for the appraisal of BECCS potential.

Degree of Scientific Development / Academic Literature Review

The research performed shows that the academic activity in Argentina only covers the BioEnergy (BE) part of BECCS and that no integral BECCS literature was identified.

The most relevant academic literature identified and reviewed related to Bioenergy in Argentina is summarized in this section.

- Pieragostini, C. "Optimal design and planning of bioethanol production from corn in Argentina including life cycle analysis ". Doctor on Chemical Technology thesis. Universidad Nacional del Litoral, Faculty of Chemical Engineering. 2014.

The life cycle analysis of bioethanol production was carried out from corn. Three technologies for ethanol production were evaluated: conventional (T1), with electricity (T2) and natural gas obtained from the network (T3), a cogeneration system powered by natural gas and corn stubble. The last two technologies practically did not require electricity from the grid but instead sell the excess to the grid. From the comparison between the production technologies considered, T3 technology, which includes cogeneration with stubble, has energy advantages compared to the other two, even without considering the by-product generated. In contrast, T2 technology, which includes natural gas cogeneration has a more unfavourable energy balance or equal to the T1 conventional technology.

- Manrique S. et al. "Agricultura; crops and their role as reservoirs of carbon and energy sources". Avances en Energías Renovables y Medio Ambiente; Vol. 16, 2012.

The objective of this work was to analyse the mitigation potential of agricultural residual biomass generated from main productions of the municipality of Coronel Moldes, province of Salta (chili, Criollo tobacco and Virginia tobacco). Two general mitigation strategies were considered: i) as a carbon reservoir (C) and ii) as a renewable energy source neutral in C emissions, which would partially replace the fossil fuels used. The use biomass would avoid around 500 tCO2/ year with economic and environmental benefits.

- Chalco Vera, J. E. "Greenhouse gas emissions in sugar cane in Tucumán, Argentina: incidence of the burning of the stubble and nitrogen fertilization". Doctoral thesis Biological Sciences, Faculty of Agronomy and Zootechnics Universidad Nacional de Tucuman. 2018.

This study quantified GHG emissions from green-cane harvested sugarcane with and without post-harvest burning in Tucumán (Argentina). Treatments were: (a) harvest without sugarcane burning (neither before nor after), and (b) harvest with trash burnt after harvest. There were significant emission rates of CO2 and N2O during the sugarcane cycle in Tucumán, but no evidence of CH4 emissions or uptakes. N2O and CO2 emission rates were higher in the no-burning treatment than in the burnt option, but only partially of the crop cycle. The former is apparently associated with the application of nitrogen fertiliser, while the higher CO2 emissions seem to be associated with trash retention. There were no significant correlations between environmental factors and emission rates. Although these results seem pessimistic, in the context of an entire crop GHG balance (including the emissions due to burning before or after harvest) green-cane harvesting without burning could effectively lead to a reduction of total GHG emissions during the crop cycle.

- Manrique, S. et al. "Native Forests: Bioenergy or Carbon Sequestering?". Avances en energias renovables y medio ambiente, Vol 16. 2012

The objective of this research was to analyse the alternative uses of native forests of the municipality of Coronel Moldes, La Viña department, Salta province, in order to maximize GHG mitigation considering two main strategies: i) their potential as carbon reservoirs and ii) their potential as a renewable fuel source. Despite seeming two contradictory proposals, the present work concludes that both can be adequately combined, allowing to obtain concrete results in

GHG mitigation, and also achieve extra benefits in the provision of goods and services generated by forests from their natural ecosystem functions.

- S. Montico. Bioenergy production capacity in the province of Santa Fe, Argentina. Cien. Inv. Agr. 36(32):465-474. 2009.

The objective of this work was to value the capacity of this province for bioenergy production from grains transformation into biofuels and the biomass energy from crop straw, and considers the impact on soils from removed crop residues. Crop residues of the ten most important grain and oilseed crops (15.2x106 Mg year-1) and bioethanol and biodiesel from soybeans and corn, would deliver 295,383 TJ. The residues would provide potentially 72.1% (32.4x106 DB, 282.9 PJ or 45.6x1012 kcal) and biofuels 27.9%. The removal of residues for this purpose would have risky consequences for the sustainability of agricultural productivity, particularly on soil conservation and stability of production systems.

- van Dam, J. et al. "Large-scale bioenergy production from soybeans and switchgrass in Argentina Part B. Environmental and socio-economic impacts on a regional level". Renewable and Sustainable Energy Reviews 13 (2009) 1679–1709.

The impacts for two bioenergy chains (soybeans and switchgrass) are assessed for a set of defined land use scenarios in La Pampa province. The carbon stock change for switchgrass ranges from 0.2 to 1.2 ton C/ha/year and for soybean from 1.2 to 0 ton C/ha/year, depending on the scenario. The GHG emission reduction ranges from 88% to 133% for the switchgrass bioenergy chain (replacing coal or natural gas) and from 16% to 94% for the soybean bioenergy chain (replacing fossil fuel) for various lifetime periods. The annual soil loss, compared to the reference land use system is 2–10 ton/ha for the soybean bioenergy chain and 1–2 ton/ha for the switchgrass bioenergy chain. It is concluded that the scenario approach enables to understand the complexity of the bioenergy chain and the underlying factors influencing the sustainability principles. It is difficult to give ex ante a final conclusion whether a bioenergy chain is sustainable or not as this depends on the previous land use system but also on other factors as the selection of the bioenergy crop, the agroecological zone and the agricultural management system applied.

- Roberts, J. J, et al. "Assessment of dry residual biomass potential for use as alternative energy source in the party of General Pueyrredón, Argentina." Renewable and Sustainable Energy Reviews Volume 41,568-583. January 2015.

The article assesses the residual biomass availability and its energy potential in the Party of General Pueyrredón, a region located southeast of the Buenos Aires province. These were considered herbaceous and vegetable residues derived from the agricultural activity developed in the region, and forest residues resulting from the pruning of urban trees and garden maintenance. The calculations resulted in an availability of residual biomass of 204,536 t/year, implying an energy potential of 2605 TJ/year. The authors concluded that the residual biomass energy potential is significant in the studied region, but a more detailed study must be conducted to assess the techno-economic feasibility of using the available residual biomass as alternative energy source.

- Chemes, E. D. "Generation of bioenergy from residual biomass in feedlot." Final Integrative Project to qualify for the Higher Academic Degree of Bioenergetic Engineering Specialist. Universidad Tecnológica Nacional, Facultad Regional Tucuman. 2019.

The possibility of generating bioenergy from the residual biomass of a feedlot is studied. Specifically, the pre-feasibility of treating organic waste or manure generated in a feedlot is analysed through the application of bio-digestion technology and the possibility of generating electricity from the obtained biogas, with the option to deliver to the distribution network the excess energy. The study shows that it is only feasible for large productive establishments, greater than 10,000 stocks or head of cattle. Specifically, a feedlot of 15,000 heads (assuming one hundred percent occupancy) has a biogas production potential of 7,150.1 m^3 / day, which translates into an electrical energy production of 14.30 MW / day, barely exceeding the minimum power of 0.5 MW established by the RenovAr 2 program.

- A. Fernandez, et al. 2016. Kinetic study of regional agro-industrial wastes pyrolysis using non-isothermal TGA analysis

This study focused on the pyrolytic behaviour at different heating rates of six kinds of lignocellulosic biomasses: peach, plum and olive pits from canneries and jam -industries, marc and stalk from wineries, and sawdust from the timber industry. All these industries are located in the San Juan province. The Cuyo Region, particularly San Juan Province, contains readily available biomass waste materials that can be used as feedstock to produce fuels and chemicals, thus improving the economy of the area and contributing to the technological development of renewable energy sources. In order to use these agro-industrial solid wastes for energy production, the thermal decomposition under different environment must be studied. The research is key to evaluate other thermal process as waste combustion and gasification.

- Manrique S.M., et al. 2020. Panorama de tecnologías de bioenergía en Argentina. INENCO

The panorama of bioenergy in Argentina, and its thermal and electrical applications, is surveyed in this study. Advances in solid biomass conditioning experiences in the form of pellets, chips and coal are analysed. Some of the most notable energy uses of the country are mentioned, which account for the diversity of resources, but still point out technical, technological and logistical aspects that must be resolved. Particularly, technology imports are required, and national production is scarce.

- FAO, 2020. Valorization of externalities of projects with dry biomass and biogas. Collections of technicals reports nr 12. Buenos Aires.

https://doi.org/10.4060/ca8761es

The objective of this document was to economically value the positive externalities of biogas and dry biomass projects in regard to wind and solar projects, since the latter have the lowest price of electricity generation and the highest power awarded in the rounds of the RenovAr program. More than 60% of the externalities value corresponds to socio-economic aspects that are an indirect and induced consequence of investment, employment and taxes, and reach up to 75% in the case of biogas. The rest of the externalities are related to the electricity sector (firm power) and environmental benefits.

Initiatives and Projects Development

By September 2020, Argentina's interconnected system's (MEM) installed capacity reached 41.164 MW, showing a compound annual growth rate of 4.6% between 2015 and today.

Argentina's installed capacity has been recently enhanced (2016- to date) due to a set of measures based in the "electricity emergency state" enacted by decree 134/2015, which launched several auction processes for increasing thermal installed capacity through power purchase agreements (PPAs).

Complementarily, as described in the government alignment section, Law 27,191 (2015) had previously set renewable energy targets for the interconnected grid, establishing a mandatory pathway to reach a renewable (excluding large hydro) share of the supply equivalent to 20% of power demand by 2025. Based on Law 27,191, several rounds of renewable energy actions were set in the framework of the RenovAR programme.

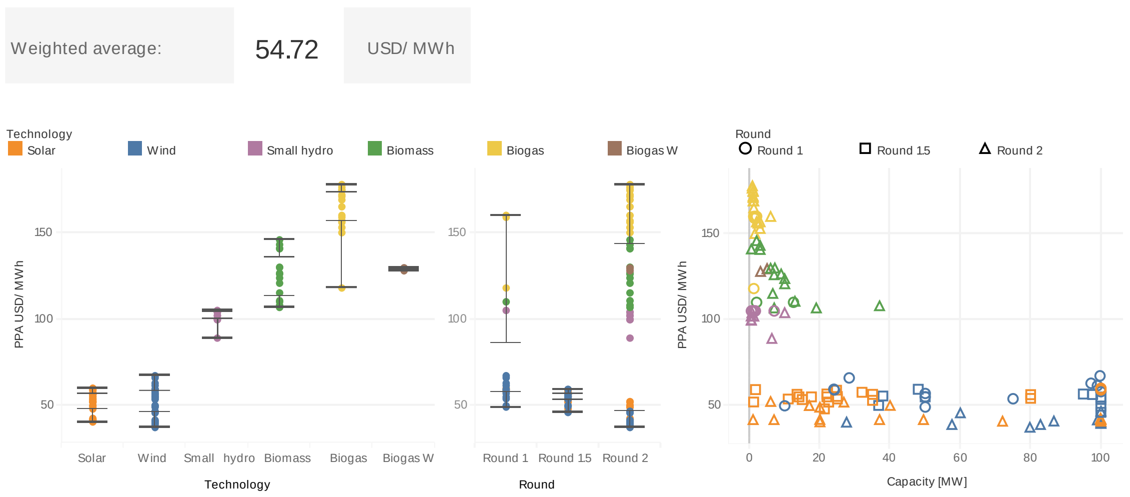
In the context of the RenovAr plan, a total of 185 projects were awarded, 20 of which correspond to biomass, 43 to biogas and 5 biogas from landfill.

RenovAr has been a successful programme in terms of catalysing the development of renewable power generation projects in Argentina and even promoted —by the introduction of specific clauses setting quotas for encouraging diversity of sources— the addition of cost-competitive technologies in the power grid. These elements, along with certain guarantees and fiscal instruments included in the programme, constitute certain precedents for encouraging BECCS in the long term.

The quick turnover of biomass and biogas projects, when compared to wind and solar PV projects resulted in an earlier connection (in terms of quantity, but due to scale factors not in terms of installed capacity) of these technologies into the grid, due to comparatively lower CAPEX requirements that resulted in relatively less exertions regarding financial requirements for these projects compared to their large-scale counterparts.

However, the higher prices of bioenergy projects when compared to other renewable sources (116.5 USD/MWh for biomass or 159.7 USD/MWh for biogas, vs. 50.35 USD/MWh solar PV, 50.07 USS/MWh wind, 101,0 USD/MWh small hydro, or vs. an average system cost of 59.5 USD/MWh) sparked controversies in the context of increasing domestic costs and subsidies[13] and introduce some uncertainties regarding future rounds and even regarding Argentina's compliance with the renewable targets set by Law 27,191.

Figure 7: Renovar PPA prices by technology



Source: Secretariat of Energy

In conclusion, there are some regulatory precedents to mandating fuel and energy resources as current and planned installed capacity of thermoelectric generation from these sources that could include CCS. Nonetheless, the impact of those operating plants is questioning (in the context of Argentine in terms of total cost of the system) the continuity in the short term of this type of new capacity (ex: PPPs and renewable auctions).

Table 7: Renovar Biomass Projects awarded

Project Name	Company	Province	Round	Capacity MW	Price USD/MWh
C.T. Generación Biomasa Santa Rosa	PAPELERA MEDITERRÁNEA / LUCENA	Corrientes	Round 1	12.5	110
C.T. Pincó Eco	PINDÓ	Misiones	Round 1	2.0	110
C.T. Rojas	GLOBAL DOMINION ACCES	Buenos Aires	Round 2	7.0	126

[13] Currently, Argentina's power sector subsidies constitute nearly 70% of the subsidies for the energy sector and users pay on average 61% of the generation and transmission costs.

C.T. Capitan Sarmiento	GRANJA TRES ARROYOS S.A.C.A.F.I.	Buenos Aires	Round 2	7.2	130
C.T. Generación Las Junturas	EMERALD RESOURCES SRL	Córdoba	Round 2	0.5	141
C.T. Ticino Biomasa S.A.	LORENZATI, RUETSCH Y CIA. S.A.	Córdoba	Round 2	3.0	143
C.T. Prodeman Bioenergia	PRODEMAN S.A.	Córdoba	Round 2	9.0	127
C.T. Venado Tuerto	GLOBAL DOMINION ACCES	Santa Fe	Round 2	7.0	107
C.T. La Escondida	INDUNOR S.A.	Chaco	Round 2	10.0	121
C.T. Biomasa Unitan	UNITAN S.A.I.C.A.	Chaco	Round 2	6.6	115
C.T. Generacion Virasoro	FORESTADORA TAPEBICUA S.A.	Corrientes	Round 2	3.0	141
C.T. San Alonso	FUENTES RENOVABLES DE ENERGIA S.A.	Corrientes	Round 2	37.0	108
C.T. Kuera Santo Tome	SANTO TOME KUERA S.A.	Corrientes	Round 2	12.9	111
C.T. Las Lomitas	BIOTERMICA LAS LOMITAS S.A.	Formosa	Round 2	10.0	124
C.T. Fermosa S.A.	PEGNI SOLUTIONS S.A.	Formosa	Round 2	6.0	130
C.T. Bm Mm Bioenergia	MOLINO MATILDE S.A.	Misiones	Round 2	3.0	143
C.T. Cogeneración Ingenio Leales	COMPAÑÍA INVERSORA INDUSTRIAL S.A.	Tucumán	Round 2	2.0	146
C.T. Biomasa La Florida	GENNEIA S.A.	Tucumán	Round 2	19.0	107
CT GAS DE BIOMASA FERMOSA	FERMOSA BIOSIDERURGIA SA	FORMOSA	Round 3	3.5	107
CT ROSARIO DE LA FRONTERA	ELECTRUM RF SA	SALTA	Round 3	5.0	106

Source: Ministry of Energy and Mining

Table 8: Renovar Biogas Projects awarded

Project Name	Company	Province	Round	Capacity MW	Price USD/MWh
C.T. Río Cuarto 1	BIOMAS CROP	Córdoba	Round 1	2.0	160
C.T. Río Cuarto 2	BIOMAS CROP	Córdoba	Round 1	1.2	160
C.T. Huinca Renancó	FECOFE / COOP. HUINCA RENANCÓ	Córdoba	Round 1	1.6	160
C.T. Yanquetruz	ACA / FERSI	San Luis	Round 1	1.2	160
C.T. San Pedro Verde	ADECO AGRO	Santa Fe	Round 1	1.4	159

C.T. Biogás Ricardone	MARTÍN NACARATO / OTROS	Santa Fe	Round 1	1.2	118
C.T. Arrebeef Energia	ARREBEEF S.A.	Buenos Aires	Round 2	1.5	150
C.T. El Mangrullo	CARNES DE LA PATAGONIA NEUQUINA S.A.	Buenos Aires	Round 2	2.0	157
C.T. General Alvear	CARNES DE LA PATAGONIA NEUQUINA S.A.	Buenos Aires	Round 2	1.0	172
C.T. Resener I	INMADE S.A.	Buenos Aires	Round 2	0.7	176
C.T. General Villegas	MARÍA ELENA S.A	Buenos Aires	Round 2	1.2	169
C.T. Pacuca Bio Energia	PACUCA S.A.	Buenos Aires	Round 2	1.0	172
C.T. Pergamino	SEEDS ENERGY	Buenos Aires	Round 2	2.4	157
C.T. James Craik	ACZIA BIOGAS, S.L.	Córdoba	Round 2	2.4	156
C.T. San Francisco	ACZIA BIOGAS, S.L.	Córdoba	Round 2	2.4	156
C.T. El Alegre Bio	ANTIGUAS ESTANCIAS DON ROBERTO S.A.	Córdoba	Round 2	1.0	175
Ampliacion Bioelectrica Dos	BIOELECTRICA DOS S.A.	Córdoba	Round 2	1.2	169
C.T. Biogeneradora Santa Catalina	BIOGENERADORA CENTRO S.A	Córdoba	Round 2	2.0	157
Ampliacion 2 Central Bioelectrica	BIOMASS CROP S.A.	Córdoba	Round 2	1.2	169
C.T. Enreco	CECILIA DEBENEDETTI	Córdoba	Round 2	2.0	157
C.T. Jigena I	CLEANERGY RENOVABLES S.A.	Córdoba	Round 2	1.0	171
C.T. Villa del Rosario	CLEANERGY RENOVABLES S.A.	Córdoba	Round 2	1.0	175
C.T. Pollos San Mateo	POLLOS SAN MATEO S.A.	Córdoba	Round 2	2.4	156
C.T. Don Roberto Bio	ANTIGUAS ESTANCIAS DON ROBERTO S.A.	San Luis	Round 2	1.0	175
C.T. Yanquetruz Ii	BIO ENERGIA YANQUETRUZ	San Luis	Round 2	0.8	178
C.T. Bio Justo Daract	BIOMASS CROP S.A.	San Luis	Round 2	1.0	175
C.T. Ab Energia	AB AGRO S.A.	La Pampa	Round 2	2.0	157
C.T. Bella Italia	ACZIA BIOGAS, S.L.	Santa Fe	Round 2	2.4	156
C.T. Recreo	ACZIA BIOGAS, S.L.	Santa Fe	Round 2	2.4	156
C.T. Avellaneda	INDUSTRIAS JUAN F. SECCO S.A.	Santa Fe	Round 2	6.0	160

C.T. Venado Tuerto	SEEDS ENERGY DE VENADO TUERTO S.A.	Santa Fe	Round 2	2.0	157
C.T. Biocaña	SESNICH, NESTOR OMAR	Santa Fe	Round 2	3.0	157
C.T. del Rey	SILVINA HACEN	Santa Fe	Round 2	1.0	169
C.T. Don Nicanor	SILVINA HACEN	Santa Fe	Round 2	1.0	169
C.T. Bombal Biogas	TANONI HNOS S.A.	Santa Fe	Round 2	1.2	165
C.T. Santiago Energías Renovables	LOS AMORES S.A.	Santiago Del Estero	Round 2	3.0	157
C.T. Citrusvil	CITRUSVIL S.A.	Tucumán	Round 2	3.0	153
CT BIOGAS SAN LUIS	DIASER SA	SAN LUIS	Round 3	2.0	157

Source: Ministry of Energy and Mining

Table 9: Renovar Biogas landfill projects awarded

Project Name	Company	Province	Round	Capacity MW	Price USD/MWh
C.T. Ensenada	INDUSTRIAS JUAN F. SECCO S.A.	Buenos Aires	Round 2	5.0	129
C.T. Gonzalez Catan	INDUSTRIAS JUAN F. SECCO S.A.	Buenos Aires	Round 2	5.0	130
C.T. Ricardone Ii	GLOBAL GREEN RICARDONE SRL	Santa Fe	Round 2	3.1	128
CT BIOGAS SAN MARTIN NORTE III D	JF SECCO	BUENOS AIRES	Round 3	5.0	130
C.T. Ensenada	INDUSTRIAS JUAN F. SECCO S.A.	Buenos Aires	Round 2	5.0	129

Source: Ministry of Energy and Mining

Based on available data from the biomass and biogas project sponsors, preliminary facts on the magnitude of the investment and employment were identified:

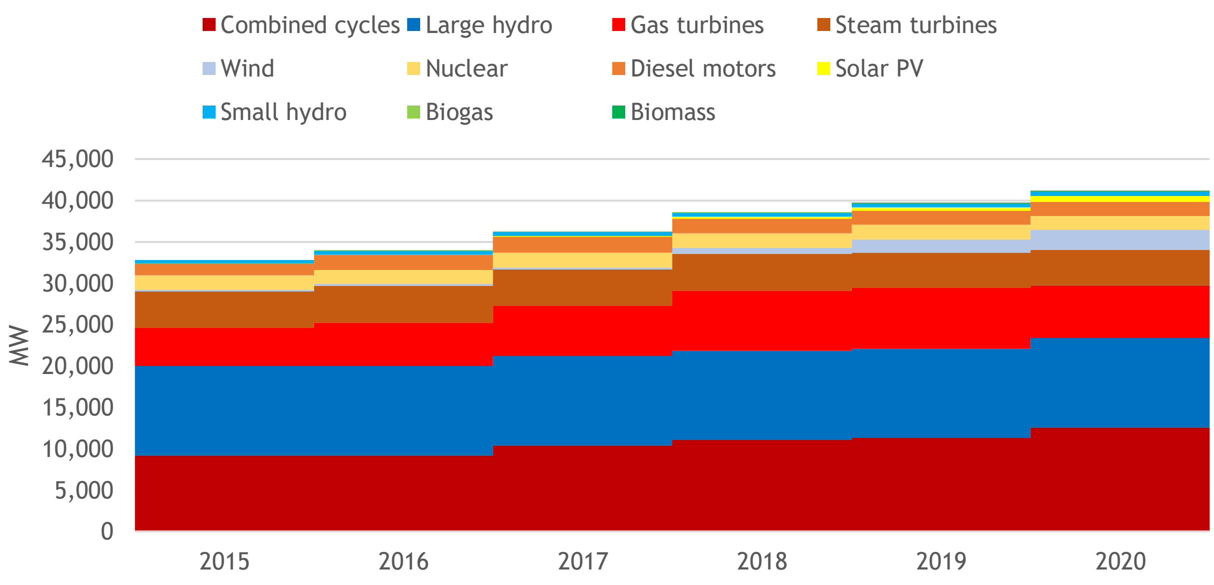
- C.T. Generación Biomasa Santa Rosa / PAPELERA MEDITERRÁNEA / LUCENA
  - CAPEX: 68.3 million dollars
  - Employment: 50 direct jobs and 150 indirect jobs
- C.T. San Alonso / FUENTES RENOVABLES DE ENERGIA S.A.
  - CAPEX: 30 million dollars
  - Employment: 30 direct jobs and between 300 to 500 jobs during construction phase
- C.T. Biomasa La Florida GENNEIA S.A.
  - CAPEX: 80 million dollars
- C.T. Avellaneda / INDUSTRIAS JUAN F. SECCO S.A.

    - CAPEX: 8.8 million dollars
- C.T. Kuera Santo Tome / SANTO TOME KUERA S.A.
    - CAPEX: 40 million dollars
    - Employment: 50 direct jobs and 300 indirect jobs
- C.T. La Escondida / INDUNOR S.A.
    - CAPEX: 20 million dollars
    - Employment: 328 direct jobs and 1000 indirect jobs

All of these projects focus on BioEnergy (BE), but no carbon capture and storage (CCS) strategy was so far identified. Nonetheless, the expected combined power generation of these projects reaches 1,206 GWh per year, and according to preliminary estimations avoid 512.8 ktCO_2 per year related to fossil fuel combustion for power generation, excluding leakage emissions and the avoidance of methane emissions from anaerobic decay of biomass residues.[14]

In consequence, while in 2015 renewable power capacity reached 634 MW 1.9% of the total capacity, by 2020 it reached 9.1%, mostly driven by wind power (5.8% over the total capacity). Currently, conventional thermal (fossil) power capacity still represents more than 60% of Argentina's total generation capacity.

Figure 8: Installed capacity by source, 2015- September 2020

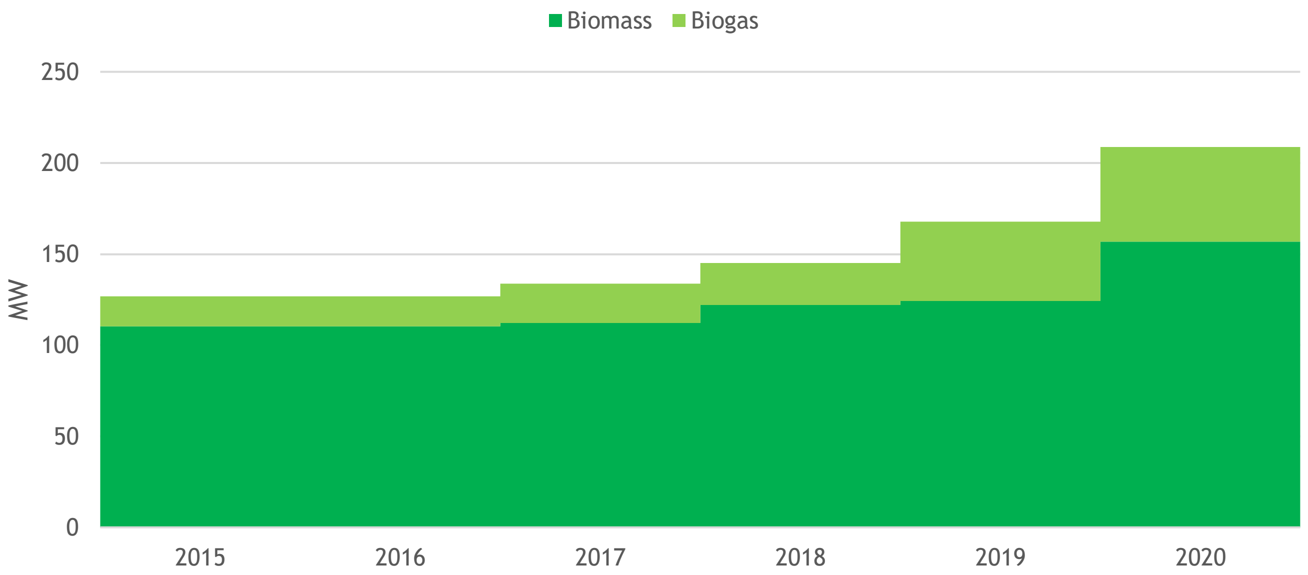


Source. Own elaboration based on data from CAMMESA.

[14] Considering —based on current dispatch data— a capacity factor of 45% for biomass projects and 70% for biogas projects, and the latest available grid emission factor por Argentina (2018) for a Combined Margin (WOM = 0,25 WBM = 0,75) of 0.4250 tCO2/MWh.

Even after these increases in the total installed capacity, bioenergy based still shows a modest share over Argentina's capacity mix, of only 0.5%. While biomass capacity grew 41% during the period (7.1% CAGR), biogas capacity (nearly inexistent previously in Argentina), increased more than two-fold in the context of these auctions.

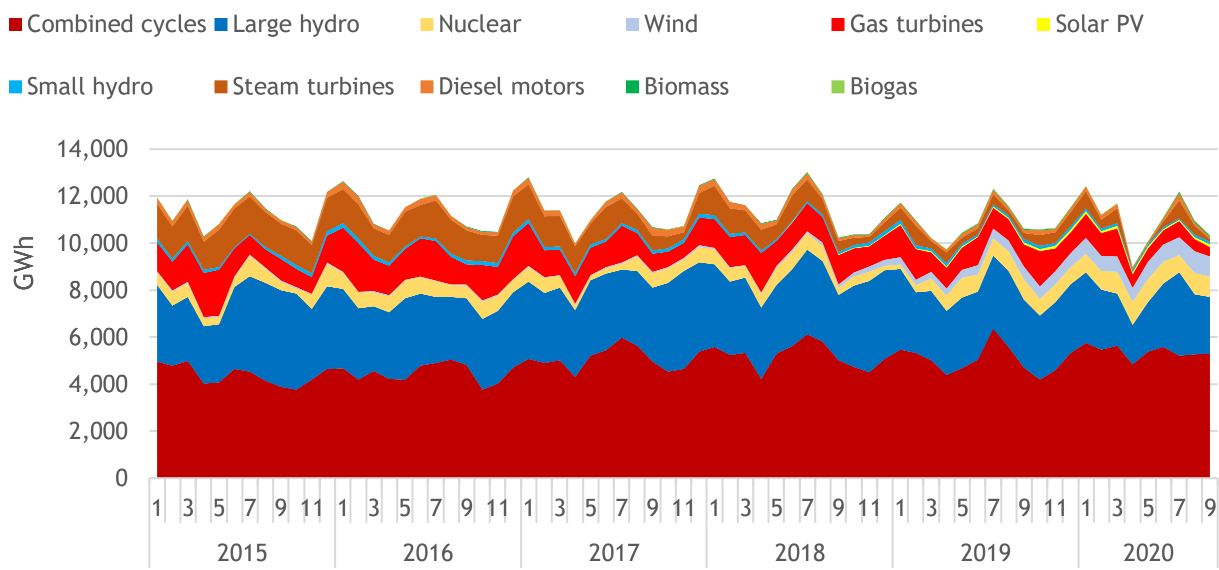
Figure 9: Detail of installed capacity from bioenergy sources, 2015- September 2020



Source: Own elaboration based on data from CAMMESA.

Argentina's power emergency decree was sanctioned in the context of an expected demand growth, which finally showed to be optimistic in terms of activity. In contrast, power generation and capacity demand stalled during the last years, showing a stable level of 10,600 GWh per month during the last two years, consistently below 2016 levels (11.000 GWh per moth).

Figure 10: Power generation by source, 2015- September 2020

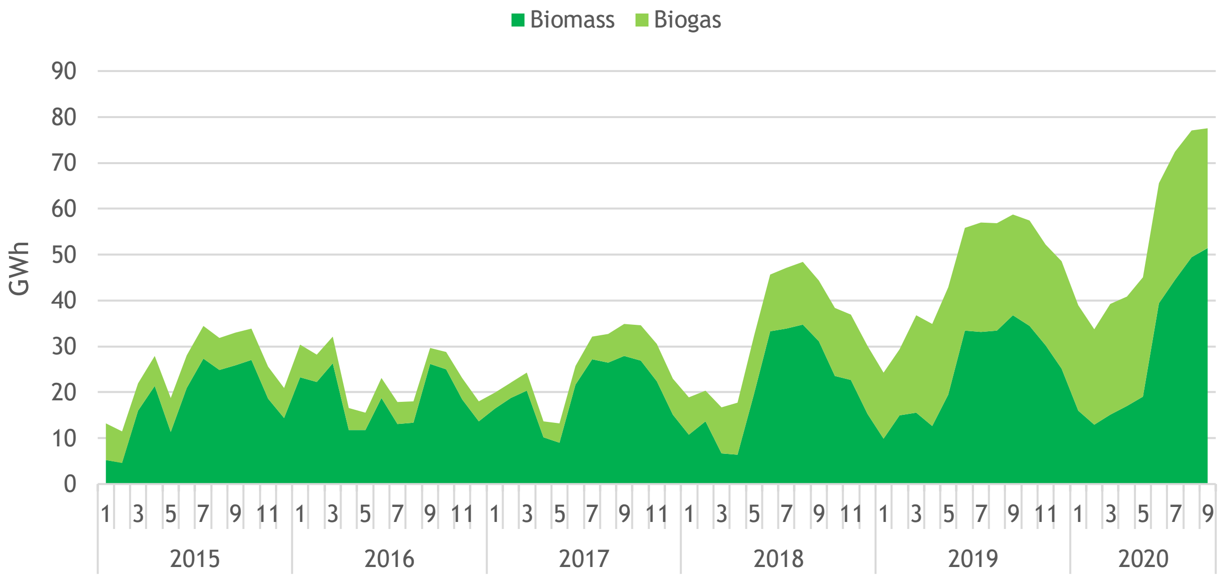


Source: Own elaboration based on data from CAMMESA.

As a result of RenovAR programme`s conditions, which established that contracts granted under the framework would have dispatch priority, Argentina's renewable generation reached an average of 8.6% over total during the last months, in contrast to 1.4% during 2015.

Particularly, biomass and biogas power generation (the first of these strongly tied to agricultural and especially sugarcane cycles), doubled when compared to 2015.

Figure 11: Detail of Power generation from bioenergy sources, 2015- September 2020



Source: Own elaboration based on data from CAMMESA.

The following table shows the current installed capacity of biogas and biomass-fired power generation in Argentina, by region, province and entry date into the interconnected system.

Table 10: Current biogas and biomass power plants, September 2020

Station ID	Agent	Region	Province	Source	Capacity (MW)	Date
SMAN	C.T.SAN MARTIN NORTE 3- ENARSA	GRAN BS.AS.	BUENOS AIRES	Biogas	5.1	05/19/2012
SMIG	CT SAN MIGUEL NORTE III-ENARSA	GRAN BS.AS.	BUENOS AIRES	Biogas	11.5	10/04/2012
BRC1	CENTRAL BIOELECTRICA R.CUARTO1	CENTRO	CORDOBA	Biogas	2	07/22/2017
YANQ	BIO ENERGÍA YANQUETRUZ S.A.	CENTRO	SAN LUIS	Biogas	1.5	08/09/2017
SPEV	ENERGIA AGRO S.A.U	LITORAL	SANTA FE	Biogas	1.4	11/03/2017
BRC2	C.BIOELECT.R.CUARTO2 REN1	CENTRO	CORDOBA	Biogas	1.2	09/21/2018
BRC2	C.BIOELECT.R.CUARTO2 REN2	CENTRO	CORDOBA	Biogas	1.2	01/17/2019
AVEL	BIOGAS CT AVELLANEDA SECCO	LITORAL	SANTA FE	Biogas	6.3	03/16/2019
ENRS	BIOGAS RS CT ENSENADA SECCO	GRAN BS.AS.	BUENOS AIRES	Biogas	5.3	03/22/2019
BRC1	C.BIOELECT.R.CUARTO1 REN2	CENTRO	CORDOBA	Biogas	1.6	08/10/2019
CITR	BIOGAS CTBG CITRUSVIL-ALCOVIL	NOROESTE	TUCUMAN	Biogas	3	09/06/2019
GIG1	BIOGAS CTBG GIGENA I	CENTRO	CORDOBA	Biogas	1.2	12/11/2019
PERG	BIOGAS CTBG PERGAMINO	BUENOS AIRES	BUENOS AIRES	Biogas	2.4	12/21/2019
JDAR	BIOGAS CTBG JUSTO DARACT	CENTRO	SAN LUIS	Biogas	1	01/14/2020
TIGO	BIOGAS CTBG TIGONBU	CENTRO	SAN LUIS	Biogas	2	03/11/2020
VROS	BIOGAS CTBG VILLA DEL ROS. CGY	CENTRO	CORDOBA	Biogas	1	05/08/2020
PACU	BIOGAS CTBG PACUCA BIO ENERGÍA	BUENOS AIRES	BUENOS AIRES	Biogas	1	08/13/2020
GALV	CTBG GENERAL ALVEAR	BUENOS AIRES	BUENOS AIRES	Biogas	1	09/01/2020
VTBG	BIOGAS CTBG VENADO TUERTO	LITORAL	SANTA FE	Biogas	2.1	09/05/2020
	Total biogas				**51.8**	
NIDE	NIDERA SAFORCADA-Junin	BUENOS AIRES	BUENOS AIRES	Biomass	7	11/01/1997
PUPI	ALTO PARANA-PTO.PIRAY	NORESTE	MISIONES	Biomass	38	08/15/2009
ISBA	AZUCARERA JUAN M.TERAN SA	NOROESTE	TUCUMAN	Biomass	16.2	07/06/2010
TABA	Ingenio y Ref.S.Martin Tabacal	NOROESTE	SALTA	Biomass	40	11/08/2011
PROV	ARCOR ING.LA PROVIDENCIA	NOROESTE	TUCUMAN	Biomass	9	10/01/2014
PESP	ECO-ENERGIA S.A.BIOMASA	NORESTE	MISIONES	Biomass	2	08/25/2017
PROD	CT PRODEMAN BIOENERGÍA	CENTRO	CORDOBA	Biomass	10	05/29/2018
LEAL	CTBM INGENIO LEALES	NOROESTE	TUCUMAN	Biomass	2	08/21/2019
JUNT	CTBM. GENERACIÓN LAS JUNTURAS	CENTRO	CORDOBA	Biomass	0.6	01/22/2020
GARR	CT BIOMASA GARRUCHOS	NORESTE	CORRIENTES	Biomass	32	08/31/2020
	Total Biomass				**156.8**	
	Total				**208.6**	

Source: Own elaboration based on data from CAMMESA.

Argentina's ISO (independent system operator, CAMMESA) presents quarterly to the market agents a list of planned new entries under the season programming. The following table shows the expected new entries for the period 2020-2022, as well as several new power plants which have not yet determined an expected connection date, and still show some uncertainty regarding the companies' ability to completely finance these expected projects under several uncertainty conditions currently being faced by the country.

Table 11: Programmed new biomass and biogas power plants, September 2020

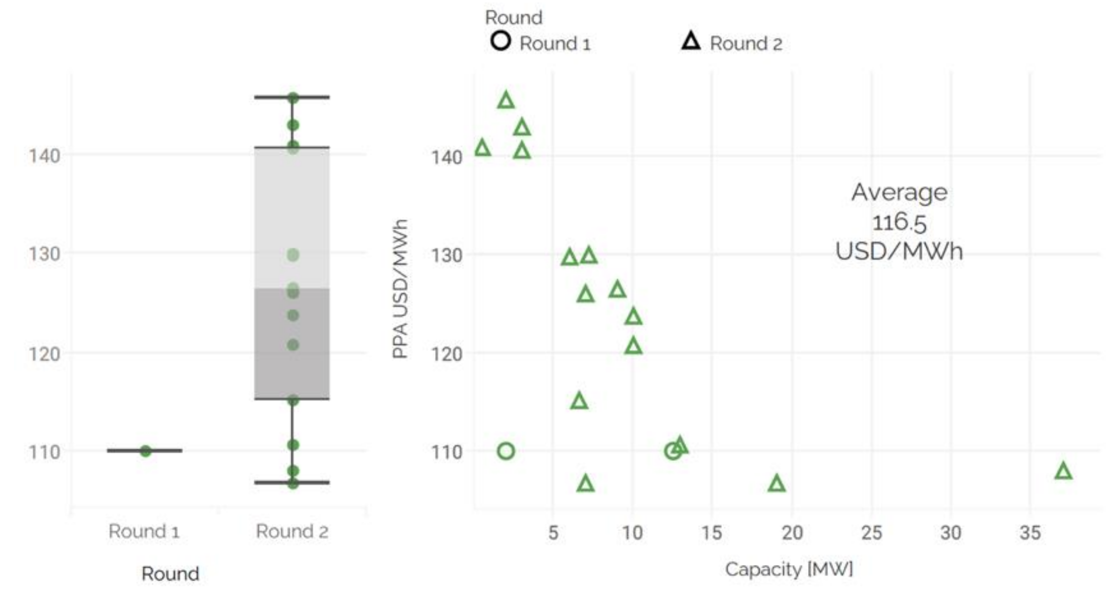
Station ID	Agent	Province	Source	Capacity (MW)	Date (expected)
ABEF	C.T. ARREBEEF ENERGIA	Buenos Aires	Biogas	1.5	Oct-2020
RES1	C.T. RESENER I	Buenos Aires	Biogas	0.72	Oct-2020
GUAT	C.T. ENRECO. GUATIMOZIN. CORDOBA	Córdoba	Biogas	2	Oct-2020
ABBG	C.T. AB ENERGIA. 25 DE MAYO . LA PAMPA	La Pampa	Biogas	2	Oct-2020
YAN2	C.T. YANQUETRUZ II	San Luis	Biogas	0.8	Oct-2020
PSMA	C.T. POLLOS SAN MATEO	Córdoba	Biogas	2.4	Oct-2020
SCAB	C.T. BIOGENERADORA SANTA CATALINA. CORDOBA	Córdoba	Biogas	2	Nov-2020
LAMO	C.T. SANTIAGO ENERGÍAS RENOVABLES. LOS AMORES S.A.	Santiago del Estero	Biogas	3	Feb-2021
GCRS	C.T. GONZALEZ CATAN. BRS	Buenos Aires	Biogas (SWD)	5	Feb-2021
VCAN	C.T. BIOCAÑA. VILLA CAÑAS. SANTA FE	Santa Fe	Biogas	3	Dec-2022
	Total biogas dated			**22.42**	
GRA3	C.T. CAP. SARM. GRANJA TRES ARROYOS S.A.C.A.F.I.	Buenos Aires	Biogas	7.2	
MANG	C.T. EL MANGRULLO. SALADILLO. BSAS	Buenos Aires	Biogas	2	
VGAB	C.T. GENERAL VILLEGAS. BG.	Buenos Aires	Biogas	1.2	
HREN	BIOGÁS HUINCA RENANCO	Córdoba	Biogas	1.62	
JCRA	C.T. JAMES CRAIK	Córdoba	Biogas	2.4	
SFRB	C.T. SAN FRANCISCO BIOGAS	Córdoba	Biogas	2.4	
RICA	Biog. Ricardone	Santa Fe	Biogas	1.2	
BITA	C.T. BELLA ITALIA	Santa Fe	Biogas	2.4	
BOMB	C.T. BOMBAL BIOGAS	Santa Fe	Biogas	1.2	
REYB	C.T. DEL REY	Santa Fe	Biogas	1.2	
DONI	C.T. DON NICANOR. RECONQUISTA. SANTA FE	Santa Fe	Biogas	1.2	
RECB	C.T. RECREO	Santa Fe	Biogas	2.4	
RIC2	C.T. RICARDONE II	Santa Fe	Biogas	3.12	
	Total biogas not dated			**29.54**	
	Total Biogas			**51.96**	

Station ID	Agent	Province	Source	Capacity (MW)	Date
BSRO	Biomasa Santa Rosa	La Pampa	Biomass	15	Oct-2020
TIRO	C.T. BIOMASA UNITAN. Puerto Tirol	Chaco	Biomass	6.6	Oct-2020
ESCO	C.T. LA ESCONDIDA. INDUNOR S.A.	Chaco	Biomass	10	Nov-2020
CAZU	C.T. BM MM BIOENERGIA. Cerro Azul.	Misiones	Biomass	3	Dec-2020
VTBM	C.T. VENADO TUERTO. BM. GLOBAL DOMINION ACCES	Santa Fe	Biomass	7	Mar-2021
ALON	C.T. SAN ALONSO	Corrientes	Biomass	37	Mar-2021
BMLO	C.T. BIOTERMICA LAS LOMITAS	Formosa	Biomass	10	Aug-2021
LFLO	Central Biomásica La Florida	Tucumán	Biomass	62	Aug-2022
FERM	C.T. FERMOSA S.A.	San Luis	Biomass	6	Dec-2022
	Total biomass dated			**156.6**	
ROJA	C.T. ROJAS	Buenos Aires	Biomass	7	
KUER	C.T. KUERA SANTO TOME	Corrientes	Biomass	12.92	
TAPE	C.T. VIRASORO. FORESTADORA TAPEBICUA S.A.	Corrientes	Biomass	3	
BIOMASA ALEM	BIOMASA ALEM	Misiones	Biomass	6	
BIOMASA POSADAS	BIOMASA POSADAS	Misiones	Biomass	2	
LFL2	C.T. BIOMASA LA FLORIDA. GENNEIA	Tucumán	Biomass	19	
	Total biomass not dated			**49.92**	
	Total Biomass			**206.52**	

Source: Own elaboration based on data from CAMMESA.

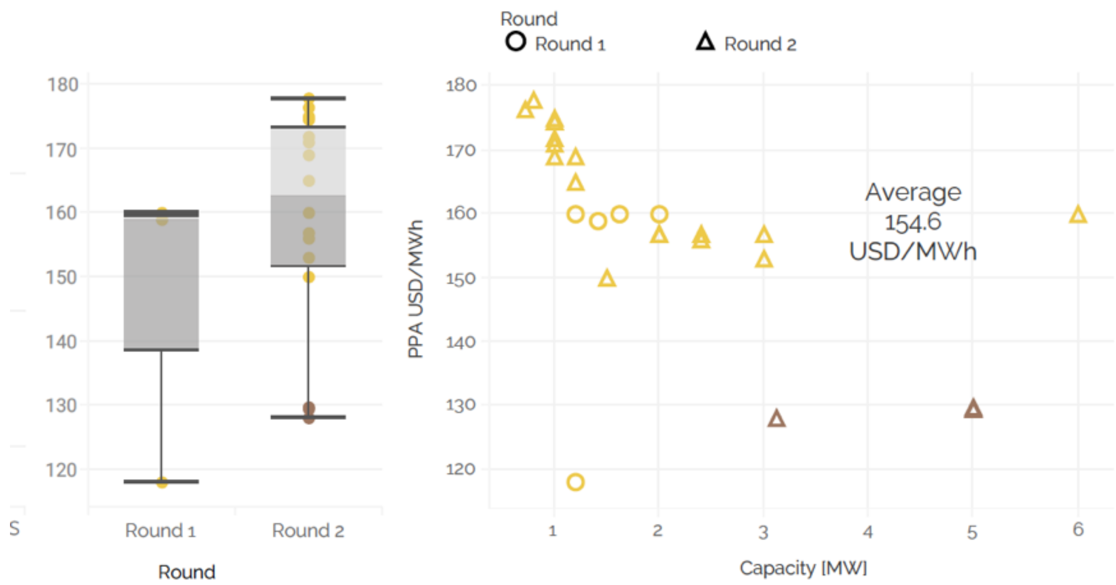
If the above-mentioned projects are completed, RenovAR programme's guarantee conditions grant 20-year PPAs at the prices shown in the figures presented below for each technology and source.

Figure 12: Most recent auction prices for Biomass PPAs (2017-2018).



Source: Own elaboration based on Secretariat of Energy visuals.

Figure 13: Most recent auction prices for Biogas PPAs (2017-2018).



Source: Own elaboration based on Secretariat of Energy visuals.

Finally, it was identified that in 2013 an interdisciplinary team of researchers from the Institute of Sciences of the General Sarmiento National University and the Faculty of Engineering of the

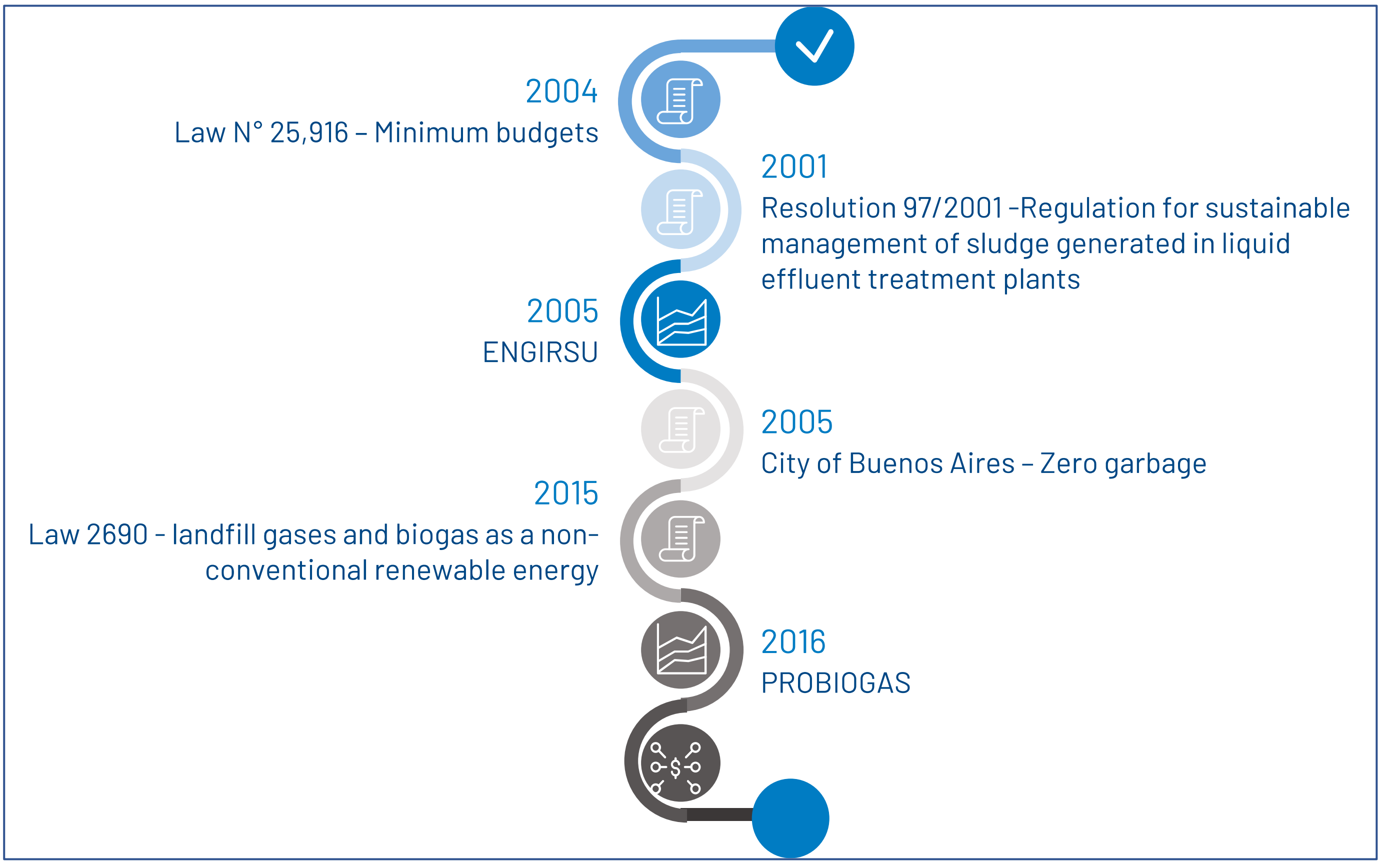
University of Buenos Aires (UBA) was studying how the CO2 in gaseous state would interact with the water found in saline aquifers. As a result of the research, the scientists observed that the increase in the injection pressure of gas facilitates its entry into the aqueous phase - its dissolution in water - and increases instability, that is, it develops more quickly. The researchers also mentioned that although still in an experimental stage and with opinions for and against, the geological sequestration of CO2 would allow the gas generated in power plants and industrial sources to be captured and injected into deep saline aquifers.

Other biomass resources, such as power generation municipal solid waste (MSW), industrial and agriculture effluents, such as poultry and cattle residues

This subsection covers other biomass resources that have been assessed in Argentina.

The following figure summarizes in a timeline, regulations, plans and programmes related to other biomass resources CDR approaches implemented in Argentina, that are developed in a detailed manner in the following sections.

Figure 14: Other biomass resources CDR approaches related to regulations, plans and programmes implemented in Argentina - Timeline



Source: own elaboration

Alignment with Government Vision and Commitment

The Urban Solid Waste Management in Argentina is regulated by the Law of Minimum Budgets N° 25,916 promulgated in 2004, which assigns to the enforcement authority the obligation to prepare an annual report including data provided by the provinces and the City of Buenos Aires, specifying the type and quantity of household waste that is collected, and identify those that have potential for their recovery in each of the jurisdictions (art. 24 B). Within this framework, the Ministry of the Environment and Sustainable Development is in charge of defining strategies and actions with the objective of raising awareness among citizens and providing information on waste management throughout the nation.

Argentina has specific programs ENGIRSU and PROBIOGAS) and two institutions (INTA and INTI) pursuing the development of biogas technology. Biogas was included in the RenovAr programme (2016), with a small share (15 MW over 1000 MW), contributing to a favourable tariff in terms of renewable energy-based electricity production (Morero, 2017).

Argentina developed the National Strategy for Urban Solid Waste Management (ENGIRSU) in 2005. The ENGIRSU strategy is based on the comprehensiveness principle (Reduction at source, Home Classification, Collection and transport, transfer and regionalization), processing (recycling of inorganic, composting of organic and others) and Final Disposal Centres (CDF).

The PROBIOGAS programme, launched in 2016, with a USD 2.7 million donation from the Global Environment Facility (GEF), plans to demonstrate the potential of energy generation from municipal waste in medium-sized urban centres in Argentina. It aims to implement pilot initiatives in selected municipalities, generating energy for self-supply and the sale of surplus energy to the distribution network, demonstrate the effectiveness of biogas production for heat generation (including cogeneration) and biomethane.

Other relevant legislation documents related to solid and industrial waste in Argentina are:

- Resolution 97/2001, Ministry of Social Development and Environment: Regulation for sustainable management of sludge generated in liquid effluent treatment plants
- Law 1854/2005, City of Buenos Aires. (“Zero Garbage”) established a new form of urban solid waste management aimed at gradual abandonment landfills. Under this new framework, recyclers’ cooperatives acquired a key role with regard to recyclables classification and commercialization centre (named “green centres”). This was a progress toward consolidating the position of the recycling organizations in the urban sanitation system while maintaining the previous recognition of them as environmental policy workers.
- Law 2690/2015 which defines landfill gases and biogas as a non-conventional renewable energy

Degree of Scientific Development / Academic Literature Review

Several articles were identified related to other biomass resources in Argentina:

- Betzabet, M., et al. 2017. Waste Energy: Assessment of biogas production in Argentina from co-digestion of sludge and municipal solid waste. Universidad Nacional del Litoral-CONICET

In Argentina, there is an important potential to utilize organic waste to generate bioenergy. This work analyses the environmental impacts and the energetic and economic requirements of the biogas produced by digesting the sewage sludge produced in a wastewater treatment plant. This one is co-digested with the organic fraction of municipal solid waste, and the basis of this study is the life cycle assessment. The co-digestion was improved with glycerol, and biogas generation was estimated using the GPS-X software. For biogas end use two alternatives were considered: combined heat and power and biomethane generation. The environmental, energetic and economic assessments showed that the co-digestion has great potential for reducing the environmental impacts and increasing the economic and energetic value of the substances via the production of biomethane, electricity and, potentially, fertilizer. The energy balance was highly positive, with energy use for the overall process (Feedstock collection and transport, Biogas Production Plant, Digestate Management and Biogas Treatment Plant) between 30 and 39% of the energy generated.

- Betzabet, M., et al. 2020. Renewable Energy: Optimal process design for integrated municipal waste management with energy recovery in Argentina. INTEC (UNL-CONICET).

This work presents a comprehensive mathematical model for the optimal selection of municipal waste treatment alternatives, accounting for co-digestion of sludge and municipal solid waste. The superstructure of alternatives includes anaerobic digestion under mesophilic or thermophilic conditions, composting, recycling, and final disposal in a landfill. Anaerobic digesters are fed with different mixing ratios of sewage sludge and the organic fraction of municipal solid waste. A mixed-integer mathematical programming formulation is proposed to find the optimal process design. In all cases, co-digestion of the full stream leads to an integrated waste-to-energy process that maximizes the economic value and reduces environmental impacts of waste by producing electricity, heat and fertilizer.

- ONGIRSU, National Observatory for the Integral Management of Solid Urban Waste, Statistical data on waste generation in municipalities, 2016 accessed 17.09.18, http://observatoriorsu.ambiente.gob.ar/estadisticas.htm.

On average, the generation of MSW per capita in Argentina is about 1 kg per day, and the composition of the MSW is categorized as 50% organic (Qof), 38% recyclable (QR), and 12% others, non-recyclable (QOT)

- Castelao Caruana, M. E. 2019. Organizational and economic modelling of an anaerobic digestion system to treat cattle manure and produce electrical energy in Argentina's feedlot sector

This study identifies the main factors that affect the economic and organizational viability of a representative power generation project that applies an anaerobic digestion technology and uses cattle manure from feedlots as feedstock. The results demonstrate that the viability of bioenergy systems depends heavily on the infrastructure installed along the whole supply chain and on the organizational changes applied in the collection and transportation stages of manure. They also highlight three important aspects to assess the economic viability of such projects: a) feedlots' production, scale and efficiency; b) organizational routines; c) the impact of the project itself on the overall performance of the production unit. These are crucial factors for the use of manure for generating energy, and they question the idea of anaerobic digestion as a cost-effective technology for manure management and energy generation, in farms of different sizes and which produce different type of livestock in Argentina.

- Goicoa, V., 2016. Technical Report: ''Relevamiento nacional de plantas de biogás" 15° Curso Internacional de agricultura y ganadería de precisión con agregado de valor en origen. INTA: <http://inta.gob.ar/documentos/relevamiento-nacionalde-plantas-de-biogas> (accessed 21.11.16).

Biogas technical capacity is well developed in Argentina. An inventory of biogas plants in Argentina list 105 anaerobic digesters in 16 provinces belonging to the public sector, the private sector, production cooperatives and non-governmental organizations. A survey of 61 of those biogas plants indicates that a large number of plants belong to the private sector (53.1%) with the objective to treat effluents and only a small portion to obtain energy (6%). There are important differences between public and private. The biogas plants in the public sector are mainly used to treat effluents and 33% are used for research and teaching. Several plants belonging to municipalities present operational and management problems. The private sector has larger plants built in rural areas using USAB, cover lagoons and continuous-flow stirred tank reactors with imported technology and materials. A common ground in both sectors is the lack of heating and mixing of the digesters indicating that the plant is not working in the optimum biological condition. The more common substrates are industrial and agro wastes (86%). The rest is organic municipal wastes with a small contribution from crops. Almost half of the plants (42.6%) do not use the biogas, 44.3% use the biogas for heating and only 12% have some sort of electrical use.

- Venier, F., et al. 2015. Analysis of the Energy Sector in Argentina: Exploring the Potential of Biogas Production.

Since 2001, Argentina has experienced continuous economic growth that has driven a rapid increase in electricity demand, especially from natural gas based thermal plants. There are two main challenges. First, the Argentinian production of natural gas cannot meet the demand for electricity generation. Also, fossil fuel power generation emits air pollutants that can harm health, affecting the ecosystem and also the emission of greenhouse gases that contribute to global warming. This research introduces an alternative approach to meet this increasing demand in a sustainable way by exploring the potential of biogas production for electricity generation in the largest province of the country, Buenos Aires. The study area was selected due to its strong livestock industry, and the potential for biogas generation from cattle manure. In addition, since Buenos Aires has the capital and largest city of Argentina, this could be also a good opportunity to promote biogas generation from solid waste management.

- Oliveira, M.O., et al. 2012. Biomass Electricity Generation Using Industry Poultry Waste. UNaM, National University of Misiones

Even though this article is focused in Southern Brazil, the main researcher is an Argentinean from a university of the Northeast of Argentina. This work presents study details of a biomass-based electricity generation project. The biomass used was industrial poultry litter. The objective of the work is to contribute to the research of poultry waste use in real life applications. The case study is an aviary industry region of southern Brazil, where is evaluated the technical and economic characteristics of power generation using biomass obtained from poultry litter. Still, it is highlighted the large energy potential and the high poultry litter production in the region, which translates into an important source of raw material for electricity generation, currently not highly explored in Brazil.

- Morero, Betzabet & Campanella, Enrique. (2012). Simulation of the Chemical Absorption Process with Amine Solutions for Biogas Purification. Información tecnológica. 24. 25-32. 10.4067/S0718-07642013000100004

The influence of some key operating parameters and of different types of amines in biogas purification is analyzed. For this a conventional single-loop absorber-stripper process configuration was simulated using four types of amines (monoethanolamine, diethanolamine, diglycolamine and methyldiethanolamine) and two mixtures of them. The variation in the amount of CO2 absorbed at different temperatures by different types of amines or amine mixtures were also analyzed. The simulation results showed good levels of purification in all cases with best results for diglycolamine (97.3% de CH4) which also has the lowest reboiler energy consumption.

- Delgado Gomez, E. et al. 2016. Development of adsorbent to capture CO2 from an agroindustrial waste. Acta de la XXXIX Reunión de Trabajo de la Asociación Argentina de Energías Renovables y Medio Ambiente Vol. 4, pp. 09.19-09.28.

Activated carbons (CAs) were developed from yerba mate sticks through the chemical activation process using KOH as an activator agent. The ACs obtained were suitable for the removal of CO2 from gaseous streams, mimicking post-combustion condition, and their high effectiveness being linked to the limited distribution of micropore diameters (<2nm) that characterize their porous structures.

- Asensio Cenice, et al. 2019. Installation of a plant for the production of electrical energy from biogas from sanitary landfill. ITBA

A pre-feasibility study for the installation of a power plant that uses energy derived from gas produced from waste at sanitary landfills. The landfill is located at the ¨Complejo Ambiental Norte III¨, more specifically from the module D, which belongs to CEAMSE.

Initiatives and Projects Development

Forty-three biogas projects and 5 biogas from landfill projects were awarded in RenovAr plan as detailed before. All of those projects have / will have installed capacities no larger than 5MW.

On other hand, the Ministry of Science and Technology, in conjunction with the University of San Martin and the company RECYCOMB, are working in a research project called Recycling and Energy Assessment of Industrial Waste (RyVERI) that aims to develop a new innovative technological package that allows energy recovery from industrial waste that is assimilated to urban solid waste obtaining a standardized solid fuel suitable for cement kilns.

In Argentina, the state-owned CEAMSE takes care of the integral management of urban solid waste of the metropolitan area of Buenos Aires, with process and standards that aim to decrease the environmental impact of the sanitary landfills. CEAMSE has a power generation plant based on biogas from waste from landfills that generates enough renewable electricity to supply 100,000 people or 25,000 homes and is injected into the national interconnected network.

Finally, the first projects of the mentioned ProBiogas program started in 2017 in the municipalities of Las Heras, Mendoza; Rafaela, from Santa Fe and Tapalqué and Olavarría, from Buenos Aires.

Only one initiative was identified to capture and transform CO2 from syngas streams, with potential application to biomass power generation. In 2018, a group of scientists from the Argentinan CONICET and Spanish National Research Council (CSIS) have developed a catalyst to reuse and transform CO2 and methane, and obtain synthesis gas (syngas). Syngas, is a gas consisting mainly of hydrogen and carbon monoxide, which can be obtained from substances with a high carbon content. Syngas is used as a raw material for the synthesis of multiple chemicals and fuels. In the first case, the material was continuously active for at least 100 hours, obtaining the maximum conversion of CO2 (at thermodynamic equilibrium) with a 100% selectivity to carbon monoxide. In the second case, the partial oxidation of methane reaction, maximum methane conversions to syngas were also obtained. The goal is to apply these processes in thermal power stations or in biomass gasification facilities to transform waste in chemical resources and energy sources. The scientists will test the catalyst at pilot plant scale. As the CSIC scientists Consuelo Alvarez Galván and José Antonio Alonso explain, **the goal is to apply these processes in thermal power stations or in biomass gasification facilities to transform waste in chemical resources and energy sources.**

Enhancing soil carbon content and Enhancing soil carbon content with biochar

Alignment with Government Vision and Commitment

No explicit mention to biochar as soil enhancer was identified in Argentinean policies and development plans, neither there are specific programs on the subject. In fact, the use of Biochar has been not considered into the list of mitigation actions or technologies for the AFOLU sector in Argentina. As matter of fact, biochar was recently included into the IPCC guidelines (IPCC 2019 methodology report) to provide guidance for inventory compilers. This technology would be considered as Carbon Capture and Storage strategy.

However, there are soil carbon sequestration programmes in cropland and grazing lands:

- INTA-Minagro- Soils Observatory ("Observatorio Nacional de Suelos") (https://www.magyp.gob.ar/sitio/areas/plan_suelos/onsa/).

One of the main actions of the Soils observatory is the monitoring of the carbon content of agricultural soils, through a sampling methodology that considers the different agroecological regions and productive systems, through the network of Delegations available to the Ministry of Agriculture, Livestock and Fishing.

With this information, Argentina prepares and periodically updates the national carbon stock map, complying with the demands of the international agenda related to sustainable development goals. This survey is also part of the the SISINTA program (http://sisinta.inta.gob.ar/)

- INTA -MInagro. Partner in the FAO initiatives SISLAC and GSOCmap

SISLAC ("Sistema de Información de Suelos de Latinoamerica") is a regional initiative promoted and sponsored by the Global Soil Partnership, which involves CIAT, EMBRAPA and 20 national institutes in Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, dominican Republic, Surinam, Uruguay and Venezuela. The system will be developed through state-of-the-art methods and tools of Digital Soil Mapping. The first phase, under CIAT leadership, involves the rescue, harmonization and storage of historical soil profiles in a regional database, which currently contains 6100 profiles, as well as the development of a regional 1:1,000,000 scale soil classification map using the national soil maps and the WRB soil classification system. The second phase, implemented by EMBRAPA in collaboration with INTA, involves capacity building and formal training in digital soil mapping and the development of soil property maps at national and regional level. Key to achieving this deliverable is the participation and leadership of the 20 countries involved in SISLAC.The SISLAC web site is currently not open to the general public: for data access user registration and use objectives statement are required.

http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1197582/

GSOC map: Soils Institute of INTA is a contributor of the Global Soil Organic Carbon Map providing data and information. This project is part of the Global Soil Partnership. http://www.fao.org/global-soil-partnership/pillars-action/4-information-and-data-new/global-soil-organic-carbon-gsoc-map/en/

Degree of Scientific Development / Academic Literature Review

Academic research on "biochar as soil enhancer" subject is still incipient in Argentina, and only a limited number of articles were identified. This practice is being studied and tested in experimental applications in Argentina. Local results come from a few studies published in the last years. The discussion is focused especially in the livestock sector, but still analysing in which areas and methodologies is feasible to obtain a significant mitigation response by reducing emissions or by capturing C in soils. In addition to technical studies about the effect biochar on soil properties, economic studies are also necessary in order to evaluate the potential extension of this practice to farmers.

IPCC defines Biochar as a “solid carbonized product from thermochemical conversion through pyrolysis (heating with limited air). The term biochar is used herein only to refer to materials that have been produced under process conditions in which relatively easily mineralizable organic materials are converted to more persistent forms by heating to above 350 °C with limited air through a gasification or pyrolysis process. This guidance does not deal with pyrolytic organic materials that result from wildfires or open fires and is only applicable for biochar added to mineral soils”.

The biochar C balance and its emission factors are depicted in equation 2.25 A, recently added into the Chapter 2 “Generic Methods”, volume 4 of the “2019 Refinement to the 2006 IPCC Guidelines”. Also, in Chapter 2, there is an appendix that provides additional information about Biochar estimating methods: “Appendix 4: Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development”.

Figure 15: Annual change in biochar carbon stock in mineral soils receiving biochar

EQUATION 2.25A
ANNUAL CHANGE IN BIOCHAR CARBON STOCK IN MINERAL SOILS RECEIVING BIOCHAR ADDITIONS

$$\Delta BC_{Mineral} = \sum_{p=1}^{n} \left(BC_{TOT_p} \bullet F_{C_p} \bullet F_{perm_p} \right)$$

Source: Refinement to the 2006 IPCC Guidelines for national GHG inventories (IPCC, 2019)

Private sectors and NGOs are progressing in terms of Studies and Decision Support systems oriented to reduce carbon emissions and estimating Soil Carbon Changes in Agriculture.

- AACREA" Sistemas de indicadores CREA" (https://www.crea.org.ar/sistema-de-indicadores/).

The Sustainability Indicator System CREA is the result of a long working process framed within the specific objective of generating technical information and indicators for decision making. It is tool that supports decision making that allows the user to take a first step in dimensioning environmental and economic parameters of agricultural field and rotations crops using a simple and fast mechanism.

Includes 8 indicators: contribution of carbon to the soil, nutrient balance, emissions of greenhouse gases, toxicological Load (DLef), use of agrochemicals for Toxicological class (color label) , energy efficiency, Energy Balance and Gross Margin . The results are displayed through graphs and tables.

- Plataforma PUMA (https://plataformapuma.com/).

This system, designed for farmers and advisors, makes possible to compute the carbon footprint using farmer's field crops database. It allows quickly, at the end of the crop season, to obtain a Carbon Balance in order to identify and quantify CO_2 emissions and captures, and evaluate what can be modified in the next agricultural season to reduce carbon footprint.

- Agreement AACREA -FVSA (Fundación Vida Silvestre Argentina) –

Grazing lands Convenio CREA-FVSA (Fundacion Vida Silvestre Argentina)- Study of soil Carbon and emissions from livestock and grasslands in agricultural systems. This study intends to also develop a DSS based con soil C models and other tools, to evaluate management practices under different soil and climate conditions in Argentina.

- INTA research on direct effect of biochar on soil C

Regarding Biochar considered as Carbon Capture and Storage strategy some researchers form INTA have started to evaluate the direct effect of biochar on soil C. Nevertheless, there is some relevant information about biomass available stock at national level for biochar production, as well as some private projects interested on this business.

- Final Report WISDOM Argentina (INTA-FAO agreement).

In 2009, INTA and FAO presented the final report providing valuable information about energy balance and availability of biomass for energy use (https://inta.gob.ar/sites/default/files/script-tmp-i0900s00_analisis_balance_energia.pdf).

The main objective of that study was promoting the energy use of biomass in the Argentina by quantifying the availability of biomass for energy use in priority areas and the institutionalization of the use of the WISDOM methodology as a tool for development of sustainable bioenergy systems in the country. The WISDOM (Woodfuels Integrated Supply / Demand Overview Mapping) methodology was developed by FAO, in cooperation with the Institute of Ecology of the National University of Mexico (UNAM), as a method to spatially visualize the areas priorities or "hot spots" for wood fuels. Even though this survey provides information to biofuels production, it can also be used by biochar production.

- Milesi Delaye, L. A., et al. 2020. Biochar application in a degraded soil under sweet-potato production. Effect on edaphic properties.

The authors analyzed the effect of biochar on a degraded soil in NE of Buenos Aires. In general, soils under horticultural/floricultural production systems present high soil degradation. Biochar application is mentioned as an alternative to mitigate soil degradation. In Argentina its study and use are incipient. In a Vertic Argiudoll, in a sweet potato production system under an agroecological management, the objectives of this work were to evaluate: a) the cumulative effect, two and a half years after its last application, of three annual biochar applications, of 30 Mg ha-1 in total, between 2013 and 2015 (from Aspidosperma quebracho-blanco feedstock), over soil properties, and b) the net change, for the 2012-2018 period, in soil properties with and without biochar applications. The authors concluded that "*Biochar application increased the soil organic carbon reserves (SOC) and pH of the 0-30 cm soil thickness, (…), but "leaving aside its direct effect on the SOC increase and the superficial bulk density reduction, the interactions biochar-soil still require study.*" It decreased the soil organic nitrogen reserves (SON) and increased the C/N ratio of the 0-20 cm soil thickness. Besides, it slightly increased the electrical conductivity of the 0-5 cm soil thickness and did not change the cationic exchange capacity. It also did not affect the water infiltration and the water holding capacity of the 0-30 cm soil thickness. However, a very marked increase in the moisture content and in the current water availability of the 10-20 and 5-10 cm soil thicknesses, respectively, were observed. When the absolute change was analysed, the same effect was observed for SOC and ph. For physical variables, edaphoclimatic conditions at sampling moment (lower moisture content in 2018) had a greater effect than the biochar. Apart from its direct effect on the SOC increase and the superficial bulk density reduction, the interactions biochar-soil still require detailed analysis.

- Dominchin, M. F., et al. 2019. Effect of poultry biochar on chemical and microbiological properties in a typical haplustol soil under different land-use intensities

The aim of the study was to evaluate the impact of different rates of poultry biochar on soil chemical and microbiological properties under a land-use intensity gradient. Three sites were selected: a pristine forest soil (SP), an agricultural soil under sustainable management (MS), and an agricultural soil under conventional tillage (LI). In general, biochar tended to increase Gram-negative bacteria compared to control. The study also showed an increase of total phospholipids fatty acids (PLFAs) in SP and LI, indicating that biochar can increase total microbial biomass. For this reason, the application of biochar could be of greater utility in the remediation of soils with a high level of edaphic degradation.

- Berger, M. 2020. Impact of the application of biochar on microbial communities in agricultural soil subject to different levels of nitrogen fertilization. Thesis. Universidad Nacional de Cordoba.

This thesis proposes the combined application of organic amendments with mineral fertilizers as a management alternative. This study evaluated the impact of the application of different doses of biochar made from peanut shells together with a nitrogen mineral fertilizer (urea), on the physical-chemical properties of the soil and on the structure and functionality of edaphic microbial communities in land for agricultural use subject to different types of management.

The aim of this study was to assess the impact of the application of different doses of biochar made from peanut shells together with a mineral nitrogen fertilizer (urea) on the physical-chemical properties of the soil and on the structure and functionality of the soil microbial communities in agricultural land subject to different management types. The collected soil belonged to the same textural type and included three types of management: pristine, under direct sowing, with 10 years of 2:1 rotation (soybeans/Maize), and under intensive tillage, without crop rotation and with conventional tillage. The results show that the application of biochar together with a mineral nitrogen fertilizer (urea) is capable of modifying the physical-chemical and microbiological characteristics of the soil, with emphasis on intensive tillage. However, although the application of biochar and urea produces important increases in pH, TOC, NT and enzymatic activity, similar trends can be observed when applying biochar without the mineral fertilizer in all the types of management analysed. Moreover, only biochar seems to affect the structure of microbial communities. Therefore, the role of biochar, on changes produced in the physicochemical and microbiological properties of the soil, seems to be more determinant than that of urea

- Rodriguez Ortiz L., et al. 2020. Influence of pyrolysis temperature and bio-waste composition on biochar characteristics. Renewable Energy, 2020, vol. 155, issue C, 837-847

The aim of this paper was to analyse the influence of the pyrolysis temperature and feedstock composition on biochar yield and physicochemical properties. The raw materials to be pyrolyzed were characterized, and an experimental design was applied to carry out a statistical study. Three operating temperatures (673, 773 and 873 K) and two bio-wastes (nut and almond shells), from San Juan Province (Cuyo Region), were used. The biochar’s presented H/C and O/C ratios and higher heating values similar to those of bituminous coal, confirming their potential as solid biofuels. They also presented high K and Ca contents. The obtained values for the aromaticity factor, stable C mass fraction and recalcitrance potential, indicated that the biochar’s could also be used for soil amendments, especially as acidic or basic compounds, according to their pH values.

- Milesi Delave, L.A., et al. Miscanthus x giganteus and Aspidosperma quebracho-blanco as feedstock sources for biochar production in Argentina. ENCONTRO BRASILEIRO DE SUBSTÂNCIAS HÚMICAS, 11., 2015, São Carlos.

Argentina is considering using new biomass sources for biofuel industry. Miscanthus and quebracho are two possible options and evaluated both feedstock to biochar production, since this material is always related to bioenergy production. As an energy feedstock, quebracho seems to have better value (higher C content). As biochar, quebracho showed higher stability, although both materials have use potential, depending on the main soil function that is wanted to be improved.

- Fermanelli, C. S. 2018. Waste recovery treatments from the agri-food industry in the Middle North Pampean Region. Universidad Tecnologica Nacional

A study of lignocellulosic biomass residues from the agri-food industry of the Middle North Pampean Region and the alternatives for their treatment and valorisation is presented. The objective was to valorise biomass residues of the agro-alimentary industry of the Middle North Pampean Region through physical and chemical treatments and to evaluate their potential to generate energy and / or products. Possible treatments of these residues were evaluated, as much for the production of energy, as for generating products of greater added value. Physical and thermochemical processes were studied among the alternatives available to produce bioenergy. Pelletizing and briquetting were described for the former and combustion, co-combustion, roasting, pyrolysis and gasification, for the latter. Among the options to generate higher value-added products, the production of activated carbon and agglomerated panels were analysed. Of the options studied, the pyrolysis of biomass was found to be a simple thermal process with great potential to be applied in the region.

Another relevant articles from earlier than the recent ten-year period defined are the following:

- Bonelli P. R., et al. 2006. Potentialities of the Biochar Generated from Raw and Acid Pre-Treated Sugarcane Agricultural Wastes. University of Buenos Aires

Chemical, thermal, and textural characteristics of the biochar generated from pyrolysis of sugarcane agricultural wastes at 600 ºC and 800 ºC have been ascertained in an attempt to examine specific end-uses for this abundant biomass. Pre-dried agricultural wastes from sugarcane (Saccharum officinarum), composed of leaves and tops, were supplied by a sugar mill located in Northwestern Argentine. According to the results, biochar produced at both temperatures is potentially suited as bio-fuel for domestic use, whereas the one resulting of 800 ºC could also be used for briquettes manufacture and in the steel sector as well as a low-cost, rough adsorbent, and/or soil amender. Besides, pyrolysis of pre-treated waste with a phosphoric acid solution at the lower temperature leads to enhance the biochar yield (41%) and to a highly developed porous structure with textural properties (BET area ~ 750 m2 /g and total pore volume of about 1 cm3 /g), comparable to those of some commercially available activated carbons.

Noticeable changes induced by the acid pre-treatment seem to be due to the catalytic action of the acid on the pyrolytic behaviour of the wastes, promoting degradation at lower temperatures compared to pyrolysis of the untreated ones. The biochar from the acid-pre-treated sugarcane agricultural wastes is found potentially appropriate as a substitute of conventional activated carbons extensively used in the sugar mills and related industries.

Initiatives and Projects Development

No large-scale projects have been identified related to biochar as soil enhancer in Argentina. However, , there is a company located in Concordia, Entre Rios province, Argentina, (LERA S.A https://www.vanmander.com/) that produces bio pellets (wood chips) and is strongly interested on migrating to Biochar production, depending on the Carbon market price in Argentina and Annex I countries in Europe.

Enhanced weathering or ocean alkalinisation

Alignment with Government Vision and Commitment

The preservation of the oceans is national priority, framed within the 2030 Agenda for Sustainable Development. The creation of the National System of Marine Protected Areas, scientific cooperation with the United States and participation in the "Our Oceans" Conference are some of the recent actions that reinforce Argentina's commitment to the preservation of the oceans and environmental protection. In compliance with international agreements, Argentina created the National System of Marine Protected Areas, through which it undertakes to allocate 10% of maritime spaces for protected areas. The equitable and sustainable use of the oceans is essential in a country like Argentina with a maritime coastline of more than 4,700 km.

Multiple scientific entities are conducting various investigations on oceans behaviour. The entities that carry out these investigations are: National Council for Scientific and Technical Research (CONICET), Naval Hydrography Service, Argentine Institute of Oceanography, Institute of Marine and Coastal Research, Institute of Coastal Geology, various national universities such as the National University of Buenos Aires, National University of Mar del Plata.

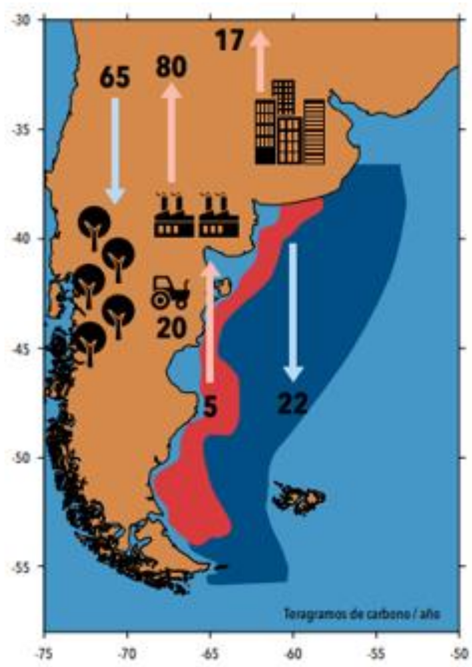
Degree of Scientific Development / Academic Literature Review

Even though there is scarce research, projects, legislation or investments in technologies related to carbon sequestration in oceans, there are entities including CONICET, INTA and Naval Hydrography Service examining the Argentine oceanic platform.

- Bianchi, A. A et al. Trapping CO2 in the Patagonian sea. Ciencia Hoy, Vol. 20 núm. 119 oct - nov 2010.

The flow of CO2 between the atmosphere and the ocean in the Patagonian Sea is studied. On a global scale, the net oceanic absorption of CO2 is leading to an increase in the concentration of CO2 and its inorganic derivatives, such as carbonic acid, reducing the pH and causing the acidification of the ocean. Acidification represents a threat to certain forms of marine life, for example the bleaching and deterioration of corals that would be associated, in part, with the increase in CO2.

Figure 16: Diagram of the main sources of emission in Argentina (arrows up, pink colour) and capture or sink of CO2 (light blue colour), according to their origins, in Tg (1012 g) carbon.



Source: Bianchi, A. A et al. Trapping CO2 in the Patagonian sea. Ciencia Hoy, Vol 20 núm 119 oct - nov 2010

In the absence of other sources or sinks, net capture of CO2 through the surface observed over a period of seven years in the Patagonian Sea could lead to an increase in the concentration of the gas in the water. Assessments concluded that the Patagonian Sea sequesters, in terms of its annual balance, four times more CO2 than the average of the global ocean, which makes it one of the regions with the highest CO2 capture on the planet.

- Kahl, Lucía Carolina. "Dinámica del CO2 en el Océano Atlántico Sudoccidental". Tesis Doctoral, Universidad de Buenos Aires. Facultad de Ciencias Exactas y Naturales, 2018.

This thesis studies the dynamics of marine carbonate system in the Southwestern Atlantic Ocean, using a wide set of in-situ data. The results show that the total alkalinity is conservative throughout the study region. In contrast, the dissolved inorganic carbon in the Patagonian Sea is strongly non-conservative. It was observed that the action of the biological pump results in a net sequestration of CO_2 in PS. North of 38 °S, there is a close relationship between the DIC and the different water masses, showing predominance of physical processes. Additionally, the current status of pH and the saturation states of calcite and aragonite (ΩCa and ΩAr) were analyzed, establishing a baseline for the study of ocean acidification.

- Osiroff A, et al. Distributions of alkalinity and dissolved inorganic carbon in the atlantic ocean southwest. Naval Hydrography Service

Explore distribution spatial alkalinity (AT) and dissolved inorganic carbon (DEC), in the Atlantic Southwest, in particular on the Argentine platform, continental slope and on an oceanic transect at 34.5 ° S. It is foreseen in the immediate future to relate the data of the carbon system with the local dynamics, especially with the subtropical front of platform and slope front. Starting in 2016, a pH measurement program will begin in the Southwest Atlantic, which added to new measurements of alkalinity and dissolved inorganic carbon, making possible to measure ocean acidification.

- Piola, A. R. et al. Argau Project measurement of CO_2 and physical-chemical and biological parameters associates, In the South Atlantic, Austral Ocean and Antarctica. Naval Hydrography Service, IV-number 1, 2001.

The main goal of the project is to determine the influence of the dynamics and of the biological processes in the CO_2 balance of the South Atlantic and the Southern Ocean. The project is an important progress towards understanding the resources of the regional environment and for other studies related to global warming.

- Cabrerizo, M. J. et al. Increased nutrients from aeolian-dust and riverine origin decrease the CO_2-sink capacity of coastal South Atlantic waters under UVR exposure. Limnology and Oceanography, Vol 63 Issue 3; 1191-1203. 2018.

Increases in ultraviolet radiation (UVR) levels due to the ongoing stratification of water bodies and higher nutrient concentrations either through riverine or aeolian-dust-inputs are expected in the near future in coastal surface waters. This study combines remote-sensing data of particulate organic carbon (POC; 1997–2016 period), observational data of solar radiation (1999–2015 period), and a mid-term experimental approach with coastal plankton communities from South Atlantic Ocean (SAO) to test how the interaction between increased nutrients by riverine and aeolian-dust inputs and high UVR may alter the community dynamics and the CO_2 sink capacity of these ecosystems in the future. The results show a decline ~ 27% in the sink capacity of the coastal ecosystems regardless of the nutrient source considered and under high UVR levels. This decreased CO_2 uptake was coupled with a high dynamic photo-inhibition and dark recovery of photosystem II and shifts in the community structure towards the dominance by nano-flagellates. Moreover, remote-sensing data also evidences an incipient tipping point with decreasing POC values in this area over the annual planktonic succession. Therefore, authors propose that to continue this climate and human-mediated pressure, these metabolic responses could be strengthened and extended to other productive coastal areas.

- Villafañe, V., et al. 2018. Dual role of DOM in a scenario of global change on photosynthesis and structure of coastal phytoplankton from the South Atlantic Ocean. CONICET

This study evaluated the dual role of DOM (i.e., as a source of inorganic nutrients and as an absorber of solar radiation) on a phytoplankton community of the western South Atlantic Ocean. Using a combination of microcosms and a cluster approach, authors simulated the future conditions of some variables that are highly influenced by global change in the region. The knowledge of the relative importance of both roles of DOM is especially important for coastal areas that are expected to receive higher inputs and will be more acidified in the future.

- Villafañe, V., et al. 2020. Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. CONICET

In this paper authors discuss five sources of anthropogenic pollution that affect marine and freshwater ecosystems: sewage, nutrients and terrigenous materials, crude oil, heavy metals and plastics. Using specific locations as examples, the study shows that land-based anthropogenic activities have repercussions in freshwater and marine environments, and details the direct and indirect effects that these pollutants have on a range of aquatic organisms, even when the pollutant source is distant from the sink. All these issues are in dire need of stricter environmental policies and legislations particularly for pollution at industrial levels, as well as solutions to mitigate the effects of anthropogenic pollutants and restore the important services provided by aquatic ecosystems for future generations.

Regarding enhanced weathering, no specific academic literature was identified in Argentina.

Initiatives and Projects Development

No specific initiative or project related to ocean alkalinisation was identified in Argentina.

However, in 2014, the Pampa Azul project has been launched with the aim of articulating the actions promoted by the different areas in the field of scientific research, technological development and innovation at sea. Pampa Azul aims to promote scientific knowledge, technological development and sustainable innovation in the South Atlantic, in order to create a culture of sea in society, promote the sustainable use of natural marine assets and strengthen the growth of the associated national industry. This project does not cover specifically ocean alkalinisation neither ocean fertilization. The Coordinating Committee is in charge of the design and implementation of a strategic plan structured around three main axes: Promotes the generation of interdisciplinary scientific knowledge that serves as a foundation for the preservation and sustainable management of marine natural assets; Targets technological innovations that contribute to the strengthening of industries linked to the sea and the economic development of the Argentine maritime regions; Promotes greater awareness in Argentine society about its maritime heritage and the responsible use of its resources. The initiative focuses on five priority geographic areas in terms of research efforts: Burdwood Bank / Namuncurá Protected Area; the Blue Hole / Continental Slope; San Jorge Gulf; the Subantarctic Islands (Georgia and the South Sandwich); and the Fluvial-Marine System of the River Plate. Among the institutions that participate in Pampa Azul are CONICET, national universities, and science and technology institutions.

Regarding enhanced weathering, neither were initiatives or large projects identified in Argentina.

Direct air carbon dioxide capture and storage

Alignment with Government Vision and Commitment

There are no specific laws, national plans nor programs in Argentina covering direct air carbon dioxide capture and storage.

Degree of Scientific Development / Academic Literature Review

A workshop on the DAC topic was held by the National University of Cuyo in Mendoza, Argentina in October 2018. The workshop was presented by the PhD. Fernando Mestre Sanchís, from the University of Zaragoza, Spain. It was mainly aimed at researchers with projects that address lines on CO_2.

No academic literature was identified in Argentina covering direct air carbon dioxide capture and storage.

However, some articles were identified analysing the CO_2 capture properties of Li_4SiO_4 and CO_2 reactivity with Mg_2NiH_4, but with no specific mention to DACCS.

- Grasso, M. L. 2020. CO_2 capture properties of Li_4SiO_4 after aging in air at room temperature. Journal of CO_2 utilization. 38 232-240.

In this study, the physicochemical stability of lithium orthosilicate (Li_4SiO_4) powders after aging in air was evaluated. Thermogravimetric (TG) analysis in CO_2 flow evidences that as-milled Li_4SiO_4 stored in a closed plastic container in air at Room Temperature (RT) suffers a time progressive CO_2 absorption. These phases enhance the reaction with CO_2 from the air to form Li_2CO_3 at RT before the first carbonation cycle. As a consequence, the CO_2 capture capacity of Li_4SiO_4 in the first carbonation cycle was smaller than the one of Li_4SiO_4 without water vapor exposure. In opposition, negligible CO_2 absorption occurred at RT under CO_2 atmosphere. The original properties of Li_4SiO_4 powders with high specific surface area could be regenerated by heating at 700 °C. Consequently, the storage conditions of Li_4SiO_4 powders should be considered for their use in different applications.

- Grasso, M. L. 2020. CO_2 reactivity with Mg_2NiH_4 synthesized by in situ monitoring of mechanical milling. Physical chemistry chemical physics: PCCP

Authors mentioned that CO_2 capture and conversion are a key research field for the transition towards an economy only based on renewable energy sources. In this regard, hydride materials are a potential option for CO_2 methanation since they can provide hydrogen and act as a catalytic species. In this work, Mg_2NiH_4 complex hydride is synthesized by in situ monitoring of mechanical milling under a hydrogen atmosphere from a $2MgH_2$:Ni stoichiometric mixture. The as-milled Mg_2NiH_4 shows high reactivity for CO_2 conversion into CH_4. Under static conditions at 400 °C for 5 hours, the interactions between as-milled Mg_2NiH_4 and CO_2 result in total CO_2 consumption and in the formation of the catalytic system Ni-$MgNi_2$-Mg_2Ni/MgO. Experimental evidence and thermodynamic equilibrium calculations suggest that the global methanation mechanism takes place through the adsorption of C and the direct solid gasification towards CH_4 formation.

Initiatives and Projects Development

A team made up of Doctors Fernando Mestre-Sanchís, María L. Feijóo and Mario X. Ruiz-González decided in 2018 to take the first step to apply a DAC technology by promoting the creation of a trust to install a capture plant in the province of Mendoza. The DAC technology is to be provided by the US-based company Global Thermostat (GT), whose CEO is an Argentinean scientist PhD Graciela Chichilnisky. The promoters of the Trust, which bears the name of Mallín I, have the technical support of the company expressed in an agreement for the development of the technology in Argentina. The planned investment is about 4 million dollars and the project duration till start-up was estimated in 18 months. Once completed it would be the first DAC plant in Argentina and South America. As for October 2020, no progress in the project has been reported.

Ocean fertilization

Alignment with Government Vision and Commitment

See ocean alkalinisation. There are no specific national plans or programs related to ocean fertilization.

Degree of Scientific Development / Academic Literature Review

No specific academic literature related to ocean fertilization was identified in Argentina.

Same documents reviewed in ocean alkalinisation are relevant to ocean fertilization, as they characterize and cover the effects of climate change in Argentine oceans.

Initiatives and Projects Development

No specific initiative or project related to ocean fertilization was identified in Argentina.

Other initiatives related to bioenergy generation that may provide a basis for further BECCS development

Alignment with Government Vision and Commitment

In January 2010, Argentina implemented a mandate of 5 percent bioethanol in gasoline and 5 percent biodiesel in diesel. This mandate was increased to nine percent in January 2014 and ten percent in February 2014. A ten percent biodiesel blend requirement was added for power generation plants technically able to use a biodiesel blend but it was never enforced and virtually none is used in the sector. Resolution 37 in April 2016 raised the minimum blends to 12 percent bioethanol and 10 percent biodiesel. In the case of bioethanol, the additional 2 percentage points had to be supplied by the sugar industry.

Law N° 26,093, as well as establishing minimum blends for biodiesel to be used in transport, established a minimum blend of 5% for biodiesel in diesel oil for power generation, focused on certain power plants, which was increased to 7% by the end of 2010.

The maximum share of biodiesel in diesel oil blends por power generation in Argentina was reached in 2012, at 4.35%, accounting for 65,517 tons, equivalent to 7.5% of the total domestic sales for that year.

Furthermore, in December 2013, by Resolution 1125/2013 the Secretariat of Energy increased the share of biodiesel in blends for power generation for each power plant in which it is «technically possible[15]».

Nonetheless, several quality problems related to blended biodiesel or pure biodiesel (B100) where faced during the first years of implementation of these measures, and the blend declined from 2012 onwards.

Based on resolution 1125/2013, the Secretariat of Energy instructed Argentina's Independent System Operator (CAMMESA) to acquire B100 for power generation setting a price equivalent to the price fixed for "big companies" destined for transportation plus the recognition for logistics costs (transportation and storage), and in turn CAMMESA made several tenders procuring the acquisition of this fuel.

[15] Article 2, Resolution 1125/2013.

As a result of these tenders, an apparent mismatch of the fuel specifications[16] and the sanctioned prices resulted in virtually no offers and thus, the withdrawal of biodiesel for domestic power generation in the interconnected system, with small volumes being currently sold to small off-grid generators.

Still, Argentina's 1,665 MW of installed capacity in reciprocating (diesel) engines currently installed in the interconnected system represent the biggest potential for switching diesel oil with B100 in power generation, in contrast to the 208.6 MW current installed capacity for biogas and biomass power plants. In 2019 these diesel engines generated 1,892 GWh, 3.4 times the biogas + biomass generation, and in consequence this installed capacity is relevant in terms of this study, when compared to the initial biogas and biomass installed capacity.

Thus, for further analysis, the current grid-connected diesel engines installed capacity will be considered for the baseline scenario as susceptible to be modelled with post-combustion carbon capture technologies. Additionally, a partial switch from diesel oil to biodiesel will be modelled for certain gas turbines, up to B20, according to their technology conditions, and considering new treatments currently applied by domestic companies, including their costs.

Degree of Scientific Development / Academic Literature Review

- Falasca, S. et al. "Agroclimatic aptitude of the arid and semi-arid areas in Argentina for the cultivation with prickly pear (Opuntia ficus indica) as bioetanol source". Quebracho, Vol 19(1,2):66-74. 2011.

The objective of the paper was to evaluate the agroclimatic aptitude of Argentina to plant Opuntia ficus indica in marginal areas for the double purpose to produce tuna as edible fruit and to use the cladodes to produce bioethanol. As a conclusion, the Argentine agroclimatic aptitude was delimited for Opuntia ficus indica plantations that may be used for dual purposes: for fruit production and as an energy crop. More than half of the surface of Argentina has appropriate aptitude for the cultivation of the Opuntia, including optimal and marginal aptitudes with irrigation.

Initiatives and Projects Development

Regarding biofuels, Argentina is one of the largest producers and exporters of bioethanol and biodiesel, with several large-scale plants installed in the last 10 to 15 years. Argentina has 22 bioethanol plants with an estimated production capacity of 1.3 million m3 (not all active in

[16] DIN EN 14214 (former DIN 51606) Automotive Fuels FAME specification, but lowering limits for Sodium and Potasium from 5 ppm (parts per million) to less than 0.5 ppm and a kinematic viscosity of less than 6 cSt (centistokes).

production). Main raw materials of bioethanol plants are sugarcane and maize. Largest plants are located in Cordoba province. Total national production was over 1.1 million m3 in 2018.

Table 12: Largest Bioethanol plants in Argentina (not exhaustive)

Plant / Company	Location	Installed Capacity MM litres/y	Start-up	CAPEX MMUSD	Raw Material
ProMaize (JV AGD y Bunge)	Córdoba	180	2013	200	Maize
Aca-Bio (ACA Bio Coop. Ltda.)	Córdoba	180	2014	150	Maize
Cía. Bionenergética La Florida SA	Tucumán	150	2010	3.5	Sugarcane
Tabacal (Alconoa SRL)	Salta	150	2009	40	Sugarcane
Vicentín SAIC	Santa Fe	110	2012	nd	Maize y Sorgum
Bioledesma (Ledesma)	Jujuy	100	2011	15	Sugarcane
BIO 4 (Porta Hnos. Alfa Laval)	Córdoba	90	2012	35	Maize
Diaser	San Luis	82	2014	40	Maize
Biomadero	Chaco	50	2011	nd	Sugarcane
Agroctanos	Córdoba	50	2013	40	Maize y Sweet potato
Maiz Energia SA	San Luis, Sgo Estero, Cordoba	32	2017	Nd	Maize
Cía Bioenergía Santa Rosa SA	Tucumán	30	2010		Sugarcane
Bioenergía La Corona SA	Tucumán	30	2009	nd	Sugarcane
Santa Barbara (Energías Ecológicas de Tucumán SA)	Tucumán	25	2010	nd	Sugarcane
Biotrinidad SA	Tucumán	22	2010	nd	Sugarcane
Río Grande Energía	Jujuy	12	2010	2	Sugarcane
Bio San Isidro SA	Salta	6	2010	nd	Sugarcane

Source: INTA; BCR

Regarding biodiesel, there are 38 biodiesel plants with a total production capacity of 4.4 million m3 per year, but only 12 of them have capacity larger than 100,000 m3 per year. Most of largest plants are located in Santa Fe province, accounting for 80% of Argentina's production.

Table 13: Largest Biodiesel plants in Argentina

Company	Location	Province	Annual production capacity (tn)
LDC Argentina	*Gral. Lagos*	*Santa Fe*	610.000
Renova	*San Lorenzo*	*Santa Fe*	480.000
Patagonia Bioenergía	*San Lorenzo*	*Santa Fe*	480.000
T6 industrial	*Puerto Gral. San Martín*	*Santa Fe*	480.000
COFCO Argentina	*Puerto Gral. San Martín*	*Santa Fe*	240.000
Cargill	*Villa Gdor Galvez*	*Santa Fe*	240.000
Unitec Bio	*Puerto Gral. San Martín*	*Santa Fe*	240.000
Viluco	*Frías*	*Sgo del Estero*	200.000
Vicentin	*Avellaneda*	*Santa Fe*	120.000
Molinos Río de la Plata	*Rosario*	*Santa Fe*	120.000
Explora	*Puerto Gral. San Martín*	*Santa Fe*	120.000
El Albardón	*Puerto Gral. San Martín*	*Santa Fe*	100.000
Diaser	*Parque Ind. S. Luis*	*San Luis*	96.000
Aripar	*Daireaux*	*Buenos Aires*	50.000
Cremer Argentina	*Arroyo Seco*	*Santa Fe*	50.000
Bio Bahía	*Bahía Blanca*	*Buenos Aires*	50.000
Pampa Bio	*General Pico*	*La Pampa*	50.000
Rosario Bioenergy	*Roldán*	*Santa Fe*	50.000
Bio Ramallo	*Ramallo*	*Buenos Aires*	50.000
Bio Bin	*Junín*	*Buenos Aires*	50.000
Bio Nogoyá	*Nogoyá*	*Entre Ríos*	50.000
Latin Bio	*Arroyo Seco*	*Santa Fe*	50.000
Bio Corba	*Ramallo*	*Buenos Aires*	50.000
Refinar Bio	*Ramallo*	*Buenos Aires*	50.000
Bio Sal	*Ramallo*	*Buenos Aires*	50.000
Energías Renovables	*Catriló*	*La Pampa*	50.000
Advanced Organic Materials	*Parque Ind. Pilar*	*Buenos Aires*	48.000

Diferoil	*General Alvear*	*Santa Fe*	48.000
Energías Renovables Argentinas	*Piamonte*	*Santa Fe*	24.000
Colalao del Valle	*Los Polvorines*	*Buenos Aires*	18.000
Soy Energy	*Villa Astolfi*	*Buenos Aires*	18.000
Hector Bolsan	*Aldea María Luisa*	*Entre Ríos*	14.400
Prochem Bio	*Ramallo*	*Buenos Aires*	12.000
New Fuel	*Villaguay*	*Entre Ríos*	10.800
BH Biocombustibles	*Calchaquí*	*Santa Fe*	10.800
Doble L Bioenergias	*Esperanza*	*Santa Fe*	10.800
Agro M&G	*Saladillo*	*Buenos Aires*	8.000
Total production capacity Argentina (ton/year)			4.398.800

Source: BCR, Energy Secretariat

2. Colombia

Colombia is committed to fighting climate change, to the success of the UNFCCC negotiations and, particularly, to the adoption in December 2015, of a new legally binding agreement that will include commitments for all Parties during the COP 21.

According to the country´s First Biennial Update Report and the Third National Communication on Climate Change, in 2010 the country produced estimated greenhouse gas emissions (GHG) of 224 Mton of CO2eq, which represents just 0.46% of total global emissions for 2010. Nevertheless, the country is highly exposed and sensitive to the impacts of climate change, given its diverse geography and economy, which is highly dependent on the climatic conditions and the use of natural resources.

Colombia presented in 2015 its first NDC, which comprises the following objectives:

- a greenhouse gas emissions reduction target of 20% below the business-as-usual (BAU) emissions scenario by 2030 (reduction of 66.5 million tCO2eq)
  - 30% below the BAU scenario conditional to international support (reduction of 99.7 million tCO2eq)
- a set of climate change adaptation milestones covering ecosystems, land use planning and vulnerable populations
- proposed means of implementation such as research and innovation programmes and financial mechanisms

Colombia's NDC includes Mitigation, Adaptation, and Means of Implementation. The most important sectors for mitigation are agriculture, forestry, and other land use (AFOLU) (46 percent of Colombia's total emissions) and energy (42 percent). Each of the major emitting sectors in Colombia are covered by at least one strategic target that is directly related to the national emissions reduction goal. In the energy sector, the participation of non-conventional renewables in the energy matrix is set to increase from 22.4 megawatts (MW) to 1,500 MW, and the energy intensity of production will decrease by about 7% as a result of energy efficiency initiatives. In the transport sector, a combined approach of alternatives to road transport, improved logistics and a less polluting vehicle fleet has been proposed. About 1,000 companies in the country's main industrial corridors should be under cleaner production programmes. Through a circular economy strategy, the national recycling rate should rise from 8.7% to 12% by 2022.

Specifically, in the AFOLU sector, the Government of Colombia has chosen to focus its efforts on three goals:

i. halting the accelerated growth of deforestation;
ii. a commitment to enhance greenhouse gas removals by expanding agroforestry, sustainable management of natural forests, silvopastoral systems, and other forms of productive land restoration in over 700,000 hectares; and,
iii. implementing best practices in Colombia's agricultural lands by applying less fertilization.

Under the Ministry of agriculture and rural development selected measures comprise:

- Rational pasturing
- Manure management in livestock (including increased usage of silvo-pastoral systems)
- Increase in permanent crops, forest plantations and tree fruits (palm oil, mango, avocado, rubber and cocoa)
- Implementation of the AMTEC system (mass adoption of technology)

Further on, sustainable intensification in the agriculture sector is integrated in to the strategies to implement emission reductions in that sector.

Significantly, efforts to reduce deforestation by 39% compared to baseline emissions are a cross-cutting responsibility shared by all ministries.

These measures are conceived also taking into consideration that major agroecosystems in the country are vulnerable to increased aridity, soil erosion, desertification, and changes in the hydrological system.

The National Development Plan established a goal to limit deforestation rates while the government launched the Amazon Vision Program under the Strategy for REDD+ and a payment for results scheme was agreed to reduce deforestation nationwide. Colombia has a vast carbon sequestration potential in terms of development and improvement of soil and biomass sequestration of carbon.

Colombia played a leading role in the development of the 2030 Agenda and the SDGs. It was one of the first countries to incorporate the SDGs into the National Development Plan and one of the 22 countries that voluntarily disclosed results in 2016 for the first time.

In 2015, the Colombian government created the inter-institutional commission for SDGs with the mission of leading and coordinating the achievement of the SDGs. Colombia also adopted a strategy for SDG implementation based on four policy guidelines: monitoring and reporting; strengthening statistical capacities; creating territorial strategies; and building partnerships and promoting dialogue with non-governmental actors. With help from the Swedish government, Colombia developed a virtual platform (https://www.ods.gov.co/) to capture and communicate SDG related developments in the country. Users can follow the 2030 Agenda for Colombia, learn how the goals have been adapted to the Colombian context, and find out more about measurement and follow up of each one.

The SDG Commission in Colombia also examined the degree of alignment between the SDGs and their targets and the country's other priority agendas, including: The National Development Plan; accession to the Organisation for Economic Co-operation and Development (OECD); the Green Growth Strategy; and the Peace Agreement.

In 2018, representatives from the public and private sectors developed a report about the business contributions to the SDGs in Colombia, titled "United for the SDGs: The contribution of our companies" ("United for the SDGs: The contribution of our companies".). In this first edition, 19 leading companies released information about their management practices across 34 indicators that reflect their direct influence on 13 SDGs and indirectly on three SDGs over the last three years. the same year, the National Department of Planning published the document CONPES 3918 (CONPES 3918) where the goals and strategies for the compliance with the 2030 Agenda were established for the country.

The following table depict the scoring for each CDR approach and each of the assessment dimensions for Colombia, with its supportive summarized evidence for such scoring, based on the detailed review of the current status of knowledge, planning and implementation.

Table 14: Colombia - Current Status of Knowledge and Development -Scoring Methodology

CDR approach	Assessment dimensions	Scoring	Evidence for Scoring
Afforestation and reforestation	*Scientific and Technical Knowledge*		• Fifteen pieces of knowledge identified covering the territory assessment with information on deforested / reforested areas and carbon capture analysis by different species of trees, among other topics
	Mainstreaming in Government planning		• As part of the government's commitment to climate change, various national plans were developed: 2000's National Forest Development Plan (restoration of 245,000 ha, establishment of 271,000 ha protective forests and 332,000 ha protective/producing forests); 2004's Support Program for the National Environmental System (20,472 ha) and 2015's National Plan for Ecological Restoration, Rehabilitation, Restoration and Recovery of Disturbed Areas. • Colombia has set ambitious goals to curb deforestation, including reducing the annual loss of natural forests to 155,000 ha or less by 2022 and 100,000 ha or less by 2025 (from current levels of 220,000 ha per year).
	Implementation of initiatives and projects		• Various programs and projects are being carried out, including Celsia from Grupo Argos with the aim of planting 10 million trees in 10 years; two projects (Tumacoco and La Pedregoza) from Tree Nation platform that already offset more than 400,000 tons of CO_2; and the Biocarbono Fund in strategic collaboration with the World Bank
Bioenergy with carbon capture	*Scientific and Technical Knowledge*		• Eleven academic articles have been identified covering biomass power generation and biofuel production in Colombia

and storage (BECCS)			• Four pieces of knowledge were identified regarding other biomass power generation covering the following topics: energy potential of agriculture, agroindustry, livestock, and slaughterhouse biomass wastes; government incentives for waste energy; comparison of operating annual cost under some types of biogas produced from poultry, bovine and porcine manure, and solid urban organic waste; municipal solid waste as a source of electric power generation. • None academic articles were identified approaching BECCS integrally in Colombia
	Mainstreaming in Government planning		• Laws N° 1,715/2014 and N° 1,955/2019, regulated the integration of non-conventional renewable energy to the national energy system; promoted investigation on the subject; granted fiscal incentives and approved a national plan that included a goal to produce 8 to 10% of Colombia's energy from renewable energy sources • "National Policy for Comprehensive Solid Waste Management by 2030" (2016) • No specific Government plan or program promoting BECCS as an integral CDR approach was identified in Colombia
	Implementation of initiatives and projects		• All identified projects are focused on BE, but none of them has reported a CCS phase, therefore there are no integral BECCS projects planned, under construction nor in operation in Colombia • Biomass-fed power generation installed capacity is mostly represented by bagasse CHP[17] and currently represents 0.8% over Colombia's installed capacity (140 MW), after an increase of 50 MW (+54%, at a CAGR[18] of 9%) between 2015 and 2020.

[17] Bagasse as a Fuel for Combined Heat and Power (CHP)
[18] Compound Annual Growth Rate

			• Despite no bioenergy project was awarded in Colombia's first two renewable energy auctions, there are a few small-scale biomass projects under study
Enhancing soil carbon content with biochar	*Scientific and Technical Knowledge*		• Nine academic articles and research initiatives have been identified related to biochar as soil carbon content enhancer in Colombia. All of them mentioned positive preliminary results for biochar on small scale (laboratory) tests.
	Mainstreaming in Government planning		• Even though not mentioning biochar explicitly, there is a national program launched in 2015 called "Colombia Siembra" which main goal was to expand by one million the hectares sown in the country, aiming to increase the area and the yields destined to the production and strengthen technological development
	Implementation of initiatives and projects		• No large-scale projects have been identified related to biochar as soil enhancer in Colombia. • However, many experimental / laboratory projects and test were performed, as detailed in the literature review
Enhanced weathering or Ocean alkalinization	*Scientific and Technical Knowledge*		• Four academic articles have been identified in Colombia related to ocean characterization and effects of climate change on it. However, no specific academic literature was identified related to Enhanced weathering or Ocean alkalinization
	Mainstreaming in Government planning		• Since beginning of 2000 decade, Colombia has instrumented its National Policy of the Ocean and Coastal Spaces and the Colombian Ocean Commission (CCO). • There are no specific national plans or programs related to Enhanced weathering or Ocean alkalinization
	Implementation of initiatives and projects		• No specific initiatives or small / large-scale projects identified

Direct air carbon dioxide capture and storage	*Scientific and Technical Knowledge*		• No academic literature was identified in Colombia covering direct air carbon dioxide capture and storage technologies, except one particular paper, but it is focused in CO2 storage in deep formations in the Llanos basin.
	Mainstreaming in Government planning		• No specific legislation, government plans / programs nor academic literature was identified in Colombia
	Implementation of initiatives and projects		• No specific initiatives or small / large-scale projects identified
Ocean fertilization	*Scientific and Technical Knowledge*		• *Idem Ocean Alkalinization*. There are no specific national plans or programs related to ocean fertilization.
	Mainstreaming in Government planning		• *Idem Ocean Alkalinization*. Indirect academic research on oceans behaviour and characterization and CO2 dynamics, but no specific article on Ocean fertilization
	Implementation of initiatives and projects		• *Idem Ocean Alkalinization*. No specific initiatives or small / large-scale projects identified

Source: Own elaboration on the basis of review of information and rating

Afforestation and reforestation

The following figure summarizes in a timeline, regulations, plans and programmes related to afforestation and forest restoration CDR approaches implemented in Colombia, that are developed in a detailed manner in the following sections.

Figure 17: Afforestation and reforestation related regulations, plans and programmes implemented in Colombia - Timeline

Source: own elaboration

Alignment with Government Vision and Commitment

Colombia is a country committed to forestry activity and forests protection. Among some of the laws that regulate the activity, Law N° 2 of 1959 establishes seven areas of forest reserves for the development of the forest economy and protection of soils, water and wildlife. These areas are: Cocuy, Sierra Nevada de Santa Marta, Central, Serrania de los Motilones, Rio Magdalena, Pacific, Amazonia (Amazonas, Cauca, Guainia, Putumayo and Vaupes) and Amazonia (Caqueta, Guaviare and Huila).

In 1994, Law N° 139 was enacted, creating the forest incentive certificate, to promote direct investments in new protective-product forest plantations on land suitable for forestry. There is also the "Law of incentives for afforestation, reforestation and the protection of forests", which establishes incentives to promote the incorporation of the private sector in the execution of reforestation and forest protection programs in order to reverse the deforestation process suffered by the country.

In 2010, Law N° 1.377 was enacted, which regulates commercial reforestation activity. Finally, in 2017, through Decree 1.257, the "Intersectoral Commission for the Control of Deforestation and Comprehensive Management for the Protection of Natural Forests" was created. Its purpose is to guide public policies, plans, programmes, activities and strategic projects to be carried out by entities for the control of deforestation and the management of natural forests.

In recent years, Colombia has been listed as one of the five countries with the highest deforestation with nearly 43 thousand hectares of forest cut down in the Colombian Amazon. Therefore, the national authorities have implemented programs in favour of reforestation. National strategy existing since year 2015 seeks to restore ecosystem services in areas that have been degraded, providing forest management with alternatives such as silvopastoral crops and other sustainable restoration strategies.

As part of the government's commitment to climate change, various national plans were developed.

- 2000's National Forest Development Plan

The main objective was to establish a strategic framework that actively incorporates the forestry sector into national development, optimizing comparative advantages and promoting the competitiveness of timber and non-timber forest products in the national and international market, based on forests. native and afforested, sustainable management. Specific objectives were also determined: incorporate, conserve and manage forest ecosystems for the provision of environmental goods and services and develop processes in which the actors related to the forest sector, participate in the preservation, protection, conservation, use and management of forest ecosystems with the objective of building a sustainable society. Within this plan, various programmes are developed, including the Program for Forests Ecosystems Management, Conservation and Restoration, carried out by Research Institutes, Universities, National Corporation for Forest Research and Development (CONIF) and Federacafe, with the support from the Ministry of the Environment and the participation of NGOs. It seeks in a period of 7 years the restoration of 245 thousand hectares, the establishment of 271 thousand hectares of protected forests and 332 thousand hectares of protected/commercial forests.

- 2004's Support Program for the National Environmental System

In 2004, with support from the Inter-American Development Bank, the Support Program for the National Environmental System (SINA II) was financed. The purpose of this program is to improve environmental management through support in the formulation, implementation and monitoring of environmental or strategic policies for environmental management, and the promotion of sustainable development, based on the execution of recovery, conservation programs and projects. The goal of this program was the implementation of 20,000 hectares, managing to establish and maintain 20,472 hectares (2% above the established goal).

- 2015's National Plan for Ecological Restoration, Rehabilitation and Recovery of Degraded Areas (PNR). 2015

Its objective is to guide and promote the ecological restoration, recovery and rehabilitation of Colombian degraded areas within a broad framework of biodiversity conservation and adaptation to global changes. The plan proposes 3 phases that will be developed in a period of 20 years. The Ministry of Environment and Sustainable Development, through the Directorate of Forests, Biodiversity and Ecosystem Services, technically supports and manages the implementation of the Plan, as well as assess the accomplishment of proposed goals, according to key indicators. The Environmental Authorities coordinate within their powers the implementation of the Plan at the regional and local levels; the Colombian Network for Ecological Restoration.

Degree of Scientific Development / Academic Literature Review

Several scientific articles have been identified on the subject, being the following ones the most relevant:

- Quinonez Collazo, L. J. 2010. Urban forest management as a mechanism to capture carbon on the campus of de Pontifical University Javeriana. Thesis for the master's degree in Environmental Management. Pontifica Universidad Javeriana.

An academic exercise was carried out that allowed identifying the balance of emissions and carbon capture in the Javeriana University since 1930 to 2008. It was found that according to the estimates of emissions caused by the students and by constructions, the emissions balance is completely negative.

- Riveros Romero M. A. 2011. Market research: Diagnosis of reforestation projects in the Colombian Orinoquia. Master oficial en dirección de marketing. Universidad Cardenal Herrera, Valencia España.

The role of forests in climate change is described, with an overview of the Colombian situation. The reforestation situation in Colombia and a brief socioeconomic analysis in the Orinoquia area are described.

- Africano, K., Cely, G. & Serrano, P. "Potential CO2 Capture Associated with Edaphic Component in Moorlands Guantiva-La Rusia, Department of Boyacá, Colombia". Perspectiva Geográfica, 21(1), 91-110. 2016

The objective was to determine the effect caused by human activities and the ability to capture CO2, in permanent sample plots (PPM); one located in an intervened area, another in an unhampered area and another in a recovery area in the complex of moors in Guantiva-La Rusia (Boyacá, Colombia). The PPM in recuperation showed greater ability to capture an average of 872.26 t.ha-1; in contrast with the minor capacity PPM which was taken with a mean value of 221.70 t.ha-1. T. This shows the negative effect exerted by human activity on the ability to capture carbon in these soils, and the role these ecosystems play as carbon drains, hence the importance of their protection and conservation.

- Sanchez Cuervo, A. M et al. "Land cover change in Colombia: surprising forest recovery trends between 2001 and 2010." PLoS ONE 7(8): e43943. doi:10.1371/journal.pone.0043943. 2012.

Monitoring land change at multiple spatial scales is essential to identify critical points of change and to develop and implement policies for the conservation of biodiversity and habitats. Annual land use and cover mapping was conducted from 2001 to 2010 in Colombia using MODIS products (250 m) together with reference data from high spatial resolution images (QuickBird) in Google Earth, to visually interpret the coverage of eight land cover classes used for the classifier training and accuracy assessment. On the basis of these maps, the land cover change was evaluated at four country spatial scales, biome, ecoregion and municipality. Of the 1,117 municipalities, 820 had a net gain in afforested vegetation (28,092 km2) While 264 had a net loss (11,129 km2), which resulted in a net gain of 16,963 km2 in wooded vegetation nationwide. Arboreal regrowth occurred primarily in areas previously classified as mixed wooded / plantations rather than agricultural /herbaceous. Most of this gain occurred in the humid forest biome, within the montane forest ecoregions, while the greatest loss of wooded vegetation occurred in the Llanos and Apure-Villavicencio ecoregions. It is concluded that the trend towards forest recovery, especially in the Andes, provides a unique opportunity to expand protected areas and promote habitat connectivity.

- Zúñiga-Escobar, O. et al. "Assessment of the impact of anthropic activities on carbon storage in soils of high montane ecosystems in Colombia". March, 2013.

The organic carbon in soil was quantified to assess the impact of anthropic activities on montane ecosystems in Chingaza Parque Nacional Natural (PNN) and Los Nevados Parque Nacional Natural (PNN). The calculation of the amount of total carbon stored in soil reflects that, in Colombia, non-degraded high montane ecosystems (520.9 t ha-1 in paramos and 323.6 t ha-1 in high Andean forests of Chingaza PNN , and 373.0 t ha-1 in paramos and 254.6 t ha-1 in high Andean forests of Los Nevados PNN) currently have more carbon than degredaded ecosystems (135.1 t ha-1 in paramos and 141.5 t ha-1 in high Andean forests of Chingaza PNN , and 356.3 t ha-1 in paramos and 217.1 t ha-1 in high Andean forests of Los Nevados PNN). It is clear that the degradation of high montane ecosystems decreases the amount of carbon in the soil.

- Sanchez-Cuervo, A. M., and T. M. Aide. "Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas". Ecosphere 4(11):143. 2013

The main objective of this work was to evaluate the implications of territorial change in present and future protected areas. Hot spots of reforestation and deforestation were identified between 2001 and 2010, and the factors that explain the earth shift within these critical points. Four reforestation foci were identified mainly located in the highlands of the Andes, and four foci of deforestation that were located in the lowlands. Although protected areas cover 12% of the country, only 4% of reforestation and deforestation hotspots included protected areas. Understanding land change dynamics is essential for future planning of protected areas, with immediate benefits for the conservation of these areas, short- and medium-term benefits for ecosystems, and medium- and long-term benefits for biodiversity.

- Salazar Lopez C. et al. 2016. Benefits of reforestation in water regulation in Colombia. Thesis for the title of Environmental Engineer. National Open and Distance University.

Studies on reforestation and deforestation in the different Colombian zones and territories were analyzed. It was found that in 1990 the forest covered 56.5% of the national territory, and by 2010 it reached 51.4%. Colombia has around 67 million hectares with forestry vocation, of which 25 million are considered suitable and suitable for reforestation. Colombia has planted approximately 9,908,927 hectares of forest in transition and 35,603 of planted forests. From these studies it is obtained that the benefits caused by reforestation are in the process of development, since the projects that have been stipulated to reverse the environmental damage caused by deforestation are from present times, however, the damage caused is identifiable.

- Ruano Parra, J. E. "Estimation of carbon capture in Las Garzas ecopark, Cali Valle del Cauca". Degree Thesis. Universidad Autonoma de Occidente. Facultad de Ciencias Basicas, Departamento de Ciencias Ambientales, Programa Administracion Ambiental. Santiago de Cali, 2019.

Las Garzas eco park is a reforested area of 4.7 hectares. The objective of this work was to evaluate if the vegetation cover that inhabits this area causes a positive impact on climate change from carbon capture. It was found that the total biomass is 471 tons, mostly concentrated in the arboreal vegetation. The total carbon captured by Lago de Las Garzas Eco Park was 224.34 tonnes and 47.73 tonnes / ha.

- Giraldo, A. et al. "Carbon capture and flow in a silvopastoral system of the Colombian Andean zone." Archivos Latinoamericanos decProduccion Animal. Vol 16, número 4: 241-245 2018.

The objective was to develop a protocol to measure carbon capture and monitoring, as an environmental service, in silvopastoral of Acacia decurrens + Pennisetum clandestinum located in the andes (2538 msnm), in two trees densities: high (1111 trees/ha), and low (407 trees/ha). In low density areas was reached 154tC/ha including pastures and soils. The carbon flow through animal lees was 0,50, 0,47 and 0,48 tC/cow/ha/year in HD, LD and without trees respectively. In average for two years, the annual average increases of carbon in the aerial part of the trees were 9,9 and 11,2 tC/ha for HD and LD respectively.

- Chrysobalanus Icaco species as a reforestation alternative to mitigate coastal erosion processes. Case study environmental sustainability of the species in the department of Bolívar-Colombia. Fundación Universitaria Tecnológico Comfenalco Cartagena, Colombia

The objective was to study the species Chrysobalanus Icaco as an alternative of reforestation for erosion management, considering the potential of the species for soil conservation and protection. The analysis indicated that the species can be used in the department to reduce erosion processes. However, environmental conditions must be adapted with fertilizers rich in trace elements for reforestation with Icaco for the purpose of agro-industrial use, erosion management and species conservation.

- Patiño, S. et al. "Capture of carbon in biomass in forestry plantations and agroforestry systems in Armero-Guayabal, Tolima, Colombia". Revista de Investigacion Agraria y Ambiental, Vol. 9, Num. 2. 2018

The study aimed to estimate the total biomass and the storage and fixation of carbon in forest plantations (FP) and agroforestry systems (AFS). FPs between 5 and 25 years old fixed between 18.6 and 64.4 Mg C ha-1; while the AFS captured 85 Mg C ha-1 (10-15 years). The average carbon fixation rate was 1.4 and 4.9 Mg C ha-1 year-1 for the FP and AFS, respectively. The results demonstrate the importance of these systems as mitigation factors of climate change and emphasize the advantages of involving SAF with forested perennials as a sink for a large amount of carbon, allowing, in turn, agricultural production.

- Ordoñez Jurado, H. M. et al. "Estimation of aerial biomass and carbon capture in scattered trees in pastures with wild motilon (Freziera canescens) in the Municipality of Pasto Nariño Colombia".

In the municipality of Pasto, Nariño, 4 circular plots of 500m2 were established, where the measurement of dasometric variables of trees dispersed in paddocks of wild motilón Freziera canescens was carried out, in order to estimate the aerial biomass and determine the carbon capture capacity. in this traditional silvopastoral practice. For the wild motilón an aerial biomass of 9.57 ton / ha was determined, which is equivalent to 4.78 ton of C / ha.

- Zúñiga-Escobar, O. et al. "Assessment of the impact of anthropic activities on carbon storage in soils of high montane ecosystems in Colombia". March, 2013.

The organic carbon in soil was quantified to assess the impact of anthropic activities on montane ecosystems in Colombia in Chingaza Parque Nacional Natural (PNN) and Los Nevados Parque Nacional Natural (PNN). The calculation of the amount of total carbon stored in soil reflects that, in Colombia, non-degraded high montane ecosystems (520.9 t ha-1 in paramos and 323.6 t ha-1 in high Andean forests of Chingaza PNN , and 373.0 t ha-1 in paramos and 254.6 t ha-1 in high Andean forests of Los Nevados PNN) currently have more carbon than degredaded ecosystems (135.1 t ha-1 in paramos and 141.5 t ha-1 in high Andean forests of Chingaza PNN , and 356.3 t ha-1 in paramos and 217.1 t ha-1 in high Andean forests of Los Nevados PNN). It is clear that the degradation of high montane ecosystems decreases the amount of carbon in the soil.

- Montenegro, A. M. 2008. Characterization of High Andean forest edges and implications for their ecological restoration (Colombia)". Biology department, Universidad Nacional de Colombia.

This study aimed to characterize three types of High Andean forest edge in Cogua Forest Reserve (Colombia): 1) edge of Chusquea scandens, 2) "paramizado", and 3) old edge, characterized for being in a later successional state. The paramizado edge needs the most intervention for its restoration. The Chusquea scandens edge forest is the most sheltered since this species acts as a protecting shield. However, it still needs to be controlled to allow the adjacent matrix colonization by the forest species and natural regeneration, as it does in the old edge type forest, which moreover has an intermediate self-regulating capacity relative to the other two. The vegetation composition reveals that most of the edge species can also grow inside, beyond the forest edge.

- Bare, M C et al. 2015. Growth of native tree species planted in montane reforestation projects in the Colombian and Ecuadorian Andes differs among site and species". Springer Science Business Media Dordrecht.

This study analyzed growth of seven common native species (Alnus acuminata, Baccharis bogotensis, Cedrela montana, Myrica pubesens, Quercus humboltii, Sambucus nigra, Smallanthus pyramidalis) on 12 montane forest sites across the northern region of the tropical Andes. Results indicate that native species can grow in a variety of soil conditions, and exhibit growth rates comparable to non-native species. However, the results suggest native species are site restricted for best growth and should be planted on particular soils, and, thus, recommendations for reforestation for the species are included in this study.

- Evert T, et al. 2017. The importance of species selection and see sourcing in forest restoration for enhancing adaptive capacity to climate change: Colombian Tropical Dry Forest as a model." CDB Technical series Nro 89.

Forest restoration projects can derive great benefit from integrating climate modeling, functional trait analysis and genetic considerations in the selection of appropriate tree species and sources of forest reproductive material, for their critical importance for the delivery of ecosystem services and the viability and adaptive capacity of restored forests. Targets in restoration projects are not only quantitative but also qualitative. There is need for political commitment to create demand for good quality forest reproductive material of native species through regulatory frameworks and resource allocations.

- Ramirez Mejia, A. F. et al. 2016. Activity patterns and habitat use of mammals in an Andean forest and a Eucalyptus reforestation in Colombia". Hystrix, the Italian Journal of Mammalogy. Mammalogy ISSN 1825-5272.

To mitigate deforestation effects, reforestation programs with native and/or exotic species have been implemented in the Colombian Andes, but little is known about how such reforestations affect wildlife. The reforestation was a monoculture and an artificial ecosystem; thus, it's expected differences in activity and habitat use by mammals in the two forest types. No significant differences were found in the species richness between the forests. This suggests that the creation of a new habitat, such as the reforestation, might influence the interactions among some species and apparently, could reduce interspecific competition and thus contribute to their co-existence at the study zone though niche differentiation in time and space.

Also some pieces of knowledge were identfied regarding wood for furniture and wood for construction in Colombia.

- Ospina Pantoja, I. M. 2018.Analysis of SMEs in the furniture sector in Colombia a from the income of foreign companies and products. Thesis degree to qualify for the title of: Professional in International Business. Universidad Agustiniana.

The aim of this project is to develop an analysis of the competitiveness of SMEs in the furniture sector in Colombia against the entry of new foreign companies. In order to determine how small and medium enterprises would face the entry of these foreign companies an impact analysis derived from the diamond analysis of Porter's competitiveness and the entry of new competitors, a situation that must be experienced by companies from developing countries within the current internationalization systems. To this end, an analysis of the furniture sector was carried out and interviews and surveys were carried out in order to understand the views of SME entrepreneurs and potential customers in the sector.

- Estimation and characterization study of wood consumption in housing and great works of infrastructure sectors. Bogotá D.C.: Colombia. Ministerio de Ambiente y Desarrollo Sostenible; ONF Andina. 2016.

The study describes the development of forest information studies for the characterization of potential markets that contribute to the formalization of the forestry sector, present wood consumption indices for two subsectors of the economy of great importance in the country such as housing construction and the development of large infrastructure works. Indexes and other information obtained in the study allow an approximation to the consumption of wood.

Initiatives and Projects Development

Several initiatives and projects were identified in Colombia with the objective of reforesting and restoring forest ecosystem.

In 2011, the National University of Colombia carried out a large project to recover degraded areas in the country, along the road that leads to Turbo, which is located in the Western Subregion of the department of Antioquia. After 7 months of execution, 11 hectares have been established that host around 11,200 trees. The goal is to plant 2,000 trees in some farmers lands and in lots assigned by the government to increase plant biodiversity.

The Red de Arboles Foundation began its activities in 2015 in the city of Bogotá, offering voluntary reforestation activities for companies under the concept of Corporate Social Responsibility. Since then it has planted more than 30,000 trees in different affected areas near the city of Bogotá and expanding its activities to other cities such as Cali, Medellin, Barranquilla, Bucaramanga and Cartagena. In 2018, in the company of Porvenir, they planted 5,000 trees in 5 main cities of the country

Celsia, from Grupo Argos, aims to develop actions that allow to conserve water as a basic resource for generating clean energy. In 2016, an initiative began together with the Regional Autonomous Corporation of Valle del Cauca (CVC) and that seeks the restoration of watersheds by means of planting native trees in protected areas of the region's water sources. During the first year, 562,000 trees were planted in 780 hectares of 16 municipalities in Valle del Cauca. The final objective is to plant 10 million cultivated and cared trees in an estimated period of 10 years with the participation of rural and peasant communities, generating around 400 direct jobs in charge of planting, isolating and maintaining reforested areas, in line with the goals of sustainable development.

Tree Nation has two forestry projects in Colombia. The Tumacoco Project in San Juan de la Costa en Tumaco - Nariño. The project seeks to cultivate coconut plantations through agroecological and agroforestry practices that promote and encourage sustainability in the Colombian Pacific. Environmental sustainability will be consolidated by means of generating agro-ecological production systems in plantations. Economic sustainability will be achieved through employment generation for approximately 25 families directly and indirectly on the Colombian Pacific coast. An agro-business model will be implemented to allow economic sustainability of coconut plantations based on the production of value-added coconut products. Social sustainability will be achieved by including families that have been victims of the armed conflict and mothers who are heads of families. Thus, the project gives social cohesion, community participation, a sense of belonging towards the territory where the project will be implemented and also achieving 300.000 Kg of CO_2 compensated.

Another project is La Pedregoza, located in the Orinoco River basin of Colombia, started in 2007. The plantation is designed to provide long-term economic sustainability for the adjacent natural reserve, dedicated to the conservation of local flora & fauna. The project has 6 main objectives: to grow plantation wood for lumber; to grow tropical trees for carbon sequestration and cloud seeding; to plant native trees in order to expand the habitat for endangered wildlife in the region; to create local socio-economic development opportunities in the areas of agro-forestry natural farming, permaculture and analog forestry, wood and lumber, forestry management, fruits and nuts, bio-diesel, organic insecticides and fungicides, liquors and medicines, renewable energy and oils; to reclaim land and improve depleted and dead soils with nitrogen fixing, carbon fixing and micro-fauna through tropical trees and natural farming techniques; and to provide financial sustainability to the Reserva Natural La Pedregoza, a natural reserve and conservation area. This project has so far compensated 416 million kg of CO_2.

In order to reduce greenhouse gas emissions generated by agriculture, deforestation and other land uses, the Ministry of Agriculture and Rural Development, the Ministry of Environment and Sustainable Development, and the National Planning Department (DNP), launched the BioCarbono Fund at the international Tropical Forest Alliance 2020 (TFA) conference, which took place in Bogotá. This initiative led by the National Government, in strategic collaboration with the World Bank, will be developed in the departments of Meta, Vichada, Casanare and Arauca, in order to promote a more productive agriculture and expand the practices and technologies of sustainable land management, for the protection of forests. It is important to highlight that only five countries in the world are part of this global initiative; Colombia and Mexico are the only countries in the Latin American region.

Mangroves - Literature Review Colombia

The present body of literature indicates that coastal ecosystems play a critical role in the global sequestration of C as well as in providing key ecosystem services. Carbon is sequestered in vegetated coastal ecosystems, specifically mangrove forests, seagrass beds, and salt marshes, and the oceanic fraction has been more recently addressed as “blue carbon”. Blue carbon is sequestered over the short term (decennial) in biomass and over longer (millennial) time scales mainly in sediments. These ecosystems generally sequester C within their underlying sediments, living biomass aboveground and belowground, and non-living biomass.

Mangrove forests, sea-grass meadows and tidal salt marshes are highly efficient C sinks, in part also due to the structural complexity of those ecosystems. Specifically, in Caribbean mangroves the sediments in which these ecosystems grow do not become saturated with C, because sediments accumulate vertically in response to rising sea level (McKee et al., 2007).

However, globally, carbon-rich mangrove forests, one of the most productive and efficient long-term natural carbon sinks, have experienced increasing deforestation and degradation, as well as frequent conversion to other land uses. Deforestation and conversion generate substantial carbon emissions that may increase with the intensification of land use change and cover.

There are different estimates of mangrove carbon stocks (aboveground and belowground) and areal extent derived from measurement and modelling (Giri et al., 2011; Hutchison et al., 2014; Kaufman et al., 2020). According to Hamilton and Friess, globally, mangroves stored 4.19 Pg of carbon in 2012, while Kaufman at al. estimate that mangroves store about 11.7 Pg C. Land use change is a major cause of loss and degradation, with loss of C carbon stocks that tend to be higher than losses associated with land-use change in upland forests Kauffman et; al, 2020).

Mangroves are prevalent strategic coastal ecosystems along the Pacific and Caribbean coasts of Colombia. They provide services that make mangroves important locally, regionally and globally. However, according to a systematic review recently undertaken,[19] the Colombian Pacific coast, that contains circa 80% of the country's mangroves, has been under-studied. In this regard, at the Institute of Marine and Coastal Research (INVEMAR), Colombia, the country has developed methodological approaches for REDD+ type projects in mangrove ecosystems,[20] considering that according to some estimations, mangroves absorb fifty times mora carbon than tropical forests.

The Ministry of Environment of Colombia issued the Resolution 1263 / 2018 which defined new terms of reference for the formulation, complementation, and updating of the mangrove characterization, diagnosis, and zoning studies; formulated the guidelines for its integral management; and adopted the "Guide for the restoration of mangrove ecosystems in Colombia" to advance restoration processes, among others.

According to Bernal (2017), the central Government is working towards meeting the target of developing a comprehensive and sustainable land use planning and management of Colombia's mangrove ecosystems by 2025.

Some of the relevant scientific literature related to mangrove in Colombia is described below:

[19] Castellanos-Galindo et al. (2020). Mangrove research in Colombia: Temporal trends, geographical coverage and research gaps. Estuarine, Coastal and Shelf Science. Elsevier.
[20] Invemar, Carbono y Bosques y CVS. 2015. Guía Metodológica para el desarrollo de proyectos tipo REDD+ en ecosistemas de manglar.

- Urrego, L.E., et al, 2014. "Environmental and anthropogenic influences on the distribution, structure, and floristic composition of mangrove forests of the Gulf of Urabá (Colombian Caribbean)"

Under this study, mangrove forests were mapped and classified following analysis of aerial photographs. Based on 87 circular 500 m2 plots, authors assessed the structure, floristic composition, and environmental attributes of mangroves. Three mangrove forest types were identified, according to the physiographic classification based on location; riverine, basin, and fringe; and a mangrove type in a highly disturbed stage. Significant differences among mangroves were found; therefore, authors hypothesis was accepted. Rhizophora mangle, Laguncularia racemosa, and Avicennia germinans exhibited the highest importance values (IVI) in fringe and riverine mangroves; and in basin mangroves, A. germinans showed the highest IVI, with the importance order of these species inverted. Small highly disturbed mangrove fragments were dominated by R. mangle. Tree diameters and heights were asymmetric unimodally distributed, suggesting large forest disturbances related to timber overexploitation, and poor conservation status. Differences among mangrove types were related to soil salinity, granulometry, and nutrient concentrations.

- Zárate, T., Maldonado, J., (2015). "Valuing Blue Carbon: Carbon Sequestration Benefits Provided by the Marine Protected Areas in Colombia". PLoS ONE. 10. 10.1371/journal.pone.0126627.

The objective of this study was to value the services associated with the capture and storage of oceanic carbon, known as Blue Carbon, provided by a new network of marine protected areas in Colombia. Authors approached the monetary value associated to these services through the simulation of a hypothetical market for oceanic carbon. To do that, authors constructed a benefit function that considers the capacity of mangroves and seagrasses for capturing and storing blue carbon, and simulated scenarios for the variation of key variables such as the market carbon price, the discount rate, the natural rate of loss of the ecosystems, and the expectations about the post-Kyoto negotiations. The results indicate that the expected benefits associated to carbon capture and storage provided by these ecosystems are substantial, but highly dependent on the expectations in terms of the negotiations surrounding the extension of the Kyoto Protocol and the dynamics of the carbon credit market’s demand and supply.

- INVEMAR, 2015. Informe del estado de los ambientes y recursos marinos y costeros en Colombia: Año 2014. Serie de Publicaciones Periódicas No. 3. Santa Marta. 176 p.

Among other natural resources, this study characterizes mangroves in Colombia. An estimation of the mangrove area is included based in official information from Ministry of Environment (MADS): Caribbean Coast (88,575 ha) and Pacific Coast (194,880 ha) totalizing 283,456 ha in Colombia.

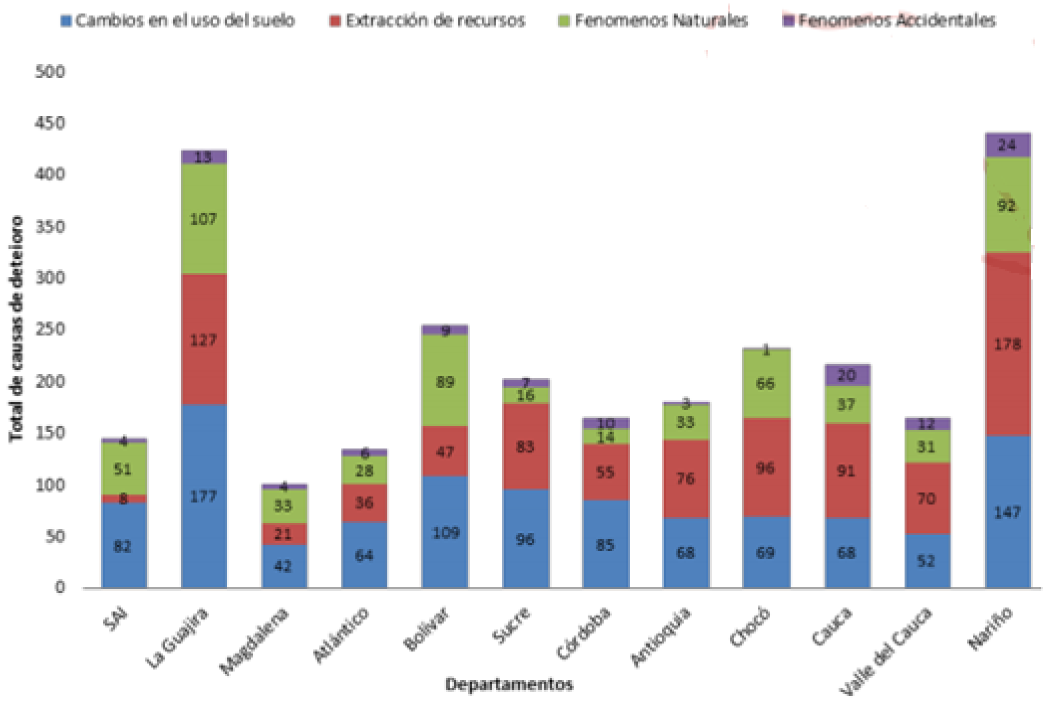
Table 15: Mangrove area in Colombia by deopartment

Department	Mangrove area (ha)
San Andrés Providencia y Santa Catalina	245
La Guajira	2,730
Magdalena	40,906
Atlántico	613
Bolívar	15,055
Sucre	12,957
Córdoba	9,077
Antioquía	6,993
Chocó	41,348
Valle del Cauca	32,073
Cauca	18,691
Nariño	102,768
TOTAL	**283,456**

Source: INVEMAR 2015 based on MADS

It also provides an analysis of the causes of deterioration identified in the mangroves of Colombia at the departmental level, being land use change (blue bars in following figure) and resources extraction (red bars) the main causes.

Figure 18: Causes of deterioration identified in the mangroves of Colombia at the departmental level



Source: INVEMAR 2015

- Yepes et al, 2016. "Tree above-ground biomass allometries for carbon stocks estimation in the Caribbean mangroves in Colombia". Rev. Biol. Trop.

The objective of this study was to analyze the above ground biomass (AGB) of the species Rhizophora mangle and Avicennia germinans from the Marine Protected Area of Distrito de Manejo Integrado (DMI), Cispatá-Tinajones-La Balsa, Caribbean Colombian coast. With official authorization, the researchers harvested and studied 30 individuals of each species, and built allometric models in order to estimate AGB. The AGB result for the studied mangrove forests of the DMI Colombian Caribbean was 129.69 ± 20.24 mega grams of biomass per ha, equivalent to 64.85 ± 10.12 mega grams of C per ha. The DMI has an area of 8,570.9 ha in mangrove forests, and then the estimated total carbon potential stored was about 555,795.93 Mega grams of C.

The bibliographic analysis of the authors highlighted that "Mangroves are among the most productive ecosystems on the planet, with an average production of 2.5 grams C / m2 / day (Jennerjahn & amp Ittekkot, 2002), and for this reason they are well known for their high carbon accumulation, with reports of superior storing at 1 000 Mega grams C / ha (Donato et al., 2011)".

- Bernal, B. et al, 2017. "Assessment of mangrove ecosystems in Colombia and their potential for emissions reductions and restoration". Winrock International

This report is a preliminary evaluation of the potential of including mangrove restoration and sustainable mangrove use in Colombia's Nationally Appropriate Mitigation Actions (NAMA) strategy.

According to the literature review of the authors, the largest mangrove forest in Colombia (in the Ciénaga Grande de Santa Marta), for example, has lost 60% of its coverage since the mid-1950's (Elster, 2000), and ten years ago about 21% of Colombia's remaining mangroves were considered degraded (INVEMAR, 2014).

Regarding mangrove loss, the authors found in their literature review that Colombia's mangroves covered about 371,250 ha in 1997, with about three-fourths located in the Pacific coast (~283,000 ha) and one-fourth in the Caribbean coast (~88,250 ha) (Sánchez-Páez et al. 1997b). By 2014, the total coverage had decreased to 286,804 ha, a 23% decrease from the 1997 coverage at a loss rate of 4,967 ha y-1 (assuming a constant rate of mangrove loss). The review by Álvarez-León (2003) reported an even higher loss rate between 1966 and 1991 of 7,965 ha y-1.

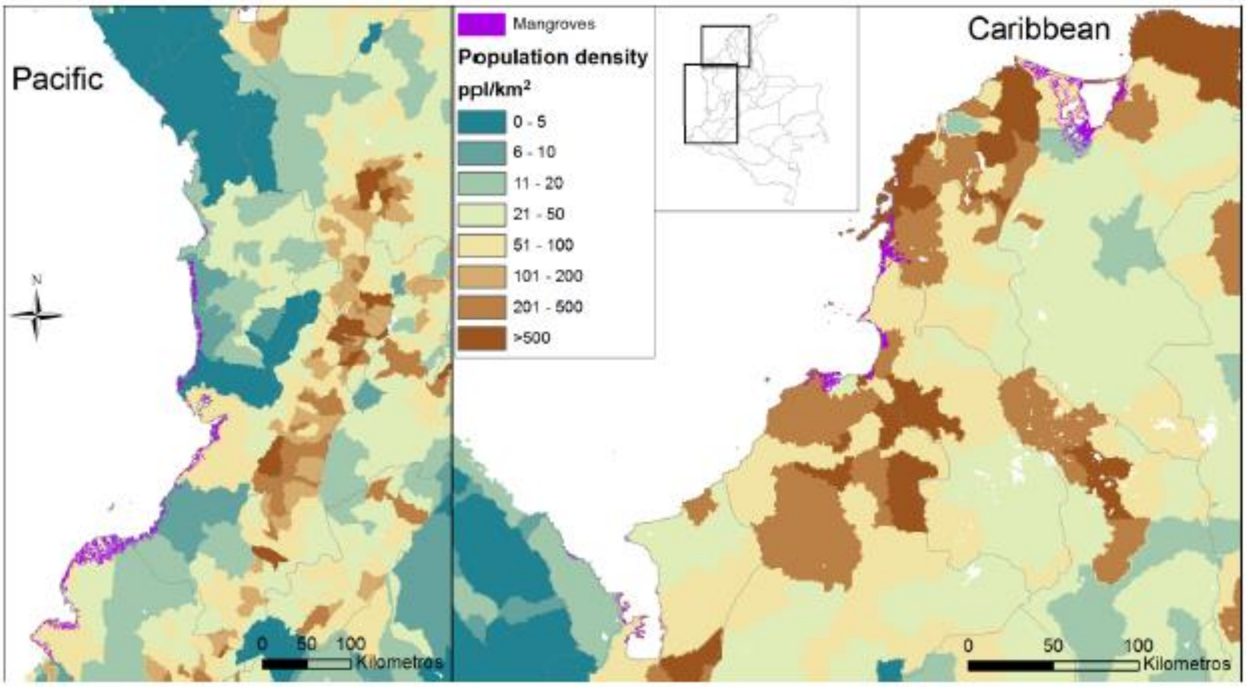
Figure 19: Latest mangrove zoning in Colombia, according to INVEMAR (2014) and to the central Government

State (*Departamento*)	Total mangrove cover (ha)	Protected mangrove area (ha)	Protected mangrove area (%)
San Andrés y Providencia	208	35	16.8
La Guajira	2,730	166	1.4
Sucre	12,190	0	0.0
Magdalena	38,042	21,106	55.5
Atlántico	237	0	0.0
Bolívar	9,739	2,929	30.1
Córdoba	8,975	0	0.0
Antioquia	5,810	0	0.0
Caribbean Region, Total	**77,938**	**24,236**	**31.3**
Chocó	40,774	33	0.1
Valle del Cauca	32,386	0	0.0
Cauca	23,204	0	0.0
Nariño	113,041	42,771	37.8
Pacific Region, Total	**209,405**	**42,804**	**20.4**
Country, Total	**286,804**	**67,040**	**23.4**

Source: Bernal et al 2017 with information from INVEMAR 2014 and central Government

Authors also analyzed the location of mangroves versus population density in order to assess the pressure that fuelwood demand has on Colombia's mangrove ecosystems.

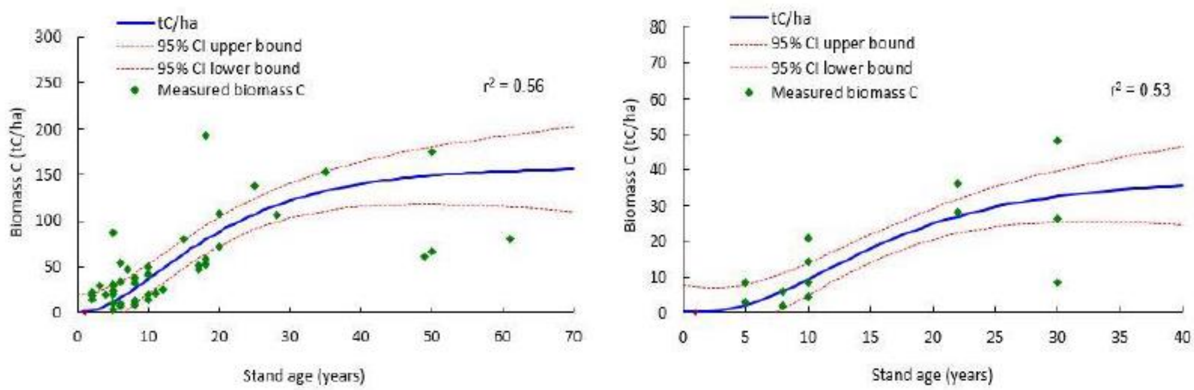
Figure 20: Map of Location of mangrove coverage and Population density



Source: Bernal et al 2017

An analysis of carbon removal in Colombian mangroves is included in the study based in above ground biomass estimation. The analysis indicates that mangrove restoration in Colombia can potentially remove CO2e, through aboveground mangrove biomass growth, at a rate of 16.1 ± 2.9 t CO2e ha-1 y-1, and 4.4 ± 0.7 t CO2e ha-1 y-1 during the first 20 years of restoration of mangrove trees and shrubs, respectively. After the first 20 years since planting, the emission removal rates would be 7.4 ± 1.9 t CO2e ha-1 y-1 for mangrove trees and 1.4 ± 1.3 t CO2e ha-1 y-1 for mangrove shrubs over the next 30 years, assuming a constant rate of growth. These removal rates can be applied to mangrove restoration areas to estimate the total CO2e removals with mangrove restoration

Figure 21: Bio mass C growth curve of mangrove trees and mangrove shrub scrub.



Source: Bernal et al 2017

Figure 22: Average potential CO2e removal rate (t CO2e y-1)) from mangrove restoration in Colombia

State (*Departamento*)	Average potential CO_2e removal rate, years 0-20 since of restoration			Average potential CO_2e removal rate, years 20-50 since of restoration		
	Unprotected mangroves	Shrub mangroves	Shrimp ponds	Unprotected mangroves	Shrub mangroves	Shrimp ponds
San Andrés y Providencia	2,785	773	No data	1,280	355	No data
La Guajira	35,372	65,624	1,610	16,258	30,162	740
Sucre	193,586	31,604	12,767	88,978	14,526	5,868
Magdalena	272,670	86,666	No data	125,326	39,834	No data
Atlántico	3,816	162,175	2,624	1,754	74,540	1,206
Bolívar	109,641	75,445	24,665	50,394	34,676	11,337
Córdoba	144,498	32,071	6,521	66,415	14,741	2,997
Antioquia	93,541	13,250	No data	42,994	6,090	No data
Caribbean Region	**855,908**	**467,608**	**48,187**	**393,399**	**214,926**	**22,148**
Chocó	655,930	43,229	No data	301,483	19,869	No data
Valle del Cauca	521,415	41,570	No data	239,656	19,107	No data
Cauca	373,584	32,345	No data	171,710	14,867	No data
Nariño	1,131,347	293,020	24,875	519,998	134,680	11,433
Pacific Region	**2,682,276**	**410,164**	**24,875**	**1,232,847**	**188,522**	**11,433**
Country, Total	**3,538,200**	**877,772**	**73,062**	**1,626,254**	**403,448**	**33,581**

Source: Bernal et al 2017

Finally, authors found that "to the date, there is no specific information available on Colombia's mangrove restoration targets. Several peer-reviewed publications and Government reports evaluate the success of mangrove restoration in some areas of the country (see the following sections on Caribbean and Pacific mangrove current status and the list of bibliographical references used). Mangroves are included in the latest National Restoration Plan34, without specifying explicit restoration locations, target areas (size) of restoration, or even a current extension of degraded mangroves in the country. Therefore, it seems that an evaluation of priority restoration targets is lacking in Colombia, as well as a restoration feasibility plan that would allow identifying benefits of restoring specific mangrove areas in the country".

- INVEMAR, 2017. "Basic Restoration And Monitoring Plan For 150 Hectares Of Mangrove In The Management District Integrated Of Cispata, Córdoba"

- Palacios Peñaranda, M., et al, 2019. "Carbon stocks in mangrove forests of the Colombian Pacific", Estuarine, Coastal and Shelf Science

The study quantified carbon stocks in mangrove forests in two bays in the Colombian Pacific, and evaluated the effect of forest structure on variations of carbon storage in the different ecosystem compartments. Significant differences were found in carbon stocks between the stations of Málaga Bay (a national marine park) and Buenaventura Bay (the main harbor area). Belowground biomass and sediment represented the greatest carbon stocks in the forest. Carbon reserves in mangroves in the Colombian Pacific were similar compared with other tropical mangrove areas.

Above-ground biomass values are a significant carbon reserve (17%of the total carbon stocks) in the mangrove forest. The lowest values were registered in San Pedro 70 mg C/ha (14%), while the highest values at Quebrada Valencia 143.2.

Soil carbon values showed differences as a function of depth in all sampling stations. The lowest values were obtained in the upper part and values increased with soil depth. The lowest values were obtained at Quebrada Valencia 130.3 Mg C/ha, (18%), while the highest values were obtained at Pianguita 180.8 Mg C/ha, (25%).

The highest values of carbon stocks in the mangrove forest studied were recorded in below ground biomass. The greatest values were obtained at Quebrada Valencia 450.26 Mg C/ha (26.3%), while the lowest values were registered at San Pedro 258.3 MgC/ha (52.2%).

Figure 23: Above-ground biomass (Agb), below-ground biomass (Bgb), height (H), and basal area (BA) of mangrove forests at several locations in the tropical zone

Region	Location	Species	Agb (t/ha)	Bgb (t/ha)	H (m)	BA (m^2/ha)	Reference
Indonesia (Halmahera)	1°10′N, 127°57′E	*Rhizophora. apiculata*	356.8	196.1	21.2	25.1	Komiyama et al. (1988)
Thailand (Southern Ranong)	9°58′N, 98° 38′E	*Rhizophora spp.*	298.5	272.9		31.30	Komiyama et al. (1988)
Australia	33° 50′S, 151°9′E	*A. marina*	144.5	147.3	7.0		Briggs (1977)
Thailand (Southern Pang-nga)	8°15′N, 79°50′E	Mixed forest	62.2	28.0	6.5	11.4	Poungparn et al. (2003)
Mui Ca Mau Vietnam	08°32′–08°41′N and 104°44′–104°55′E	*Avicennia. alba* *A. officinalis* *B. parviflora* *R. apiculata* *S. caseolari*	90.2	629.0		148.3	N.T. Tue et al. (2014)
Panama	9°N	Rhizophora mangle	279.2	306.2	–	–	Golley et al.(1975)
Colombian Pacific (Quebrada Valencia)	04° 06′ 35.9″ N and 77° 15′ 03.9″W	*Rhizophora* spp. *Mora oleifera*	142.46	580.54	11.29 ± 8.93 17.32 ± 8.46	235.13 ± 24.82 1082.82 ± 38.86	Present study
Colombian Pacific (San Pedro)	03° 50′ 11″N and 77° 15′ 30″W	*Rhizophora* spp *Pelliciera rhizophorae*	69.49	425.54	17.53 ± 1.1 6.13 ± 3.81	28.13 ± 76.85 93.64 ± 4.10	Present study
Colombian Pacific (Pianguita)	03° 50′ 32″N and 77° 12′ 23″W	*Rhizophora* spp. *Mora Oleifera* *Pelliciera rhizophorae*	109.18	619,30	6.78 ± 5.07 6.82 ± 3.57 5.76 ± 2.56	6.01 ± 6.01 2.03 ± 2.56 3.25 ± 55.565	Present study

Source: Palacios Peñaranda, M., et al, 2019

- Blanco-Libreros, J. F.et al, 2019. "Mangroves of Colombia revisited in an era of open data, global changes, and socio-political transition: Homage to Heliodoro Sánchez-Páez". Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales,

The voluminous information collected by Heliodoro Sánchez-Páez and his colleagues in the largest national inventory of mangroves (MCP: Mangroves of Colombia Project, Ministry of the Environment) undertaken in the mid 1990's provides an opportunity to re-assess biogeographic hypotheses (ex:, that high rainfall promotes the increase in the importance value of red mangroves) and to explore macroecological patterns when combined with open data sets. The objective of this paper was to introduce HELIO_SP.CO v.1, an open database derived from this mangrove inventory as a homage to Heliodoro Sánchez-Páez, who passed away in 2017, as a platform for macroecological studies and benchmark for future impact assessments of climate change and land-use change on mangroves in Colombia. In addition, the contributions of the MCP were reviewed and the general geographic patterns were explored by using HELIO_SP.CO v.1.

- INVEMAR, 2019. "20 years (1999-2018) of mangrove monitoring in San Andrés and Providencia Islands"

CORALINA and INVEMAR present this publication fulfilling the scope to the mangrove monitoring protocol published in 2014 by both entities, presenting a historical diagnosis in the Archipelago of San Andrés, Providencia and Santa Catalina in the framework of the Cooperation Agreement 001-19, in order to present the current state of this ecosystem of special interest taking into account the current and historical tensors of anthropic and natural origin, to give guidelines to future administrations on the planning and monitoring of management actions to be taken to give continuity to its sustainability.

- Castellanos-Galindo, G. A., et al, 2020. "Mangrove research in Colombia: Temporal trends, geographical coverage and research gaps". Estuarine, Coastal and Shelf Science

Mangroves are prevalent coastal ecosystems along the Pacific and Caribbean coasts of Colombia, with several structural features and service provisions that make them important regionally and globally. Despite this importance and the existence of national laws to protect them, research on these ecosystems has been historically scarce if compared to the terrestrial ecosystems of the country. Here, authors analyse historical trends of mangrove research in Colombia for the time period 1900 until 2018. To do so, a systematic literature search was carried out based on the Web of Science (WoS), Scopus and Google Scholar scientific citation databases. A noticeable increase in the number of mangrove studies in Colombia was found in the 2001–2010 decade. Although the Colombian Pacific contains ca. 80% of the country's mangroves, a greater number of mangrove studies has been conducted on the Caribbean coast. Ciénaga Grande de Santa Marta, a degraded but productive coastal lagoon, is by far the most studied mangrove site in Colombia. Google Scholar was able to capture ~10 times more studies (mostly grey literature and peer reviewed articles in Spanish) than the Web of Science and Scopus databases, indicating the need to include this type of information in systematic reviews. Authors propose that future mangrove research in Colombia should prioritize: (1) historically understudied areas where degradation threats are strongest (ex: near planned infrastructure projects), (2) areas poorly examined but likely to contain healthy, carbon-rich and tall mangroves (ex: most of the Pacific coast) and (3) interdisciplinary studies that provide for a more holistic social-ecological understanding of Colombian mangrove systems.

In addition to the communities, non-profit organizations such as WWF Colombia and The Nature Conservancy are already working on mangroves' restoration in Colombia; efforts also include local companies such as Grupo Familia, Bavaria and Grupo Argos (through Fundación Argos); local technical institutes as Institute for Marine and Coastal systems (Invemar); and both national (MinAmbiente) and local (Mayor of Cartagena) authorities.

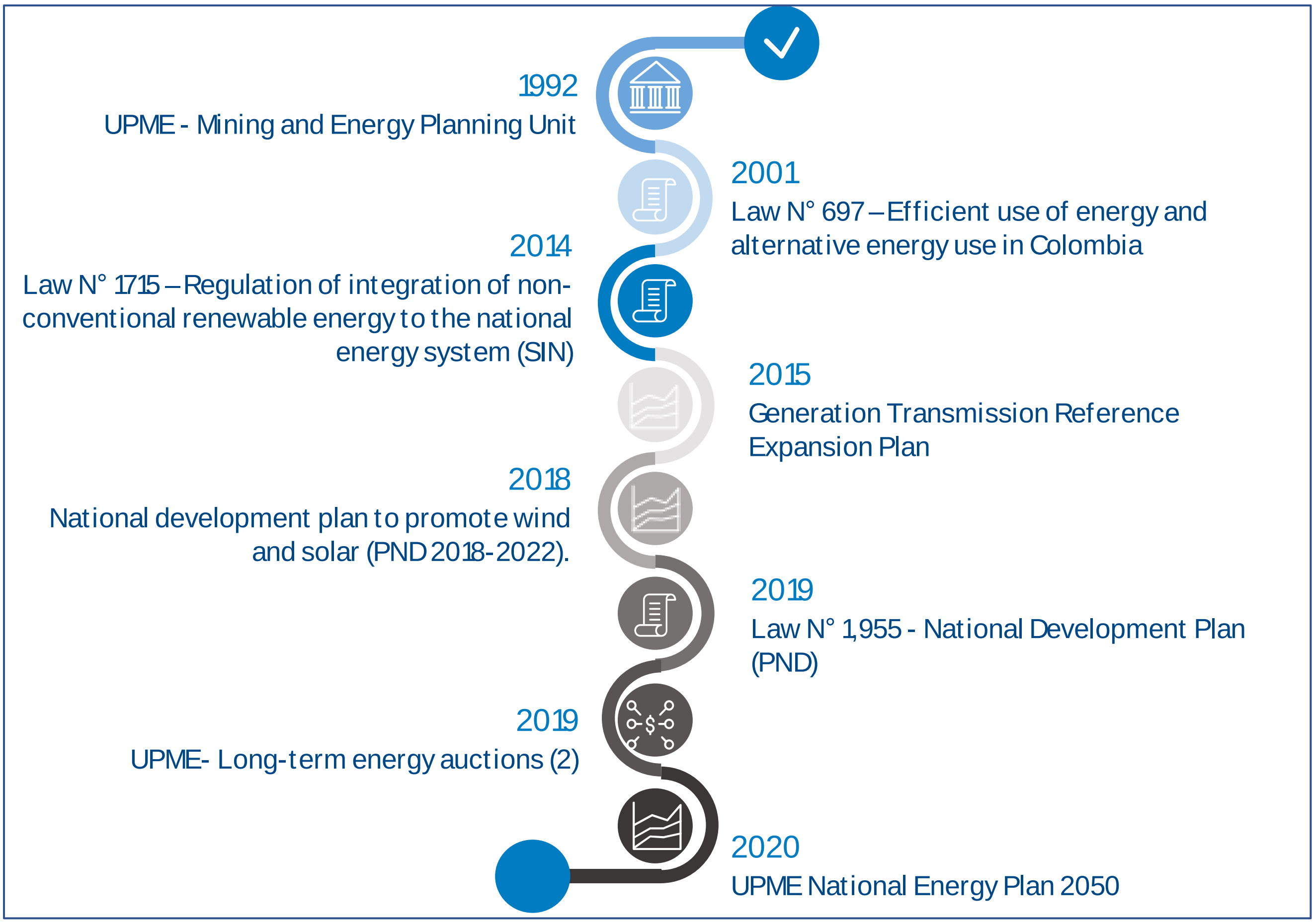
Large international companies are supporting research projects with the technical support of the Institute for Marine and Coastal systems (Invemar) aiming atmore efficient ways to measure carbon stored in the mangrove forests of Colombia, using new available technologies, that would eventually allow to sell carbon offsets to fund the protection and restoration of mangroves, given what they assume to be their capacity to sequester about 10 times as much carbon per unit area as terrestrial forests.

In terms of initiatives, through Apple's Earth Day 2018 Give Backcampaign, the US company has partnered with Conservation International to protect a 27,000-acre mangrove forest in Cispatá Bay on the Caribbean coast of Colombia. As indicated by project sponsors, over the course of its lifetime, the Cispatá Bay's mangrove forest could sequester 1 million metric tons of carbon dioxide.

Bioenergy with carbon capture and storage (BECCS)

The following figure summarizes in a timeline, regulations, plans and programmes related to BECCS CDR approaches implemented in Colombia, that are developed in a detailed manner in the following sections.

Figure 24: BECCS related regulations, plans and programmes implemented in Colombia - Timeline



Source: own elaboration

<u>Alignment with Government Vision and Commitment</u>

Almost 20 years ago, in 2001, Colombia passed Law N° 697 "Efficient use of energy and alternative energy use in Colombia" which declares the rational and efficient use of energy and promotes alternative energy use within Colombia, creates a program for such objective called PROURE and sets the first stages for renewable energy development.

In 2014, the Colombian Congress issued Law N° 1715, which regulates the integration of non-conventional renewable energy to the national energy system (SIN) with the intention to promote efficient energy management through taxation mechanisms, cooperation arrangements, and investment incentives. This law also aimed to promote investigation in the production and use of non-conventional energy resources. Establishes a dedicated fund and creates the legal basis for development of renewable energy support initiatives, thus paving the way for further policy and regulatory action. Fiscal incentives were also provided by the law, including:

- income tax deduction: up to 50% of taxable income during 5 years considering 50% of the investment value
- VAT exemption for renewable energy equipment and services
- import duty exemption for renewable energy equipment imported
- accelerated depreciation of up to 20% per year for renewable energy investments.

Five years later, In May 2019, Law N° 1,955 was sanctioned. It. issues the National Development Plan (PND) for 2018-2022 called "Pact for Colombia, Pact for Equity", which replaces the previous National Development Plan 2010-2014. One of the main goals of the plan was related to renewable energy, targeting to increase the supply of energy from clean sources from a capacity of 22 MW to 1500 MW.

Colombia's Mining and Energy Planning Unit (UPME), established in 1992, is the special administrative/technical unit responsible for the sustainable development of the country's mining and energy sectors, including hydrocarbons. Dependent on the Ministry of Mines and Energy, UPME's main objectives are to comprehensively plan, support and assess the development of both industries, as well as to support the ministry to design national policies and regulations.

In order to guarantee an adequate supply of the country's electricity demand, the National Government, through the Ministry of Mines and Energy, adopted the Generation Transmission Reference Expansion Plan 2015 -2029 prepared by UPME, a strategic document for generation resources planning and the expansion of electricity transmission networks nationwide.

Historically, the renewable energy market in Colombia has been negligible compared to Colombia’s hydroelectric and thermal generation. Installed renewable energy capacity in Colombia was estimated around 50 MW. The Colombian government launched a national development plan to promote wind and solar (PND 2018-2022). One of its goals is that by 2022, 8% to 10% of Colombia’s energy will be produced from renewable energy sources. In accordance to those goals, during 2019, UPME conducted two long-term energy auctions:

- CLPE No. 01-2019: Despite 22 projects were enrolled and 8 offers presented, the auction was declared empty by UPME in February 2019 because insufficient demand-side participation and no PPAs were awarded. According to specialized media "the auction had certain technical and financial requirements that were not considered commercially attractive by generators, and purchase offers submitted by offtakers were too low. In addition, antitrust conditions that had been put in place to avoid undue advantage by companies that were participants in both the sell and buy sides were not met".

- CLPE No. 02-2019: In October 2019, the auction awarded contracts for nine projects accounting for 1,374 megawatts (MW) of new wind and solar power generation, at a historic-low average price for the country of approximately $28 per megawatt hour (MWh). No biomass or biogas projects were awarded. Projects selected in the auction will be entitled to a 15-year PPA and must come into operation by January 1, 2022. The newly awarded clean energy suppliers will mobilize an estimated $1.3 billion in investment, boost Colombia's generating capacity by 2,250 megawatts, and attract another $2 billion of estimated private-sector investment.

Some challenges and critics to Colombian renewable energy auctions were identified by Norton Rose Fulbright, for improvement in future auctions. "The government is expected to hold a third renewable energy auction in 2020, but it recognizes that various challenges remain.

- A major hurdle to increasing renewable energy production is the lack of infrastructure in non-interconnected areas. Bidders in future auctions should assume their projects will have to include grid infrastructure as well as storage.
- Notwithstanding criticism from foreign investors in response to the initial auction, the PPAs awarded in the second auction still set the energy prices in Colombian pesos, and payments will be made in pesos at a price that will be adjusted on a monthly basis. This remains a major challenge for foreign investors due to Colombian peso volatility and currency risk. Investors have to use financial instruments, such as currency swaps, to hedge against this type of currency risk.
- Various developers complain that there has been a lack of planning around community engagement in areas where projects are to be located, and that conditions placed on bidders with respect to coordination with communities were overly burdensome and complicated". [Norton Rose Fulbright, 2020]

Recently, in February 2020, UPME presented a preliminary version of the National Energy Plan 2050, a report that aims to set the basis of the energy planning for the next 30 years in Colombia. Renewable energy is projected to be the fastest growing source of energy, gaining share on the country's energy matrix.

Degree of Scientific Development / Academic Literature Review

Similarly as in Argentina, the research performed for Colombia shows that the academic activity only covers the BioEnergy (BE) part of BECCS and that no integral BECCS literature was identified.

The most relevant academic literature identified and reviewed related to Bioenergy in Colombia is summarized in this section.

- Henson, I. E. et al. The greenhouse gas balance of the oil palm industry in Colombia: a preliminary analysis. I Carbon sequestration and carbon offsets.

The first section of the study examines changes in carbon stock in Colombia resulting from expansion of oil palm cultivation together with factors (offsets) that act to minimize carbon emissions.

- Sagastume Gutiérrez A. et al, The energy potential of agriculture, agroindustrial, livestock, and slaughterhouse biomass wastes through direct combustion and anaerobic digestion. The case of Colombia, Journal of Cleaner Production (2020).

An inventory of the main crops and livestock produced in Colombia, and the share processed in agroindustry was developed to identify the available biomass wastes for energy applications. Based on the inventory, the biomass-based energy potential was calculated for direct combustion use and anaerobic digestion systems. The results show a bioenergy potential of 60,000 to 120,000 GWh per year, with higher potentialities for direct combustion systems than for anaerobic digestion. In total, the combined use of direct combustion and anaerobic digestion can support the use of gaseous and solid fuels from 50 to 97%. Using combined heat and power systems for heat and electricity production can increase the biomass share in the end-use energy mix up to 15 to 28%, including 27 to 53% of the 68,943 GWh of electricity produced in 2018.

- W Reyes-Calle et al. Drivers of biomass power generation technologies: Adoption in Colombia. 2020 IOP Conf. Ser.: Mater. Sci. Eng. 844 012010

A structural analysis was carried out for decision making: international experiences were used to identify Social, Environmental, Technical and Economic indicators and with the MICMAC method, key variables were identified to define improvement strategies. Due to the flexibility of existing technologies and energy in the areas of influence, international experiences present biomass as a reliable alternative for the supply of electricity in areas that are isolated from the electricity grid. This highlights the need for tariff policies to promote project development and technology diversification. The electricity market should provide precision in the guidelines concerning the sale of surplus electricity produced by companies that are not agents in the electricity sector.

- Sagastume Gutierrez, A. et al. Data supporting the forecast of electricity generation capacity from non-conventional renewable energy sources in Colombia. Data in brief 28 (2020). 2019

The forecast developed in this study was calculated based on data provided by the national project registry provided by the Colombian government. The study forecasts the evolution of the power generation capacity registered in non-conventional renewable energy source projects in three scenarios of implementation of the power generation capacity registered.

- Gomez, E. A.et al. Wood, Potencial Lignocellulosic Material for the Production of Biofuels in Colombia. Inf. tecnol. vol.23 no.6 La Serena 2012.

The availability of wooded resources in Colombia is to assess their potential for ethanol production. Forest species available in Colombian territory have high enough volumetric biomass yields and short growth turns to guarantee a fast and constant supply of lignocellulosic biomass to be used as raw material in a biofuel production process. Given the great technological and highly competitive commercial products derived from pine and eucalyptus, Colombia should take advantage of its situation and promote reforestation with these native species.

- Garcia Ubaque, C. A. et al. Use of Pelleted Biomass in the Brick Industry in Bogota-Colombia: Energy and Environmental Analysis. Inf. tecnol. vol.24 no.3 La Serena 2013

This study compared the energy and environmental performance of fuels from two types of pelleted biomass: wood waste from pruning and waste from furniture production, mainly sawdust. The biomass with better performance was sawdust, which presented the optimum energy and environmental variables.

- Perez, J. F. et al. Decentralized power generation through biomass gasification: a technical – economic analysis and implications by reduction of CO2 emissions. Rev. Fac. Ing. Univ. Antioquia N.° 62 pp. 157-169. Marzo, 2012

This article presents the feasibility analysis of two electricity generation projects with wood biomass. The first one considers wood harvested from a forest with pine plantation as fuel source(case 1), and the second one, biomass residues from a teak plantation (case 2). The most suitable electricity generation technology is thermo-chemical process of gasification coupled with combustion engines. Generation cost (USD/kWe-h) is calculated for each technological alternative with a technical-economic analysis, as result the lowest costs are approx. 0.061 USD/kWe-h for 1.0 MWe, and 0.058 USD/kWe-h for 2.2 MWe, and 4.387,46 y 1.994,30 ton CO_2e estimated reductions. The conclusions reached are that the two biomass plants would have the potential to generate 6,381.76 CERs per year.

- Galan Riveros, X. F. Energy potential of agricultural residual biomass in Colombia. Thesis for the title of Specialist in Environmental management. Faculty of Permanent and advanced Education. Bogota, 2016.

The authors evaluate the energy potential of agricultural residual biomass in Colombia, by analysing the advantages and implementation of successful cases. There is a diversification of the use of agricultural biomass in the agroindustrial sector, although this has not been the result of the application of the regulations but rather by the results obtained in electric power self-generation processes at the initiative of certain productive unions.

- Patino Martinez, P. E. Biomass: feasibility study to implement a system of energy generation from vegetable waste. University of Santander. Postgraduate Directorate Master in Advanced Energy Systems. Bucaramanga 2014.

A considerable amount of waste from the natural and artificial pruning creates a great potential for the generation of biogas and electricity generation. A qualification and quantification of the energy potential was made, and analysed the different processing technologies for vegetable waste. Among these, the most feasible technology transformation from the environmental, energy, economic and social, is anaerobic digestion. The construction of an anaerobic digester requires special design, but in turn uses inexpensive materials. Santander University has implemented an environmental policy that supports the development of such projects.

- Plata Campo, L. A. Agricultural and forestry biomass as a competitive source of alternative energy in non-interconnected areas: Perspectives and viability of implementation in Colombia. Universidad de Los Andes. Bogota, 2006.

This paper describes the situation of the energy sector in Colombia. It presents agricultural and forest biomass as an energy alternative for non-interconnected areas.

Finally, it is relevant to mention that in 2010 UPME published a comprehensive Atlas of the energy potential of residual biomass in Colombia, with several detailed maps and statistics on the subject.

Table 16: Energy potential of crop residues

Crop	Production (ton)	Residue	Residues (ton)	Energy potential (TJ/year)
Palm	*1.137.984*	*Pit*	246.714	*3.428*
		Fiber	712.946	*8.845*
		Rachis	1.206.490	*8.622*
Sugar cane	*2.661.348*	*Residual cane harvest (RAC)*	8.741.194	*42.761*
		Bagasse	7.186.013	*78.814*
Panel cane	*1.284.771*	*Bagasse*	4.817.888	*52.842*
		RAC	3.250.469	*15.901*
Coffee	*1.092.361*	*Pulp*	2.327.929	*8.354*
		Husk	224.262	*3.870*
		Stalk	3.303.299	*44.701*
Maize	*1.206.467*	*Stubble*	1.126.840	*11.080*
		Husk	325.746	*3.389*

		Cob	254.564	*3.863*
Rice	*2.318.025*	*Chaff*	5.447.359	*19.476*
		Husk	463.605	*6.715*
Banana	*1.834.822*	*Rachis*	1.834.822	*786*
		Stem	9.174.108	*5.172*
		Residue	275.223	*484*
Plantain	*3.201.476*	*Rachis*	3.201.476	*1.374*
		Stem	16.007.378	*9.024*
		Residue	480.221	*844*
Total				*330.350*

Source: UIS-UPME-IDEAM

Table 17: Energy potential of cattle residues

Cattle	Residues (ton)	Energy potential (TJ/year)
Bovine	99.168.808	*84.256*
Poultry	3.446.348	*29.183*
Porcine	2.803.111	*4.306*
Total		*117.748*

Source: UIS-UPME-IDEAM

Table 18: Energy potential of other residues

Other	Residues (ton)	Energy potential (TJ/year)
Prunning waste	44.811	*318*
Collection points	120.210	*92*
Total		*410*

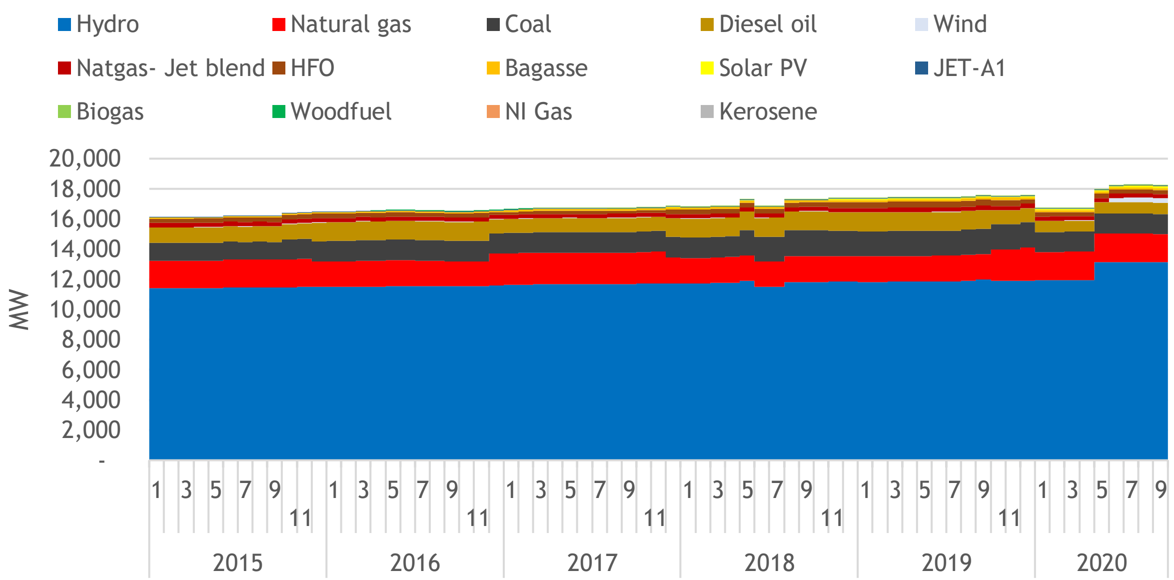
Source: UIS-UPME-IDEAM

Initiatives and Projects Development

Colombia’s installed capacity reached 18,217 MW by September 2020, showing an increase of 12% (a CAGR of 2.4%) since 2015, and is largely based on hydro power (72%.).

Bioenergy-based power generation (bagasse, woodfuel and biogas) is mostly incorporated by combined heat-and-power (CHP) plants, in some cases co-firing biofuels and natural gas or coal.

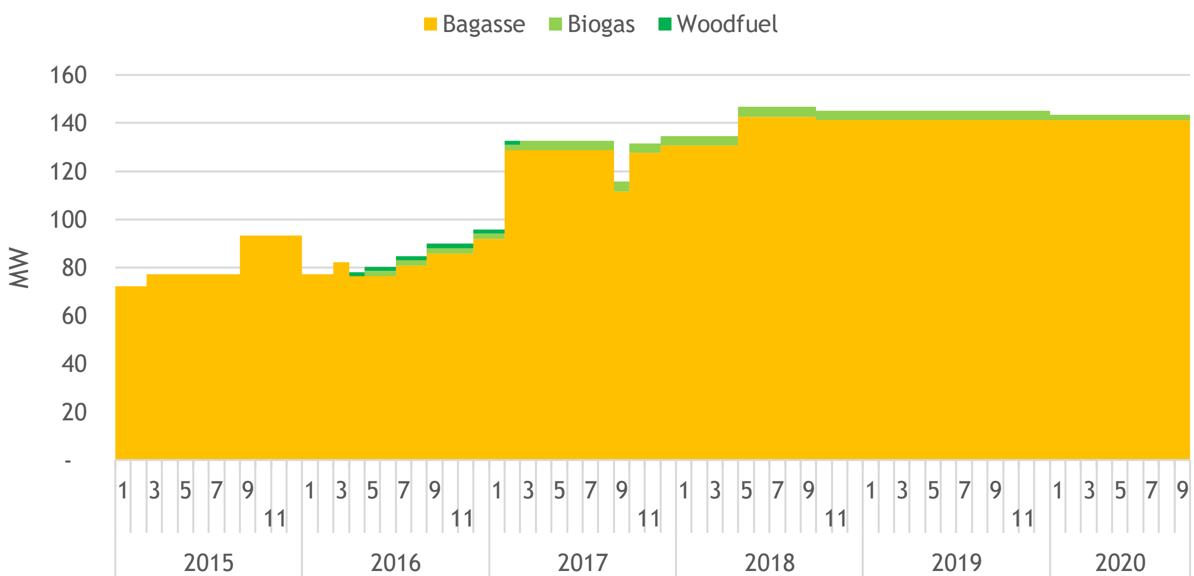
Figure 25: Installed capacity by source, 2015- September 2020



Source: Own elaboration based on data from XM via UPME.

Biomass-fed power generation installed capacity is mostly represented by bagasse CHP and currently represents 0.8% over Colombia's installed capacity (140 MW), after an increase of 50 MW (+54%, at a CAGR of 9%) between 2015 and 2020.

Figure 26: Detail of installed capacity from bioenergy sources, 2015- September 2020



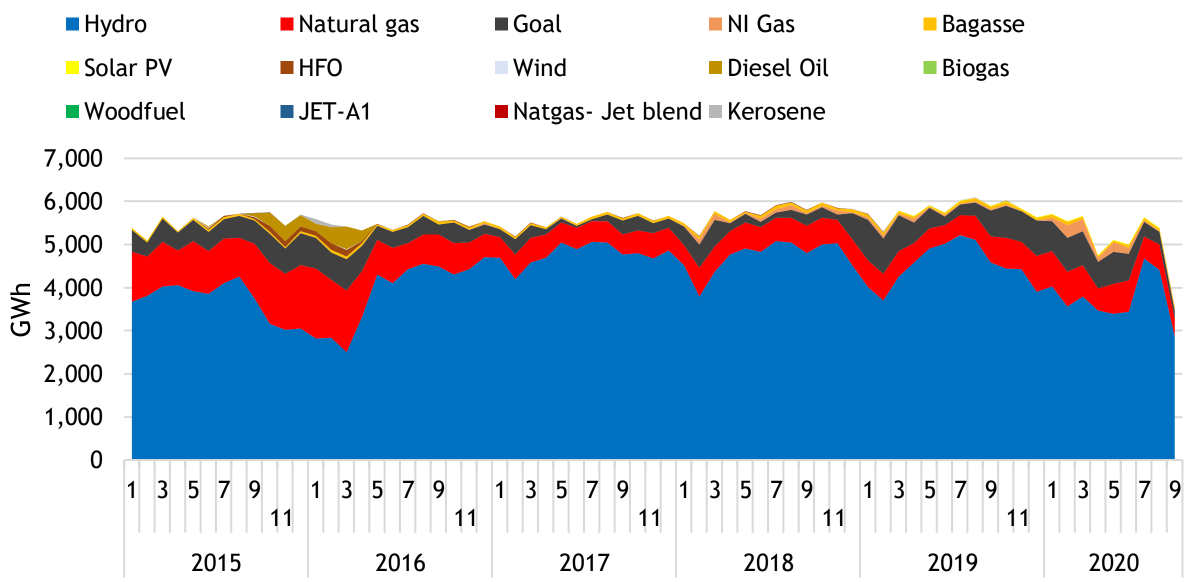
Source: Own elaboration based on data from XM via UPME.

The large hydro power installed capacity in Colombia creates power generation dependent and strongly influenced by hydro cycles (please refer in the figure to the end of 2015 and the first quarter of 2016), resulting in the need of relatively high-power backup capacity in order to compensate for low-hydraulic seasons and phenomena such as La Niña events.

In this context, while we mentioned that large hydro represented 72% of installed capacity by the end of 2020, when it comes to power generation this share reaches more than 85% when water is available and averages 75% per year.

As mentioned in the case of Argentina, power generation in Colombia remained stable during the last five years, around 5,500 GWh per month (or 7,000 mean MW -month), but was strongly affected in 2020 so far by restrictions resulting from low demand.

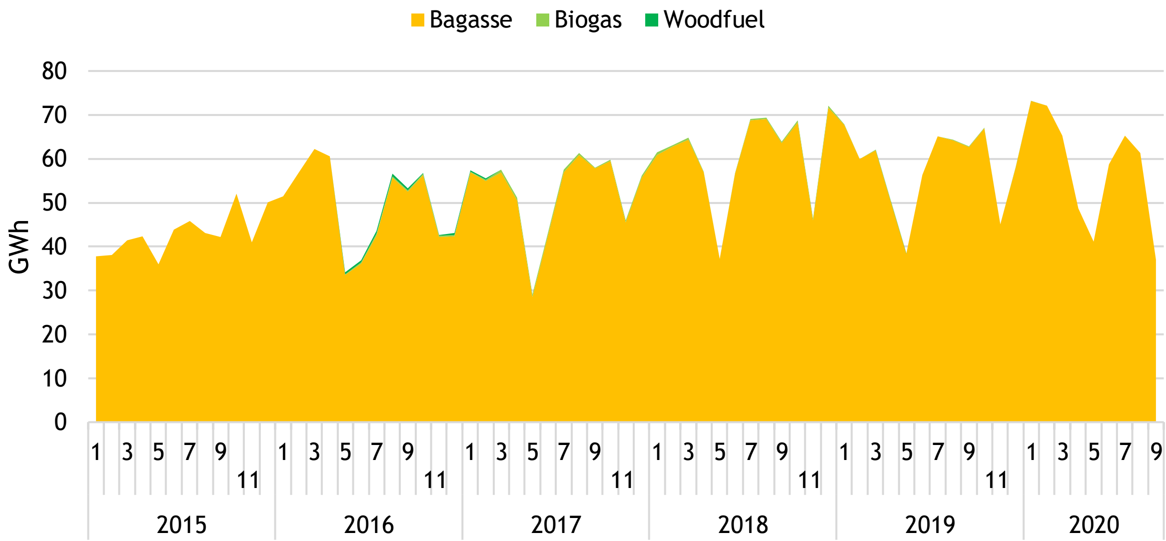
Figure 27: Power generation by source, 2015- September 2020



Source: Own elaboration based on data from XM via UPME.

As mentioned before, biomass-fed power generation is mostly associated to bagasse (sugarcane residues), and in consequence is also affected by seasonal and agricultural cycles, averaging 697.4 GWh per year (based on 2019 data due to current demand conditions), or 1.1% of total power generation in Colombia.

Figure 28: Detail of Power generation from bioenergy sources, 2015 - September 2020



Source: Own elaboration based on data from XM via UPME.

Colombia's energy and natural gas regulatory commission (CREG, by its acronym Spanish) currently surveys by month the state of the key CHP plants in the country. The following table summarizes the key characteristics of current CHP plants in Colombia by fuel, department and installed capacity.

Table 19: Current bioenergy combined heat and power capacity, September 2020

Agent	Department	Source	Capacity (MW)
TERMOCARTAGENA S.A. E.S.P.	BOGOTÁ D.E.	Biogas	1.7
CELSIA COLOMBIA S.A. E.S.P.	MAGDALENA	Biogas	2.25
Total Biogas			**3.95**
COMERCIALIZADORA DEL CAFÉ S.A.S E.S.P	CAUCA	Bagasse	10
PROYECTOS ENERGETICOS DEL CAUCA S.A. E.S.P.	CAUCA	Bagasse	19.9
ELECTRIFICADORA DEL META S.A. E.S.P.	META	Bagasse	1.6
CEMEX ENERGY S.A.S E.S.P.	META	Bagasse	19.9
EMPRESA DE ENERGIA DEL PACIFICO S.A. E.S.P.	RISARALDA	Bagasse	17
GENERADORA UNION S.A. E.S.P.	VALLE DEL CAUCA	Bagasse	2
RIOPAILA ENERGÍA S.A.S E.S.P.	VALLE DEL CAUCA	Bagasse	19

COMERCIALIZADORA DEL CAFÉ S.A.S E.S.P	VALLE DEL CAUCA	Bagasse	19.9
CELSIA COLOMBIA S.A. E.S.P.	VALLE DEL CAUCA	Bagasse	31.9
EMPRESA MUNICIPAL DE ENERGIA ELECTRICA S.A E.S.P	VALLE DEL CAUCA	Bagasse	
Total Biomass			**141.2**
Total			**145.15**

Source: Own elaboration based on data from CREG and from XM via UPME.

Despite no bioenergy project was awarded in Colombia's first two renewable energy auctions, there are a few biomass projects under study. UPME publishes a registry of all generation projects. Registered projects are classified by UPME in three phases: Phase1 Pre-feasibility; Phase 2 Feasibility; Phase 3 Detailed Engineering. According to that registry dated from week 24 of year 2020, there were four biomass-based generation projects registered, totalizing over 25 MW of planned capacity.

Table 20: Registered biomass project in UPME (as for Week 24 of 2020)

Project Name	Source	Capacity MW	Departament	Municipality
PROYECTO VILLANUEVA	Energetic crop	25	CASANARE	VILLANUEVA
AUTOGENERACIÓN SABANA S.A.S.	Bagasse	0.43	SANTANDER	RIONEGRO
GENERACIÓN DE ENERGÍA ELÉCTRICA A PARTIR DE CASCARILLA DE ARROZ	Biogas	0.35	TOLIMA	PIEDRAS
PLANTA DE BIOGÁS MR PIG	Bagasse	0.03	TOLIMA	HONDA

Source: UPME

The largest biomass project "Villanueva Project" is developed by SPV VILLANUEVA S.A.S. and is expected to start operations by the end of year 2021. By mid-2020, this project was in Phase 2 Feasibility, while all other biomass projects were in Phase 1

There is another project (not included in the previous list) of biomass power generation in the municipality of Carreño Port, close to the border with Venezuela, which aims to gain energy independence for the Vichada village. The project called "RefoEnergy Bita" would generate energy from wood chips with an installed capacity of 4.5 MW. The Uruguayan company Berkes has an EPC contract for the project that has an estimated startup date in 2021. Berkes BD Director declared in a recent interview that there is an important potential for biomass generation in Non-Interconnected Zones (ZNI), in which conventional solutions for the provision of electrical energy are based primarily on the use of diesel generator sets. He also suggested that government should separate auction by source and implement intraday hourly blocks in the tenders for bioenergy.

UPME has issued connection approval to more than 120 non-conventional renewable energy (NCRE) projects outside the auction framework, which could potentially result in roughly 7,700 MW of new installed capacity. These figures were provided by the Colombian Minister of Mining and Energy, Maria Fernanda Suarez, who at a recent forum in Bogota highlighted the positive economic impact of renewables on the country's economic growth. Solar potential attracted most of the interest, with UPME approving connection to 107 projects that account for 5,177 MW. Wind power projects, 18 in total, secured rights for 2,531 MW, while biomass will potentially yield 48 MW across four projects, according to Suarez. All this new capacity is expected to come on top of 2,500 MW of renewables that Colombia will accumulate by 2022 due to its two power auctions held in 2019.

Other biomass resources, such as power generation municipal solid waste (MSW), industrial and agriculture effluents, such as poultry and cattle residues

This subsection covers other biomass resources independently.

Alignment with Government Vision and Commitment

Energy recovery from solid waste is considered to be a renewable energy source in Colombia, in accordance with Law N° 1,715, Article 18, enacted by the Congress of Colombia. In line with Article 18, the energy content of solid waste that cannot be reused or recycled is considered to be a non-conventional energy source.

According to the Colombian Superintendence of Domiciliary Public Utilities (SSPD, for its acronym in Spanish) 1102 municipalities generated 26,528 T/day of solid waste in 2014, of that waste 80.4% was disposed in sanitary landfills, 3.09% was used in recovery plants, and 1.27% was taken to containment buildings. Although, the regulations in force (Decree 838 of 2005, Decree 2820 of 2010, and Resolution 1890 of 2011) prohibit other waste disposal methods, a high share of the adopted methods to dispose the remaining SW persist: release into bodies of water (0.45%), uncontrolled burning (0.18%), garbage dumps (10.34%), and temporary trenches (4.26%).

Under the formulation of CONPES 3874 of 2016, the National Policy for Comprehensive Solid Waste Management by 2030 was adopted. The primary objective is to "implement a solid waste comprehensive management as a national policy of social, economic, environmental and health interest, to contribute to the promotion of the circular economy, sustainable development and adaptation and mitigation to climate change”. To achieve this objective, the policy is based on four strategic axes: adoption of measures aimed at (i) preventing the generation of waste, (ii) minimizing the amount of waste finally disposed at a site, (iii) promoting the reuse, use and treatment of solid waste, and (iv) avoid the generation of greenhouse gases.

Another relevant legislation is the Decree N° 596 of 2016, which encourages to increase the rates of use of solid waste in the country.

Degree of Scientific Development / Academic Literature Review

Several articles were identified related to other biomass resources in Colombia:

- Sagastume, A. et al. 2020. The energy potential of agriculture, agroindustrial, livestock, and slaughterhouse biomass wastes through direct combustion and anaerobic digestion. The case of Colombia. Journal of Cleaner Production.

In Colombia, agriculture and livestock production, and the processing agroindustry are a significant source of biomass wastes. Waste-to-energy technologies are an alternative to revalorize these wastes as energy sources while reducing their environmental impacts. An inventory of the main crops and livestock produced in Colombia and the share processed in agroindustry was developed to identify the available biomass wastes for energy applications. Based on the inventory, the biomass-based energy potential was calculated for the use of direct combustion and anaerobic digestion systems. The results show a bioenergy potential of 60,000 to 120,000 GWh per year, with higher potentialities for direct combustion systems than for anaerobic digestion. Using combined heat and power systems for heat and electricity production can increase the biomass share in the end-use energy mix up to 15–28%, including 27–53% of the 68,943 GWh of electricity produced in 2018.

- Alzate-Arias, S., et al. 2018. Assessment of Government Incentives for Energy from Waste in Colombia.

This work evaluates the pre-feasibility of energy from waste projects in Colombia under the guidelines of Law N° 1,715. The potential of electric power generation from municipal solid waste of each conversion technology was estimated with mathematical models. Additionally, the economic evaluation considered five cases that combine loan options, accelerated depreciation, and income tax deductions. The results reveal that only anaerobic digestion and landfill gas technologies constitute viable projects in case of traditional investment with and without loans.

- Acevedo, C. H., et al. 2018. Techno-economic analysis of on-grid biomass renewable energy power station: A case study in Caribbean region of Colombia

In this article a techno-economic study of an electric-biomass on-grid power plant is presented, in order to compare the performance and the operating annual cost under some types of biogases produced from poultry, bovine and porcine manure, and solid urban organic waste, using the Homer® software to develop many solutions. The results presented a significant operational cost reduction when the biogas generator is operating on grid, finding an 8.61% of cost decrease using biogas generated from poultry, bovine, and porcine manure, and a 10.53% of cost decrease using biogas from solid urban organic waste from centers and grocery marketplaces at Caribbean.

- Alzate, S., et al. 2019. Municipal Solid Waste as a Source of Electric Power Generation in Colombia: A Techno-Economic Evaluation under Different Scenarios.

This work evaluates the techno-economic pre-feasibility of waste to energy projects in Colombia using four different conversion technologies of incineration, gasification, anaerobic digestion, and landfill gas. Three study cases were selected: Guayatá, Andes and Pasto. The cash flows produced by each technology in the three scenarios were evaluated to obtain the Internal Rate of Return (IRR), which was found to be influenced by the benefits of this legislation. The results show that these types of projects can have positive economic results if tax and government incentives are considered.

Initiatives and Projects Development

There are no large-scale biogas projects identified in Colombia.

Besides the small-scale biogas projects registered in UPME and mentioned before, in Puerto Tejada (Cauca) there is a project for the construction of a modern 4.4 MW power generation plant from processed chicken, as part of a program called "Incubadora Santander". The project was completed in 2017 with an estimated investment of 4.6 million dollars.

Enhancing soil carbon content and Enhancing soil carbon content with biochar

Alignment with Government Vision and Commitment

There are no specific laws or national plans in Colombia covering the enhancement of soil with biochar.

Even though not mentioning biochar explicitly, there is a national program launched in 2015 called "Colombia Siembra" which main goal was to expand by one million the hectares sown in the country by 2018. The program is promoted by the Ministry of Agriculture. The objectives of the program included:

- Increase the agricultural supply to guarantee food availability in the country
- Increase the area and the yields destined to the production and to promote agricultural and agro-industrial exports
- Promote the development of agricultural businesses to improve the income of producers
- Strengthen technological development and services in the agricultural sector

Indirectly biochar could help to achieve higher yields and strengthen technological development.

Degree of Scientific Development / Academic Literature Review

Several scientific articles have been identified related to biochar as soil carbon content enhancer in Colombia:

- Molina D, et al. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant soil.

The application of biochar to soil has been shown to improve crop yields, but the reasons for this are often not clearly demonstrated. The effect of a single application of 0,8 and 20 t ha−1 of biochar to a Colombian savanna Oxisol for 4 years (2003–2006) was studied, under a maize-soybean rotation. Soil sampling to 30 cm was carried out after maize harvest in all years but 2005, maize tissue samples were collected, and crop biomass was measured at harvest. Maize grain yield did not significantly increase in the first year but increases in the 20 t ha−1 plots over the control were 28, 30 and 140% for 2004, 2005 and 2006, respectively. The availability of nutrients such as Ca and Mg was greater with biochar, and crop tissue analyses showed that Ca and Mg were limiting in this system. Soil pH increased, and exchangeable acidity showed a decreasing trend with biochar application. The greater crop yield and nutrient uptake were primarily associated to the 77–320% greater available Ca and Mg in soil where biochar was applied.

- Pachón, L. (2013). *Economic analysis in the use of traditional knowledge in* anthropogenic Amazonian soils: Biochar. University of Bogota Jorge Tadeo Lozano

This research makes a comparison between two processes of soil improvement according to the economic, social, cultural and environmental standpoint. The variables used were obtained by review of secondary data and information produced with the Amazonian farmers, considering different levels on attributes. Researchers also analysed a financial approach in order to know the costs and benefits for the implementation of each method of soil improvement, to evaluate some economic viability of each alternative. The main result shows the importance for the indigenous people that ancestral soil modification in the Amazon region has, against the economic efficiency that present contemporary techniques on soils improvement, such as the Biochar case.

- Alonso-Gómez, L.; et al. 2016. *Biochar as an amendment in an oxisol and its effect on the growth of corn*. Rev. U.D.C.A Act. & Div. Cient.

In this study, the effect of applying different levels of biochar in a representative oxisol of Colombian Altillanura and its effect on corn growth was evaluated. Soil samples were collected and treated with African palm shell biochar, thermochemically obtained in a cylindrical fixed bed reactor, in a concurrent flow regime. Different temperatures were handled to prioritize obtaining biochar. Doses of biochar (m/m) of 0, 2, 5 and 10% were used and compared with treatment with lime. After 45 days incubation, under external environmental conditions, seeds of maize (Zea mays L.), Guacavía variety were planted in each container, without addition of fertilizer or amendment. The experimental units were plastic containers of 5kg. Although the plant material was collected 90 days after planting, it presented a vegetative phase V5. Nutrient uptake by corn was analysed in whole plant. Independent biochar samples were analysed and found predominance negative charges. In the mix biochar-soil increased P, Ca, Mg and K was observed, but did not increase Na. Al+ 3 proportional to the application of biochar was reduced. The Zn and Mg absorption increased significantly in maize, but also Fe uptake increased to toxic levels.

Table 21: Soil final assessment, after a 45-day incubation period

Porcentaje de mezcla Biochar	Text Tacto	M.O. %	P. ppm	pH 1:1	CATIONES meq/100g					CATIONES p.p.m.					
					Al	Ca	Mg	K	Na	Cu	Fe	Mn	Zn	B	S
0%	Ar	0,80	1,20	4,8	1,50	0,30	0,01	0,07	0,01	0,02	9,35	1,55	0,05	0,04	5,34
2%	Ar	0,80	2.90	5,0	1,45	0,40	0,05	0,21	0,03	0,25	9,75	1,80	0,65	0,20	5,91
5%	Ar	1,10	2,90	5,3	0,80	0,40	0,30	0,47	0,03	0,40	16,25	2,95	1,50	0,07	7,06
10%	FArA	1,90	10,60	5,4	0,40	0,80	0,20	0,77	0,03	0,70	18,12	3,80	11,00	0,11	13,26
Cal	Ar	0,60	0,80	5,9	0,10	2,50	1,00	0,05	0,02	0,05	6,30	0,85	0,05	0,11	8,84

Table 22: Maize assessment, after 90 days of sowing

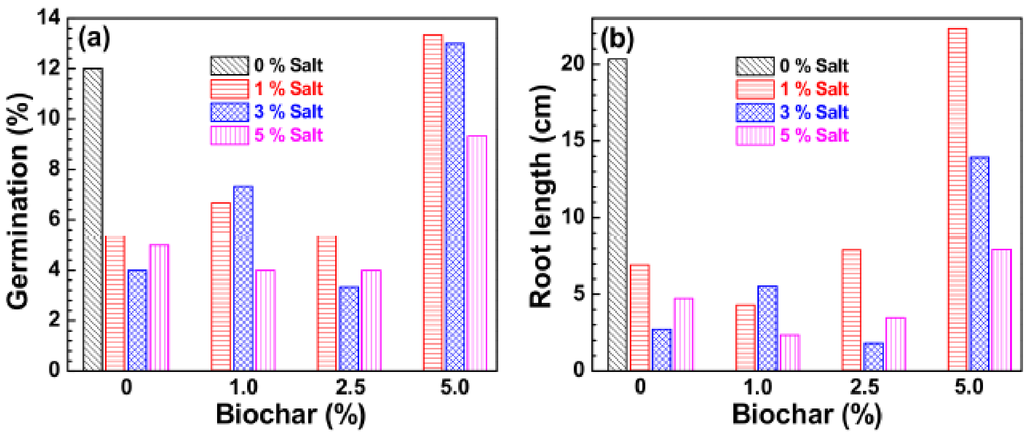
Identificación en campo	MACRONUTRIENTES (%)				MICRONUTRIENTES p.p.m.			
Porcentaje de mezcla Biochar	Ca	Mg	K	P	Cu	Fe	Mn	Zn
0%	0,19	0,06	0,84	0,02	8,00	5910,0	64,50	32,00
2%	0,18	0,08	2,64	0,04	8,50	3730,0	57,00	62,00
5%	0,18	0,10	2,19	0,04	6,00	3690,0	60,00	58,50
10%	0,20	0,12	1,86	0,05	6,50	6380,0	72,00	100,00
Cal	0,62	0,22	1,01	0,03	5,50	5365,0	40,00	23,50

The study also mentioned that several entities such as the Universidad de los Llanos, the CIAT International Center for Tropical Agriculture, the Colombian Corporation for Agricultural Research CORPOICA and the National University of Colombia, have developed research aimed at understanding and improving the conditions of these soils, for their better use (Alarcón- Jiménez et al. 2016; Jamioy Orozco et al. 2015; Malagón Castro, 2003). These entities have concluded that, to convert these soils to a commercially viable agriculture, it is required the formation of a cultivable soil layer, through deep tillage, to improve the soil structure and the application of correctors, like lime, to increase the pH.

- Muegue, L.C.D.; et al. 2017. *Characterization and Potential Use of Biochar for the Remediation of Coal Mine Waste Containing Efflorescent Salts*.

In open pit coal mining, soil and vegetation are removed prior to the initiation of mining activities, causing physical, chemical, and microbiological changes to the soil and landscape. The study shows the results of an integrated study of the remediation of mine waste with a high level of salt contamination in areas of the Cesar Department (Colombia), employing biochar as an amendment. Soil remediation was evaluated in Petri dish seed germination bioassays using Brachiaria decumbens. Biochar was shown to be effective in the improvement of pH, and positively influenced the germination percentage and root length of Brachiaria grass seeds.

Figure 29: Biochar effects on germination and root length



The study also recommends that "in the near future, more tests will be required to reduce any errors arising from the experiments. Another constraint is the scaling of biochar remediation from Petri dishes to pots and experimental plots".

- Rodriguez et al. 2019. Effectiveness of Biochar Obtained from Corncob for Immobilization of Lead in Contaminated Soil.

The aim of the study was to analyse the efficiency of biochar, obtained from the gasification of corncob, for the immobilization of lead in contaminated soils. Biochar from corncob was used as an amendment for soil contaminated with lead (extracted from the municipality of Malambo, Colombia) in order to estimate its ability to immobilize leaching lead. A comparison laboratory test applied a modified biochar produced with a 10% hydrogen peroxide chemical treatment. Laboratory tests indicated that unmodified biochar obtained a maximum retention of 61.46% of lead, while the modified biochar obtained only 44.53% retention. In the pot experiments, the modified biochar indicated high germination and growth of seeds (up to 89.8%). Although the lead immobilization in soil was positive for both cases, the use of soil with high concentrations of lead (167.62 g/kg) does not indicate biochar's effectiveness for purposes of comparison with the current United States Environmental Protection Agency (USEPA) limit value (400 ppm for bare soil in urban play areas). Therefore, further studies are recommended using soil with lower lead concentration levels.

- Sánchez-Reinoso AD, et al. 2019. Use of Biochar in Agriculture. Acta Biologica Colombiana. Universidad Nacional de Colombia

The objective of this review is to show how biochar (BC) can be obtained and its effects on the physicochemical properties of soils and physiological behaviour of cultivated plants. It has been found that BC application improves the physicochemical characteristics of the soil, including fertility. This improvement generates positive responses in the physiological behaviour of plants such as: the increase of germination, accumulation of dry matter, photosynthesis, yield, and quality.

The use of BC opens essential opportunities for the sustainable management of agriculture in Colombia. As mentioned before, BC can be considered in systems in which vegetables are irrigated with contaminated water (Miranda et al., 2011) and in perennial crops exposed to heavy metals due to activities related to mining and hydrocarbon exploitation (Jiménez, 2015), in order to reduce their impact on human health. In this sense, the cocoa crop is cultivated in contaminated soils with high cadmium content; in these scenarios, biochar can be an important alternative in bioremediation of heavy metals (Lau et al., 2011). Another interesting opportunity is to evaluate the different sources of plant and animal material as alternatives to be used in the pyrolysis process, especially by-products such as sugar cane bagasse (Rodríguez et al., 2009), the leaves and empty fruits of oil palm crops (Sukiran et al., 2011), corn, sorghum and rice chaffs, cotton waste, as well as waste from livestock activities (pig, poultry and cattle manure). The knowledge of the effects on the physiology of cultivated plants is one of the main challenges that should be taken into consideration. A clear example is the use of solid vegetable residues of coffee production systems as the pulp obtained from the fruit processing represents about 43.58 % of the coffee fruit on a fresh weight basis (Montoya, 2006). It has been reported that about 2258 kg ha-1 of coffee pulp are produced annually (Rodríguez, 2007). Collectively, about 162 900 t of fresh pulp are generated per each million bags of 60 kg of dried parchment coffee that is exported from Colombia. If not used correctly, the pollution caused by these residues would be equivalent to the one generated by the excrements and urine of a population of 868 736 inhabitants (Rodríguez, 2009). For this reason, alternatives such as the application of BC can improve the productivity, quality and profitability of farmers.

Biochar opens essential doors for the sustainable management of agriculture in Colombia. It can be considered in agricultural regions exposed to heavy metals, in order to reduce its impact on human health.

- Gallo-Saravia M. et al. 2018. Evaluation of biochar as substrate alternative in tomato cultives. Universidad de Antioquia

In this work, two specific types of biochar are evaluated as potential substrate substitutes in open small-scale cultures. A crop of Solanum lycopersicum (tomato) was used as reference, and the effect on plant development and harvest (number, diameter and weight of fruits) was observed when replacing the commercial substrate by biochar in proportions of 0, 20, 50, 80 and 100%. It was observed that with substitutions of 20% and 50% of substrate by biochar, the plants show a normal development, and the tomato production is comparable to the one obtained in the absence of biochar; However, when replacing 80% or 100% of the substrate by biochar, the effect on plant growth is negative, apparently due to the absence of nutrients. From an economic and environmental perspective, these results are quite satisfactory; since using 20% or 50% of biochar can represent significant savings for the farmer (less use of substrates), while also giving utility to agro-industrial waste (biochar).

- Garzón E., M. (2010). Biochar from oil palm trunks: an alternative use of biomass and improvement of soil quality during the renovation stage. Cenipalma.

Cenipalma assessed the agronomic potential of biochar from oil palm trunks undergoing renovation at the Unipalma S.A. plantation (Colombian Eastern oil palm-growing zone). In a first stage, researchers determined the amount of biomass from trunks present in one hectare, characterized the material and quantified the nutrient reserves. In the second stage, the biochar produced from the trunks was characterized physically and chemically, nutrient reserves were quantified and the level of nutrients in the soil was assessed. The main results were: a) In biochar there was an average storage of 23.5 t / ha of carbon; b) In the biochar, between 52 and 76% of the carbon stored in the stipe was conserved. c) The incorporation of biochar in different doses significantly affected the concentrations of K and P; acidity and exchangeable Al also decreased.

Table 23: Effects for different biochar doses

(t ha^{-1})	Mes 3	Mes 6	Mes 3	Mes 6	Mes 3	Mes 6	Mes 3	Mes 6
0	0,99	1,03	1,3	1,33	0,18	0,17	14,5	14,9
7,5	1,03	1,04	1,32	1,43	0,39	0,27	22,7	16,5
15	1,05	1,12	1,37	1,44	0,53	0,36	22,3	17,6
30	1,02	1,23	1,37	1,61	0,57	0,57	27,6	23,7

- Nates Ocampo, E. 2014. Evaluation of the effect of biochar on the soil and the quality of the fruits in a cape gooseberry crop (uchuva). Pontificia Universidad Javeriana

The aim of this study was to establish the impact of the application of biochar in the quality of the fruits of an organic crop Cape gooseberry (Physalis peruviana L.) as well as the Physicochemical and microbiological characteristics of the soil. The effect of biochar after a year of soil-applied in two doses (3.5 and 8 ton ha1) in Santa Rosa de Viterbo, Boyacá was determined. For the quality of the fruits, a greater weight of these was found in the 3.5 ton biochar treatment (P = 0.007 F = 6.04), but in terms of brix degrees, pH and diameter there were no differences between treatments. For the physicochemical characteristics of the soil, no significant differences between treatments were found, nor correlation between soil variables and characteristics of the fruit. It is concluded that after one year of application of biochar (in a dose of 3.5 ton / ha of crop Cape gooseberry and without further fertilization) a positive effect on the weight of the fruit was already observed. It is recommended to continue the study seeking to know if there are subsequent changes in the physicochemical characteristics of the soil or crop production, with the addition of biochar.

Initiatives and Projects Development

No large-scale projects have been identified related to biochar as soil enhancer in Colombia. However, many experimental / laboratory projects and test were performed, as detailed in the literature review.

Some other examples not included in the academic literature review are the following:

The Physics Department of the Colombia National University (UNC), led by professor Dussan Cuenca, is working on an initiative for obtaining biochar from coffee plantations waste and apply it to decontaminate rain and turbid waters in very short times and at low cost. Another application is for water treatment from mining industry with high levels of heavy metals like lead and mercury.

The company "r3 Environmental Technology Colombia SAS" conducted a research project from June 2016 to March 2017, funded by the UK government and supported by the Colombian Ministries of Mining and Environment and Sustainable Development. The project focused on strategies for rehabilitating mercury contaminated mining lands for renewable energy and other self-sustaining re-use strategies. Specific activities included (among others) technology evaluations and bench scale test work including biochar for mercury stabilization to form an on-site field-testing plan for techniques promising to be replicable to other similarly contaminated sites.

Another project seeks to develop a new soil improver for Urabá Antioqueño from biochar produced with waste from the palm sector. The project, starting in September 2020, is a joint work of the National University of Colombia (Unal) Medellín Headquarters, the EIA University and the Pontificia Bolivariana, together with the Sobiotech company.

Enhanced weathering or ocean alkalinization

Alignment with Government Vision and Commitment

In 2000, through Decree N° 347, the Colombian Oceanography Commission was restructured, adopting the name of the Colombian Ocean Commission (CCO), responsible of proposing to the National Government a National Policy for the Ocean and Coastal Spaces, for its administration and sustainable development, carrying out the necessary inter-institutional and intersectoral coordination.

Since 2002, the Guidelines for the National Policy of the Ocean and Coastal Spaces (LPNOEC) were designed, thus establishing a starting point for the design and adoption of a State policy that allowed identifying the main problems and needs of the regions (Caribbean-Pacific); and suggested comprehensive strategies for the competitive and effective development of the country through them. Therefore, since 2007, Colombia has a policy instrument that responds to the need to assume the ocean from a comprehensive, systemic and total perception, which has achieved international significance and recognition.

Colombia is a country of immense richness, it has coasts in two oceans and activities that take place there are vital. The CCO promotes sustainability, integral development, competitiveness of the ocean and its coasts, the scope of national maritime interests and insertion in new international scenarios. For the period 2016-2030, the LPNOEC document projects Colombia's path towards an Oceanic Medium Power (PMO), through guidelines for cooperation and integration in marine affairs, economic development, sustainable use of resources, planning of the marine territory and coastal protection of biodiversity and defence of sovereignty.

However, there are no specific laws or national plans or programmes in Colombia covering enhanced weathering neither ocean alkalinization.

Degree of Scientific Development / Academic Literature Review

Even tough not explicitly covering ocean alkalinization, some academic literature has been identified related to ocean characterization, its effects due to climate change and initial studies on carbon sequestration of marine areas.

- Zarate-Barrera TG, Maldonado JH. Valuing Blue Carbon: Carbon Sequestration Benefits Provided by the Marine Protected Areas in Colombia. PLoS ONE 10(5): e0126627. doi:10.1371/journal. pone.0126627. 2015

The objective of this study is to value the services associated with the capture and storage of oceanic carbon provided by a new network of marine protected areas in Colombia. Marine protected areas are aimed to protect and conserve key ecosystems for the provision of a number of ecosystem services that are the basis for numerous economic activities. The capacity of sequestering (organic carbon is a regulating service, provided mainly by mangroves and seagrasses, that gains importance as alternatives for mitigating global warming become a priority in the international agenda. The results indicate that the expected benefits associated to carbon capture and storage provided by these ecosystems are substantial but highly dependent on the expectations in terms of the negotiations surrounding the extension of the Kyoto Protocol and the dynamics of the carbon credit's demand and supply. The authors also find that the natural loss rate of these ecosystems does not seem to have a significant effect on the annual value of the benefits. This approach constitutes one of the first attempts to value blue carbon as one of the services provided by conservation.

- Rojas Higuera, P. J, et al. On global ocean warming and acidification and its possible expression in the Colombian coastal marine environment. Rev. Acad. Colomb. Cienc. Ex. Fis. Nat. 39(151):201-217, 2015

Based on the analysis of the data on sea surface temperature and pH recorded in sectors of the Colombian Caribbean and Pacific coast, were deduced the potential impacts on the marine ecosystems. Based on the review of the evidences published by other authors about the impacts caused on ecosystems by the recent sea temperature increase and the pH reduction, it can be assumed that Colombian ecosystems will be dramatically impacted given that changes in the physical environment are greater than those reported up to day, a situation that will worsen with time.

- Zarate, T. The monetary value of the Colombian Blue Carbon: Benefits of carbon sequestration and storage provided by the Areas Subsystem Protected Marinas. Universidad de los Andes, Economy Faculty. 2013.

The objective of this document is to assess the services associated with capture and oceanic carbon storage –Blue Carbon- provided by the Subsystem of Marine Areas proposed for Colombia. Through the construction of a profit function and the estimation of possible future scenarios give the carbon market and its price, obtain the monetary value associated with this service. The results indicate that the annual expected benefits associated with carbon capture and storage, provided by ecosystems such as mangroves and seagrasses, is highly dependent on parameters that reflect the expectations regarding the negotiations on the extension of the Kyoto Protocol and the dynamics between supply and demand of emission permits. Furthermore, it is found that the annual rate of loss of these ecosystems does not seem to have greater effect on profits.

- Popoyan Hernandez, J. G. Capture of CO2 in the Colombian Pacific Ocean between 2000 and 2011. Revista de Investigaciones Agroempresariales, Volumen 1, Enero - Diciembre 2015

The flux of CO_2 was estimated between the atmosphere and the Colombian Pacific Ocean derived using satellite data (Sea Surface Temperature, wind speed) between 2000 and 2011 and validated with in situ data available at the Carbon Dioxide Information and Analysis Center. The statistical analysis indicated that while validating satellite data flux vs. the in situ showed a good performance as a preliminary tool for estimating the fluxes, it is concluded that it is necessary to have greater amounts of data on site, in order to adjust and improve the estimation model.

Regarding enhanced weathering, no specific academic literature was identified in Colombia.

Initiatives and Projects Development

No specific initiative or project related to ocean alkalinization was identified in Colombia.

Regarding enhanced weathering, neither were initiatives nor large projects identified in Colombia.

Direct air carbon dioxide capture and storage

Alignment with Government Vision and Commitment

There are no specific laws or national plans or programs in Colombia covering direct air capture and storage.

Degree of Scientific Development / Academic Literature Review

No academic literature was identified in Colombia covering direct air carbon dioxide capture and storage technologies, except one particular paper, but it is focused in CO2 storage in deep formations in the Llanos basin.

- Mariño-Martínez, et al. (2018). Possibilities for CO2 capture and storage (CCS) in Colombia - case Tauramena (Casanare). Universidad Pedagógica y Tecnológica de Colombia

Although in Colombia there is a considerable concern regarding greenhouse gas emissions, only a few studies has been focused on the real possibilities of injecting CO2 into the subsoil; for this reason it is necessary to study the state of the art and consider areas with good possibilities for capturing CO2. Sedimentary basins are the best option currently available for long-term CO2 storage. The conditions for the implementation of the method of CO2 storage in the Llanos basin (Tauramena, Casanare) are favourable due to the presence of several members of the Carbonera formation with good thickness and permeability; additionally, the presence of the overlaying regional seal of the León formation, and the development of technologies in the hydrocarbon industry, favouring the selection of this basin for potential pilot projects and subsequent commercial implementation of the CCS method in the basin. The study only mentions CO2 capture technology in theoretic and broad terms, with no specific mention to Colombia.

Initiatives and Projects Development

The DAC technology provider Global Thermostat (GT) announced in year 2013 that it would start operations in Colombia. Top management of the US firm held meetings with the Ministry of Energy and Mines in Colombia. Despite those initial intentions, no specific project was announced in the following years till present.

Ocean fertilization

Alignment with Government Vision and Commitment

See ocean alkalinization. We have identified no specific national plans or programs related to ocean fertilization.

Degree of Scientific Development / Academic Literature Review

No specific academic literature related to ocean fertilization was identified in Colombia.

Same documents reviewed in ocean alkalinization are relevant to ocean fertilization, as they characterize and cover the effects of climate change in Colombian oceans.

Initiatives and Projects Development

No specific initiative or project related to ocean fertilization was identified in Colombia.

Other CDR approaches in Colombia

- PATIÑO RESTREPO, C. A. 2012. Study of the penetration of carbon capture and storage technologies by systems dynamics. Master's Thesis Master in Systems Engineering. Universidad Nacional de Colombia.

For carbon capture and storage technologies (CCS) there is information available related to current status of the main variables which influence on the weather and its changes, such as atmospheric CO2. The model built in this study is going to be contrasted with other models to analyze the adoption process and its barriers. Through the systems dynamic approach, the interaction between the qualitative and quantitative variables of the model is simulated, such as global warming perception, reduction goals and competence with carbon cap-and-trade. Using a Logit model, the system dynamics model simulates competition with other technology and gives a probability of choice of technologies, based on comparison of similar variables for each type of technology.

- Rodriguez Acevedo, E. et al. 2019. Develop of nanomaterials for CO2 geostorage in shallow reservoirs. 2nd Latin American Engineering Congress. Colombia.

This study proposes, for the first time, an enhanced CCS process (eCCS), in which the stage of CO2 separation is eliminated, and the flue gas is injected directly in shallow reservoirs located at less than 300 m deep, where the adsorptive phenomena control CO2 storage. Carbon nanomaterials were used as modifying agents of the reservoir porous texture in order to improve both the CO_2 adsorption capacity and selectivity. For this purpose, sandstone was impregnated with nanofluids composed of carbon nanospheres dispersed in deionized water. As a main result, the best materials for industrial application allows increase the adsorption capacity at 0°C to an increment factor of 499 (from 0.00125 to 0.6265 mmol g^{-1}) with only 20 % of nanomaterials at atmospheric pressure, and by more than 800 (from 0.00125 to 1.1 mmol g^{-1}) at 3.0 MPa. The increment factor of adsorption capacity under shallow reservoir conditions (50°C and 3.0 MPa) was more than 670 (from 0.00125 to 0.9 mmol g^{-1}).

- San Martín Cañas Janowsky, Stephanie & Tassinari, Colombo. (2019). Geological storage of carbón dioxide: perspectives for Colombia. August 2019. Conference XVII Colombian Geology Congress. Santa Marta, Colombia.

This work seeks to determine the theoretical potential of the geological storage capacity of carbon dioxide in Colombia. The study was carried out based on the information available from the Colombian oil basins, analyzing key geological parameters such as mineralogy, organic matter content, thermal maturity, type of kerogen, porosity and its main characteristics, permeability and thickness of layers. Additionally, to gain a clear perspective on the potential for CCS project implementation in Colombia, pilot projects in Algeria, Brazil, France and Norway were analysed in technical, environmental and social terms. As a result, this work summarizes the main lithological systems that could be considered for the implementation of CCS in Colombian oil basins, characterizing them according to their location, depth, type of reservoir, seal and kind of trap. Additionally, the benefits and challenges for Colombia and its oil industry.

Other initiatives related to bioenergy generation that may provide a basis for further BECCS development

Alignment with Government Vision and Commitment

Regarding biofuels in Colombia, Marin et al (2011) made an analysis of the initial legal framework. Since 2002 the government of Colombia decided to strongly support the use and production of biofuels. The law for the promotion of ethanol had been already adopted in 2001 (Law 693 2001) while the current law to incentive biodiesel was approved in 2004 (Law 939 2004). These legal instruments constituted the firsts steps of an ambitious biofuels strategy that estimates more than 7 million hectares of land as the potential area for biofuels crops (palm oil and sugarcane). To support this strategy the government resorted to existing policy tools that supported private investment and adopted new legal instruments specifically aimed at stimulating biofuels consumption and production (Policy Guidelines Biofuels CONPES 3510/2008; Policy Guidelines Palm Oil CONPES 3477/2007). Instruments to stimulate production include incentives for both the agricultural and industrial processes. Sugarcane and palm oil were identified as the most promissory crops for ethanol and biodiesel production, respectively.

As explained by Gomez (USDA, 2019), the establishment of obligatory blending targets constitute an important mediating factor in the promotion of biofuels in Colombia. Since March 2018, the

Colombian government introduced E10 and B10 across most of the country, except for three border departments with Venezuela where no blend mandate is established for ethanol and only two percent for biodiesel given cross-border smuggling issues. E10 and B10 are the highest blend mandates ever established. They were introduced to help with high levels of pollution in major metropolitan cities, contribute to Colombia's climate change commitments under COP21, and incentivize local production. In June 2019, the MME published a draft resolution for comments that increase the biodiesel blend mandate to B12.

Degree of Scientific Development / Academic Literature Review

- Ramón Fernando Colmenares-Quintero, Camilo José Rico-Cruz, Kim E. Stansfield & Juan Carlos Colmenares-Quintero | Yibing Li (Reviewing editor) (2020) Assessment of biofuels production in Colombia, Cogent Engineering, 7:1, DOI: 10.1080/23311916.2020.1740041

The methodology to assess biofuels production is as follows: the current drivers and barriers for biofuels production in Colombia were reviewed. The results exposed that Colombia presents some special conditions for the production of biofuels that allow to generate a competitive advantage compared to other countries. However, some barriers can affect the adoption and production of biofuels in the country. Secondly, a survey to biofuel producers, suppliers and researchers was done, in order to validate their motivations and perceptions. Some similitudes and differences with regard to the literature were found in the surveys. Hence, this information allowed the authors to understand the reality of biofuels in Colombia from the stakeholders´ view. Additionally, a set of policies were analysed. The authors believe that this set of policies will help stakeholders to improve biofuels production in Colombia.

Initiatives and Projects Development

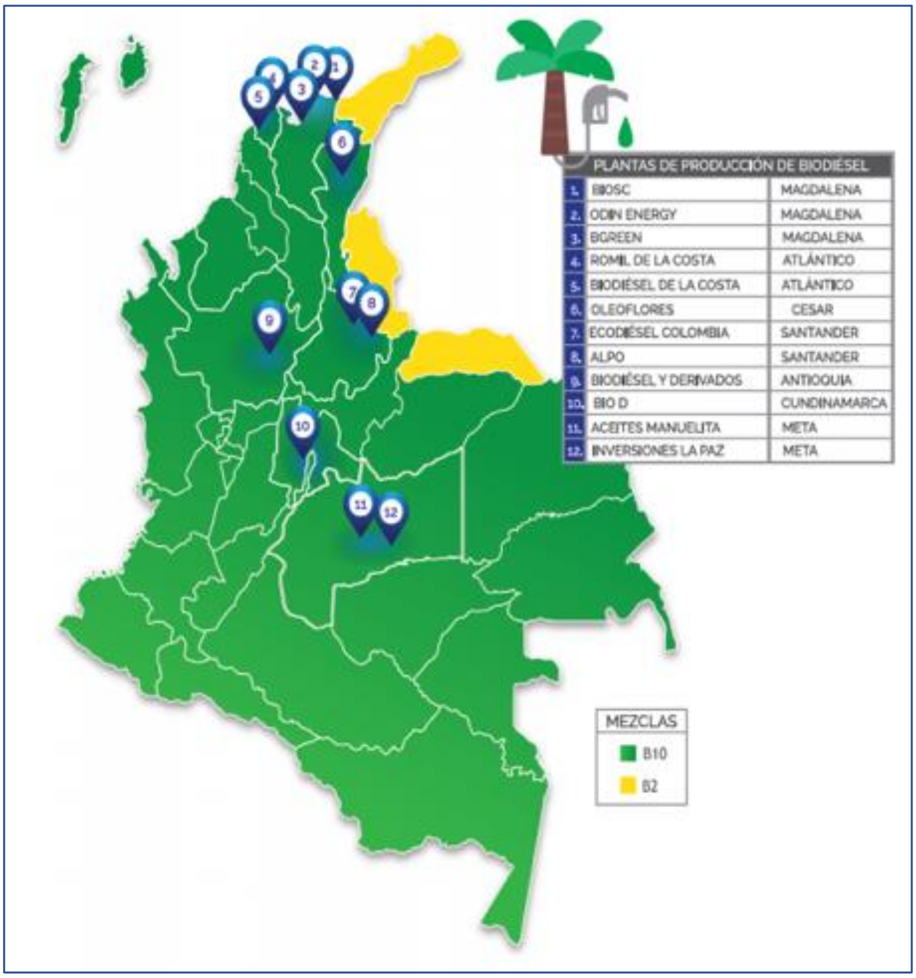
Colombia is the third largest biofuel producer in South America behind Brazil and Argentina. There are twelve biodiesel production plants in Colombia with an aggregate installed capacity of nearly 850,000 tons per year. Currently this liquid biofuel is produced in Colombia from the palm, sunflower, soybean and rapeseed oil.

Table 24: Biodiesel plants in Colombia - Installed Capacity

Plant	Location	Capacity (Liters/day)	Start-Up
BioD	Facatativá, Cundinamarca	200	2009
Biocombustibles Sostenibles del Caribe	Santa Marta, Magdalena	152	2009
Aceites Manuelita	San Carlos de Guaroa, Meta	120	2009
Ecodiesel Colombia	Barrancabermeja, Santander	115	2008
Oleoflores	Codazzi, Cesar	70	2008
Inversiones La Paz	San Carlos de Guaroa, Meta	70	na
Biocosta Green Energy	Santa Marta, Magdalena	70	na
Odín Energy	Santa Marta, Magdalena	35	na
ALPO	Barrancabermeja, Santander	12	na
Romil de la Costa	Barranquilla, Atlántico	na	na
Biodiésel de la Costa	Gálapa, Atlántico	na	na
Biodiesel y Derivados	Antioquia	na	Na

Source: Federacion Nacional de Biocombustibles

Figure 30: Map of biodiesel production plants



Source: Federacion Nacional de Biocombustibles

There are also seven bioethanol plants with an aggregate installed capacity of nearly 800,000 m3 per year (equivalent to 2.15 million liter per day). Most of the plants are located in the department of Valle de Cauca and their main raw material is sugarcane bagasse.

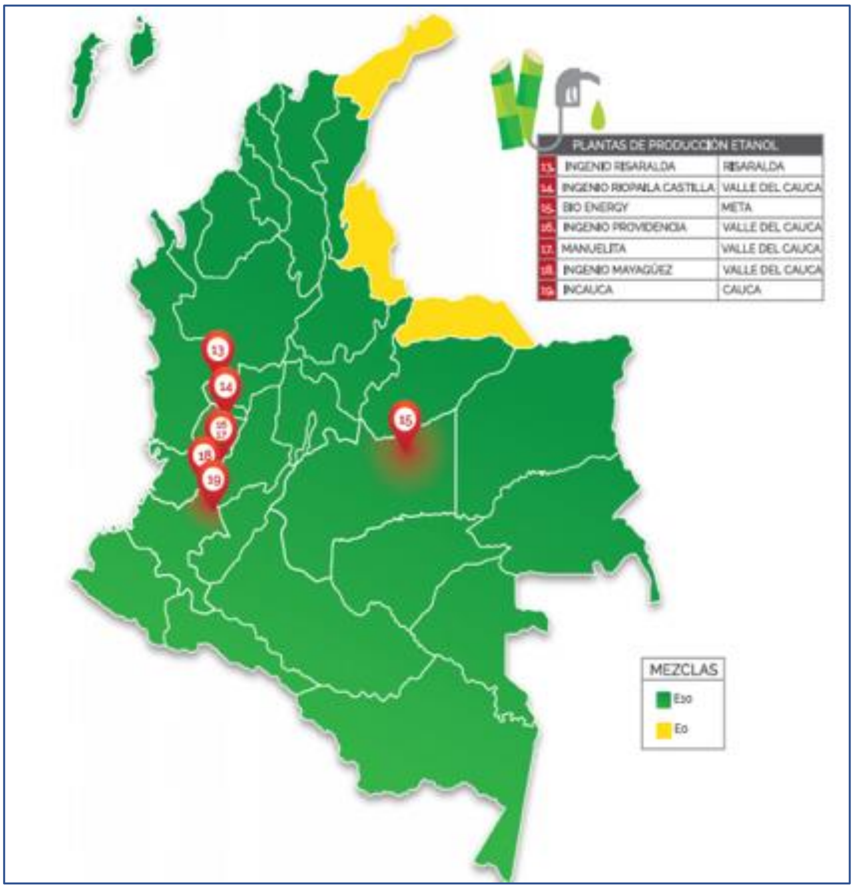
According to the association Procaña, in a presentation of the sugar cane agro-industrial sector from 2018, "biofuels contribute 6% to the reduction of GEI according to the national goal with the current mixtures 8.4% for ethanol and 9.2% for biodiesel • In Colombia 1.3 million tons of CO2 are no longer emitted due to the use of ethanol".

Table 25: Bioethanol plants in Colombia - Installed Capacity

Plant	Location	Capacity (Ton/Year)
Incauca,	Miranda (Valle de Cauca)	350,000
Ingenio Riopaila Castilla	La Paila (Valle de Cauca)	400,000
Ingenio Risaralda	La Virginia (Risaralda)	100,000
Bioenergy	Puerto López (Meta)	500,000
Ingenio Providencia	Palmira (Valle del Cauca)	300,000
Ingenio Mayagüez	Candelaria (Valle del Cauca)	250,000
Manuelita	Palmira (Valle del Cauca)	250,000

Source: Federacion Nacional de Biocombustibles; Asocaña

Figure 31: Map of biodiesel production plants



Source: Federacion Nacional de Biocombustibles; Asocaña

3. Latin American and Caribbean Countries

This section includes a brief review of the current knowledge and degree of development of the CDR approaches in Latin America and Caribbean countries.

Afforestation and reforestation

- Brazil has various national research plans and programs on biodiversity and ecosystems, including: National Research Program on Biodiversity and Ecosystems, SISBIOTA BRASIL Program, PELD Program, REFLORA Program, PROTAX Program, Biodiversity Research Program, Regional Networks of Research in Biodiversity and Biotechnology. Brazil joined Initiative 20x20 in 2016 with a pledge to restore 22 million ha of degraded land by 2030. The National Plan for the Recovery of Native Vegetation (Planaveg) plans to restore 12 million ha through forest restoration, reforestation, and natural regeneration by 2030 as part of Brazil's NDC to the Paris agreement. The other 10 million ha will be restored as part of the Ministry of Agriculture, Livestock and Supply's Low Carbon Agriculture Program (ABC Plan), which runs from 2010-2020. The ABC Plan intends to restore 5 million ha of land through two programs, Livestock-Forestry Integration and Agroforestry Systems. The restoration of the remaining 5 million ha is planned to be achieved through recovery of degraded pasture.
- In Chile, forests cover an area of 17.6 million hectares, which represents 23.2% of the surface of the national territory. According to its Nationally Determined Contribution, a national plan is carried out and set the sustainable management and recovery of 100,000 ha of forest, mainly native, and to reforest 100,000 ha, mostly with native species (2020-2030). National Consensus within the framework of the Forest Policy Council on the goal of 500,000 ha afforested by 2035, on lands of preferably forestry aptitude, without substituting native forest, and which belong to small and medium landowners or are fiscally owned. It also has an urban reforestation plan, whose goal is set between 5 to 6 million trees. On the other hand, the Green Climate Fund approved a 63.6 million dollars project that will promote afforestation actions in more than 25,000 hectares, of which 7,000 will be forestry and more than 17,000 for management, sustainability, and conservation. The project will last 6 years and seeks to reduce the accumulated 1,147,800 tons of CO2 emissions. The Chilean National Forestry Corporation (CONAF) will execute the project, with the support of the United Nations Food and Agriculture Organization (FAO).
- Both Brazil and Chile also have made progress on industrialized wood-construction. The Chilean company E2E is a joint venture between Arauco and the Belgian company Etex created in 2018. Its factory, which has been operating since February 2019 in Santiago, Chile, has the capacity to build 1,000 units per year – between prefabricated houses and timber buildings.E2E estimated a US$25 million sales projection in the first 3 years and counts on a US$15 million investment plan, of which US$ 6 million was invested in the WEINMANN machine production plant – a company of the HOMAG Group. Tecverde, based

in Curitiba, Brazil is a company established in 2009 by entrepreneurs who were seeking to disrupt and transform the civil construction industry in a sustainable, scalable way. Tecverde received the support of private equity funds Global Environment Fund (GEF) and Performa Investimentos. It employs 250 people and has a production capacity of 3,500 houses per year. In 2019, Chilean E2E signed an agreement to acquire a majority stake in Brazilian Tecverde.

- Mexico has an ambitious reforestation program to plant fruit and timber trees, including cocoa and coffee, on almost 570,000 ha in the south of the country. Two government programmes, CONABIO’s Restoration and Environmental Compensation Programme, led the execution of restoration projects between 2004 and 2016; and CONAFOR´s (National Forestry Commission), an initiative implementing a major reforestation project since 2013. In addition, 2019's Sembrando Vida Program, Mexico commits to restore 8.5 million hectares of degraded land under Initiative 20 × 20.
- Since 2005, Peru has the National Reforestation Plan, which consists of different programs. The program of forest plantations for commercial and / or industrial purposes, which aims to reach, by 2024, a total area of 864,500 ha of forest plantations and industrial agroforestry, and an average annual rate of 104,500 ha. The forest plantations program, with purposes of environmental protection and watershed management, seeks to achieve, by 2024, an annual reforestation rate of 84,500 ha and a surface area of 909,500 ha, channeling public investments and international cooperation, for an approximate amount of 688 million dollars and induce the creation of more than 225 thousand permanent jobs prioritizing women and vulnerable groups.
- Ecuador has the 2006 national afforestation and reforestation plan. Its objective is to achieve forest plantations of 1 million ha in 20 years, 750 thousand ha for industrial and commercial production plantations, 150 thousand ha of agroforestry plantations and 100 thousand ha plantations of conservation and protection of natural resources.
- Uruguay pledged to restore 200,000 ha by 2030 within the National Restoration Program.
- Paraguay has a National Reforestation Plan, its objective is the installation of forest plantations in order to generate raw material for the industrial forestry sector, as well as to cover the demand for biomass for energy purposes. The goal is the installation of 450,000 ha in a period of 15 years. In addition to the Bosques Project and PROEZA.
- Different researchers agree that Latin America and the Caribbean has the second largest area of mangroves in the world. Examples of climate actions protecting and restoring mangrove forests comprise those included in Belize’s NDC that indicates that “Restoration and protection have the potential to turn Belize’s mangrove system into a net carbon sink by avoiding current emissions of around 11.2Gg $CO2$ per year and removing additional 2.2 - 35Gg $CO2$ per year, between 2020 and 2030. These national initiatives will be studied in depth by reviewing the respective NDCs to identify all the countries that have included this type of climate action, efforts associated with Blue Carbon mitigation and within REDD+ programmes and countries in the region participating in the Global Mangrove Alliance.

Mangroves - Literature Review Latin America

According to a recent publication from FAO (2020), there are 2.1 millon hectares of mangroves in South America, accounting for 14.4% of the total world area of mangroves. "There was an increase in the area of mangroves in South America in 2010–2020 at an average annual rate of 14,800 ha, reversing the declining trend in 1990–2000, when the region lost mangroves at a rate of 10,200 ha per year. This reversal was due mainly to the process in Guyana, which reported an average annual increase in mangrove area of 19,500 ha in 2010–2020, due partly to a mangrove restoration project and partly to improvements in mapping (and therefore the increase does not necessarily reflect actual changes in mangrove area)". Brazil is ranked number two among the largest mangrove area countries in the world, behind Indonesia, with 9% of world's mangrove area.

Altought the updated 2020 FAO publication does not include detailed statistics by country, there is a previous study "The world's mangroves 1980–2005" (FAO, 2007) that includes breakdown by country within South America. About 90 % of South America's mangrove area is found in five countries: Brazil, Colombia, the Bolivarian Republic of Venezuela, Ecuador and Surinam, while Guyana, French Guiana and Peru share the remaining 140,000 hectares. During the 1980s and 1990s, mangrove lands were often considered unproductive and unhealthy. This perception and the resultant activities caused a loss of some 250 000 ha of mangroves in the region (11 percent of the 1980 extension).

Figure 32: Status and trends in mangrove area – South America (1980–2005)

Country/ area	Most recent reliable estimate		1980	1990	Annual change 1980–1990		2000	Annual change 1990–2000		2005	Annual change 2000–2005	
	ha	Ref. year	ha	ha	ha	%	ha	ha	%	ha	ha	%
Brazil	1 012 376	1991	1 050 000	1 015 000	–3 500	–0.3	1 000 000	–1 500	–0.1	1 000 000	0	0
Colombia	371 250	1997	440 000	393 000	–4 700	–1.1	360 300	–3 270	–0.9	350 000	–2 060	–0.6
Ecuador	149 556	1999	203 000	163 000	–4 000	–2.2	150 200	–1 280	–0.8	150 500	60	n.s.
French Guiana	55 000	1980	55 000	55 000	0	0	55 000	0	0	55 000	0	0
Guyana	80 432	1992	91 000	82 200	–880	–1	80 000	–220	–0.3	80 000	0	0
Peru	4 550	1995	8 300	5 800	–250	–3.5	4 500	–130	–2.5	4 500	0	0
Suriname	114 600	1998	115 000	114 800	–20	n.s.	114 600	–20	n.s.	114 400	–40	n.s.
Venezuela (Bolivarian Rep. of)	250 000	1986	260 000	244 500	–1 550	–0.6	231 000	–1 350	–0.6	223 500	–1 500	–0.7
South America	2 037 764	1992	2 222 300	2 073 300	–14 900	–0.69	1 995 600	–7 770	–0.38	1 977 900	–3 540	–0.18

Source: FAO 2007

Note: n.a. = not available; n.s. = not significant

The mangrove tree species diversity of South America region is low – only ten native species– the lowest worldwide. Three species (Avicennia germinans, Laguncularia racemosa and Rhizophora mangle) are very common and are found in all eight countries; others, such as Avicennia bicolor and Pelliciera rhizophorae, are found with less frequency or their presence is less well determined (FAO, 2007).

Figure 33: Mangrove species composition in South American countries

Species	Brazil	Colombia	Ecuador	French Guiana	Guyana	Peru	Suriname	Venezuela (Bolivarian Rep. of)
Acrostichum aureum		√	√				√	
Avicennia bicolor		?[a]						
Avicennia germinans	√	√	√	√	√	√	√	√
Avicennia schaueriana	√				√			√
Conocarpus erectus	√	√[b]	√		√	√		√
Laguncularia racemosa	√	√	√	√	√	√	√	√
Pelliciera rhizophorae		√	√					
Rhizophora harrisonii	√	√[c]	√			√		√
Rhizophora mangle	√	√	√	√	√	√	√	√
Rhizophora racemosa	√	?[a]		√				√
Total no. of species	7	9	7	4	5	5	4	7

Source: FAO 2007
a Uncertain.
b Found on both coasts, but rare on the Pacific coast.
c Found only on the Pacific coast.

Bioenergy with carbon capture and storage (BECCS)

This briefing of BECCS literature review relies comprehensively in a very complete research from Silva-Martínez, R. et al (2020) titled "The state-of-the-art of organic waste to energy in Latin America and the Caribbean: Challenges and opportunities"

- Bagasse from sugarcane is an important source of electricity in Brazil with an operating power potential of more than 9 GW, considering that burning bagasse is still by far the most cost-effective option in comparison with other thermochemical routes [Portugal-Pereira, J. et al, 2015]. Additionally, Brazil is one of the largest agricultural producers globally with large generation of agricultural residues, and also has already a considerable number of biomass combustion power plants running on different feedstock beyond sugarcane bagasse. For example, black liquor (1.7 GW), wood residues (371 MW), rice husk (36 MW), charcoal (35 MW), elephant grass (32 MW) and palm oil (4 MW). In addition, the first thermoelectric plant for eucalyptus residues was already authorized, with a capacity of 50 MW in the State of Mato Grosso do Sul and should start its operation by 2021. The owner is also planning to install two more plants in the near future. [Ambiente Energia, 2018] [Silva-Martínez, R. et al, 2020]

- In Brazil, there are two plants evidencing viable production of cellulosic bioethanol from sugarcane bagasse and straw. They are: GranBio power plant installed in Sao Miguel dos Campos, Alagoas, and Raízen in Piracicaba, Sao Paulo. However, only Raízen is already successfully producing 2G bioethanol on commercial scale [Gonçalves, F.A., et al, 2015]
- The RenovaBio Program is designed to support Brazil's COP21 goals. RenovaBio was launched in December 2016 by the Ministry of Mines and Energy (MME) and was instituted as the "National Biofuels Policy". The RenovaBio operation is based on three main instruments: 1. annual carbon intensity reduction targets (gCO2/MJ) for a minimum period of ten years; 2. certification of biofuels by efficiency in reducing GHG emissions, and 3. Decarbonization Credits (CBIO). Brazil's total 2019 ethanol production is estimated at 34.45 billion liters per year, while biodiesel production is estimated at 5.8 billion liters per year. No changes have been made to the current ethanol mandate, which remains at 27 percent (E27) for Gasoline C (gasolina comum, more commonly referred to simply as "gasoline") since March 16, 2015. The last increase of the biodiesel blend mandate to twelve percent (B12) took place in March 2020, there is a plan to further increase it to 15% by March 2023. Brazil has the largest biofuel blend mandate in Latin America. [USDA, 2019]
- In Mexico, there are around 59 projects for self-power supply through combustion processes using biomass residues (i.e., mostly sugarcane bagasse) with an installed capacity of 500 MW [Aleman-Nava, G. S. et al, 2015] [Silva-Martínez, R. et al, 2020]
- In Mexico, in 2008, the Law for the Promotion and Development of Bioenergy was published, in order to contribute to energy diversification and sustainable development. This laid the foundation for the production of biodiesel at industrial level in the country. Six first- and second-generation biodiesel production plants were installed in the states of Chiapas, Michoacán and Nuevo León, capable of processing Jatropha Curcas L., palm oil, waste vegetable oils and animal tallow. [Montero, G. et al 2015] However, the development of biofuels production capacity in Mexico is incipient. Biofuel blend mandate have suffered setbacks recently discouraging investments in new installed capacity.
- One of the largest sugar mills in the region is located in Nicaragua; The San Antonio sugar mill (NSEL), is the top electricity producer from sugarcane bagasse in the region, currently with an installed capacity of around 79 MW [Proparco, 2018] [Silva-Martínez, R. et al, 2020]
- In Belize, there is cogeneration powerplant using sugarcane bagasse as fuel, with an installed capacity of 31.5 MW [Lincoln, A. E., et al, 2015] [Silva-Martínez, R. et al, 2020]

Other biomass resources, such as power generation municipal solid waste (MSW), industrial and agriculture effluents, such as poultry and cattle residues

- Research and Development (R&D) in the region has been mostly focused on small-scale anaerobic digesters (AD) and landfilling [Garfi, M et al, 2016]. In addition, R&D has examined fermentation to a lesser extent. Nonetheless, interest in large-scale biodigesters, second-generation (2G) biofuels, and MFCs has been gaining ground in countries such as Argentina, Brazil, Chile, Colombia, and Mexico [Silva-Martínez, R. et al, 2020]
- Brazil and Mexico are amongst the top five countries worldwide that receive more income from mitigation projects. Most of the Certified Emissions Reductions (CERs) were the result of biogas capture projects in landfills [Aleman-Nava, G. S. et al, 2015] [Silva-Martínez, R. et al, 2020]. Landfills with gas capture infrastructure in Mexico receives more than 19 million tonnes of waste annually, amounting to an installed capacity of 16 MW. In the case of Brazil, the use of biogas from landfills is well implemented for electricity production and increasing. There are at least 39 projects in operation in the country. In Sao Paulo, for example, there are nine landfills where gas capture has been used to produce electricity [De Spuza, et al, 2014] [Silva-Martínez, R. et al, 2020]
- In Brazil, large-scale projects are based in vinasse from sugar mills with 2 plants and landfills with 38 waste to energy (WtE) plants. There are 14 WtE plants using sewage to produce energy, mostly thermal and/or electricity, but only 1 plant producing biogas as vehicle fuel in Franca, Sao Paulo State. The plant treats an average of 500 L of sewage per second and produces around 2500 Nm3 of biogas per day, enough to replace 1500 litters of common gasoline daily. The development of biogas in Brazil has the potential to avoid CO_2 emissions, which may be up to 19.8 $MtCO_2eq$ per year, approximately 5% of the National emissions. In 2016, the Brazilian government launched an auction call aimed to contracting electricity from new generation projects. The winning project was the first commercial scale biogas plant in the world using by-products of sugarcane (ex: filter cake and vinasse) as raw material. The project is located in the north-western region of Sao Paulo State, which is renowned for its sugar and ethanol production capacity in the country. The biogas plant enters in operation in 2021 and focuses on electricity generation, with an installed capacity of 21 MW [Investe Sao Paulo, 2019] [Silva-Martínez, R. et al, 2020]
- In Brazil, the first large-scale co-digestion plant is located in Parana State. The plant produces biogas from 600 m3 of sewage sludge and 150 tonnes of OFMSW per day. The installed capacity is 2.8 MW, which is enough to supply electricity to 2100 households or 8400 people [C.S. Bioenergia, 2019]
- Today around 74 large-scale biodigester exist to treat residues from meat industry (mostly from pig farming), dairy waste and wastewaters in Chile. Some of the outstanding cases are the treatment plant “La Farfana” in Santiago, which produces around 24Mm3 of biogas annually; the plants “Santa Irene” y “Las Pampas”, with a combined installed capacity of 800 kW and supplying electricity for approximately 2500 families [INDAP, 2016]. Chamy

and Vivanco (2007) estimate biogas presents a power generation potential of approximately 3.5% of the installed capacity of Chile. [Silva-Martínez, R. et al, 2020]

- On May 2017, an AD plant was inaugurated in Mexico City (Milpa Alta), for the treatment of cactus and vegetable waste, generating almost 106 m3 per day of biogas. Since late 2016, the city of Culiacan installed the first large-scale dry anaerobic digestion plant (DAD) for treating 4500 tonnes per year of agricultural residues. The plant has an installed capacity of 100 kW. Another project is the AD plant in Atlacomulco, which co-digest OFMSW and wastewater [Silva-Martínez, R. et al, 2020]

Enhancing soil carbon content (ESCC) and Enhancing soil carbon content with biochar

Enhancing soil carbon content (ESCC)

Literature about Increasing of soil Carbon stocks may be grouped in two main issues: soil C changes in Cropland (A) and Soil C changes in Grasslands (B).

The main drivers of soil C balance are Soil type, Climate and Management. These factors determine the C inputs (annual biomass production and humification rates) and the Soil C outputs (decomposition rates by mineralization).

Soil and climate define the “site quality” that determine the potential conditions for biomass production. Management practices determine the actual biomass production as well as the mineralization rates. The main concept in C removal strategies is to maximize the biomass production (C inputs) and reducing soil C losses. For example, in Croplands a main management driver is tillage system (no tillage, reduced tillage and full tillage). In grasslands, the main management driver is grazing pressure.

Soil Carbon sequestration studies in cropland and grazing lands

A - Croplands

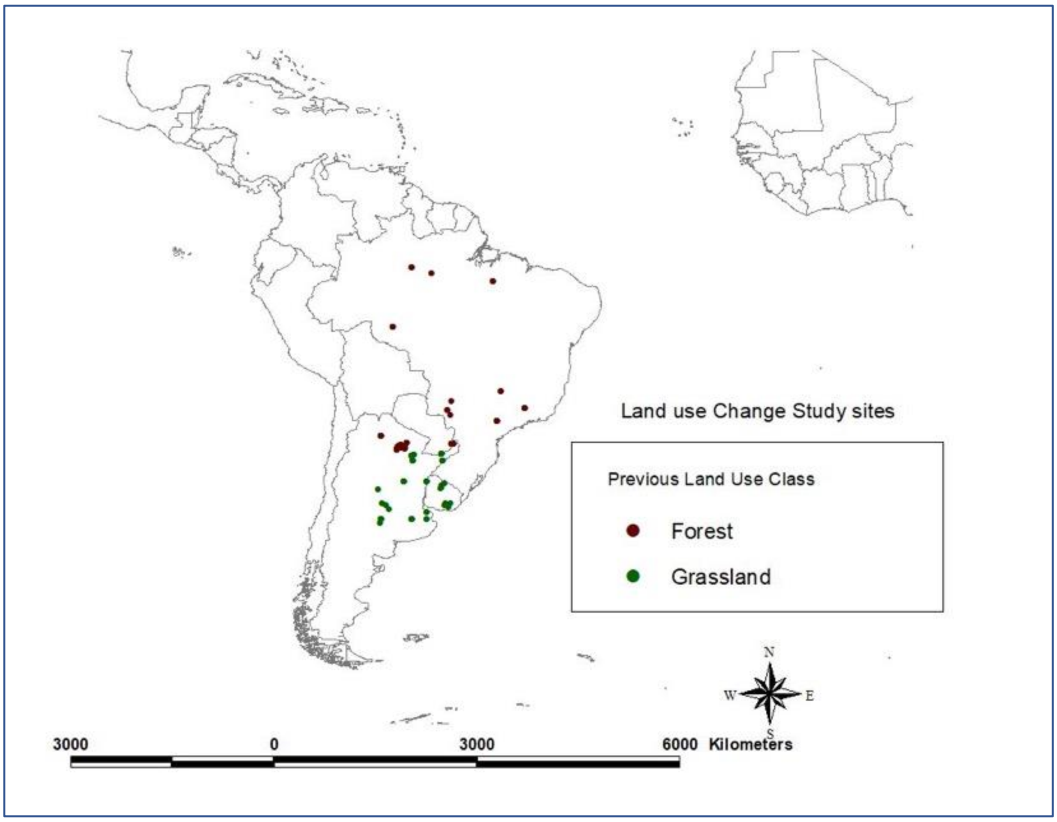
Recently, IPCC revised emission factors for soil C stocks changes. An updated literature review was carried out and the revised factors were included in the chapters 2 and 5 of the volume 4 (2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories). A long list of papers, form all countries, used in the 1996, 2006 and 2019 are included in the references section of this publication.

The following list of papers, from Argentina and neighbour countries, were included, in 2018, in the recent meta-analysis of the IPCC database related to Soil C changes due to Land Use Changes, Soil Tillage and Crop intensification practices.

Land Use Change Factor – Literature review Southern south America

- Rojas, J. M., Prause, J., Sanzano, G. A., Arce, O. E. A. & Sánchez, M. C. (2016). Soil quality indicators selection by mixed Models and multivariate techniques in deforested areas for agricultural use in NW of Chaco, Argentina. Soil and Tillage Research, 155, 250–262. http://doi.org/10.1016/j.still.2015.08.010
- Berhongaray, G., Alvarez, R., Paepe De, J., Caride, C., Cantet, R., 2013. Land use effects on soil carbon in the Argentine Pampas. Geoderma 192, 97–110.
- Villarino SH, Studdert GA, Baldassini P, Cendoya MG, Ciuffoli L, Mastrángelo M, Piñeiro G .2017. Deforestation impacts on soil organic carbon stocks in the Semiarid Chaco Region, Argentina. Sci Total Environ 575:1056-1065. doi: 10.1016/j.scitotenv.2016.09.175
- Berthrong ST, Pin˜ eiro G, Jobbagy EG, Jackson RB (2012) Changes in soil carbon and nitrogen with afforestation of grasslands across gradients of precipitation and plantation age. Ecological Applications, 22, 76–86.
- Cerri CC, Volkoff B, Andreaux F (1991) Nature and behaviour of organic matter in soils under natural forest, and after deforestation, burning and cultivation, near Manaus. Forest Ecology and Management, 38, 247–257.
- Rangel, O. J. P.; Silva, C. A. 2007. Estoques de carbono e nitrogênio e frações orgânicas de Latossolo submetido a diferentes sistemas de uso e manejo. Revista Brasileira de Ciência do Solo, v. 31, p. 1609-1623, 2007.
- Lisboa C, Conant R, Haddix M, Cerri C, Cerri C (2009) Soil carbon turnover measurement by physical fractionation at a forest-to-pasture chronosequence in the Brazilian Amazon. Ecosystems, 12, 1212–1221.
- Batlle-Bayer L, Batjes NH, Bindraban PS (2010) Changes in organic carbon stocks upon land use conversion in the Brazilian Cerrado: a review. Agriculture, Ecosystems & Environment, 137, 47–58.
- Lilienfein J, Wilcke W, Vilela L, Ayarza MA, Lima SDC, Zech W (2003) Soil fertility under native cerrado and pasture in the Brazilian Savanna. Soil Science Society of America Journal, 67, 1195–1205.
- Maquere V, Laclau JP, Bernoux M et al. (2008) Influence of land use (savanna, pasture, Eucalyptus plantations) on soil carbon and nitrogen stocks in Brazil. European journal of soil science, 59, 863–877.
- Desjardins T, Barros E, Sarrazin M, Girardin C, Mariotti A (2004) Effects of forest conversion to pasture on soil carbon content and dynamics in Brazilian Amazonia. Agriculture, Ecosystems & Environment, 103, 365–373.
- Eclesia RP, Jobbagy EG, Jackson RB, Biganzoli F, Piñeiro G (2012) Shifts in soil organic carbon for plantation and pasture establishment in native forests and grasslands of South America. Glob Chang Biol 18(10):3237–3251

Figure 34: Land use change study location



Source: Own elaboration based on the updated literature review included in the "Refinement to the 2006 IPCC Guidelines for national GHG inventories" (IPCC, 2019)"

<u>Tillage Factor - Tillage Studies carried out on the Pampa region</u>

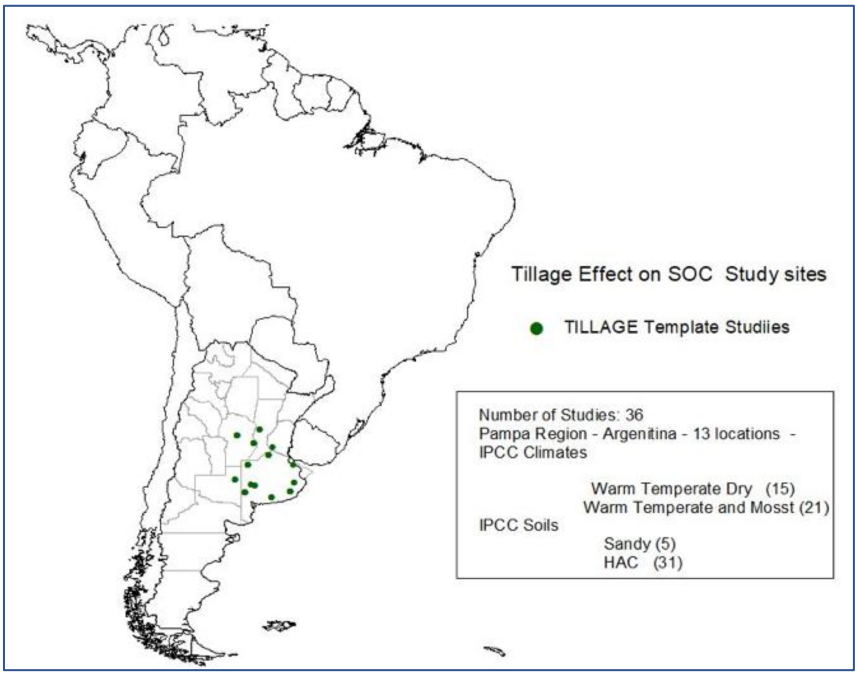
Results from 36 studies were compiled to be used on the revision of the current default Tillage factors included in the 2006 IPCC Guidelines. One third of the studies were published after 2004 (cutting date for literature for 2006 IPCC GL) and two thirds were completed before 2004, but not included into the 2006 IPCC GL references for Tillage factors.

Many of the compiled datasets came from studies included into the meta-analysis carried out by Steinbach and Alvarez (2006). The authors included results from many long term and paired field experiments, comparing the differences on SOC in the topsoil layer (0-20 cm), between No tillage, Reduced Tillage and Full Tillage effect and full tillage, in Pampa region. Reduced tillage treatments vary including either a chisel or a harrow fieldwork.

Besides, some other studies were also included into the database. When possible, some of those studies were track back to disaggregate, SOC by depth, as reported by the main authors, who provided their dataset to fill the "template database" (Studdert et al., 2017; Dominguez et al., 2016).

The compiled paired datasets represented Sandy (5) and HAC (31) soils (most of them mollisols, Hapludolls and Argiudolls) and belonged to both Warm Temperate Moist and Warm Temperate Dry, IPCC climate regions.

Figure 35: Tillage study sites



Source: Own elaboration based on the updated literature review included in the "Refinement to the 2006 IPCC Guidelines for national GHG inventories" (IPCC, 2019)"

Even though the datasets were compiled into a bigger database, the observed SOC stock changes, from these studies, was consistent with the 2006 IPCC default factors for Temperate regions for both Reduced Tillage (RT) and No-Tillage (NT).

Most of authors have studied Tillage effects on SOC stocks on the first 20 or 30 cm, assuming there are no "significant" effects below the top layer. Based on the papers reviewed, and some other not reported, it seems there is no new evidence or studies to contradict this general thought.

However, Alvarez et al (2014), found significant differences, at 50 and 100 cm depth, when comparing NT and RT, under two rotations: Soybean-Soybean and Maize-Soybean rotations. Authors concluded that this can be explained by the greater residue contribution of the corn crop in the Mz-Sy sequence

On the other side, most of new studies on land use change analyze SOC till one-meter depth, with different results depending on the pristine and current uses.

In this regard, the results are showing a more significant effect of NT than RT, on C sequestration comparing to Full tillage management in Pampa region.

In general, SOC increasing rate, under NT, did not showed any significant relationship with time, because of the lack of enough data, over a 20-year period.

These regional studies were integrated into the IPCC master database to derive a global factor for Dry and Moist Warm temperate Climates, which were published in the Updated tables of the 2019 IPCC Methodology report (2006 revised guidelines).

In addition to the reviewed *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, a recent paper compiled and analyzed the impact of soil Tillage by soil type and climate:

- Ogle, S.M., C. Alsaker, J.Baldock, M.Bernoux, F.J. Breidt, B. McConkey, K. Regina, and G.G. Vazquez-Amabile, 2019. "Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions". Nature Scientific Reports vol 9, Article number: 11665 https://doi.org/10.1038/s41598-019-47861-7

IPCC references for Tillage Factor

- Dominguez, G.F., G.V. Garcia; G.A Studdert; M.A. Agostini, S.N. Tourn, M.N. Domingo. 2016. Is anaerobic mineralizable nitrogen suitable as soil quality/health indicator? Spanish J. Soil Sci. 6:82-97
- Studdert, G.A.; M.N. Domingo; G.V. Garcia; M.G. Monterubbianesi; G.F. Dominguez. 2017. Soil organic Carbon under contrasting cropping systems and its relationships with Nitrogen supply capacity Ciencia del Suelo (Argentina) 35(2): in Press.
- Diaz-Zorita, M., M. Barraco, and C. Alvarez. 2004. Effects of twelve years of tillage practices on a Hapludoll from the Northwetern of Buenos Aires Province, Argentina. Cienc. Suelo 22:11-17.
- Diaz-Zorita, M. 1999. Six years of tillage in a Hapludoll from the Northwestern of Buenos Aires, Argentina. Cienc. Suelo 17:31-36.
- Galantini, J.A., J.O. Iglesias, L. Cutini, H.R. Kruger, and S. Venanzi. 2006 Tillage Systems in the SW of Buenos Aires province. Long term effect on soil organic fractions and porosity. Rev. Investigaciones Agropecuarias, RIA, 35 (1): 15-30
- Kruger, H.R. 1996. Tillage methods and variation of chemical properties in an Entic Haplustoll. Cienc. Suelo 14:53-55.

- Steinbach, H and R. Alvarez. 2006. Changes in Soil Organic Carbon Contents and Nitrous Oxide Emissions after Introduction of No-Till in Pampean Agroecosystems. J.Environ. Qual. 35:3-13 (Metanalisis)

References included into the metanalysis by Steinbach and Alvarez (2006)

- Alvarez, R., R.A. Diaz, N. Barbero, O.J. Santanatoglia, and L. Blotta. 1995a. Soil organic carbon, microbial biomass and CO2-C production from three tillage systems. Soil Tillage Res. 33:17-28.
- Alvarez, R., M.E. Russo, P. Prystupa, J.D. Scheirer, and L. Blotta. 1998b. Soil carbon pools under conventional and no-tillage systems in the Argentine Rolling Pampa. Agron. J. 90:138-143.
- Alvarez, R., O.J. Santanatoglia, P.E. Daniel, and R. Garcia. 1995b. Respiration and specific activity of soil microbial biomass under conventional and reduced tillage. Pesqui. Agropecu. Bras. 30:701-709.
- Fabrizzi, K.P., A. Moron, and F.O. Garcia. 2003. Soil carbon and nitrogen organic fractions in degraded vs. non-degraded Mollisols in Argentina. Soil Sci. Soc. Am. J. 67:1831-1841.
- Studdert, G.A., Echeverría, H.E., Casanovas, E.M., 1997. Crop-pasture rotation for sustaining the quality and productivity of a Typic Argiudoll. Soil Science Society of America Journal 61, 1466–1472
- Alvarez, C.R., R. Alvarez, M.S. Grigera, and R.S. Lavado. 1998a. Associations between organic matter fractions and the active soil microbial biomass. Soil Biol. Biochem. 30:767-773.
- Alvarez, R., O.J. Santanatoglia, and R. Garcia. 1995c. Soil respiration and carbon inputs from crops in a wheat-soyabean rotation under different tillage systems. Soil Use Manage. 11:45-50.
- Chagas, C.I., O.J. Santanatoglia, and M.G. Castiglioni. 1995. Tillage and cropping effects on selected properties of an Argiudoll in Argentina. Commun. Soil Sci. Plant Anal. 26:643-655.
- Lavado, R.S., C.A. Porcelli, and R. Alvarez. 1999. Concentration and distribution of extractable elements in a soil as affected by tillage systems and fertilization. Sci. Total Environ. 232:185-191.

Papers comparing No Tillage versus Reduced Tillage

- Alvarez C., C.R. Alvarez, A. Constantini, M. Basanta. 2014. Carbon and nitrogen sequestration in soils under different management in the semi-arid Pampa (Argentina) Soil Tillage Research 142 (2014) 25–3126
- Ferreras, L.A., J.L. Costa, F.O. Garcia, and C. Pecorari. 2000. Effect of no-tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern "Pampa" of Argentina. Soil Tillage Res. 54:31-39.

Cropland INPUT Factor Studies carried out on Pampa region, Argentina

Results from nine (9) studies, published in six different papers, were selected to evaluate the impact of intensification of C inputs on SOC. Results from these studies were sent using the standard "template" in order to be compiled into the master database for Input Factor derivation.

All these studies were not included into the 2006 IPCC guideline literature review and belong to Pampa region,[21] which is a representative biome for Mollisols under dry and moist warm temperate climates.

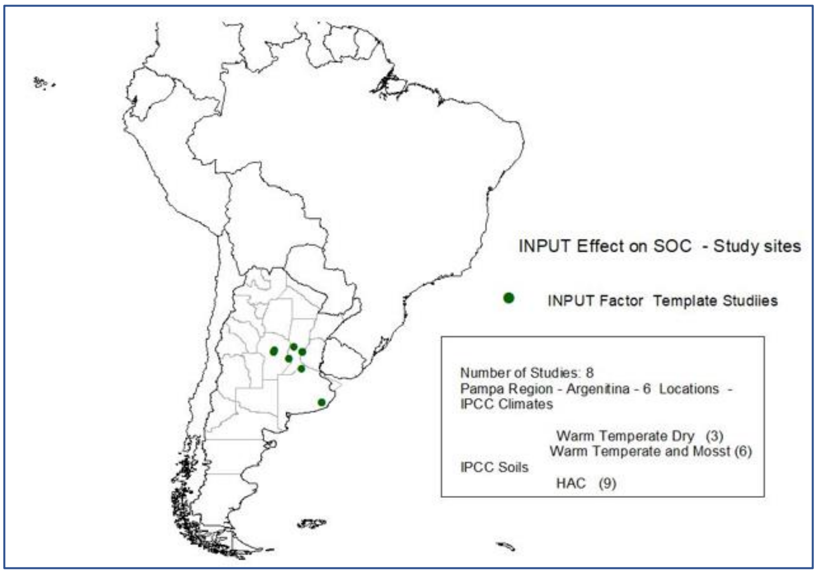
Most of them are long term-experiments, with the exception of Novelli et al. (2017). This experiment is a small part of 15 years old No-tillage-field-experiment, which was re-direct to evaluate the impact of " Crop Intensification" under continuous annual cropping.

The compiled paired datasets represented **HAC** soils (most of them Mollisols, Hapludolls and Argiudolls) and belonged to both **Warm Temperate Moist (6) and Warm Temperate Dry (3)**, IPCC climate regions.

The "Medium- input Level" have been considered as "control", according to table 5.5 (Vol 4, 2006 IPCC Guideline).

[21] Authors Selection criteria were: (i) experi¬mental designs were clearly defined and experiments were performed using machinery and practices commonly used by farmers; (ii) only tillage system varied; (iii) sampling depth was equal to or deeper than tillage depth; and (iv) SOC mass per unit area was reported or SOC concentration and soil bulk density were available so that SOC mass could be calculated to the depth of sampling (fixed depth). It was assumed that there were not effects of tillage system below sampling depth.

Figure 36: Effect on SOC study sites



Source: Own elaboration based on the updated literature review included in the "Refinement to the 2006 IPCC Guidelines for national GHG inventories" (IPCC, 2019)"

The 2006 IPCC guidelines consider a "high-Input" management for croplands, when cover crops, green manures, or perennial grasses (pastures) are included in annual crop rotations.

The literature review for temperate regions in Argentina, suggests that the higher the biomass produced (aboveground, belowground and total biomass), the higher SOC stock.

The studies that evaluated the inclusion of 4-year perennial pastures into the annual crop rotation, showed a significant impact on SOC stock, when comparing versus a continuous cropland under a Medium-input management (Studdert et al., 1997).

On the other hand, for continuous cropping, the increase in cropping intensity (CI) has been suggested as a strategy to improve crop residue inputs, which in turn, may increase soil aggregation and soil organic C (SOC) storage while maintaining or even increasing total sequence yields (Novelli et al., 2017).

The papers revised to be integrated into the master database, are consistent with the current Input factor for Temperate region included into the 2006 IPCC guidelines

- Steinbach, H.S., Alvarez, R., 2006. Changes in soil organic carbon contents and nitrous oxide emissions after introduction of no-till in Pampean agroecosystems. Journal of Environmental Quality 35, 3–13.
- Fabrizzi, K.P., A. Moron, and F.O. Garcia. 2003. Soil carbon and nitrogen organic fractions in degraded vs. non-degraded Mollisols in Argentina. Soil Sci. Soc. Am. J. 67:1831-1841.

- Alvarez C., C.R. Alvarez, A. Constantini, M. Basanta. 2014. Carbon and nitrogen sequestration in soils under different management in the semi-arid Pampa (Argentina) Soil Tillage Research 142 25–3126
- Giubergia J.P,E. Martellotto,R.S. Lavado. 2013. Complementary irrigation and direct drilling have little effect on soil organic carbon content in semiarid Argentina. Soil & Tillage Research (134) 147–152
- Novelli L.E., O.P.Caviglia and G.Piñeiro. 2017. Increased cropping intensity improves crop residue inputs to the soil and aggregate-associated soil organic carbon stocks. Soil & Tillage Research (165) 128–136
- Studdert, G.A., Echeverría, H.E., Casanovas, E.M., 1997. Crop-pasture rotation for sustaining the quality and productivity of a Typic Argiudoll. Soil Science Society of America Journal 61, 1466–1472

B - Grazing Lands

Recently, IPCC also revised emission factors for soil C stocks changes in Grasslands, but there were not enough new studies to perform a new meta-analysis to update emission factors.

However, in the last years there were some large metanalysis that used a large number of studies, in order to figure out the potential of soil C sequestration in grazing lands and its main drivers.

This question is still controversial, and many issues and management practices are under study on this respect.

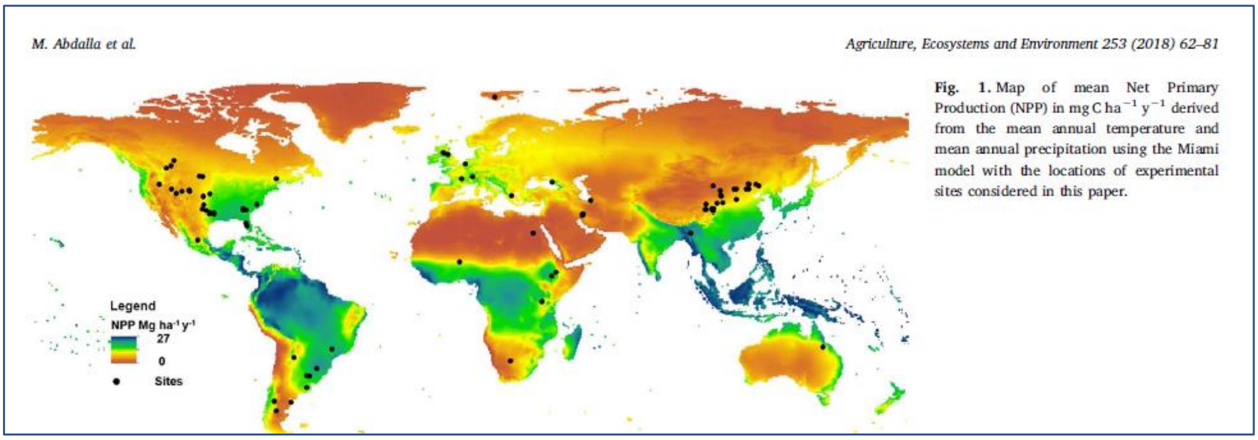
An important paper on the matter is Pete Smith's: Do grasslands act as a perpetual sink for carbon? (2014), that analyzed many studies. The author concluded that *"…it is untenable that grasslands act as a perpetual carbon sink, and the most likely explanation for observed grassland carbon sinks over short periods is legacy effects of land use and land management prior to the beginning of flux measurement periods. Simply having grassland does not result is a carbon sink, but judicious management or previously poorly managed grasslands can increase the sink capacity"*.

- Smith, P., 2014. Do grasslands act as a perpetual sink for carbon? Global change biology 20, 2708-2711

On this regard, two recent metanalysis may be mentioned as well:

- Abdalla, M., Hastings, A., Chadwick, D. R., Jones, D. L., Evans, C. D., Jones, M. B., Rees, R. M., & Smith, P. (2018). Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands. Agriculture Ecosystems & Environment, 253, 62-81. https://doi.org/10.1016/j.agee.2017.10.023

Figure 37: Sites analyzed by Abdallah et al., 2018



Source: Abdallah et al., 2018

Another recent paper that hypothesizes about the potential of soil C sequestration in grazing lands of the Mercosur countries to offset GHG emissions is:

- Viglizzo E.F., M.F. Ricard, M.A. Taboada, G. Vázquez-Amábile. 2019. Reassessing the role of grazing lands in carbon-balance estimations: Meta-analysis and review. Science of The Total Environment 661, 531-542.

The main discussion about the potential sequestration is about the management strategies and technologies to make it possible in extensive grazing system.

Enhancing soil carbon content (ESCC) with biochar

- In 2019, Wake Forest University worked intensively on a project in the Amazon to restore Peruvian rainforests devastated by illegal mining using biochar. Some research is being carried out, for examples Trujillo A. studied the generation of biochar from organic poultry waste. Miltner, B. C studied the use of biochar in swidden-fallow agroforestry systems in the Peruvian Amazon.
- In Ecuador a study has been identified covering soil ecological restoration applying biochar (charcoal) and its effects on the Medicago sativa production [Fiallos Ortega, L. R, et al. 2015]
- In Brazil a research from 2014 concludes that biochar decreases dissolved organic carbon but not nitrate leaching in relation to vinasse application in a Brazilian sugarcane soil. [Eykelbosh, A. et al. 2014]
- Another research in Brazil aimed to evaluate the conditions (temperature and residence time) to produce biochar from Acai processing residues and its potential for use as soil conditioner in the Amazon region. Authors concluded that considering the favourable agronomic characteristics of biochar, the temperature of 600 °C and residence time of 60

min are the most suitable conditions for the production of biochar from Acai seeds. [Sato, M. et al 2019]

Enhanced weathering or ocean alkalinization

- Already in year 2000, there were studies suggesting the use of native-rocks (stone meal) as the ultimate way to restore to the leached tropical soils in Brazil [Leonardos O.H. et al 2000]
- Increased construction and building activities in Brazil have promoted the exploitation of basaltic reserves, and interest is growing in recycling the accumulating fine basalt dust waste (with a particle size distribution that peaks in the fine silt range of 10–20 µm diameter) as a natural agricultural fertilizer. [Nunes, 2014]
- Another relevant study assessed the potential of soil carbonation and enhanced weathering to sequester atmospheric CO2, through Life Cycle Assessment in a case study for Sao Paulo State in Brazil. In this paper, authors investigated the established mining industry that extracts basaltic rocks for construction from the Paraná Basin. Through a Life Cycle Assessment, they determined the balance of carbon dioxide emissions involved in the use of this material, the relative contribution of soil carbonation and enhanced weathering, and the potential carbon dioxide removal of Sao Paulo agricultural land through enhanced weathering of basalt rock. Results show that enhanced weathering and carbonation respectively emit around 75 and 135 kg carbon dioxide equivalent per tonne of carbon dioxide equivalent removed (considering a quarry to field distance of 65 km). The authors underline transportation as the principal process negatively affecting the practice and uncover a limiting road travel distance from the quarry to the field of 540 ± 65 km for carbonation and 990 ± 116 km for enhanced weathering, above which the emissions offset the potential capture. [Lefebvre, D. et al, 2019]
- Another article presents a techno-economic assessment framework to analyse the potential and costs of carbon dioxide removal by enhanced weathering of rocks, concluding that Brazil is among the best suited locations globally to realize this potential. [Jessica Strefler et al 2018]
- In Mexico a study analysing the intensification of production in organic agriculture (coffee case) was identified. For the remineralization of soil, it was promoted to incorporate nonmetallic secondary minerals, such as zeolites, dolomite and rock phosphate [Altamirano et al, 2014]
- No relevant academic literature, nor initiatives or projects were identified regarding ocean alkalinization in other Latin American and Caribbean countries.

Direct air carbon dioxide capture and storage

- No relevant academic literature, nor initiatives or projects were identified regarding DACCS in other Latin American and Caribbean countries.

Ocean fertilization

- In year 2007 the company Planktos Inc. was planning to dump 100 tonnes of iron dust into the ocean near Ecuador's Galápagos Islands, to create a 10,000-square-kilometre "plankton bloom". The project did not progress due to opposition of environmental groups and marine scientists.
- In 2017, Oceaneos Marine Research Foundation of Vancouver, Canada, also tried to carry out an ocean fertilization project in Chile and Peru which also failed due to opposition from environmentalists. The company was seeking permits from the Chilean government to release up to 10 tonnes of iron particles 130 kilometres off the coast of Coquimbo as early as 2018. "These experiments would violate international moratoria, and scientific evidence indicates that the risks and impacts far outweigh the supposed benefits," said Samuel Leiva from Terram, a Chilean NGO.

Other CDR approaches

- Several studies have been found on the potential of storing gas with high CO_2 content in salt caverns built in ultra-deep water in Brazil [Da Costa, 2018] [Rockett, et al 2012]
- Simulation results obtained by Da Costa et al 2018, shows the technical feasibility of huge storage volumes of natural gas and CO_2 in giant salt caverns offshore. For the case study presented in this paper, using giant salt caverns, 450 m high by 150 m in diameter, one cavern can store 4 billion Sm^3 or 7.2 million tons of CO_2. The salt dome studied can accommodate the construction of 15 caverns, thus providing the confinement of approximately 108 million tons of CO_2.
- Another study from 2020 regarding technology readiness assessment of ultra-deep salt caverns for carbon capture and storage in Brazil, estimated a salt cavern could storage 1 billion Sm^3 of a natural gas stream with high CO_2content.
- Potential of storing gas with high CO_2 content in salt caverns built in ultra-deep water in Brazil. [Da Costa, 2018]
- Related to other CDR approach, in Mexico, scientists from the Universidad Autónoma Metropolitana, Cuajimalpa Unit (UAM-C), created a microalgae bioreactor to capture carbon dioxide (CO_2) from combustion gases of the cement industry.

II. Impact Analysis

Based on the analysis on the current status of knowledge, planning and implementation of CDR approaches in LAC countries and, specifically, in Argentina and Colombia, the following four CDR approaches were selected to further deep dive in terms of impact analysis:

- Afforestation and reforestation
- Bioenergy with carbon capture and storage (BECCS)
- Enhancing soil carbon content and Enhacing soil carbon content with biochar
- Enhanced weathering (land)

Regarding enhanced weathering in land, uncertainties surrounding the technology are still large. The broader implications of Enhanced weathering (land) technologies for delivering sustainable development are insufficiently understood at this time and thus, presents limitations to perform the impact analysis done for the rest of CDR technologies in Argentina and Colombia. The technology is untested at scale, not exhibiting enough quantitative and qualitative information, presenting a limitation for impact analysis.

This selection for the impact analysis does not mean the other CDR approaches (DACS, Ocean Fertilization and Ocean Alkalinization) do not present potential for deployment and/or should not adressed by policy makers.

This section describes the methodologies adopted, estimation of the impact analysis of the large-scale deployment for the selected CDR approaches in Argentina and Colombia and the limitations encountered during the study.

1. Methodology for Impact Analysis

Initially, a compilation of historical statistics for macro and CDR specific variables was performed, covering the 2000-2020 period subject to data avilability.

In terms of key macroeconomic variables for Argentina and Colombia, the following variables were identified and analyzed at national level:

- Gross Domestic Product (constant prices in local currency)
- Gross Agreggate Value (constant prices in local currency)
- Gross Production Value (constant prices in local currency)
- Gross Fixed Capital Formation (Investment) (constant prices in local currency) and its breakdown in Production Equipment and/or Machinery and Equipment components
- Registered Jobs (number of jobs)
- Active Enterprises (number of enterprises)

The sources of data for the above-mentioned variables were mainly the national statitics institutes of Argentina and Colombia, INDEC and DANE respectively.

Also, CDR specific key variables were identified for Argentina and Colombia and their historical statistics compiled and analyzed:

- Afforestation and reforestation
  - Cultivated forest area (hectares)
  - Native forest area (hectares)
  - Wood forestry production (tons)
  - Gross Agreggate Value in Silviculture and Wood Extraction Sector (constant prices in local currency)
  - Gross Production Value in Silviculture and Wood Extraction Sector (constant prices in local currency)
  - Registered Jobs in Silviculture and Wood Extraction Sector (number of jobs), when available
  - Active Enterprises in Silviculture and Wood Extraction Sector (number of enterprises), when available
- BECCS
  - Total Installed Capacity (MW) and breakdown by source
  - Total Power generation (GWh) and breakdown by source
  - Biofuels Production (tons)
  - Gross Agreggate Value in Generation Sector (constant prices in local currency)
  - Gross Production Value in Generation Sector (constant prices in local currency)
  - Registered Jobs in Generation Sector (number of jobs), when available
  - Active Enterprises in Generation Sector (number of enterprises), when available
- Enhancing soil carbon content and Enhacing soil carbon content with biochar
  - Sown Area and Harvested Area (hectares) by crop type
  - Crops Production (tons) by crop type
  - Gross Agreggate Value in Agricultural Crops Sector (constant prices in local currency)
  - Gross Production Value in Agricultural Crops Sector (constant prices in local currency)
  - Registered Jobs in Agricultural Crops Sector (number of jobs), when available
  - Active Enterprises in Agricultural Crops Sector (number of enterprises), when available

Secondly, for each CDR approach and country, a technical scenario forescating was performed according to the guidelines defined in the Terms of Reference of the study.

- Afforestation and reforestation
  - Baseline scenario according to historic trends

  - Scenario resulting from the annual increasing of commercial forest plantations according to the countries' NDCs and plans
  - Scenario of Maximum potential area suitable for forestlands in Argentina and Colombia, based if possible on "site quality" criteria (soil, topography and climate), regardless of any economic benefit associated with afforestation and reforestation activities
- BECCS
  - Baseline scenario, based on official Energy Scenarios in Argentina (SGE, 2019) for the period 2019-2030, extended to 2050 / Plan Energético Nacional Colombia 2020- 2050 (UPME, 2019).
  - An enhanced biomass/biogas power generation scenario, with low CCS adoption
  - An enhanced biomass/biogas power generation scenario, with high CCS adoption
- Enhancing soil carbon content and Enhacing soil carbon content with biochar
  - Baseline scenario: no biochar applied
  - An enhanced soil carbon content scenario, with low biochar applied
  - An enhanced soil carbon content scenario, with high biochar applied

Finally, several linkages among macro and intrasectorial variables for each CDR approach and country were identified, estimating long-term impacts of CDR deployment on key variables contributing to the achievement of the SDGs (Grenhouse emissions, GDP, Employment, others), based on the aforementioned technical scenario. Also costs and investments needed for the different CDR deployment scenarios were quantified.

Detailed methodology description for BECCS scenario analysis

This sub-section presents a simplified scenario analysis for the penetration of BECCS in Argentina and Colombia, considering national sectoral plans and scenarios to 2030 and 2031, respectively, extended by the consultants to year 2050.

In both cases an assessment on the potential of increasing the share of bioenergy and BECCS is performed based on the current official scenarios extended to 2050, capped by —but not reaching— the feedstock availability featured in the *Update of the Biomass Balance for energy purposes in Argentina* (FAO, 2020) for forest residues and bagasse and in the *Atlas of the energy potential of residual biomass in Colombia (UPME, 2010*) for sugarcane and panel cane bagasse.

The rationale behind each scenario is described in each country's section. Power generation and capacity scenarios were built for each country for the analysis period, focused in increasing the share of biomass-fired conventional power plants (boiler and steam turbine), subject to the available resources and historic physical (such as power plant efficiency, capacity factor and emission factors), as well as economic parameters, such as CAPEX requirements O&M and fuel costs.

Although specifics will be provided in each country's section, scenarios are differentiated by increasing ambition both regarding the use of biomass and the penetration of BECCS in the power grid.

Emissions for each scenario are calculated and exposed taking into account the carbon sequestered during the lifecycle of the feedstock, including the sequestered carbon during the biogenic growth of the fuel, transport and processing emissions, computed at 16% of the carbon content of the fuel, the emissions resulting from the biomass combustion (equivalent to the biogenic capture during growth), and finally three capture rate scenarios as a percentage of Carbon input during the CDR phase in the BECCS facility, ranging from 40% to 80%.

A Levelized Cost of Electricity (LCOE) resulting for BECCS facilities is estimated for both countries taking into account CAPEX requirements and Operation and Maintenance costs based on Langholtz 2020 and supplemental information contained in Stavrakas, 2018, as well as capacity factors and fuel costs based on country-specific data (SGE, 2020 and UPME 2019), for a non-co-fired steam turbine firing bagasse with post-combustion capture technologies and excluding CO_2 transport and storage costs.

Finally, a CO2 avoidance cost (CAC) range is calculated for each scenario, taking into account BECCS LCOE ranges estimated for each country and avoided (due to the displacement of fossil fuel thermal power generation when applicable) and captured CO_2, adapting the methodology presented in Langholtz 2020, comparing the LCOE of BECCS vs. the LCOE of a reference scenario, as well as the emission reduction or removal resulting from the implementation of BECCS vs. the reference scenario:

$$\frac{LCOE_{BECCS} - LCOE_{ref}}{E_{ref} - E_{BECCS}}$$

Where:

$LCOE_{BECCS}$ is the levelized cost of electricity production from BECCS in USD/MWh,

$LCOE_{ref}$ is the levelized cost of electricity production from a reference scenario in USD/MWh.

E_{ref} are the emissions per MWh expressed in tCO_2e/MWh associated with the reference scenario or displaced technology.

E_{BECCS} are the per MWh in tCO_2e/MWh associated with the BECCS facility.

In the short-run, the displaced units are considered to be the marginal units of natural gas turbines in the case of Argentina or coal-fired power plants in the case of Colombia.

In the long-run, according to the presented scenarios, for the horizon of 2050, 100% of the additional fossil fuel-fired installed capacity is introduced to the system for stability and capacity purposes. In this context, the Build Margin (UNFCCC 2015) which could be used as an analogue purpose to calculate the Emission Factor of the reference power grid approaches to zero. In consequence, the reference emissions (of the displaced units) could be considered approaching to "null", hence the denominator of the presented equation approaching to EBECCS. However, results are also presented comparing Scenarios 1 and 2 vs. reference emissions and mean power generation costs for the baseline scenario, for each capture rate scenarios.

For modelling purposes, these scenarios exclude battery storages and rely on thermal power generation for frequency stabilization and capacity services, and CHP plants are considered non-co-fired (i.e. 100% biomass-fired).

2. Argentina

According to the World Bank, Argentina is one of the largest economies in Latin America with a Gross Domestic Product (GDP) of approximately US$450 billion. Argentina has vast natural resources in energy and agriculture. Within its 2.8 million square kilometers of territory, Argentina is endowed with extraordinary fertile lands, gas and lithium reserves, and has great potential for renewable energy.

However, the historical volatility of economic growth and the accumulation of institutional obstacles have impeded the country's development. The COVID-19 pandemic and social isolation as a way to combat it aggravated the situation. Urban poverty in Argentina remains high and in the first semester it reached 40,9% of population, while extreme poverty increased to 10,5% and children poverty rose to 56,3% (World Bank, 2020).

Domestic economy continues to show strong macroeconomic imbalances. Annual inflation, although it has slowed since the beginning of the year, is still above 40%, despite price controls.

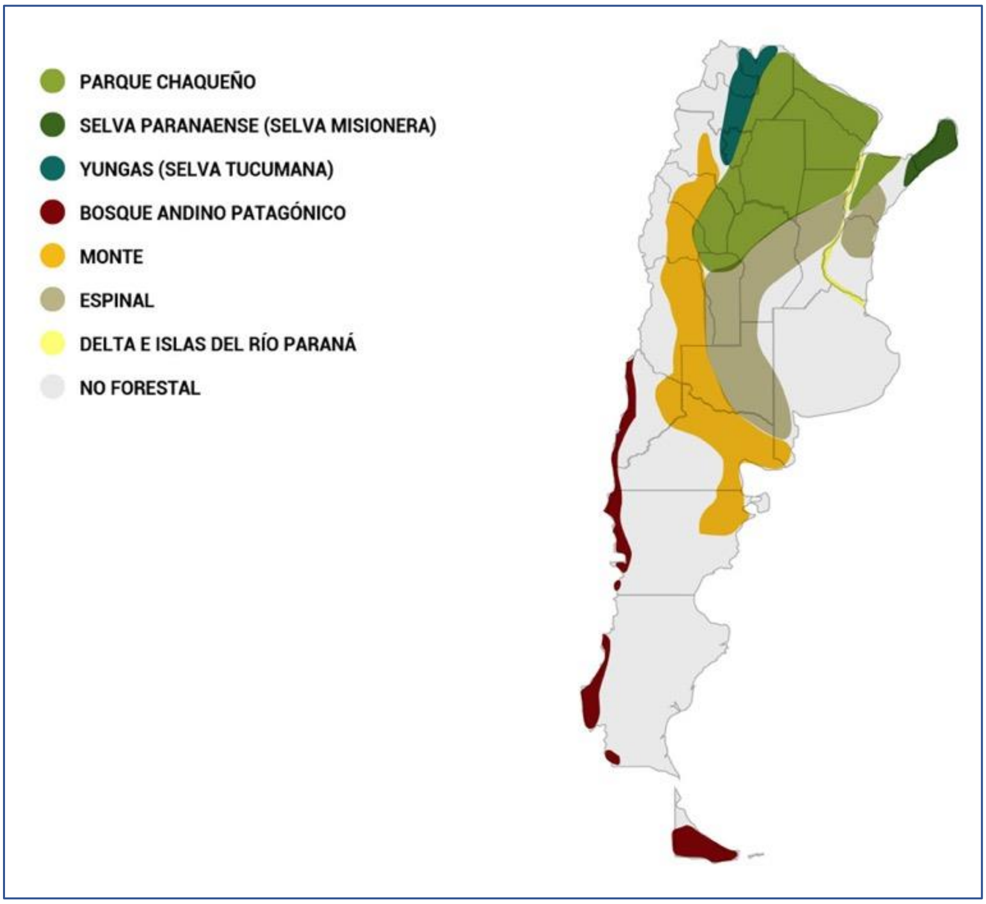
The Government has managed to conclude the process of restructuring all its debt in foreign currency (both local and external), significantly improving the maturity profile for the next eight years. In turn, the authorities have formally begun to talk with the International Monetary Fund to agree a new program for the maturities of the Stand-By loan in the next 3 years.

Afforestation and reforestation

A) Status and trends of forestry sector

There are 53 million hectareas of native forest in Argentina, about 6% of the forest area in South America. Native forest is concentrated in the Northcenter sector of the country, covering the provinces of Formosa, Chaco, Tucumán, Santiago del Estero, Córdoba, Santa Fe, Misiones, Corrientes, La Pampa, Río Negro, Neuquén, Mendoza, San Juan, San Luis and Catamarca.

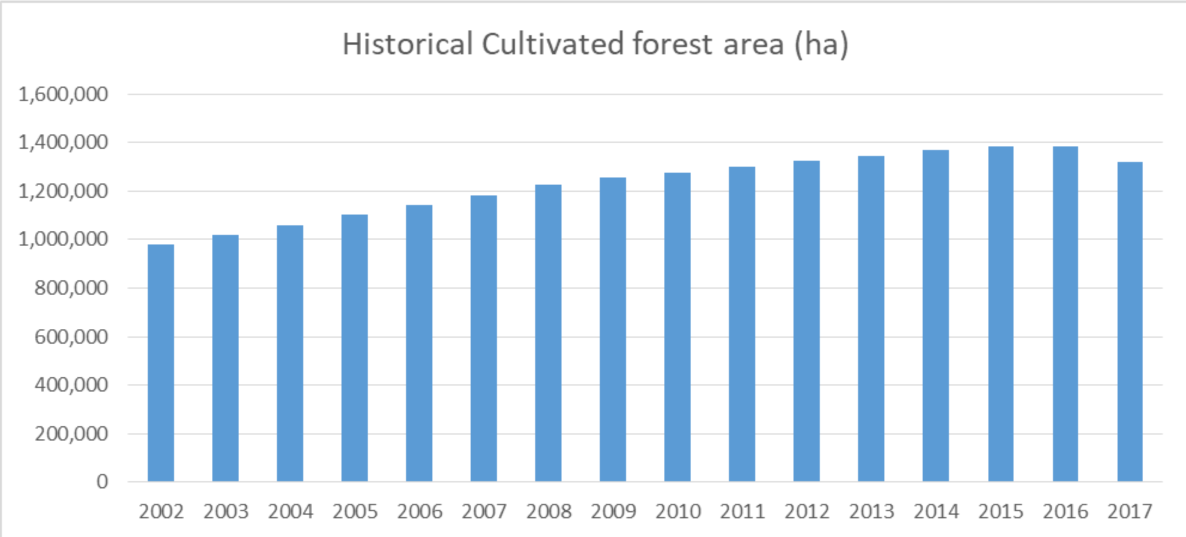
Figure 38: Main Regions of Native Forest in Argentina



Source: Regiones forestales de Argentina. Archivo de la Secretaría de Medio Ambiente de la Nación

According to the latest official consolidated data by the Dirección de Producción Forestal, the cultivated forest area in year 2017 was 1,317,793 hectares, representing a CAGR growth of 1.7% over the 2002-2017 period.

Figure 39: Historical cultivated forest area in Argentina

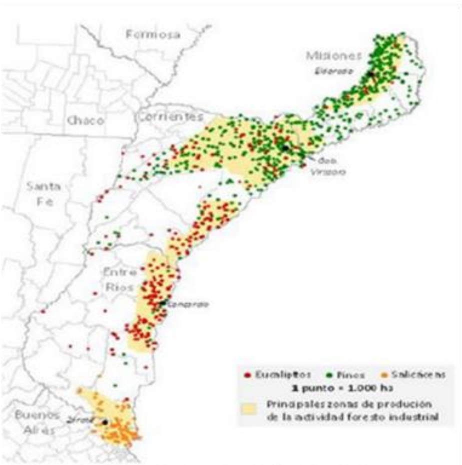


Source: SSPMicro based onDirección de Producción Forestal 2017; Biennial Update Report (BUR) 2016

The Mesopotamia region (Misiones, Corrientes and Entre Rios provinces) is the largest area of forest plantations in Argentina. Both in Misiones and Corrientes, the predominant species is pine, while in Entre Ríos the predominant species is eucalyptus. Salicaceae (willows and poplars) are found mainly in the north of Buenos Aires and the south of Entre Ríos.

Figure 40: Characterization of cultivated forest area in Argentina

Plantations in Meopotamia and Delta regions. Year 2017



Cultivated forest área by Region and species. Year 2017

Provincia / Región	Coníferas	Eucaliptos	Salicáceas	Otras	Total	Participación
Corrientes	345.965	121.857		6.161 (**)	473.983	36%
Misiones	348.305 (*)	40.902		16.617 (**)	405.824	31%
Entre Ríos	14.156	112.785	23.279	577	150.797	11%
Buenos Aires	4.027	7.818	65.091	78 (***)	77.014	6%
Patagonia	109.031		1.744 (a)		110.775	8%
Noroeste	5.404	15.875	114	3.654	25.047	2%
Centro	34.172	14.632	1.602	2.520	52.926	4%
Cuyo			8.015 (b)		8.015	1%
Resto	290			13.122 (c)	13.412	1%
Total País	861.350	313.869	99.845	42.729	1.317.793	100%

Source: SSPMicro 2019. Foestry, Paper and Furniture Value Chain Report. ISSN 2525-0221

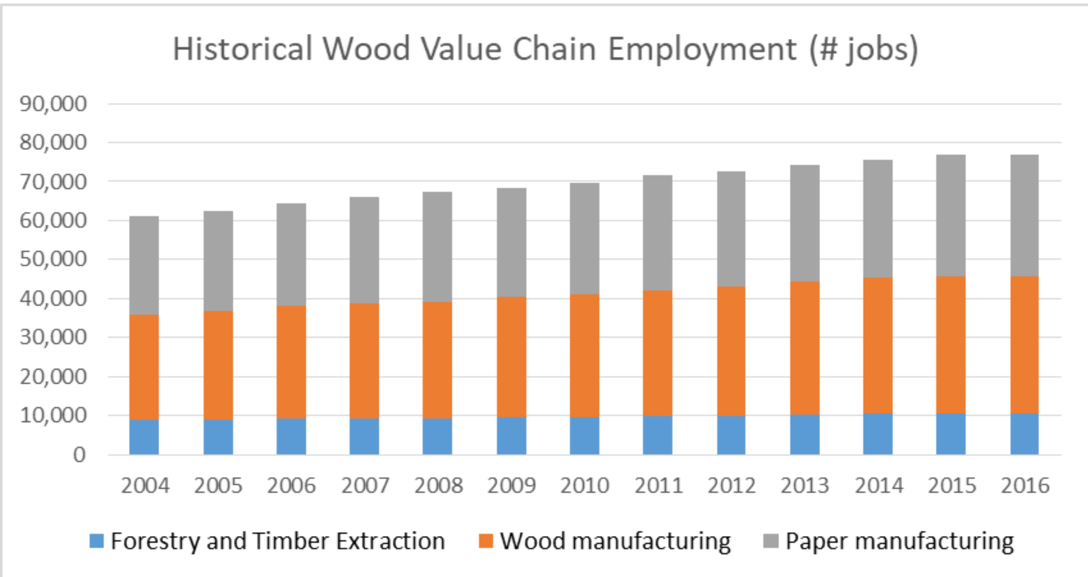
Different estimations on the potential for forest plantations in Argentina have been made by several entities, including:

- 5 millon hectares (SENASA)
- 18 and 20 million hectares of land suitable for forestry, of which 5 million do not compete in use with other alternative agricultural activities (FAO, 2001)
- 15 million hectares of areas with wood energy potential (FAO, 2020)

Additionally, ForestAr 2030 national plan set a target to increase cultivated forest area in Argentina from current 1.3 millon ha to 2.0 millon ha by year 2030. The cornerstone of ForestAr 2030 is the understanding that forests offer the single largest "natural climate solution" through the conservation, restoration and improved land-management techniques that increase carbon storage or avoid greenhouse-gas emissions in landscapes worldwide.

The National Statitstics Institute (INDEC) publishes statistics on registered jobs by economic activity in the private sector in Argentina. According to the latest publications, the value chain employs near 80 thousand jobs, from which the main are concentrated in the wood manufacturing with almost 45%.

Figure 41: Historical wood value chain employment in Argentina



Source: INDEC

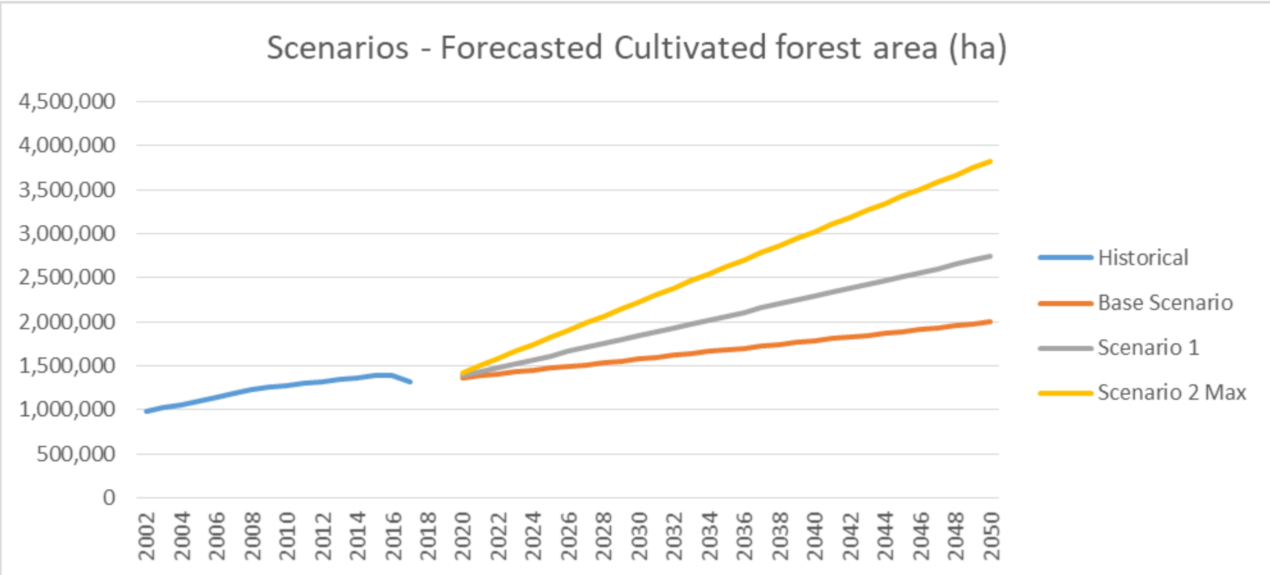
The official "ForestAr 2030" publication estimated that in the forestry industrial sector the ratio between direct jobs and indirect jobs is 1.6 indirect jobs per direct job.[22]

B) Impact assessment

Under the current study, three scenarios were defined, and forested area estimated according to their hypothesis:

- Base Scenario: Scenario based on historical trends
- Scenario 1: Increased activity scenario (NDC)
- Scenario 2: Scenario of Maximum potential area suitable for forestlands in Argentina

Figure 42: Scenarios of cultivated forest area in Argentina (2020-2050)



Source: Own elaboration

These projections imply a 1.3%, 2.3% and 3.3% CAGR annual growth in cultivated forest area for Base Scenario, Scenario 1 and Scenario 2 respectively.

[22] Forestry-Industrial Competitiveness Table, 2019, "Strategic Forest Plan and Industrial Forest Argentina 2030"

Table 26: Comparison of growth rates by Scenario - Cultivated Forest Area - Argentina

Period / Scenario	CAGR	Avg Variation (ha/y)
Historical 2003-2009	3.8%	41,091
Historical 2010-2014	2.0%	28,092
Historical 2015-2017	-0.5%	-1,317
Proj 2020-2050 -Base	*1.3%*	*21,000*
Proj 2020-2050 -Sc1	*2.3%*	*45,000*
Proj 2020-2050 -Sc2 Max	*3.3%*	*80,000*

Source: Own elaboration

The investment (CAPEX) was estimated based on the cost of implantation[23] per hectare of pine and eucalyptus in the province of Misiones (Resolution 116/2020 from the Secretary of Agriculture, Livestock and Fisheries). Costs of pruning and thinning activities were also considered along the years following implantation. An average weighting 75% pine costs and 25% eucalyptus costs was adopted (representative of Argentinean planted area breakdown by species). Therefore, resulting in an average cost of implantation of 770 USD/ha and average pruning and thining costs of 72 USD/ha for the following eight years. A curve with efficiences in investment over time for scenarios 1 and 2 was assumpted due to sinergies of increased activity and development of the value chain.

Table 27: Investment by scenario for Afforestation in Argentina

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
Baseline	875	29
Scenario 1	1,785 *(+104% vs Base)*	59
Scenario 2	3,006 *(+243% vs Base)*	100

Source: Own elaboration

In order to quantify C sequestration and GHG removal, first step was to estimate the density, yield and growth rates by species and by provinces. The biomass extracted was calculated for each group of species considering differences in the cutting schemes for conifers and other species among provinces, ex: 18 to 40 years for conifers; 12 years for eucalyptus; 11 years for

[23] Cost of implantation: Includes land preparation, cost of seedlings, fault replacement, control of weeds and ants of first year

salicaceae and 15 to 35 years for other species. For scenarios 1 and 2 of increased level of afforestation, a curve of decreasing yields was assumpted, as new plantations move to less productive lands.

Table 28: Density values and annual growth rates by species for Argentina

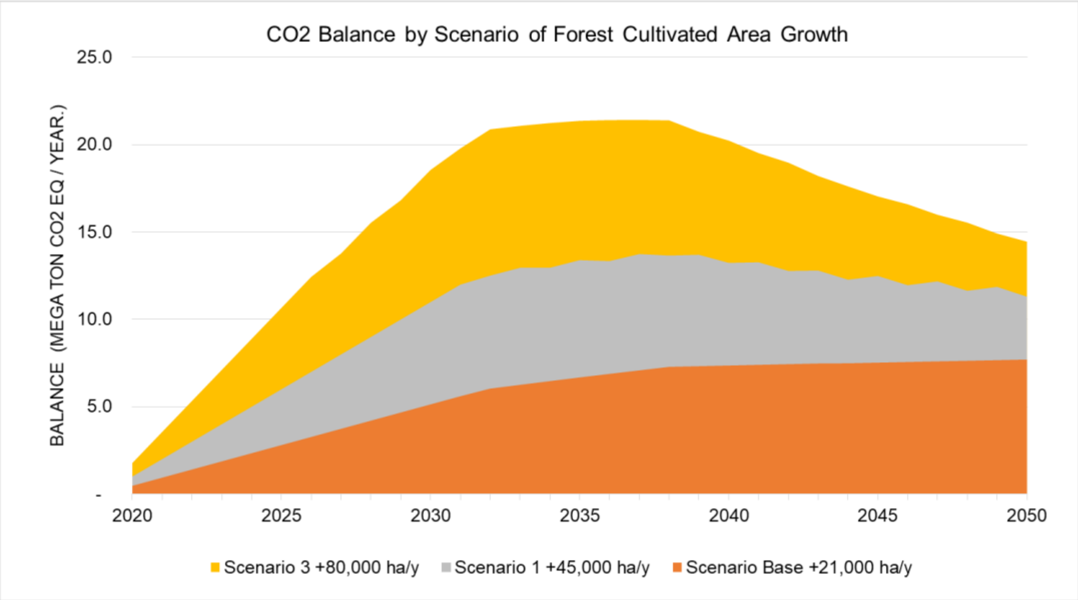
Species	Density (ton dm/m3)	Yield (m3/ha/year)	Growth (ton dm/ha year)
Conifers	0.4	20	8
Eucalyptus	0.65	40	26
Salicaceae	0.35	23	8.05
Other	0.45	18-20	8.1-9

Source: BUR 3 (2019)

The balance or net carbon capture was calculated as the difference between the captures from annual growth and the emissions from annual extraction. The fixation data correspond to the initial implanted area (2018), fixing carbon at the corresponding growth rate for each species/region to which the annual area increase is added (cumulative until 2050). The annual emission data correspond to the initial implanted area divided by the cutting scheme, according to the area implanted from 2018 onwards. The biomass values were converted to carbon and then CO_2.

The following figure corresponds to the CO_2 balance for the three scenarios proposed for the the area of forest plantations increase. In this estimate of the CO_2 balance, emissions from intermediate treatments of plantations (pruning and thinning) are not included, neither are considered emissions / removals of products originating from afforestation.

Figure 43: Balance of CO2 by Scenarios of cultivated forest area in Argentina (2020-2050)



Source: Own elaboration

According to the scenarios of afforestation deployment defined and the associated investment and CO2 capture potential, impacts were analyzed. The following table shows key metrics of impact analysis for Afforestation deployment in Argentina.

- Contribution to GDP was estimated as impact in Gross Aggregated Value for Forestry and Timber extraction activities consistent with the different planted area scenarios.
- Net changes in employment were also estimated based on registered private sector jobs for forestry and timber extraction activities and wood manufacturing activies with the different planted area scenarios.
- Also, an estimation on the indirect jobs was considered based on the aforementioned ratio for the forestry-industrial value chain (Strategic Forest Plan and Industrial Forest Argentina 2030).

Table 29: Impact analysis of Afforestation in Argentina

Scenario	Net changes in employment* per cultivated forest area ∆ # jobs / '000 ha	Contribution to GDP** per cultivated forest area ∆ MM USD GDP / '000 ha	GHG emissions per cultivated forest area MM CO2 ton eq / ha
Base	+20 direct +32 indirect	*+1.0*	*11*
1	+19 direct +30 indirect	*+1.3*	*8*
2	+17 direct +28 indirect	*+1.6*	*5*

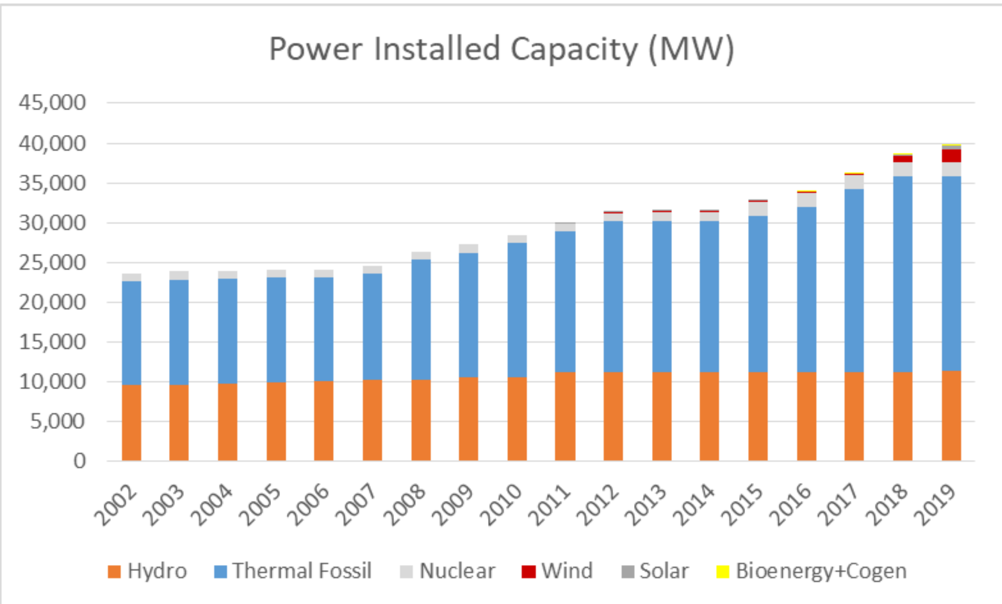
*Note: * Employment impact estimates only for Forestry and Timber extraction activities and Wood manufacturing activities. Paper production and Furniture production not included. ** Contribution to GDP estimated as impact in Gross Aggregated Value for Forestry and Timber extraction activities*
Source: Own elaboration

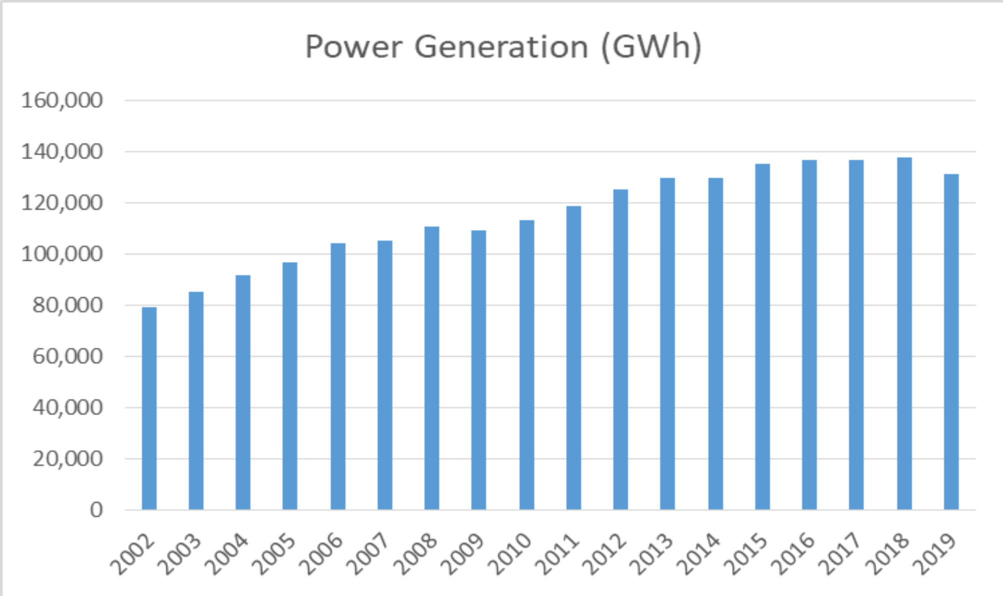
Bioenergy with carbon capture and storage (BECCS)

A) Status and trends of BECCS

Power Installed Capacity in Argentina grew to 39,826 MW in 2019 at an average 3.1% annual growth rate (CAGR 2002-2019), led mainly by Thermal Fossil (62% of total installed capacity). Although incipient, Bioenergy and Cogeneration summarized 168 MW of installed capacity by 2019 (0.4% of total installed capacity). Power Generation totalized 131,246 GWh in 2019, achiving a 3.0% annual growth (CAGR 2002-2019).

Figure 44: Historical Power Installed Capacity (MW) and Power Generation (GWh) in Argentina



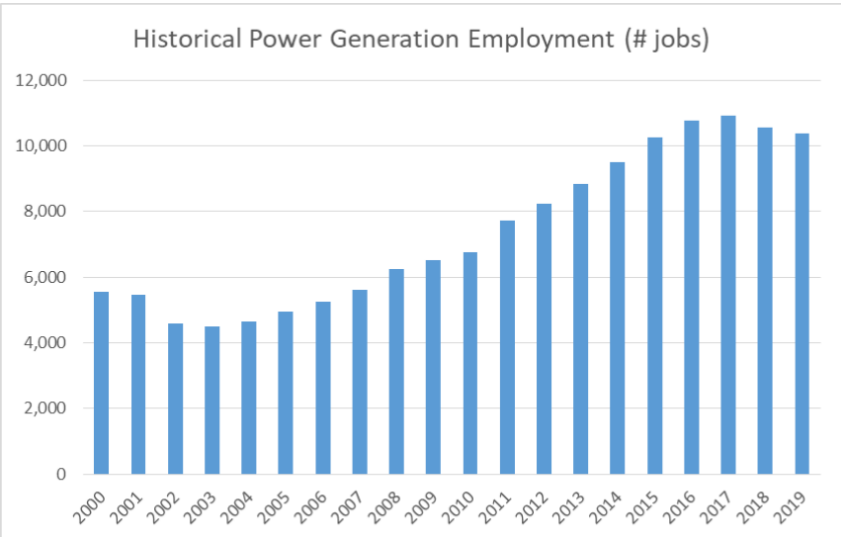


Source: CAMMESA

By year 2020, there were no CCS implemented projects on bioenergy installed capacity in Argentina nor plans to be developed.

The National Statitstics Institute (INDEC) publishes statistics on registered jobs by economic activity in the private sector in Argentina. According to the latest publications, there are near 10 thousand jobs in power generation sector.

Figure 45: Historical power generation employment in Argentina



Source: Observatorio de Empleo y Dinámica Empresarial, MTEySS based on SIPA.

B) Impact assessment

Under the current study, three scenarios were determined

- Baseline scenario, considering official Energy Scenarios in Argentina (SGE, 2019) for the period 2019-2030, extended to 2050. In 2019, the Secretary of Energy Planning issued a study with energy scenario towards year 2030, which were considered as BAU.
- Scenario 1: An enhanced biomass/biogas power generation scenario, with low CCS adoption
- Scenario 2: An enhanced biomass/biogas power generation scenario, with high CCS adoption

Table 30: Configuration of BECCS Scenarios for Argentina

		Baseline	Scenario 1	Scenario 2
2020-2030	*Renewables*	According to National Energy Scenarios, with renewable technologies assigned by the consultants in line with renewable power auctions, reaching 23.8% of the system's power generation excluding Hydro (54.6% including Hydro).	Consistent with the baseline scenario.	Consistent with the baseline scenario, with additional 1 percentage points displacing conventional thermal power generation.
	BE	Capacity consistent with the generation assigned following the aforementioned criteria.	Consistent with the baseline scenario.	Consistent with the baseline scenario, adding 1 percentage point to biomass power generation in 2030, what represents an increase of 129% of BE for power generation vs. the baseline.
	BECCS	No CCS installed capacity.	BECCS reach 5.0% of the bioenergy power generation in 2030.	BECCS reach 19.1% of the bioenergy power generation in 2030.
2031-2050	*Renewables*	In the consultants' baseline scenarios, renewable power generation (excluding Hydro) reaches 46.3% of the system generation by 2050 and 72.2% including Hydro.	Consistent with the baseline scenario.	In the consultants' baseline scenarios, renewable power generation (excluding Hydro) reaches 48.2% of the system generation by 2050, displacing thermal conventional power plants vs. the baseline scenario.
	BE	Bioenergy represents 2.5% of the power generation.	Consistent with the baseline scenario.	Bioenergy represents 4.4% of the power generation.
	BECCS	No CCS installed capacity.	BECCS reach 10.0% of the bioenergy power generation in 2050.	BECCS reach 39.1% of the bioenergy power generation in 2050.

Source: Own elaboration partially based on Secretariat of Energy.

2020—2030

Baseline scenario

In the case of Argentina, the baseline scenario is determined by the "Trend Scenario" to 2030 of the Secretariat of Energy, published in 2019 (SGE 2019). Electricity demand for this period has been computed according to the official *Trend Scenario* and represents a CAGR of 2.4% between 2020 and 2030.

Please note that the official energy scenarios for Argentina provide information for power generation and for capacity classifying power generation technologies as "Hydro, Thermal Conventional, Nuclear and Renewables (excluding Hydro)", while the official sources don't provide information regarding the primary sources (solar, wind, biomass and biogas) which constitute the "renewable" set of technologies.

In this context, the consultants assigned the primary sources for renewable power generation for the 2020-2030 period accordingly to the assignment of technologies during the RenovAr renewable energy auction rounds launched by the Argentine government during 2016 and 2017, as shown in the Progress Report (SGE 2017), while the capacity has been assigned accordingly to the power generation and dispatch factors.

Scenario 1

Scenario 1 considers that the electricity demand and power generation to 2030 is equivalent to the electricity demand in the baseline scenario, and that renewable power generation reaches an equivalent level and distribution to that shown in the baseline scenario, but introducing Carbon Capture Technologies to the biomass-fired installed capacity from 2025 onwards, reaching 5.0% of the bioenergy generation in 2030 and 20 MW in pilot projects (out of 397 MW) of Biomass power plants.

Scenario 2

Scenario 2 considers the same level of demand used in Scenarios 1 and 2, but increasing the share of biomass power generation, reaching 1.72% of the system generation, reducing the share of conventional thermal power generation. BECCS represents 19.1% of the whole biomass power generation (183 MW installed capacity).

2031—2050

Baseline scenario

From the year 2031 onwards, the Argentine government does not provide official inputs for electricity demand, nor for power generation or capacity. In this context, the consultants built a baseline scenario considering a deacceleration by the horizon of the scenario modelling (2050) of electricity demand consistent with an increased use of electricity in certain sectors (mostly for mobility) but overtaken by a decoupling of GDP growth to energy consumption, in line with the premises from the Secretariat's efficient scenario to 2030.

In the baseline scenario, renewable power generation (excluding Hydro) reaches 46.3% of the power generation mix (prominently Solar PV 23.6% and Wind power 20.1%), and when computing Hydro and other non-fossil power generation technologies, such as Nuclear, Thermal Fossil power generation accounts for 18.2%, fueled by Natural Gas. Bioenergy is present in the horizon of 2050 and represents 2.5% of the power generation, but does not include Carbon Capture Technologies (i.e., "there is BE but no BECCS").

Scenario 1

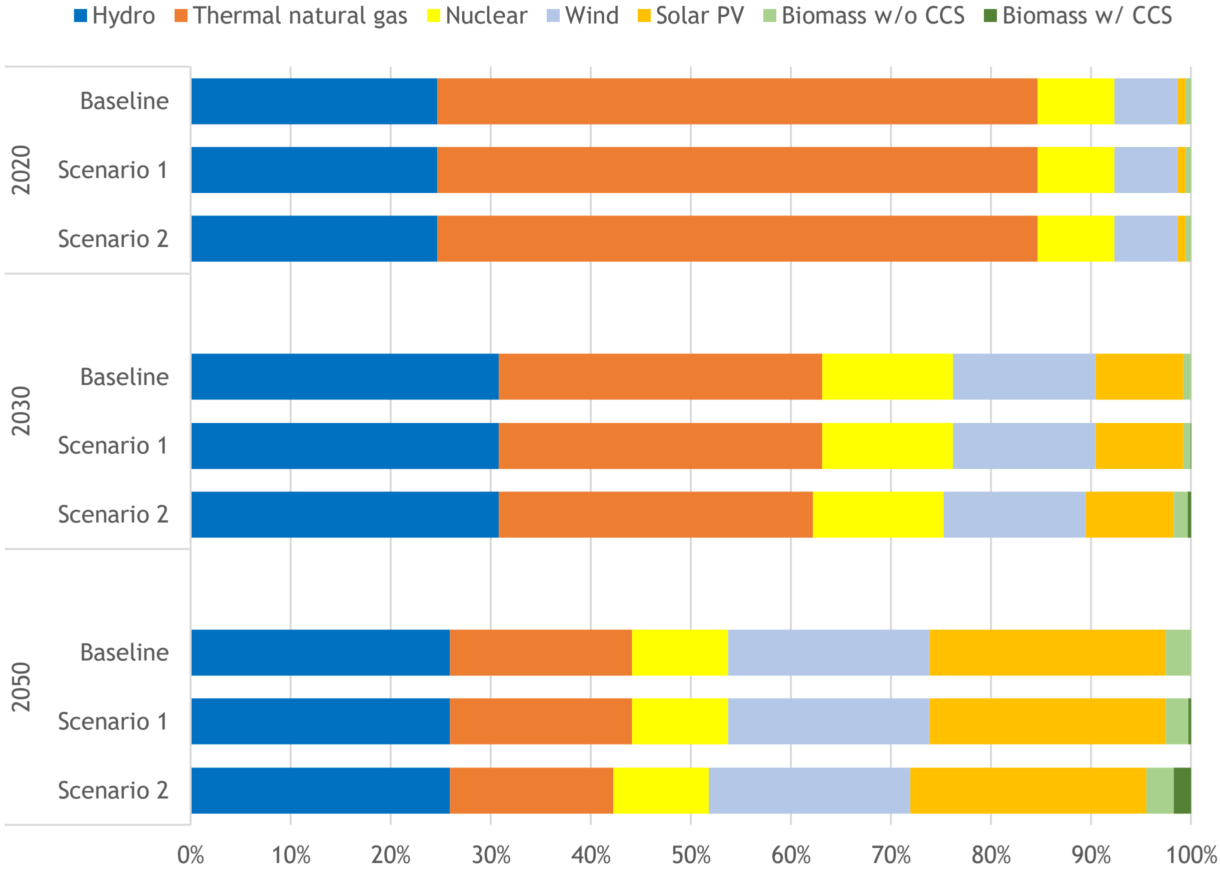
Scenario 1 represents a similar ambition in terms of the penetration of renewables in Argentina's integrated power grid but introducing Carbon Capture and Storage technologies to a portion of the biomass-fired installed capacity.

While the share of renewables in 2050 also reaches 46.3% (Solar PV 23.6% and Wind power 20.1%) and non-fossil power generation also accounts for 81.8%, Bioenergy installed capacity reaches 6,521 MW (biomass-fired power plants), and BECCS power generation represents 10% of the total bioenergy power generation, or 0.25% of the system generation.

Scenario 2

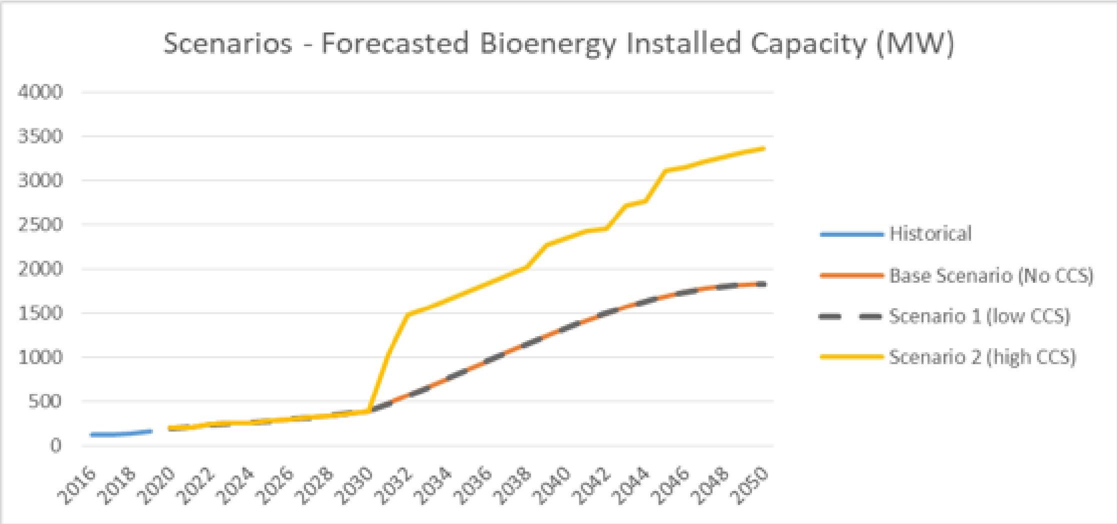
In the Scenario 2, from 2030 onwards, while the rest of renewable sources maintain their share of the system generation, Bioenergy displaces a larger share of Thermal-fossil power generation, reaching 4.4% of the mix by 2050. Additionally, 39.1% of the Bioenergy generation features CCS technologies (biomass-fired power plants), associated to a BECCS installed capacity of 1,316 MW.

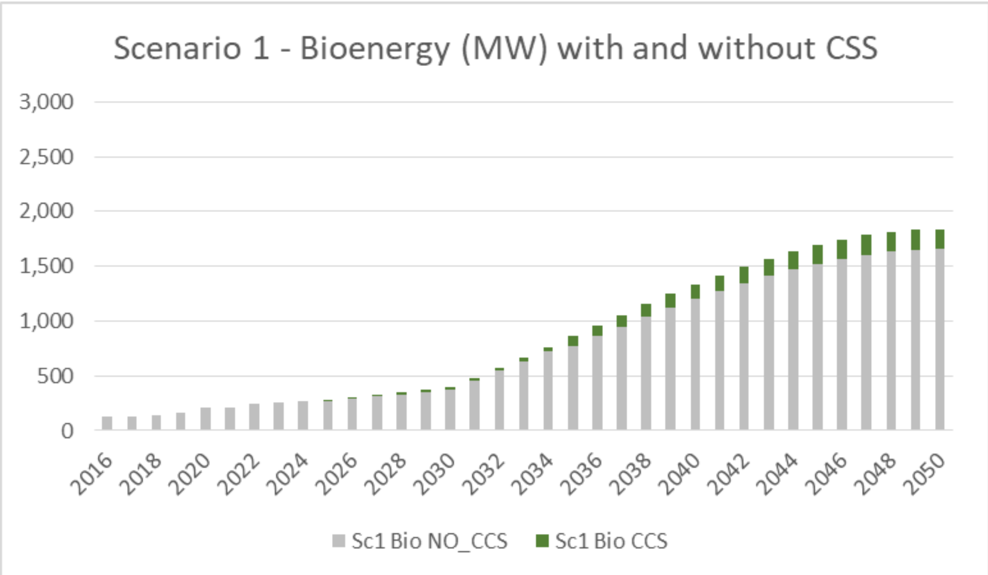
Figure 46: Power generation by source for 2020, 2030 and 2050 under the described scenarios. Argentina

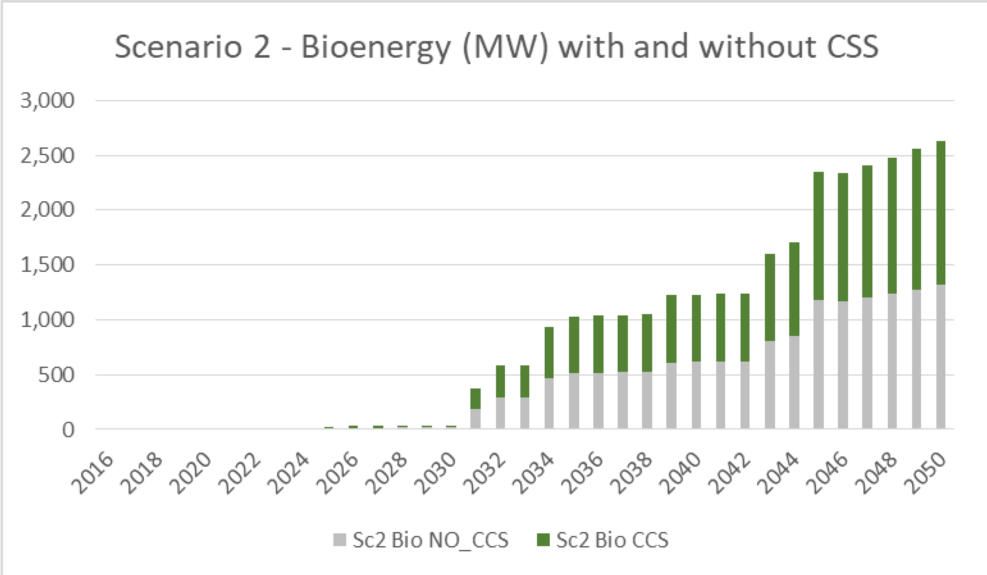


Source: Own elaboration.

Figure 47: Scenarios of bionergy installed capacity in Argentina (2020-2050)







Source: Own elaboration

These estimates imply a 7.5%, 7.5% and 9.7% CAGR annual growth in bionergy installed capacity for Base Scenario, Scenario 1 and Scenario 2 respectively. Baseline Scenario does not consider CCS, meanwhile in Scenario 1 BECCS would achieve over 180 MW of capacity and in Scenario 2 that figure would increase to over 1300 MW.

Table 31: Comparison of growth rates by Scenario - Bionergy Installed Capacity - Argentina

Period / Scenario	CAGR	Avg Variation (MW/y)
Historical 2016-2019	*9.8%*	*14*
Proj 2020-2050 -Base	*7.5%*	*54*
Proj 2020-2050 -Sc1	*7.5%*	*54*
Proj 2020-2050 -Sc2	*9.7%*	*105*

Source: Own elaboration

The following table exhibits a summary of key BECCS scenario metrics for Argentina, regarding power generation, installed capacity and investment.

Table 32: Key BECCS scenario metrics for Argentina

			Baseline	Scenario 1	Scenario 2
Power generation (net)	TWh	2020	131.8	131.8	131.8
		2030	166.7	166.7	166.7
		2050	227.7	227.7	227.7
Non-fossil fueled power generation / total	%	2020	40.0%	40.0%	40.0%
		2030	67.6%	67.6%	68.6%
		2050	81.8%	81.8%	83.6%
BE power generation	TWh	2020	0.6	0.6	0.6
		2030	1.3	1.3	2.9
		2050	5.8	5.8	10.1
BE / power generation	%	2020	0.5%	0.5%	0.5%
		2030	0.8%	0.8%	1.7%
		2050	2.5%	2.5%	4.4%
BE / thermal power generation exc. Nuclear	%	2020	0.8%	0.8%	0.8%
		2030	2.3%	2.3%	5.2%
		2050	12.2%	12.2%	21.3%
BECCS/ BE Power generation	%	2020	-	-	-
		2030	-	5.0%	19.1%
		2050	-	10.0%	39.1%
BE Installed capacity	MW	2020	208.6	208.6	208.6
		2030	396.9	396.9	560.1
		2050	1,838.2	1,838.2	3,369.7
BECCS Installed capacity	MW	2020	-	-	-
		2030	-	19.8	183.0
		2050	-	183.8	1,316.3
Investment in BE (no CCS)	MUSD/year	2020-2030	51.8 – 56.5	51.8 – 56.5	96.6 – 105.4
		2031-2050	208.6 – 227.6	208.6 – 227.6	406.7 – 443.6
Investment in BECCS (includes power plant)	MUSD/year	2020-2030	-	8.1 – 8.7	75.0 – 80.5
		2031-2050	-	35.4 – 38.0	244.6 – 262.5

Source: Own elaboration.

For BECCS CAPEX estimation the following assumptions were taken:

- BECCS: 4.100–4.400 USD/kWe (Adapted from Langholtz et al (2020) "The Economic Accessibility of CO2 Sequestration through Bioenergy with Carbon Capture and Storage (BECCS) in the US")

Scenarios 1 and 2 would totalize aproximately 800 and 5,000 million dollars cummulated investments respectively for the period 2020-2050.

Table 33: Investment by scenario for BECCS in Argentina

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
1	800	35
2	5,000	165

Source: Own elaboration.

The following table shows a summary of key scenario results for Argentina

Table 34: Summary of key BECCS emission scenario results in Argentina

			Baseline			Scenario 1			Scenario 2		
BECCS capture rate Scenarios as % of C input:			*40*	*60*	*80*	*40*	*60*	*80*	*40*	*60*	*80*
Combustion Emissions in power generation	$MtCO_2e$	2020		34.1			34.1			34.1	
		2030		23.6			23.6			24.7	
		2050		21.5			21.5			24.6	
Emissions intensity of combustion for power generation	tCO_2e/ MWh	2020		0.259			0.259			0.259	
		2030		0.141			0.141			0.148	
		2050		0.095			0.095			0.108	
Carbon fixed in biomass feedstock used for power generation	MtCO2e	2020		(0.46)			(0.46)			(0.46)	
		2030		(0.88)			(0.88)			(2.02)	
		2050		(4.08)			(4.08)			(7.11)	
Other lifecycle emissions from transport and processing of feedstock and energy use	$MtCO_2e$	2020		0.07			0.07			0.07	
		2030		0.14			0.14			0.32	
		2050		0.65			0.65			1.14	
Post-combustion capture	$MtCO_2e$	2020	-	-	-	-	-	-	-	-	-
		2030	-	-	-	(0.02)	(0.03)	0.14	(0.15)	(0.23)	(0.31)
		2050	-	-	-	(0.16)	(0.25)	0.08	(1.11)	(1.67)	(2.22)
Net scenario emissions	$MtCO_2e$	2020	33.72	33.72	33.72	33.72	33.72	33.72	33.72	33.72	33.72
		2030	22.82	22.82	22.82	22.81	22.80	22.79	22.85	22.77	22.70
		2050	18.11	18.11	18.11	17.95	17.87	17.79	17.49	16.93	16.37
Adjusted intensity for power generation	tCO_2e/ MWh	2020	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256
		2030	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.136
		2050	0.080	0.080	0.080	0.080	0.078	0.078	0.080	0.074	0.072
Avoided and captured emissions vs. baseline	$MtCO_2e$	2020	-	-	-	-	-	-	-	-	-
		2030	-	-	-	(0.02)	(0.03)	(0.04)	0.03	(0.05)	(0.13)
		2050	-	-	-	(0.16)	(0.25)	(0.33)	(0.63)	(1.18)	(1.74)
Avoided and captured emissions vs. baseline	%	2020	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		2030	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.2%	0.1%	-0.2%	-0.6%
		2050	0.0%	0.0%	0.0%	-0.9%	-1.4%	-1.8%	-3.5%	-6.5%	-9.6%

Source: Own elaboration

The penetration of BECCS in Argentina in the short-term is primarily conditioned by increasing power generation system costs, and in the long-term by the increasing availability of cost competitive alternatives with declining prices, such as Solar PV and Wind Power, as well as the availability of competitive natural gas.

The declining use of conventional Thermal power-generation by 2030 implies additional volumes of natural gas available competing pricewise for demand, hence lowering conventional Thermal power generation LCOE.

In the long-term, the needs for complementing non-dispatchable sources such as Wind and Solar PV could increase the competitiveness of Bioenergy and BECCS as an alternative to conventional thermal but increasing system costs (in absence of relevant carbon taxes for natural gas).

Estimated full LCOE (considering CAPEX and O&M costs) for BECCS in Argentina ranges from 283.3 USD/MWh to 330.3 USD/MWh vs. current average system costs around 61 USD/MWh and estimated at levels of 63 USD/MWh to 68 USD/MWh in 2050. (See Annex for further detail).

Towards the horizon of 2050, non-fossil power generation reaches 81.8% to 83.6% of the mix in the three analyzed scenarios. In this context:

- The relevance of renewable power sources in displacing fossil fuels for power generation in challenged by decreasing marginal carbon dioxide avoidance,
- In consequence, the cost of carbon dioxide avoidance and removal, computed as the difference between LCOEs over the difference between specific CO2 emissions/removals increases, due to a lowering denominator, which converges into the carbon capture component of BECCS, and reaches between 346 USD/tCO2e and 745.3 USD/tCO2e for the analyzed scenarios (considering CAPEX and O&M costs).
- However, as the potential of displacing fossil fuels becomes irrelevant, CDR technologies, such as BECCS, become some of the few available options to promote system-wide decarbonization potentially transforming the power sector of Argentina into a Carbon Dioxide sink.

Further research should explore extending this analysis to the potential of CDR in Argentina’s sugarcane and maize Bioethanol, as official scenarios promote the deployment of flex fuel use for road transportation.

Impact on Employment

A study from the Imperial College London from 2018 (Patrizio, et al 2018) on early deployment of BECCS in the US and replacing 50% of aging coal plants with natural gas plant, estimates that 1.9 permanent jobs per million dollars invested can be created in early deployment of BECCS[24]. By 2050, that ratio might decrease to 0.8 jobs / MMUSDA invested from deployment learning curve, economies of scale and larger operative efficiencies achieved.

Deployment of BECCS plant generates Operation and Maintenance direct jobs, but also jobs are created during the Construction phase (ex: 4,000 MW Drax BECCS project in UK would generate up to 17,000 jobs during its peak construction activity, equivalent to over 4 construction jobs / MW installed). Also, according to Patrizio et al, BECCS facilities generate additional indirect jobs in the forestry sector and connected to logistics activities (almost 1 to 1 ratio of additional jobs generated).

Under these assumptions BECCS deployment could generate nearly 3,000 permanent jobs by 2050 in Scenario 1, and over 20,000 permanent jobs by 2050 in Scenario 2. Construction of BECCS plants could generate an average of 35 construction jobs per year in Scenario 1 and over 250 jobs/year in Scenario 2.

The following table shows key metrics of impact analysis for BECCS deployment in Argentina. Contribution to GDP was estimated based on the investment in production equipment required in the different BECCS deployment scenarios.

Table 35: Impact analysis of BECCS deployment in Argentina

Scenario	Net changes in employment* per BECCS installed capacity ∆ # jobs / MW	Contribution to GDP** per BECCS energy generation ∆ MM USD GDP / TWh	Emissions removal for BECCS generation tCO2e/ MWh
1 *BECCS*	2 permanent 4 construction	50	*0.67 average*
2 *BECCS*	7 permanent 4 construction	140	*0.67 average*

** Not considering jobs lost in other sources of energy outplaced*
*** Investment in Durable Production Equipment vs GDP*
Source: Own elaboration

[24] Patrizio, et al (2018). "Reducing US Coal Emissions Can Boost Employment". Joule. 2. 10.1016/j.joule.2018.10.004.

Enhancing soil carbon content with biochar

A) Status and trends of biochar

In Argentina there were over 530 thousand hectares of fruit tree planted in year 2016, as indicated in Biennial update reports 3 (BUR3) from 2019.

Table 36: Share per type of crop - Year 2018 - Argentina

Crop	Share of cultivated area
Oilseeds	38.5%
Cereals	30.4%
Fodder crops	21.2%
Forests and forests implanted	3.3%
Industrial crops	2.4%
Fruit trees	1.4%
Legumes	1.0%
Vegetables	0.,4%
Aromatic, medicinal and spices	0%
Greenhouse	0%
Flowers	0%
Other	1.5%

Source: National agricultural census (2018)

The planting of fruit trees covered 1.4% of the total planted area, with more than 500 thousand has, showing the highest geographical concentration in the province of Mendoza, where almost 38% of the total were planted, followed by the province of Tucumán with 10.3% and San Juan with 10.1%.

As for 2020, there is no large-scale biochar project implemented nor planned projects to be developed in Argentina.

B) Impact assessment

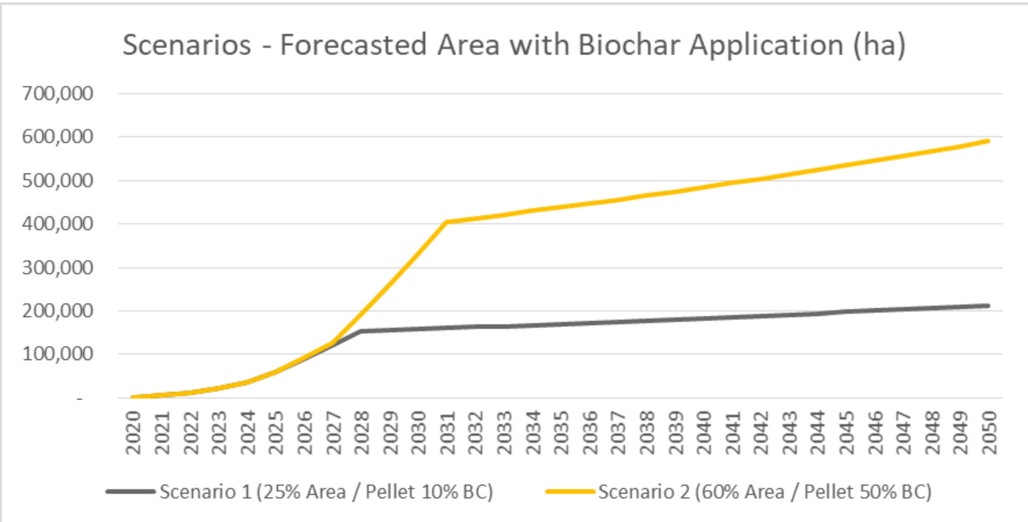
In Argentina, in the agricultural sector, Biochar would have as main use the application on degraded soils due to a high number of tillages, such as intensive horticultural crops, and non-degraded soils of intensive fruit trees production. Also, its use could be extended to large areas of degraded soils under agricultural or livestock use. In the latter, biochar use could be more restricted due to the cost-benefit relation. For the purposes of this study only the fruit tree area will be considered for potential large-scale biochar deployment.

Under the curret study, two scenarios were considered and elaborated:

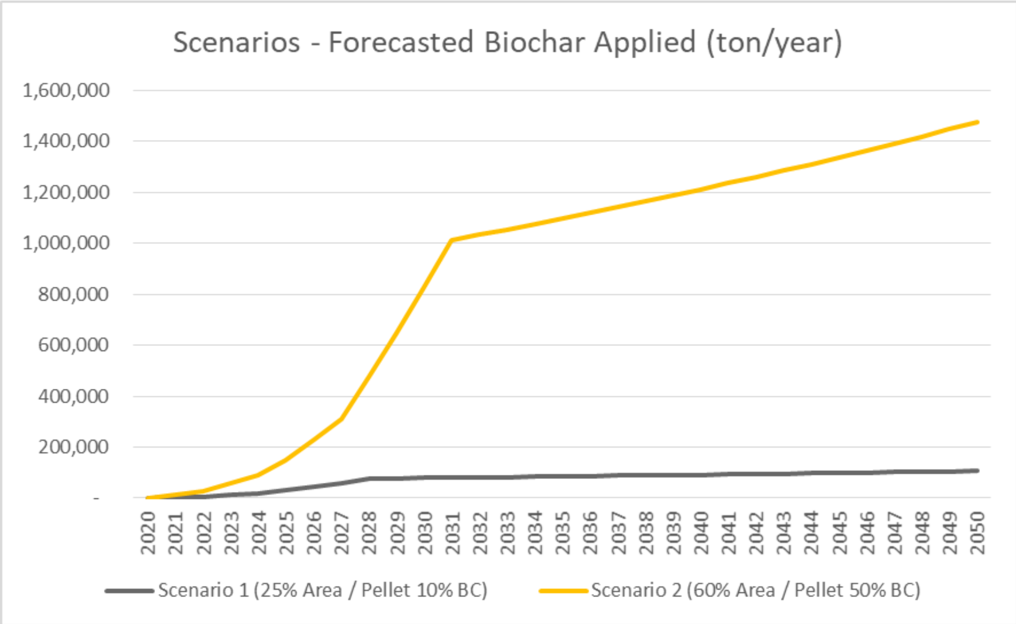
- Baseline Scenario: Business as ususal without Biochar application
- Scenario 1: Biochar application on up to 25% of fruit tree planted area with pellets of 10% biochar mix. The fruit tree planted area was forecasted to grow at 1.5% annually over the period 2020-2050
- Scenario 2: Biochar application on up to 60% of fruit tree planted area with pellets of 50% biochar mix. The fruit tree planted area was forecasted to grow at 2.0% annually over the period 2020-2050

Considering the aforementioned assumption on the percentage of the fruit tree planted area with biochar application of up to 25% and up to 60% in the Scenario 1 and Scenario 2 respectively, the following figure exhibits the area estimates for biochar application for the 2020-2050 period in Argentina. An assumption of 5 ton per ha per year dose of organic-mineral fertilizers in the form of pellets was taken. In Scenario 1 those pellets present a 10% biochar mix while in Scenario 2 the mix increases to 50% biochar. The change in the slope of the area with biochar application, reflects both the fruit tree planted area assumptions over time and the curve of adoption of biochar within that area over time.

Figure 48: Scenarios of Biochar application area in Argentina (2020-2050)



Source: Own elaboration



Source: Own elaboration

The estimated investment to produce biochar for agricultural purposes varies depending on the type and quality of biochar to be produced. For example, "pure" biochar, or in combination with composting of organic waste, also know as "organic-mineral" fertilizers (with a certain mix of biochar).

The production of Biochar is made from biomass by pyrolysis which is an exothermic process. The energy released can be partially utilized (aproximately 30% of the total energy) in the processing plant or nearby facilities. This production characteristic makes it attractive to be installed in industrial parks where energy use is more required. The production of a ton of Biochar, from 4 ton of dry base biomass, allows generation of about 5 MW of energy.

The installation of a 1,000 ton/year biochar production plant requires an approximate investment (CAPEX) of 600,000 USD. If the objective is to produce an organic-mineral pellet from biochar and compost, an additional investment of 400,000 USD is required for composting and pelleting processes, therefore totalizing 1,000,000 USD per 1,000 ton/year facility[25]. A curve with efficiencies in investment over time for scenarios 1 and 2 was assumpted due to sinergies of increased activity, technology maturity and development of the value chain.

25 Biochar plant CAPEX assumptions from interviews with sectorial experts and industry players

Scenarios 1 and 2 would totalize aproximately 100 and 900 million dollars investments respectively for the period 2020-2050.

Table 37: Investment by scenario for Biochar in Argentina

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
1	*100*	*3*
2	900	*30*

Source: Own elaboration

Regarding employment, it is estimated that a 1,000 ton per year biochar plant would generate 4 direct jobs[26], resulting in approximate 425 jobs by year 2050 in Scenario 1 (equivalent to 2 directs jobs per thousand hectares of biochar application) and around 6,000 jobs by 2050 in Scenario 2 (equivalent to 10 directs jobs per thousand hectares of biochar application). Jobs generated during biochar application on plantations could not be quantified due to lack of information.

Although the "organic-mineral" fertilizer is mostly composed of carbon (from compost and biochar), only a fraction of the Carbon contained in the biochar is considered as "sequestration". The Fraction considered as sequestration is defined by IPCC (2019) on its equation 4A.1 and depends on two factors: the C content of the biochar (Fcp) and and the fraction of Biochar that remains in the soil after 100 years (Fpermp). Therefore, the increase in soil carbon results from multiplying the incorporated mass of Biochar by the C content and the permanence factor. The latter depends on the temperature at which the Biochar was produced. The lowest temperature of the pyrolysis process is 350 to 450 degrees Celsius and would correspond to the lowest quality Biochar, whose permanence fraction is 0.65 (Table 4Ap.2, IPCC, 2019). In the current study, the values adopted for factors Fcp and Fpermp were 0.7 and 0.65, respectively.

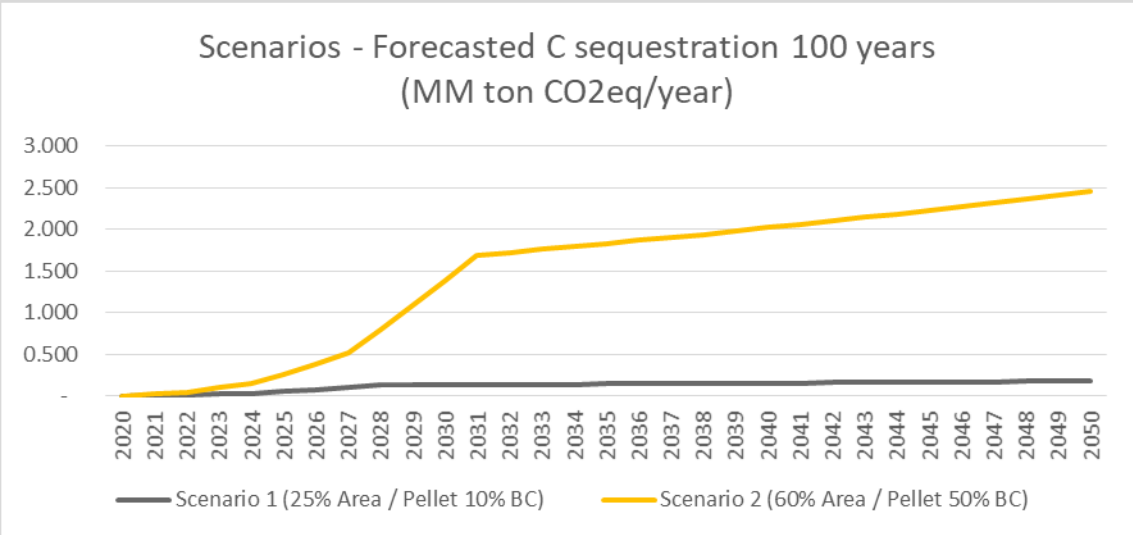
In both scenarios where biochar is added, the required biomass to produce biochar and the required waste to produce compost, are both well within the limits of availability in Argetina as estimated by the WISDOM report (FAO-INTA, 2009).

The applied methodology for Argentina results on 2.5 million tons of CO2 equivalent per year sequestrated for 100 years in Scenario 2 by 2050. Meanwhile Scenario 1 with lower area for

[26] Biochar plant employment generation assumptions from interviews with sectorial experts and industry players

biochar application and lower biochar mix in pellet results in much lower C sequestration of 0.2 MM ton CO2eq/year by 2050.

Figure 49: Scenarios of forecasted C Sequestration - Biochar (2020-2050)



Source: Own elaboration

The following table shows key metrics of impact analysis for Biochar deployment in Argentina. Contribution to GDP was estimated based on the investment in machinery and equipment required in the different biochar application scenarios.

Table 38: Impact analysis of Biochar deployment in Argentina

Scenario	Net changes in employment* per biochar applied area ∆ # jobs / '000 ha	Contribution to GDP per biochar applied area ∆ MM USD GDP / '000 ha	GHG emissions*** per biochar applied area CO2 ton eq / year / '000 ha
1	*+2 industrial*	*+0.10*	*835*
2	*+6 industrial*	*+0.35*	*4,200*

** Direct jobs generaed in biochar plant. Jobs generated during biochar application on plantations could not be quantified due to lack of information.*
*** Investment in Machinery and Equipment vs GDP*
**** C sequestration 100 years (65% Fperm; Biochar with 70% C)*
Source: Own elaboration

3. Colombia

According to the World Bank, Colombia has a track record of prudent macroeconomic and fiscal management, anchored on an inflation targeting regime, a flexible exchange rate, and a rule-based fiscal framework, which allowed the economy to grow uninterrupted since 2000. Also, Colombia halved poverty over the past ten years.

However, productivity growth is low and it has actually been a drag on economic growth. A large infrastructure gap, low labor productivity, low trade integration and barriers to domestic competition are among the factors that weigh on total factor productivity. Exports are highly concentrated in non-renewable commodities (oil in particular), which increases the exposure of the economy to price shocks. Finally, Colombia is one of the countries with the highest income inequality and labor market informality in Latin America.

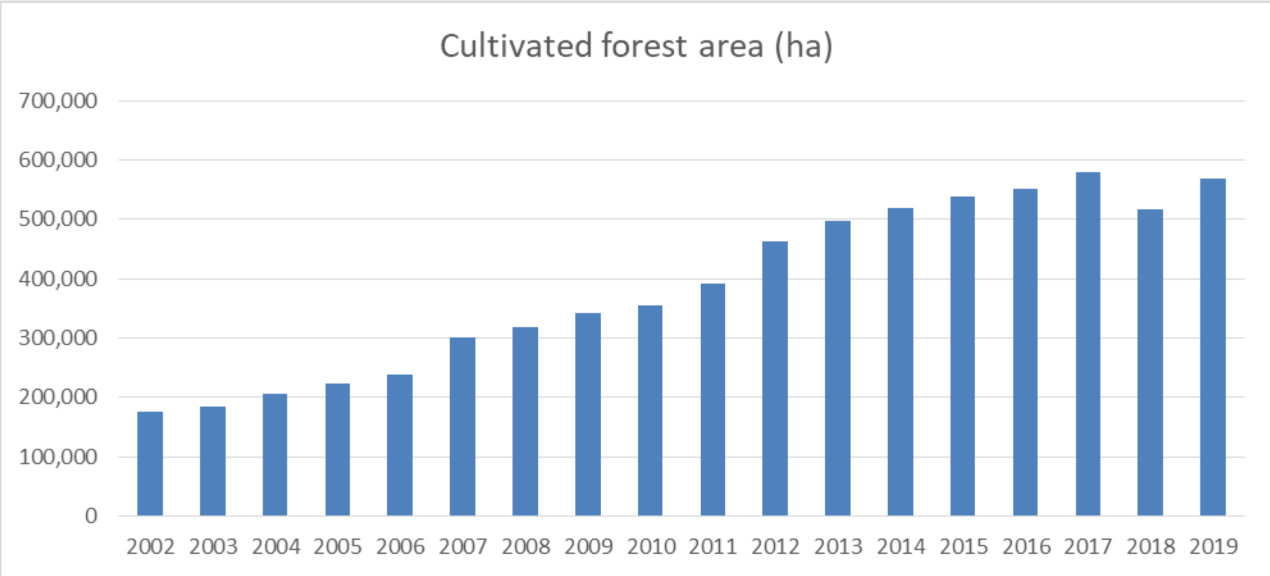
After slowing down to 1.4 percent in 2017, economic growth accelerated to 3.3 percent in 2019, driven by robust private consumption and stronger investment. Growth was on track to accelerate further in 2020, but the COVID-19 pandemic hit the economy hard, causing a very deep recession (World Bank, 2020).

Afforestation and reforestation

A) Status and trends of forestry sector

According to consolidated data by the Ministry of Agriculture and Rural Development (MADR) on its Forestry Statistical Bulletin Year 2019, cultivated forest area in year 2019 was 568,769 hectares, representing a CAGR growth of 7.0% over the 2002-2019 period.

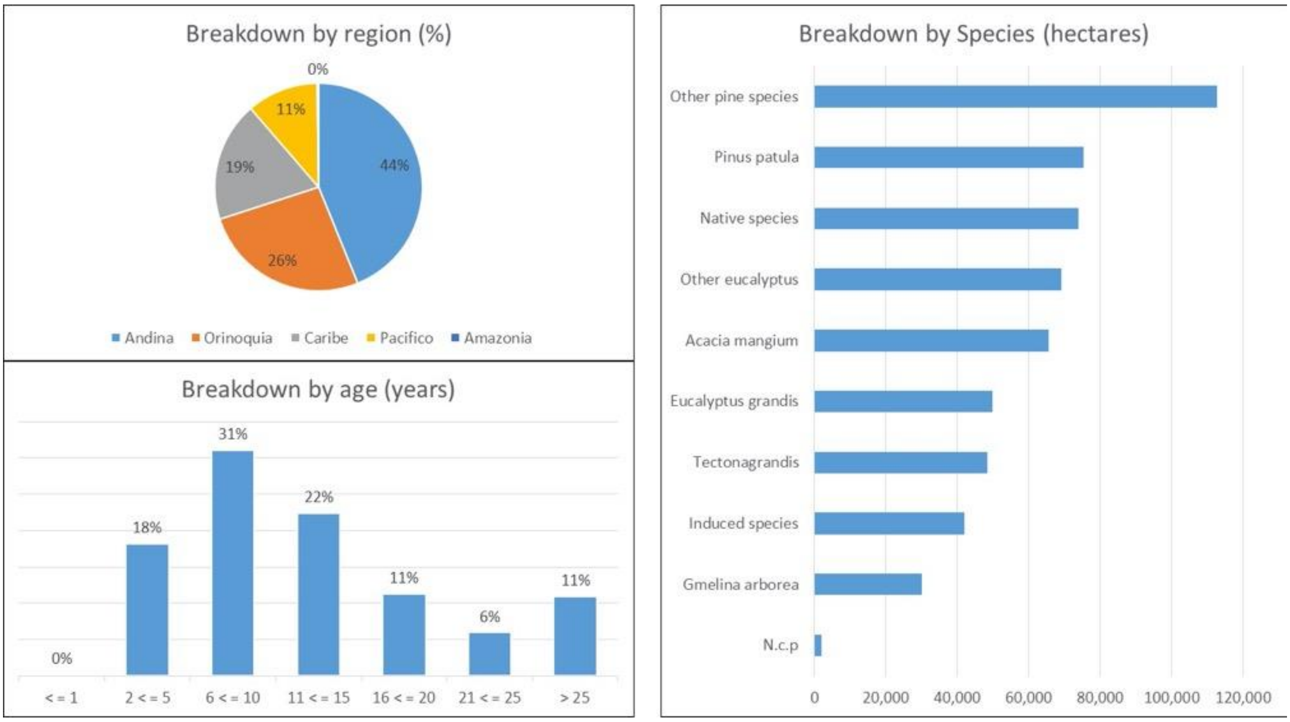
Figure 50: Historical cultivated forest area in Colombia



Source: MADR based on ICA, FINAGRO and FEDERACIÓN DE CAFETEROS; Evaluaciones Agropecuarias Municipales por Consenso from Dirección de Desarrollo Rural Sostenible

Andina (44%) and Orinoquia (26%) are the main regions in terms of cultivated forest area (being Antioquia, Vichada, Meta and Córdoba the main department). The largest species are "Pinus patula+Other pine species" (33%) and "Eucalyptus grandis+Other eucalyptus species" (21%). Most of the current cultivated area present an age in the range of 6 to 10 years (31%), 11 to 15 years (22%) and 2 to 5 years (18%).

Figure 51: Characterization of cultivated forest area in Colombia (Year 2019)

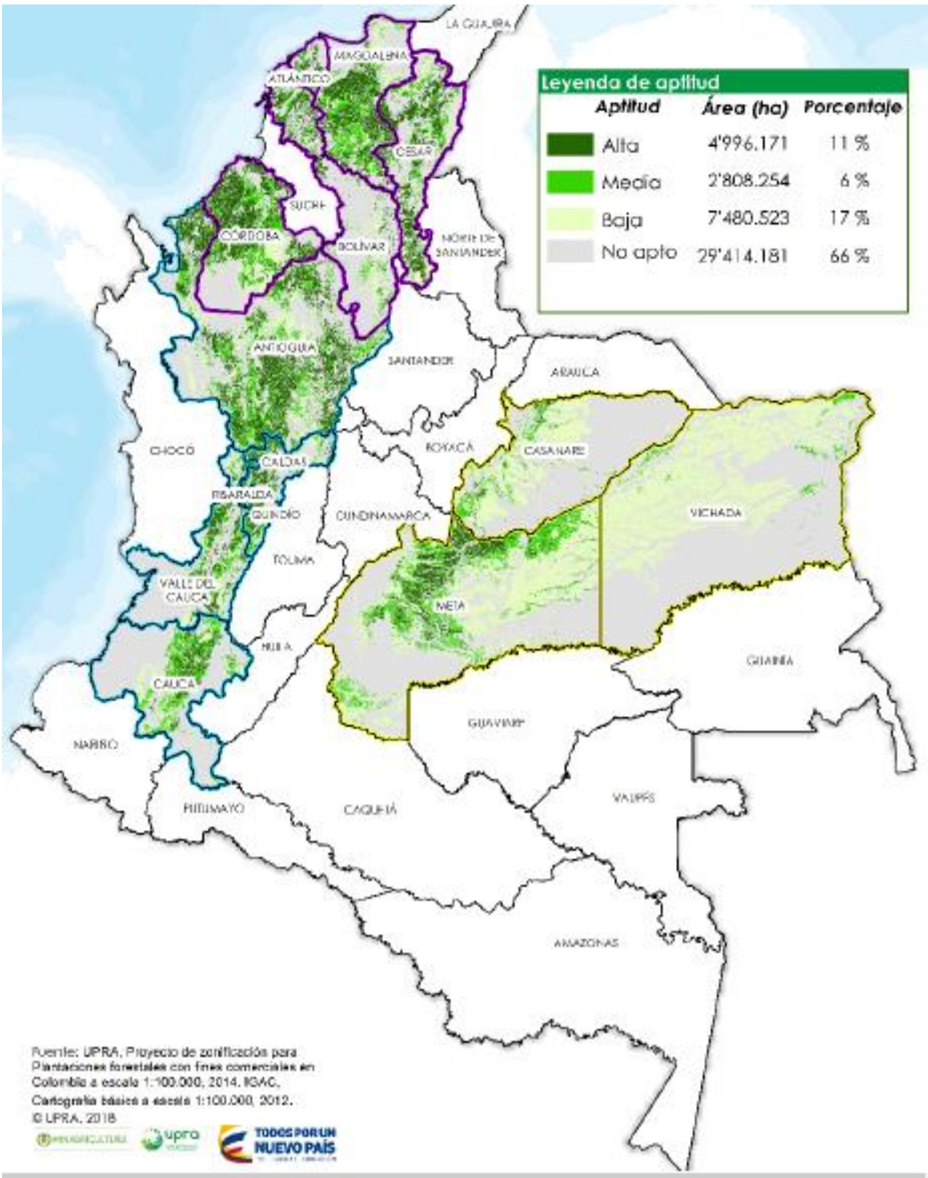


Source: Own elaboration based on Forestry Statistical Bulletin Year 2019

The Unidad de Planificación Rural Agropecuaria (UPRA) estimated in 2015 that 7,258,442 ha (equivalent to 7% of Colombian territory) presented high aptitude for forest cultivation for commercial purposes.[27] Two years later, a new study from UPRA analyzed in detail 3 regions and 14 departments of Colombia, concluding that 4.996.171 ha presented high aptitude for forest cultivation for commercial purposes.[28]

[27] UPRA, 2015. "Zonificacion para Plantaciones forestales con fines comerciales - Colombia - Escala 1:100.000"
[28] UPRA, 2017. "Mapa de Zonificación de Aptitud para plantaciones forestales con fines comerciales en 3 regiones y 14 departamentos de Colombia. Escala: 1:100.000"

Figure 52: Map of Zones with Aptitude for Forest Plantations with Commercial Purposes



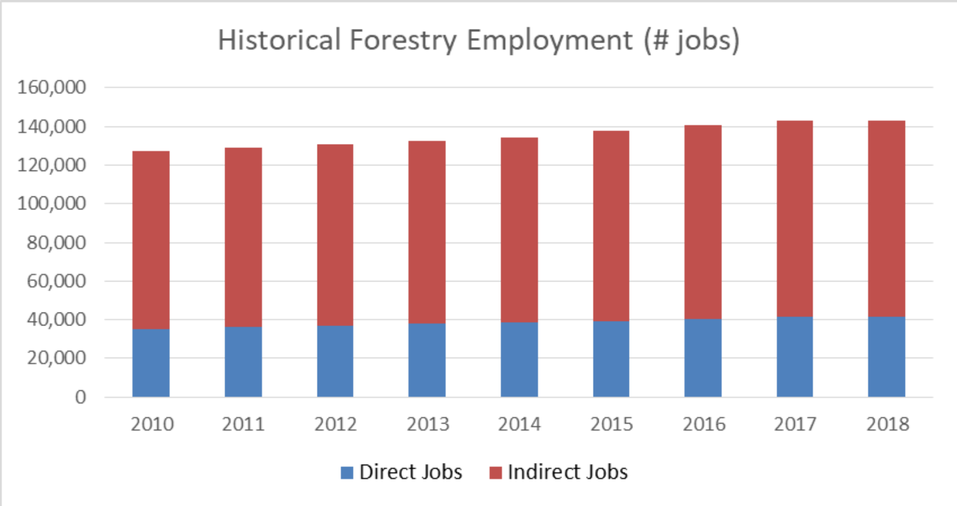
Source: UPRA 2017

Another relevant reference is the National Development Plan of the current Government that has three goals on forest plantations:

- Increase the participation of the forest economy in national GDP by one percent (currently 0.6 percent)
- Increase the commercial reforestation area up to 122,000 hectares by 2022 (3,000 ha in 2019; 33,000 ha in 2020; 43,000 ha each in 2021 and 2022) and reach 1.5 million hectares by 2030
- Generate areas with planned productive transformation through forestry cluster initiatives

According to the MADR (2019), there were nearly 40 thousand direct jobs in the forestry sector and about 100 thousand indirect jobs (representing a ratio of aproximate 2.5 indirect jobs per direct job). The growth rate (CAGR) of forestry direct jobs in Colombia was 2.2% annually for the period 2010-2018.

Figure 53: Historical forestry employment in Colombia



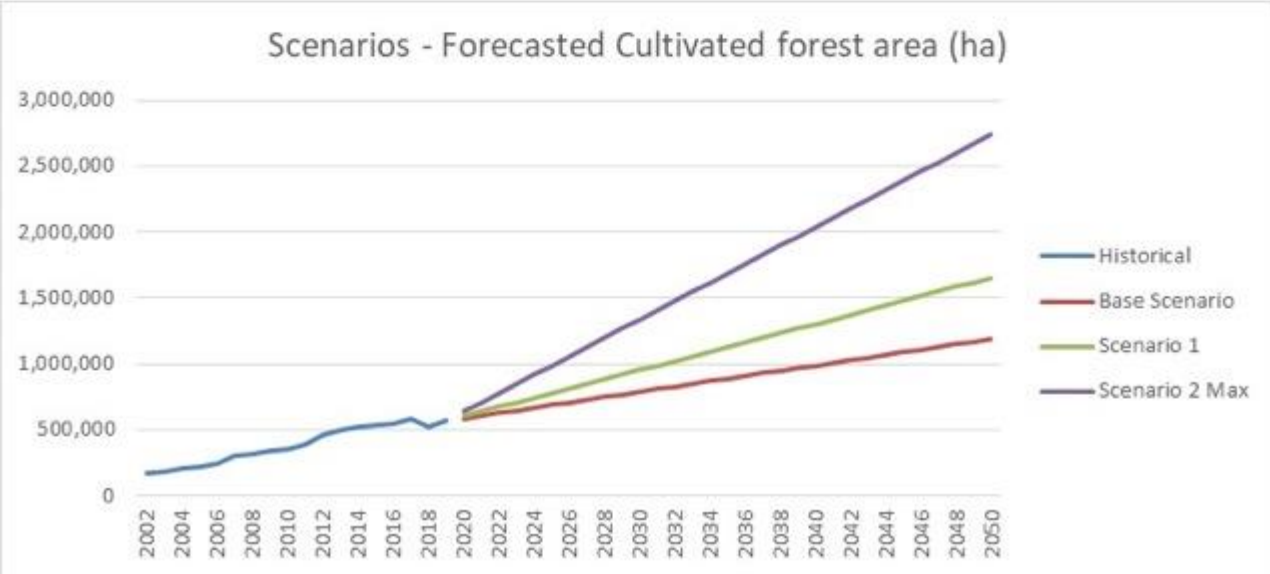
Source: MADR 2019

B) Impact assessment

Under the current study, three scenarios were determined and elaborated:

- Base Scenario: Scenario based on historical trends
- Scenario 1: Increased activity scenario (NDC)
- Scenario 2: Scenario of Maximum potential area suitable for forestlands in Colombia

Figure 54: Scenarios of forecasted cultivated forest area in Colombia (2020-2050)



Source: Own elaboration

These estimates imply a 2.4%, 3.4% and 5.0% CAGR annual growth in cultivated forest area for Base Scenario, Scenario 1 and Scenario 2 respectively.

Table 39: Comparison of growth rates by Scenario - Cultivated Forest Area - Colombia

Period / Scenario	CAGR	Avg Variation (ha/y)
Historical 2003-2009	10.8%	23,750
Historical 2010-2014	9.9%	35,636
Historical 2015-2019	1.4%	9,898
Proj 2020-2050 -Base	*2.4%*	*20,000*
Proj 2020-2050 -Sc1	*3.4%*	*35,000*
Proj 2020-2050 -Sc2 Max	*5.0%*	*70,000*

Source: Own elaboration

In terms of investment and costs required, MADR estimated in 2018 a CAPEX of 1,085 USD/ha for plantation and a Maintenance Operational Expenditures (OPEX) ranging from 200 to 370 USD/ha over the following four years.

Table 40: CAPEX and OPEX - Cultivated Forest Area - Colombia - Year 2018

CAPEX Forest Plantation (Year 2018)				
Activity	$/ha	USD/ha		
Labor	$ 1,672,200	$ 565.61		
Supplies	$ 1,166,200	$ 394.46		
Technical Advisory	$ 316,800	$ 107.16		
Administration	$ 52,800	$ 17.86		
Total	$ 3,208,000	$ 1,085.09		
Maintenance (2018)	Year 1	Year 2	Year 3	Year 4
OPEX Maintainance $/ha	$ 1,100,000	$ 1,100,000	$ 700,000	$ 600,000
OPEX Maintainance USD/ha	$ 372	$ 372	$ 237	$ 203

Source: MADR 2019

A curve with efficiences in investment over time for scenarios 1 and 2 was assumpted due to sinergies of increased activity and development of the value chain. Scenarios 1 and 2 would totalize aproximately 2,300 and 4,300 million dollars investments respectively for the period 2020-2050.

Table 41: Investment by scenario for Afforestation in Colombia

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
Base	1,431	48
1	2,327 *(+63% vs Base)*	78
2	4,331 *(+203% vs Base)*	144

Source: Own elaboration

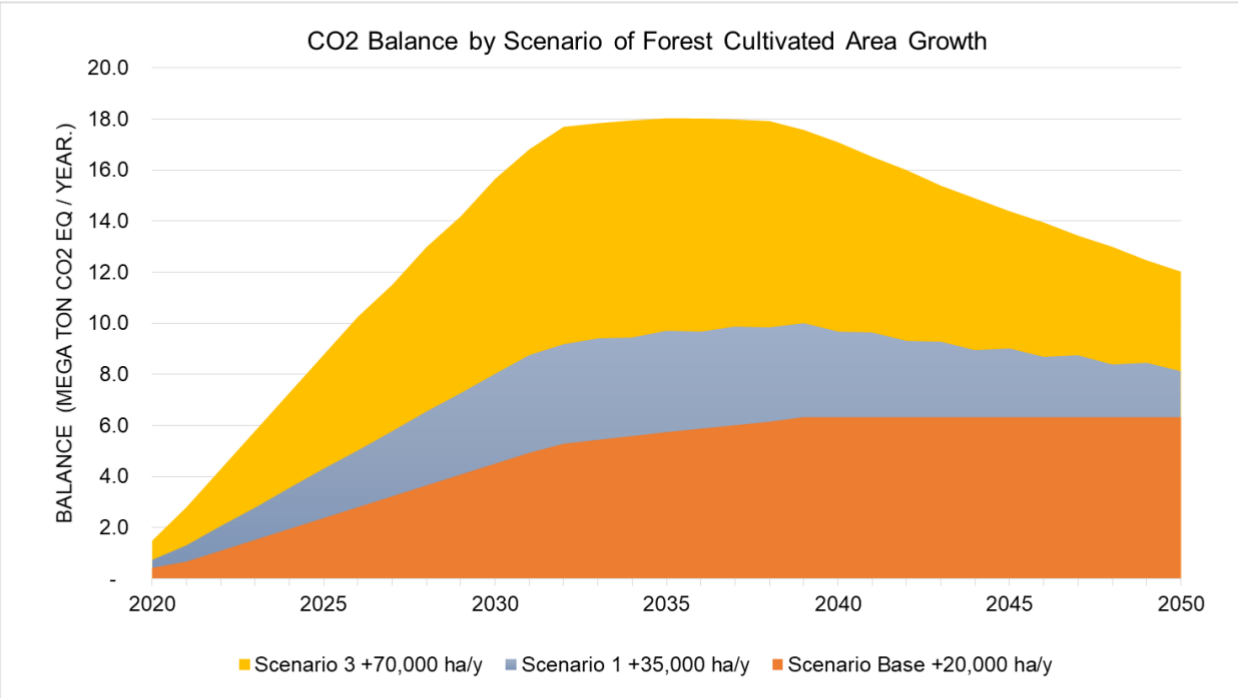
In order to quantify C sequestration and GHG removal, the first step was to estimate the density, yield and growth rates by species and by department. The biomass extracted was calculated for each group of species considering differences in the cutting schemes for conifers and other species among regions (ex: 18 to 40 years for conifers; 12 years for eucalyptus; 11 years for salicaceae and 15 to 35 years for other species. For scenarios 1 and 2 of increased level of afforestation, a curve of decreasing yields was assumpted, as new plantations move to less productive lands.

The balance or net carbon capture was calculated as the difference between the captures from annual growth and the emissions from annual extraction. The fixation data correspond to the initial implanted area (569 thousand ha in 2019), fixing carbon at the corresponding growth rate for each species/region to which the annual area increase is added (cumulative until 2050).

The annual emission data correspond to the initial implanted area divided by the cutting scheme, according to the area implanted from 2019 onwards. The biomass values were converted to carbon and then CO2.

The following figure corresponds to the CO2 balance for the three scenarios proposed for the the area of forest plantations increase. In this estimate of the CO2 balance, emissions from intermediate treatments of plantations (pruning and thinning) are not included, neither are considered emissions / removals of products originating from afforestation.

Figure 55: Balance of CO2 by Scenarios of cultivated forest area in Colombia (2020-2050)



Source: Own elaboration

The following table shows key metrics of impact analysis for Afforestation deployment in Colombia. Contribution to GDP was estimated as impact in Gross Agregatted Value for Forestry and Timber extraction activities based on the different planted area scenarios. Net changes in employment was also estimated based on direct forestry jobs (as classified by MADR) with the different planted area scenarios.

Table 42: Impact analysis of Afforestation in Colombia

Scenario	Net changes in employment* per cultivated forest area ∆ # direct jobs / '000 ha	Contribution to GDP** per cultivated forest area ∆ MM USD GDP / '000 ha	GHG emissions per cultivated forest area MM CO2 ton eq / ha
Base	*19 direct* *47 indirect*	*+0.35*	*10*
1	*16 direct* *40 indirect*	*+0.31*	*8*
2	*13 direct* *32 indirect*	*+0.25*	*6*

*Note: * Employment impact estimates for direct forestry jobs (as classified by MADR). ** Contribution to GDP estimated as impact in Gross Agregatted Value for Forestry and Timber extraction activities*

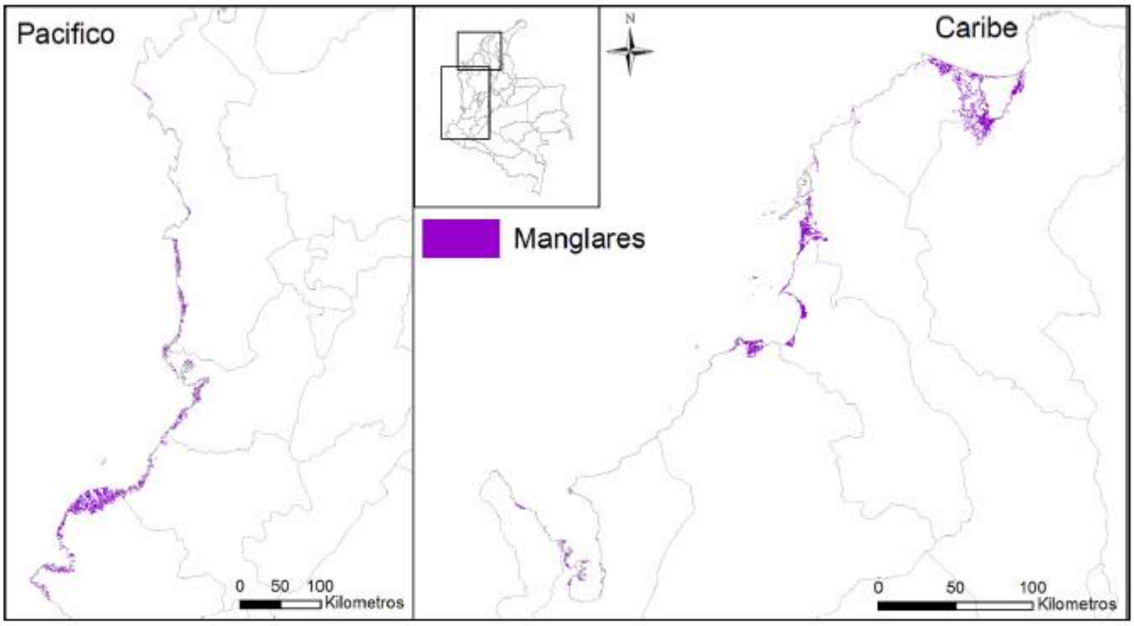
Mangroves - Impact Analysis Colombia

This subsection covers the impact analysis of mangrove restoration in Colombia.

Colombia is a unique as well as globally significant country in terms of mangroves, with world-class high biomass and carbon reservoirs, and is placed -with 2% of the global mangrove carbon stock found in Colombia- within the top 20 countries in the world ranking (Hamilton and Friess, 2018).

As mentioned before, Colombia holds the second largest mangrove area in South America behind Brazil (FAO, 2007). It is the only country in South America with coasts in both the Pacific and the Atlantic Oceans (in the Caribbean Sea), with about three-fourths of the surface of its mangroves located in the Pacific coast and one-fourth in the Caribbean coast.

Figure 56: Mangrove distribution in the Pacific (left) and Caribbean coasts (right) of Colombia



Source: Bernal et al, 2017 based in INVEMAR data (2014)

The total mangrove surface amounted to 370,000 ha in 1997 (Sánchez-Páez et al., 1997). By 2014, the total coverage had decreased by about 23% to 2014, or 285,000 ha (INVEMAR, 2015; Bernal et al, 2017). On the other hand, the areas of mangroves and seagrasses currently protected in Colombia are approximately 67,000 ha, about 23.4% of total mangrove cover.

Most recent official figures from the Ministry of Environment show a recovery in mangrove area in Colombia reaching 290,704 hectareas in 2020[29].

Mangroves were included in the 2015 National Restoration Plan. Restoration locations and target areas specifying the size of planned restoration may need to be further defined. An estimation of unprotected mangrove area amounts to about 219,000 hectares (Bernal et al., 2017). Carbon sequestration through mangrove restoration zoning, according to Bernal et al. could extend to 59,000 hectares.

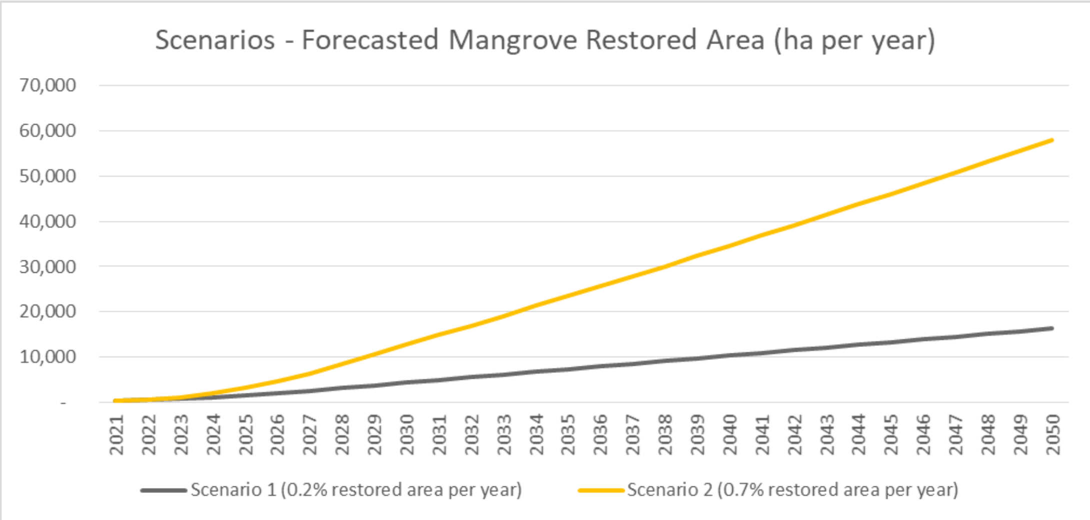
Two scenarios of mangrove restoration in Colombia were built for this study:

- Scenario 1: Mangrove restoration plan of 0.2% of total mangrove area annually (16,000 total restored hectares by year 2050)

[29] Ministry of Environment of Colombia Website: https://www.minambiente.gov.co/index.php/noticias/4764-narino-choco-y-magdalena-con-el-85-de-los-manglares-del-pais (accessed January 10th 2021)

⊃ Scenario 2: Mangrove restoration plan of 0.7% of mangrove area annually (58,000 total restored hectares by year 2050) (Maximum mangrove restoration area according to Bernal et al 2017)

Figure 57: Scenarios of forecasted Mangrove Restoration area in Colombia (2020-2050)



Source: Own elaboration

Within these projections, total mangrove area in Colombia would add to 306,000 hectares and 348,000 hectares by 2050 in Scenarios 1 and 2 respectively.

Reported marine coastal restoration costs for mangrove restoration where large contributions of effort by communities and volunteers are common, is estimated in around 9,000 USD/ha (mean value of 109 mangrove restoration projects from Bayraktarov et al., 2016a study). A curve with efficiencies in investment over time for scenarios 1 and 2 was assumed due to sinergies of increased activity and development of the value chain. Scenarios 1 and 2 would totalize aproximately 140 and 460 million dollars accumulated investments respectively for the period 2020-2050.

Table 43: Investment by scenario for Mangrove Restoration in Colombia

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
1	*139*	*5*
2	460	*15*

Source: Own elaboration

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

Table 44: Above Ground Biomass (AGB) growth rates for Mangrove Restoration in Colombia

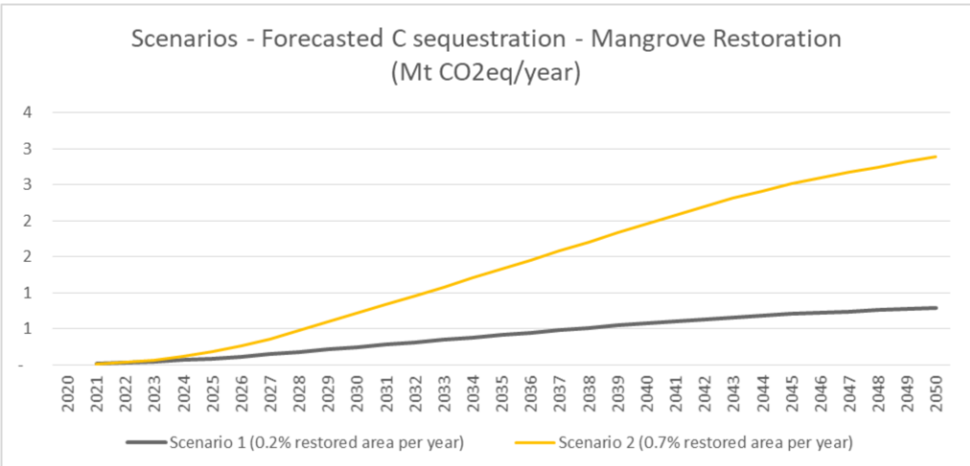
ton CO2e / ha / year	AGB Years 0-20	AGB Years 21-50
Mangrove Tree	*16.1*	*7.4*
Mangrove shrub-scrub	4.4	*1.4*

Source: Bernal et al 2017

Palacios Peñaranda et al (2019) estimated that AGB represents 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 our carbon sequestration projections. A conservative factor of 70% was applied to biomass growth rates due to restoration plantations on previously erosioned/damaged mangroves land.

The applied methodology for Colombia results on nearly 2.9 million tons of CO2 equivalent per year sequestrated in Scenario 2 by 2050. Meanwhile Scenario 1 with lower area for mangrove restoration results in much lower C sequestration of 0.8 million ton CO2eq/year by 2050.

Figure 58: Scenarios of C Sequestration - Mangrove Restoration - Colombia (2020-2050)



Source: Own elaboration

30 Described above in subsection Mangrove literature review for Colombia.

There is limited information on jobs created in mangrove restoration. A ratio of 50 direct jobs created in mangrove plantation per 1000 hectares restored was adopted, based on information published from a 2,100 ha mangrove restoration project in the Ayeyarwady Delta in Myanmar in which 100 planters were trained and employed (3 million trees were planted up to year 2018)[31].

The following table shows key metrics of impact analysis for Mangrove Restoration in Colombia. Contribution to GDP was estimated based on the investment in machinery and equipment required in the different mangrove restoration scenarios.

Table 45: Impact analysis of Mangrove restoration in Colombia

Scenario	Net changes in employment* per mangrove restored area ∆ # jobs / '000 ha	Contribution to GDP per mangrove restored area ∆ MM USD GDP / '000 ha	GHG emissions per mangrove restored area CO2 ton eq / year / '000 ha
1	*50 direct plantation*	*3.7*	*48,300*
2	*50 direct plantation*	*3.7*	*49,800*

** Direct jobs generated in mangrove restoration plantations. Jobs generated on other activities derived from mangrove ecosystem not included.*
*** Investment in Machinery and Equipment vs GDP*
Source: Own elaboration

Bioenergy with carbon capture and storage (BECCS)

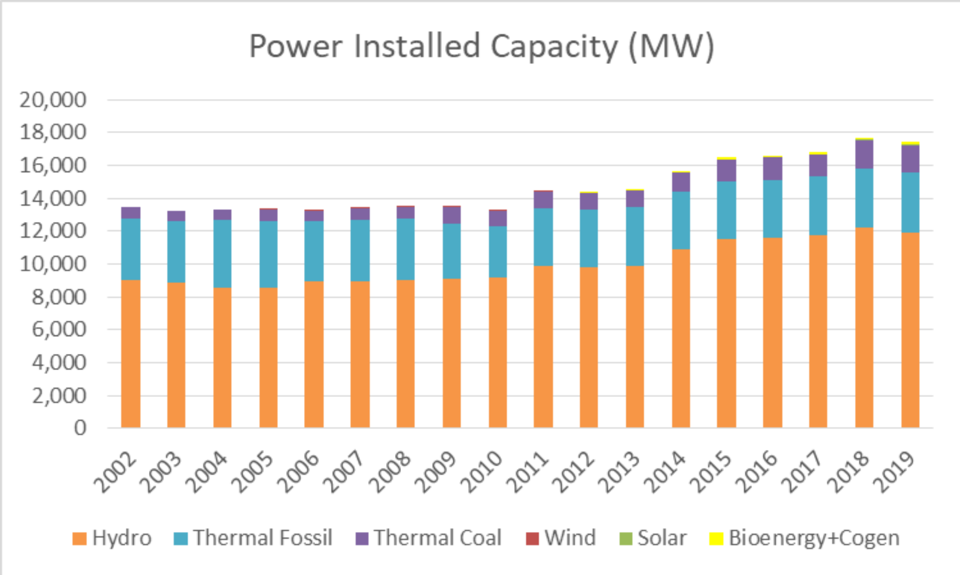
A) Status and trends of BECCS

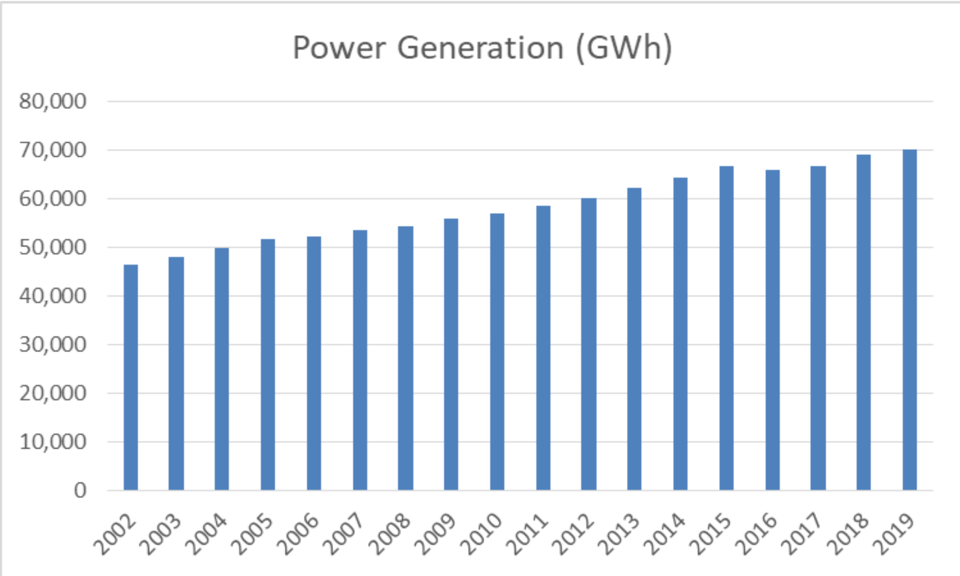
After a relatively slow growth rate during decade 2000-2010, Power Installed Capacity in Colombia grew to 17,467 MW in 2019 at a 3.1% annual growth rate (CAGR 2010-2019), led mainly by Hydro and Thermal Coal. Altough incipient, Bioenergy and Cogeneration summarized 145 MW of installed capacity by 2019.

Power Generation grew to 70,115 GWh in 2019 at a 1.7% annual growth rate (CAGR 2006-2019).

[31] Foundation myclimate, 2019. "Mangrove Restoration and Women Empowerment"

Figure 59: Historical Power Installed Capacity (MW) and Power Generation (GWh) in Colombia





Source: UPME

By year 2020, there were no CCS implemented projects on bioenergy installed capacity in Colombia nor planned projects to be developed.

UPME, in its Energy National Plan to 2050 issued in year 2015, already set some long-term targets for bioenergy (biomass):

- Regarding electricity generation, a shift from fossils to renewable sources is observed. Wind, solar and biomass are the ones with the highest growth rates. Wind energy increases its participation in the matrix from 5% to 26% in 2050. Solar energy goes from 1% to 9% and biomass from 4% to 8%

- In the most feasible scenario, it is considered that non-conventional sources of energy can account for 6% of the electric energy basket, which would correspond to an installed capacity of 1,207 MW in 2028. [..] it is considered possible the installation of 143 MW of solar energy, 275 of geothermal energy and 314 MW of cogeneration with biomass.

B) Impact assessment

Under the current study, three scenarios were elaborated:

- Baseline scenario, considering Plan Energético Nacional Colombia 2020- 2050 (UPME, 2019)
- Scenario 1: An enhanced biomass/biogas power generation scenario, with low CCS adoption
- Scenario 2: An enhanced biomass/biogas power generation scenario, with high CCS adoption

Table 46: Configuration of BECCS Scenarios for Colombia

		Baseline	Scenario 1	Scenario 2
2020-2030	*Renewables*	According to UPME expansion plan 2017-2031 (Scenario 2), with renewable power generation based on historic dispatch values and capacity factors, reaching 7.36% of the system power generation in 2030, excluding Hydro.	Consistent with the baseline scenario, but displacing an additional 1.48 percentage points of coal-fired power generation in 2030 with additional biomass power generation.	Consistent with the baseline scenario, but displacing an additional 1.89 percentage points of coal-fired power generation in 2030 with additional biomass power generation.
	BE	According to UPME expansion plan 2017-2031, with biomass power generation based on historic dispatch values and capacity factors. Biomass power generation Installed capacity reaches 257 MW in 2030.	Biomass power generation reaches 2.93% of the total system power generation in 2030, an increase of 102% vs. the baseline scenario. Biomass power generation Installed capacity reaches 519 MW in 2030.	Biomass power generation reaches 3.34% of the total system power generation in 2030 an increase of 131% vs. the baseline scenario. Biomass power generation Installed capacity reaches 592 MW in 2030.
	BECCS	No CCS installed capacity.	BECCS reach 3.2% of the bioenergy power generation in 2030.	BECCS reach 15.1% of the bioenergy power generation in 2030.
2031-2050	*Renewables*	In the consultants' baseline scenarios, renewable power	Consistent with the baseline scenario.	In the consultants' baseline scenarios, renewable power generation (excluding Hydro)

		generation (excluding Hydro) reaches 22.2% of the system generation by 2050, and 85.1% including Hydro.		reaches 48.2% of the system generation by 2050, displacing thermal conventional power plants vs. the baseline scenario.
	BE	Bioenergy represents 3.2% of the power generation.	Bioenergy represents 5.0% of the power generation.	Bioenergy represents 9.0% of the power generation.
	BECCS	No CCS installed capacity.	BECCS reach 7.3% of the bioenergy power generation in 2050.	BECCS reach 48.3% of the bioenergy power generation in 2050.

Source: Own elaboration partially based on UPME.

2020—2030

Baseline scenario

In the case of Colombia, the baseline scenario has been constructed based on the Reference Expansion Plan for Power Generation and Transmission 2017 – 2031 (UPME 2018). Electricity demand for this period has been computed according to the expansion plan adjusted by the 2020 values and represents a CAGR of 3.2% between 2020 and 2030.

Please note that the Expansion Plan for Colombia provides information for additional installed capacity, while it does not provide information regarding power generation, which has been estimated based on historic capacity factors for each technology.

Scenario 1

Scenario 1 considers that the electricity demand and power generation to 2030 is equivalent to the electricity demand in the baseline scenario, and that renewable power generation displaces additional 1.48 percentage points of coal-fired power generation in 2030, covered with additional biomass power generation. Renewables reach 8.9% of the systems power generation excluding Hydro in 2030, and 81.32% including Hydro.

Biomass power generation reaches 2.93% of the total system power generation in 2030, an increase of 102% vs. the baseline scenario, reaching 519 MW in 2030, and BECCS pilot projects are introduced, reaching 3.2% of the bioenergy power generation in 2030 (16.4 MW).

Scenario 2

Electricity demand and power generation are consistent with the baseline scenario, but displace an additional 1.89 percentage points of coal-fired power generation in 2030 with additional biomass power generation. Renewables reach 9.3% of the systems power generation excluding Hydro in 2030, and 81.7% including Hydro.

Biomass power generation reaches 3.3% of the total system power generation in 2030, an increase of 131% vs. the baseline scenario, reaching 592.5 MW in 2030, and BECCS penetration is faster than in Scenario 1, reaching 15.1% of the bioenergy power generation in 2030 (89.5 MW).

2031—2050

Baseline scenario

From the year 2032 onwards, the Colombian government does not provide official inputs for new power generation or capacity, other than information regarding primary energy sources in preliminary discussion documents such as the current consultation on the National Energy Plan 2020-2050. In this context, the consultants built a baseline scenario considering a deacceleration by the horizon of the scenario modelling (2050) of electricity demand consistent with an increased use of electricity in certain sectors but overtaken by a decoupling of GDP growth to energy consumption. In all the modelled scenarios for the purpose of this document, electricity demand grows at a CAGR of 1.9%.

In the baseline scenario, renewable power generation (excluding Hydro) reaches 22.2% of the power generation mix (Solar PV 10.9%, Wind power 8.2% and Biomass 3.2%), and when computing Hydro it reaches 85.1%, while Thermal Fossil power generation accounts for 14.9%, fueled by Natural Gas (8.0%) and Coal (6.9%). Bioenergy in the horizon of 2050 and represents 3.2% of the power generation, but does not include Carbon Capture Technologies (i.e., “there is BE but no BECCS”).

Scenario 1

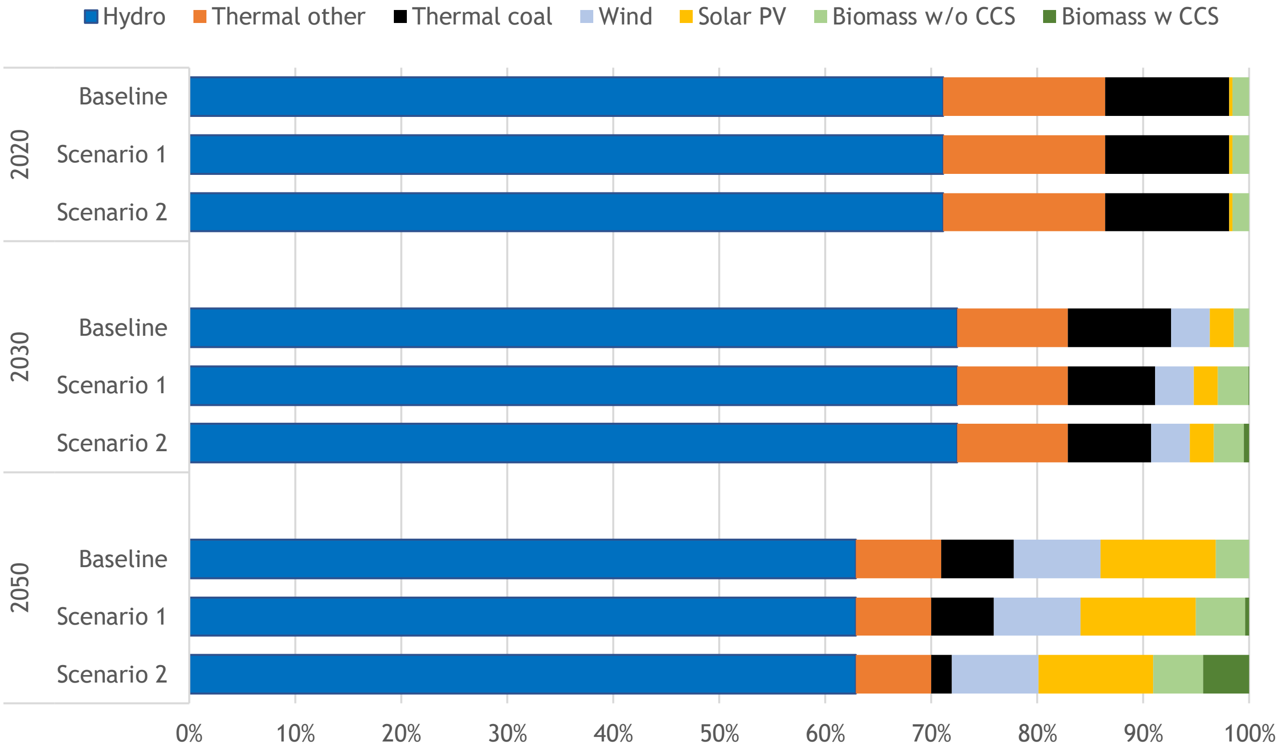
Scenario 1 represents a slightly larger ambition in terms of the penetration of renewables in Colombia’s power grid, reaching 24.1% of the system’s power generation (Solar PV 10.9%, Wind power 8.2% and Biomass 5.0%) excluding Hydro or 87% including Hydro, and introduces Carbon Capture and Storage technologies to 7.8% of the biomass-fired installed capacity.

Bioenergy installed capacity reaches 1,309 MW (biomass-fired power plants). BECCS power generation represents 7.3% of the total bioenergy power generation, or 0.37% of the system generation.

Scenario 2

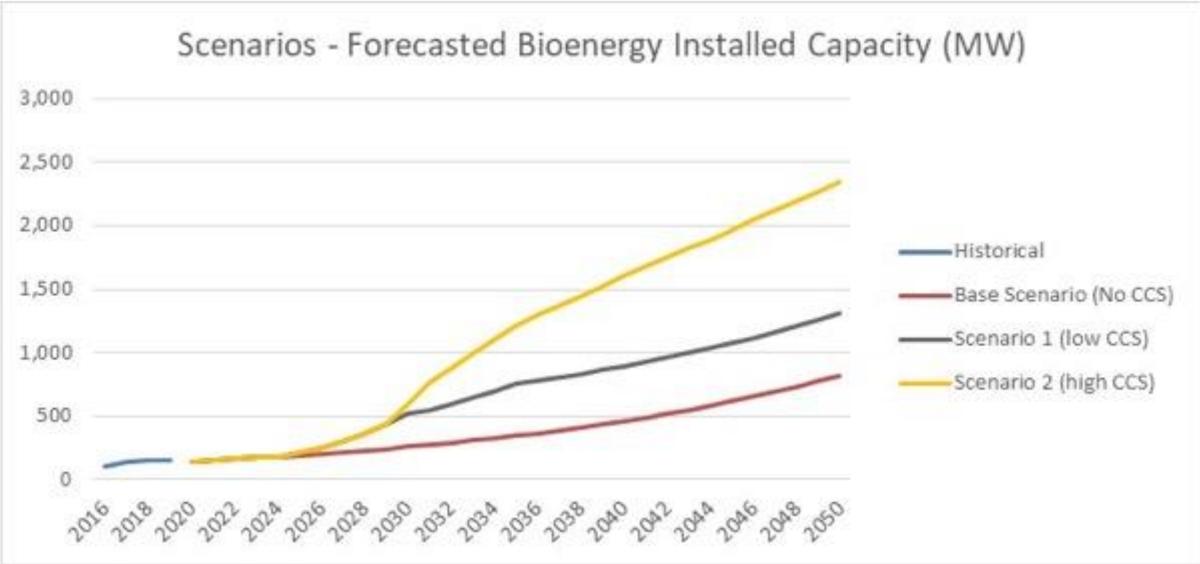
In the Scenario 2, from 2030 onwards, while the rest of renewable sources maintain their share of the system generation, Bioenergy displaces a larger share of coal-fired power generation, reaching 9.0% of the mix by 2050. Additionally, 48.3% of the Bioenergy generation features CCS technologies (biomass-fired power plants), associated to a BECCS installed capacity of 2,348 MW.

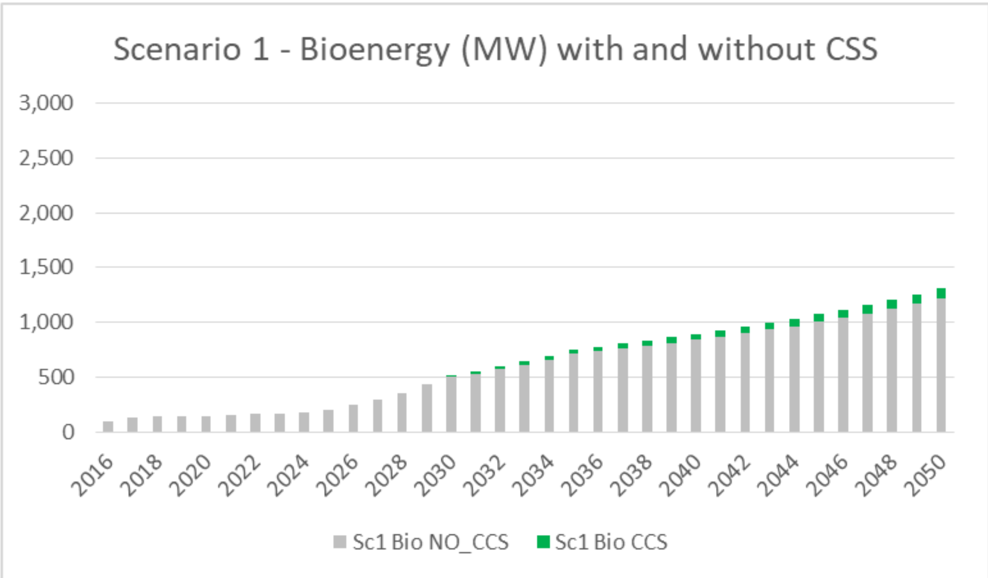
Figure 60: Power generation by source for 2020, 2030 and 2050 under the described scenarios. Colombia

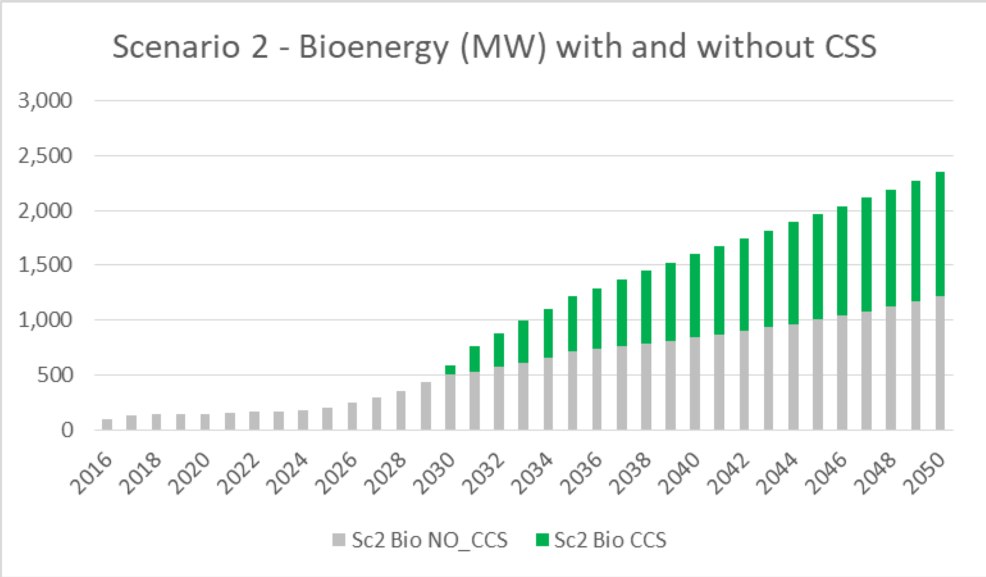


Source: Own elaboration partially based on UPME.

Figure 61: Scenarios of Bioenergy Installed Capacity in Colombia (2020-2050)







Source: Own elaboration

These estimates imply a 6.0%, 7.6% and 9.8% CAGR annual growth in bionergy installed capacity for Baseline Scenario, Scenario 1 and Scenario 2 respectively. Baseline Scenario does not consider CCS, meanwhile in Scenario 1 BECCS would achieve over 100 MW of capacity and in Scenario 2 that figure would increase to over 1100 MW.

Table 47: Comparison of growth rates by Scenario - Bioenergy Installed Capacity - Colombia

Period / Scenario	CAGR	Avg Variation (MW/y)
Historical 2015-2019	*11.7%*	*13*
Proj 2020-2050 -Base	*6.0%*	*23*
Proj 2020-2050 -Sc1	*7.6%*	*39*
Proj 2020-2050 -Sc2 Max	*9.8%*	*73*

Source: Own elaboration

The following table exhibits a summary of key BECCS scenario metrics for Colombia, regarding power generation, installed capacity and investment.

Table 48: Key BECCS scenario metrics for Colombia

			Baseline	Scenario 1	Scenario 2
Power generation (net)	TWh	2020	62.8	62.8	62.8
		2030	86.3	86.3	86.3
		2050	126.3	126.3	126.3
Non-fossil fueled power generation / total	%	2020	73.0%	73.0%	73.0%
		2030	79.8%	81.3%	81.7%
		2050	85.1%	87.0%	91.0%
BE power generation	TWh	2020	1.0	1.0	1.0
		2030	1.2	2.5	2.9
		2050	4.0	6.4	11.4
BE / power generation	%	2020	1.6%	1.6%	1.6%
		2030	1.4%	2.9%	3.3%
		2050	3.2%	5.0%	9.0%
BE / thermal power generation exc. Nuclear	%	2020	5.6%	5.6%	5.6%
		2030	6.7%	13.6%	15.5%
		2050	17.5%	27.9%	50.0%
BECCS/ BE Power generation	%	2020	0.0%	0.0%	0.0%
		2030	0.0%	3.2%	15.1%
		2050	0.0%	7.3%	48.3%
BE Installed capacity	MW	2020	143.5	143.5	143.5
		2030	256.6	519.4	592.5
		2050	821.3	1,309.0	2,348.2
BECCS Installed capacity	MW	2020	-	-	-
		2030	-	16.4	89.5
		2050	-	95.4	1,134.5
Investment in BE (no CCS)	MUSD/year	2020-2030	26.7 – 28.3	88.7 – 94.2	105.9 – 112.5
		2031-2050	70.1 – 74.5	98.0 – 104.1	341.9 – 360.4
Investment in BECCS (includes power plant)	MUSD/year	2020-2030	-	6.1 – 6.4	33.1 – 34.9
		2031-2050	-	15.4 – 16.2	203.5 – 214.5

Source: Own elaboration partially based on UPME.

For BECCS investment estimation the following assumptions were taken:

- BECCS: 3,700 to 3,900 USD/kWe (Adapted from Langholtz et al (2020) "The Economic Accessibility of CO2 Sequestration through Bioenergy with Carbon Capture and Storage (BECCS) in the US")

Scenarios 1 and 2 would totalize aproximately 360 and 4,300 million dollars cummulated investments respectively for the period 2020-2050.

Table 49: Investment by scenario for BECCS in Colombia

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
1	360	12
2	4,300	146

Source: Own elaboration

The following table in next page shows a summary of key scenario results for Colombia:

Table 50: Summary of key BECCS emission scenario results in Colombia

			Baseline			Scenario 1			Scenario 2		
BECCS capture rate Scenarios as % of C input:			*40*	*60*	*80*	*40*	*60*	*80*	*40*	*60*	*80*
Combustion Emissions in power generation	MtCO2e	2020		13.5			13.5			13.5	
		2030		19.5			18.9			18.7	
		2050		23.7			24.0			21.7	
Emissions intensity of combustion for power generation	tCO2e/ MWh	2020		0.216			0.216			0.216	
		2030		0.226			0.219			0.217	
		2050		0.188			0.190			0.172	
Carbon fixed in biomass feedstock used for power generation	MtCO2e	2020		(1.17)			(1.17)			(1.17)	
		2030		(1.46)			(2.95)			(3.36)	
		2050		(4.66)			(7.43)			(13.33)	
Other lifecycle emissions from transport and processing of feedstock and energy use	MtCO2e	2020		0.19			0.19			0.19	
		2030		0.23			0.47			0.54	
		2050		0.75			1.19			2.13	
Post-combustion capture	MtCO2e	2020	-	-	-	-	-	-	-	-	-
		2030	-	-	-	(0.04)	(0.06)	(0.07)	(0.20)	(0.30)	(0.41)
		2050	-	-	-	(0.22)	(0.32)	(0.43)	(2.58)	(3.86)	(5.15)
Net scenario emissions	MtCO2e	2020	12.56	12.56	12.56	12.56	12.56	12.56	12.56	12.56	12.56
		2030	18.25	18.25	18.25	16.39	16.37	16.35	15.72	15.61	15.51
		2050	19.82	19.82	19.82	17.51	17.40	17.29	7.93	6.64	5.36
Adjusted intensity for power generation	tCO2e/ MWh	2020	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
		2030	0.212	0.212	0.212	0.190	0.190	0.190	0.182	0.181	0.180
		2050	0.157	0.157	0.157	0.139	0.138	0.137	0.063	0.053	0.042
Avoided and captured emissions vs. baseline	MtCO2e	2020	-	-	-	-	-	-	-	-	-
		2030	-	-	-	(1.86)	(1.88)	(1.90)	(2.53)	(2.64)	(2.74)
		2050	-	-	-	(2.32)	(2.42)	(2.53)	(11.89)	(13.18)	(14.47)
Avoided and captured emissions vs. baseline	%	2020	0%	0%	0%	0%	0%	0%	0%	0%	0%
		2030	0%	0%	0%	-10%	-10%	-10%	-14%	-14%	-15%
		2050	0%	0%	0%	-12%	-12%	-13%	-60%	-66%	-73%

Source: Own elaboration

The penetration of BECCS in Colombia in the short-term is primarily conditioned by the strong relevance of hydropower in the power generation mix, highly sensitive to hydraulicity levels and requiring additional thermal installed capacity to cope with high and low water availability cycles, with coal presenting a relevant share (around 40% of thermal power generation, followed by natural gas, but varying according to hydraulicity levels and fuel availability).

In the long-term, the increasing share of non-dispatchable technologies (such as Solar PV and Wind Power) require additional thermal capacity until storage costs reach more competitive values, possibly promoting the competitiveness of Bioenergy and BECCS displacing coal-fired power plants.

Estimated full LCOE (considering CAPEX and O&M costs) for BECCS in Colombia ranges from 199.6 USD/MWh to 239.4USD/MWh vs. current average system costs around 68 USD/MWh and estimated at levels of 65 USD/MWh to 76 USD/MWh in 2050. (See Annex for further detail).

Towards the horizon of 2050, non-fossil power generation reaches 85.1% to 91.0% of the mix in the three analyzed scenarios. In this context:

- The short-term relevance of Bioenergy and BECCS in displacing coal for power generation is high, providing substantive emission reductions for the power sector.
- In consequence, although BECCS LCOE is considerably higher than the system cost and also than every other current alternative, the short-term Carbon Dioxide Avoidance and Removal cost of BECCS —computed as the difference between LCOEs over the difference between specific CO2 emissions/removals— is notably low when compared to the available literature, ranging from 50.2 USD/tCO2e to 92.7 USD/tCO2e (considering CAPEX and O&M costs).
- In the long-term, the cost of carbon dioxide avoidance and removal increases, due to a lowering denominator, which converges into the carbon capture component of BECCS, and reaches between 123 USD/tCO2e and 279 USD/tCO2e for the analyzed scenarios.
- However, as the potential of displacing fossil fuels decreases, CDR technologies in the power sector, such as BECCS, become some of the few available options to promote system-wide decarbonization.

Impact on Employment

According to official statistics from DANE in its Households Survey 2019, there were 56,309 registered jobs in the generation, transmission, distribution and commercialization private sector of Colombia. No historical data on evolution or breakdown by sub-sector was available.

A study from the Imperial College London from 2018 (Patrizio, et al 2018) on early deployment of BECCS in the US and replacing 50% of aging coal plants with natural gas plant, estimates that

1.9 permanent jobs per million dollars invested can be created in early deployment of BECCS[32]. By 2050, that ratio might decrease to 0.8 jobs / MMUSDA invested from deployment learning curve, economies of scale and larger operative efficiences are achieved.

Deployment of BECCS plant generates Operation and Manintenance direct jobs, but also jobs are created during the Construction phase (ex: 4,000 MW Drax BECCS project in UK would generate up to 17,000 jobs during its peak construction activity, equivalent to over 4 construction jobs / MW installed). Also, according to Patrizio et al, BECCS facilities generate additional indirect jobs in the forestry sector and connected to logistics activities (almost 1 to 1 ratio of additional jobs generated).

Under these assumptions BECCS deployment could generate nearly 1,300 permanent jobs by 2050 in Scenario 1, and over 16,000 permanent jobs by 2050 in Scenario 2. Construction of BECCS plants could generate an average of about 25 construction jobs per year in Scenario 1 and 300 jobs/year in Scenario 2 (over the 2030-2050 period).

The following table shows key metrics of impact analysis for BECCS deployment in Colombia. Contribution to GDP was estimated based on the investment in production equipment required in the different BECCS deployment scenarios.

Table 51: Impact analysis of BE/BECCS deployment in Colombia

Scenario	Net changes in employment* per BE/BECCS installed capacity ∆ # jobs / MW	Contribution to GDP** per BE/BECCS energy generation ∆ MM USD GDP / TWh	Emissions Removal for BECCSpower generation tCO2e/ MWh
1 *BE+BECCS*	1.2 permanent 4 construction	25	1.3 (average 2020-2050)
2 *BE+BECCS*	7.4 permanent 4 construction	165	1.3 (average 2020-2050)

** Not considering jobs lost in other sources of energy outplaced*
*** Investment in Durable Production Equipment vs GDP*
Source: Own elaboration

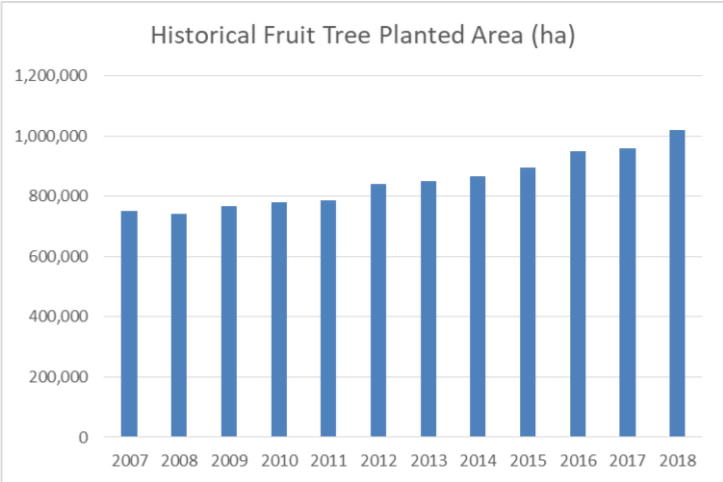
[32] Patrizio, et al (2018). "Reducing US Coal Emissions Can Boost Employment". Joule. 2. 10.1016/j.joule.2018.10.004.

Enhancing soil carbon content with biochar

A) Status and trends of Biochar

In Colombia there were in 2018 over 1 million hectares planted with fruit tree, out of which 50% correspond to plantains. The historical annual growth rate is 2.8% (CAGR 2007-2018).

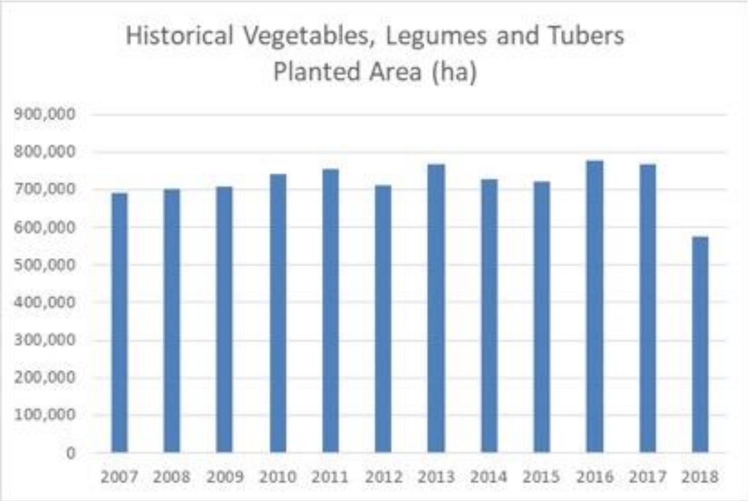
Figure 62: Historical Fruit Tree Planted Area in Colombia



Source: Evaluaciones Agropecuarias Municipales EVA 2007-2018 from MADR

Regarding Vegetables, Legumes and Tubers, there were in 2018 over 0.6 million hectares planted in Colombia. Yucca, potatoes and beans are the most relevant crops. The historical annual growth rate was 0.5% (CAGR 2007-2017). However, in 2018, a sharp 25% decrease in planted area was reported according to MADR.

Figure 63: Historical Vegetables, Legumes and Tubers Planted Area in Colombia



Source: Evaluaciones Agropecuarias Municipales EVA 2007-2018 from MADR

As for 2020, there is no large-scale biochar project implemented nor planned to be developed in Colombia.

B) Impact assessment

For the purpose of this study the fruit tree area will be considered for potential large-scale biochar deployment.

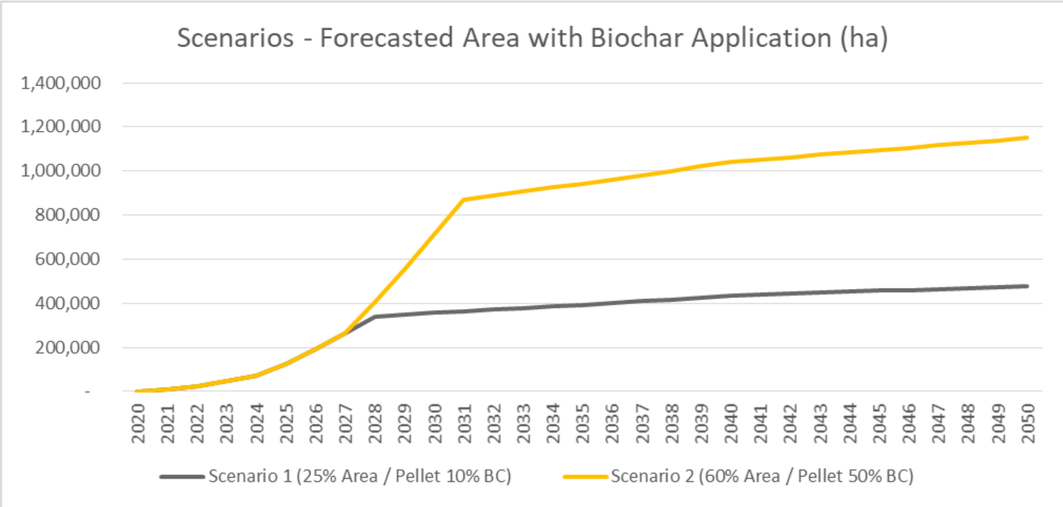
Under the current study, three scenarios were elaborated:

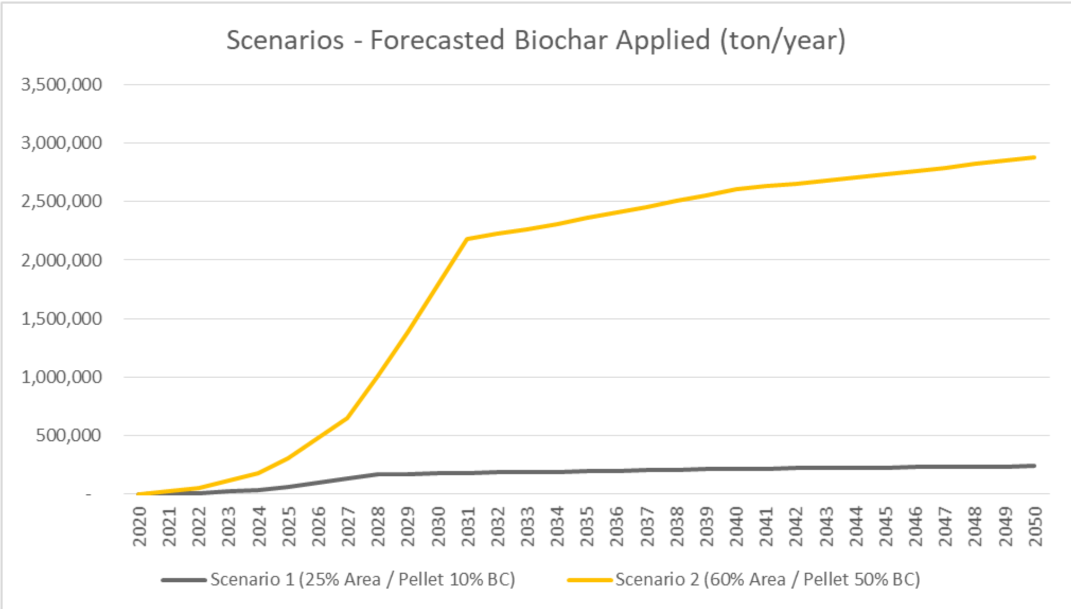
- Baseline Scenario: No biochar (business as usual)
- Scenario 1: Biochar application on up to 25% of fruit tree planted area with pellets of 10% biochar mix
- Scenario 2: Biochar application on up to 60% of fruit tree planted area with pellets of 50% biochar mix

The fruit tree planted area was forecasted to grow at its historical 2.8% (CAGR 2007-2018) over the period 2020-2030, then decreasing it pace to 2.0% annual for the period 2031-2040 and 1.0% annual for the period 2041-2050.

Considering the aforementioned assumption on the percentage of the fruit tree planted area with biochar application of up to 25% and up to 60% in the Scenario 1 and Scenario respectively, the following figure exhibits that estimated area for biochar application for the period 2020-2050 in Colombia. An assumption of 5 ton per ha per year dose of organic-mineral fertilizers in the form of pellets was taken. In Scenario 1 those pellets present a 10% biochar mix while in Scenario 2 the mix increases to 50% biochar. The change in the slope of the area with biochar application, reflects both the fruit tree planted area assumptions over time and the curve of adoption of biochar within that area over time.

Figure 64: Scenarios of forecasted Biochar application area in Colombia (2020-2050)





Source: Own elaboration

The production of Biochar is made from biomass by pyrolysis which is an exothermic process. The energy released can be partially used (aproximately 30% of the total energy) in the processing plant or nearby facilities. This production characteristic makes it attractive to be installed in industrial parks where energy use is more demanded. The production of a ton of Biochar, from 4 ton of dry base biomass, allows generation of about 5 MW of energy.

The estimated investment to produce biochar for agricultural purposes varies depending on the type and quality of biochar to be produced. For example, “pure” biochar, or in combination with composting of organic waste, also know as “organic-mineral” fertilizers (with a certain mix of biochar). The installation of a 1,000 ton/year biochar production plant requires an approximate investment (CAPEX) of 600,000 USD. If the objective is to produce an organic-mineral pellet from biochar and compost, an additional investment of 400,000 USD is required for composting and pelleting processes, therefore totalizing 1,000,000 USD per 1,000 ton/year facility[33]. A curve with efficiences in investment over time for scenarios 1 and 2 was assumpted due to sinergies of increased activity, technology maturity and development of the value chain. Scenarios 1 and 2 would add aproximately 215 and 1,700 million dollars investments respectively for the period 2020-2050.

Table 52: Investment by scenario for Biochar in Colombia

Scenario	Total Investment 2020-2050 MM USD	Average Annual Investment MM USD / year
1	*216*	*7*
2	1,700	*58*

Source: Own elaboration

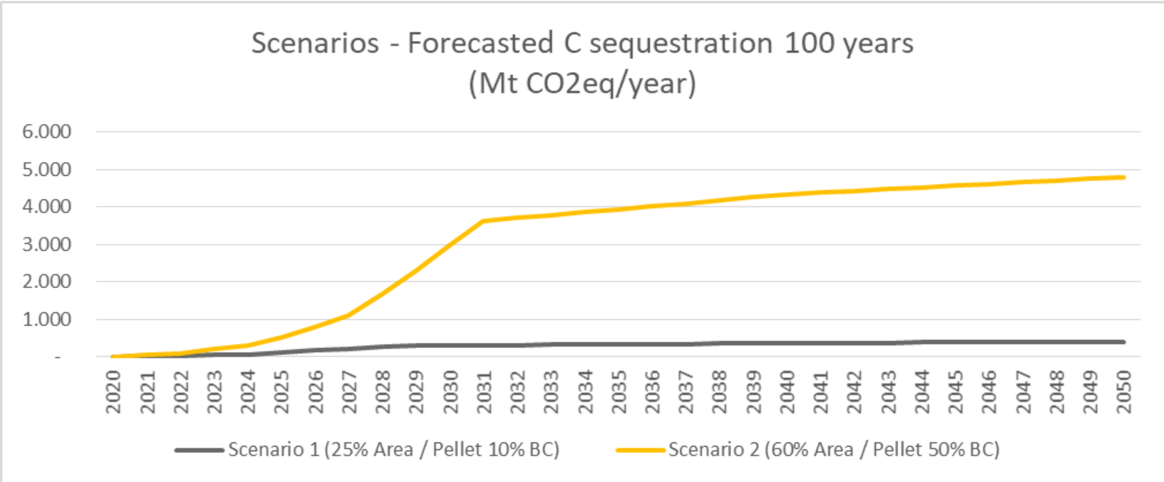
Regarding employment, it is estimated that a 1,000 ton per year biochar plant would generate 4 direct jobs, resulting in approximate 1,000 jobs by year 2050 in Scenario 1 (equivalent to 2 directs jobs per thousand hectares of biochar application) and over 11,000 jobs by 2050 in Scenario 2 (equivalent to 10 directs jobs per thousand hectares of biochar application)[34]. Jobs generated during biochar application on plantations could not be quantified due to lack of information.

Although the “organic-mineral” fertilizer is mostly composed of carbon (from compost and biochar), only a fraction of the Carbon contained in the biochar is considered as “sequestration”. The Fraction considered as sequestration is defined by IPCC (2019) on its equation 4A.1 and depends on two factors: the C content of the biochar (Fcp) and and the fraction of Biochar that remains in the soil after 100 years (Fpermp). Therefore, the increase in soil carbon results from multiplying the incorporated mass of Biochar by the C content and the permanence factor. The latter depends on the temperature at which the Biochar was produced. The lowest temperature of the pyrolysis process is 350 to 450 degrees Celsius and would correspond to the lowest quality Biochar, whose permanence fraction is 0.65 (Table 4Ap.2, IPCC, 2019). In the current study, the values adopted for factors Fcp and Fpermp were 0.7 and 0.65, respectively.

[33] Biochar plant CAPEX assumptions from interviews with sectorial experts and industry players
[34] Biochar plant employment generation assumptions from interviews with sectorial experts and industry players

The applied methodology for Colombia results on nearly 5 million tons of CO2 equivalent per year sequestrated for 100 years in Scenario 2 by 2050. Meanwhile Scenario 1 with lower area for biochar application and lower biochar mix in pellet results in much lower C sequestration of 0.4 MM ton CO2eq/year by 2050.

Figure 65: Scenarios of C Sequestration - Biochar (2020-2050)



Source: Own elaboration

The following table shows key metrics of impact analysis for Biochar deployment in Colombia. Contribution to GDP was estimated based on the investment in machinery and equipment required in the different biochar application scenarios.

Table 53: Impact analysis of Biochar deployment in Colombia

Scenario	Net changes in employment* per biochar applied area ∆ # jobs / '000 ha	Contribution to GDP per biochar applied area ∆ MM USD GDP / '000 ha	GHG emissions*** per biochar applied area CO2 ton eq / year / '000 ha
1	*+2 industrial*	*+0.13*	*835*
2	*+6 industrial*	*+0.48*	*4,200*

** Direct jobs generated in biochar plan. Jobs generated during biochar application on plantations could not be quantified due to lack of information.*
*** Investment in Machinery and Equipment vs GDP*
**** C sequestration 100 years (65% Fperm; Biochar with 70% C)*
Source: Own elaboration

4. Potential Impacts in LAC countries

The following tables summarize the key potential constrains, positive and negative impacts identified for CDR large-scale deployment in LAC countries.

Afforestation and reforestation

Table 54: Key potential impacts of Afforestation in LAC countries

Key constraints	• Land competition with other purposes (ex: crop planted area for food production) • Water and nutrients requirements • Lack of financing for long-term investments • Development of the value chain downstream: wood manufacturing and pulp and paper industry are CAPEX intensive activities
Key positive impacts	• Proven and known technology / practices (for implantation and maintenance), and know how developed along the years in the country makes it feasible with higher probability than other undeveloped CDR approaches, that will be extended in the following years • Women are critical to ensuring the sustainability of forests and forestry (full contributions of women to forestry have not been realized yet) • Reduction of poverty levels due to job creation, economic development, land health improvement • Economic development and growth • Direct and indirects jobs for forestry and wood extraction • Potential direct and indirect jobs in wood manufacturing and pulp and paper industries • Potential development of wood related industries: construction and furniture (value-added products and responsible production and consumption) • Affordable and clean energy provision taking advantage of forestry residues
Key negative impacts and risks	• Impacts on food supply and land tenure • Bioversity (depending on the species to be planted) • NOX emissions from nitrogen fertilizers • Changes in evapotranspiration, albedo and cloud cover • Water scarcity

Source: Own elaboration; Vivid Economics 2020 "An investor guide to negative emission technologies and the importance of land use"

Bioenergy with carbon capture and storage (BECCS)

Table 55: Key potential impacts of BECCS in LAC countries

Key constraints	• Land availability/ competition • Biomass feedstock availability • CO_2 storage availability (technical feasibility) and CO_2 storage infrastructure investment (economic feasibility) • CO_2 transportation infrastructure • Poor knowledge and development of CCS phase (and therefore related technological challenges)
Key positive impacts	• Clean energy supply that increases power autonomy and security in the energy supply • Direct and permanent jobs generated in BECCS plants operation. • Jobs created for BECCS plants constructions and Indirects jobs related • Health improvement related to clean energy and forestry requirements • Know how and technical capabilities to be developed • Potential development of related industries
Key negative impacts and risks	• Supply chain and land-use change (LUC) emissions • Water scarcity • Soil depletion • Pollution due to fertiliser use • Risk of CO_2 leaks during transportation and/or storage • Impacts on food supply and land tenure • In case of wood biomass, lost C sequestration of harvested forest • Impact on country's power generation cost curve (in case of large-scale adoption and significant share in the power generation matrix due to higher costs per MWh than other sources - ex: hydro-)

Source: Own elaboration; Vivid Economics 2020 "An investor guide to negative emission technologies and the importance of land use"

Enhancing soil carbon content with biochar

Table 56: Key potential impacts of Biochar in LAC countries

Key constraints	• Availability of biomass for biochar production (competition with other uses of biomass) • Logistic constrains: Trade-off distance from raw material (biomass) vs distance to plantations where to be applied • Technological challenges for the development, construction and operation of biochar plants in Argentina • Lack of long-term financing alternatives for biochar plant CAPEX
Key positive impacts	• Enhanced soil properties and therefore increasing yields (responsible production and consumption). Potential increase in fruit tree yields (to be confirmed by further research), expanding food supply • Technological know how for the development, construction and operation of biochar plants • Long-term C sequestration in soil • Lower N2O and CH4 emmisions • Higher soil water balance's • Potential expansion for biochar application on other crops beyond intensive crops as fruit trees (ex: vegetables, legumes and tubers) • Biochar pyrolysis is an exotermic process which can be utilized for power generation • Other valuable co-products including wood flavoring and adhesives can also be obtained as a byproduct of biochar (Czernik and Bridgwater, 2004) • Direct and permanent jobs generated in biochar plants operation. • Jobs created for biochar plants constructions. • Jobs created for biochar application in plantations. Indirects jobs related
Key negative impacts and risks	• Logistics costs and environmental impacts of raw material and biochar transportation • Lower albedo and radiative forcing

Source: Own elaboration; Vivid Economics 2020 "An investor guide to negative emission technologies and the importance of land use"

5. Limitations of the analysis

The impact analysis face certain challenges that might impact in terms of its accuracy and certainty:

- Large-scale CDR deployments are a novel field of research and project implementation in Argentina, Colombia and the other Latin America countries (and, to certain extent, globally)
- Despite some knowledge gained in the technical aspects of CDR approaches, the understanding of their large-scale deployment impacts in the economy and at the societal level is at least scarce; moreover, the quantification of the magnitude of those impacts is still largely incipient.
- Impact analysis is estimated based on
  - historical statistics with their level of accuracy depending on data collection (not always on an annual basis) and levels of informality in the Argentine and Colombian economies
  - long-term scenario definitions that inherently present uncertainties
- Over the long-term, new breakthrough technologies not yet fully developed today would significantly impact scenarios conceived for this study
- Investment and operating costs may see significant decreases, as each technology is massively deployed
- Comparison between countries can be affected by differences in statistical bases
- Accurate assessment of relative risk in between different technologies is not yet possible but should also be weighed against the risks that alternative options, including following current trajectories, would pose to successful SDG delivery.
- The relative level of potential effects identified may also be a function of the current quantity or level of maturity of the literature available, plans and projects assessed throughout the report.
- There are large uncertainties resulting from incomplete knowledge, from the complexity of the ecosystems involved and due to interactions in between different combinations of options implemented.

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Research projects

- *Hydrological impacts of solar radiation management in the La Plata Basin in South America. Argentina. SRMGI*

Annex: BECCS - Cost estimation

Bioenergy with carbon capture and storage (BECCS) - Cost Estimation – Argentina

The full LCOE (considering CAPEX and O&M costs) for BECCS in Argentina has been estimated based on the following parameters:

Table 57: Key BECCS LCOE calculation inputs and results for Argentina

	Unit	Value
CAPEX	USD/kW	4,100—4,400
Fixed O&M	USD/kWe/y	95.8
Variable O&M	USD/MWh	90.6
Fuel costs	USD/MWhe	0—35
Discount rate	%	10%
Capacity Factor	%	34%
Power Generation efficiency	kJe/ kJfuel	32%
Fuel		Bagasse
LCOE	USD/MWh	283.3—330.3

Source: Own elaboration partially based on Secretariat of Energy and Langholtz 2020.

A preliminary estimation of CO2 avoidance full LCOE cost associated with BECCS deployment In Argentina was performed.

Table 58: Summary of Carbon Avoidance Costs associated with BECCS in Argentina - Full LCOE

		MIN			MAX		
		40	60	80	40	60	80
Short-run							
LCOE BECCS	USD/MWh	283.3	283.3	283.3	330.0	330.0	330.0
LCOE Natural gas combined cycle	USD/MWh	69.1	69.1	69.1	69.1	69.1	69.1
BECCS emissions	tCO_2e/MWh	(0.28)	(0.42)	(0.56)	(0.3)	(0.4)	(0.6)
Gas-fired plant emissions (cc)	tCO_2e/MWh	0.4	0.4	0.4	0.4	0.4	0.4
CAC USD/tCO_2e	**USD/tCO_2e**	**305.0**	**254.0**	**217.7**	**371.6**	**309.5**	**265.2**
Long-run							
LCOE BECCS	USD/MWh	283.3	283.3	283.3	330.0	330.0	330.0
LCOE System	USD/MWh	60.7	60.7	60.7	60.7	60.7	60.7
BECCS emissions	tCO_2e/MWh	(0.3)	(0.4)	(0.6)	(0.3)	(0.4)	(0.6)
Reference baseline system emissions	tCO_2e/MWh	0.1	0.1	0.1	0.1	0.1	0.1
CAC USD/tCO_2e	**USD/tCO_2e**	**615.9**	**443.1**	**346.0**	**745.3**	**536.2**	**418.7**

Source: Own elaboration partially based on Secretariat of Energy and Langholtz 2020.

Also a preliminary estimation of CO2 avoidance only considering CAPEX was performed.

Table 59: Summary of Carbon Avoidance Costs associated with BECCS in Argentina - Only CAPEX LCOE

		40	60	80
LCOE BECCS (only CAPEX)	USD/MWh		161 to 173	
Emissions BECCS	tCO2e/MWh	(0.28)	(0.42)	(0.56)
Emissions ref first 15 years	tCO2e/MWh	0.42	0.42	0.42
Emissions ref following 15 years	tCO2e/MWh	0.08	0.08	0.08
Removal first 15 years	tCO2e/MWh	(0.70)	(0.84)	(0.98)
Removal following 15 years	tCO2e/MWh	(0.36)	(0.50)	(0.64)
Reducción promedio	tCO2e/MWh	(0.53)	(0.67)	(0.81)
CAC USD/tCO_2e MIN	**USD/tCO_2e**	302.3	239.0	197.6
CAC USD/tCO_2e MAX	**USD/tCO_2e**	324.4	256.5	212.1
CAC USD/tCO_2e Avg	**USD/tCO_2e**	313.4	247.7	204.8

Source: Own elaboration partially based on Secretariat of Energy and Langholtz 2020.

Bioenergy with carbon capture and storage (BECCS) - Cost Estimation - Colombia

The full LCOE (considering CAPEX and O&M costs) for BECCS in Colombia has been estimated based on the following parameters:

Table 60: Key BECCS LCOE calculation inputs and results for Colombia

	Unit	Value
CAPEX	USD/kW	3,700—3,900
Fixed O&M	USD/kWe/y	95.8
Variable O&M	USD/MWh	90.6
Fuel costs	USD/MWhe	0—35
Discount rate	%	10%
Capacity Factor	%	56%
Power Generation efficiency	kJe/ kJfuel	30%
Fuel		Bagasse
LCOE	**USD/MWh**	**199.6—239.4**

Source: Own elaboration partially based on UPME and Langholtz 2020.

A preliminary estimation of CO2 avoidance full LCOE cost associated with BECCS deployment in Colombia was performed.

Table 61: Summary of Carbon Avoidance Costs associated with BECCS in Colombia - Full LCOE

			MIN			MAX	
		40	60	80	40	60	80
Short-run							
LCOE BECCS	USD/MWh	199.6	199.6	199.6	239.4	239.4	239.4
LCOE Coal Steam Turbine	USD/MWh	101.2	101.2	101.2	101.2	101.2	101.2
BECCS emissions	tCO_2e/MWh	(0.5)	(0.7)	(0.9)	(0.5)	(0.7)	(0.9)
Coal-fired plant emissions (gt)	tCO_2e/MWh	1.0	1.0	1.0	1.0	1.0	1.0
CAC USD/tCO_2e	**USD/tCO_2e**	**66.0**	**57.0**	**50.2**	**92.7**	**80.1**	**70.6**
Long-run							
LCOE BECCS	USD/MWh	199.6	199.6	199.6	239.4	239.4	239.4
LCOE System	USD/MWh	65.0	65.0	65.0	65.0	65.0	65.0
BECCS emissions	tCO_2e/MWh	(0.5)	(0.7)	(0.9)	(0.5)	(0.7)	(0.9)
Reference baseline system emissions	tCO_2e/MWh	0.2	0.2	0.2	0.2	0.2	0.2
CAC USD/tCO_2e	**USD/tCO_2e**	**215.78**	**157.02**	**123.42**	**279.63**	**203.49**	**159.94**

Source: Own elaboration partially based on UPME and Langholtz 2020.

Also a preliminary estimation of CO2 avoidance only considering CAPEX was performed.

Table 62: Summary of Carbon Avoidance Costs associated with BECCS in Colombia - Only CAPEX LCOE

		40	60	80
LCOE BECCS (only CAPEX)	USD/MWh		89 to 94	
Emissions BECCS	tCO2e/MWh	(0.47)	(0.70)	(0.93)
Emissions ref first 15 years	tCO2e/MWh	1.03	1.03	1.03
Emissions ref following 15 years	tCO2e/MWh	0.16	0.16	0.16
Removal first 15 years	tCO2e/MWh	(1.49)	(1.73)	(1.96)
Removal following 15 years	tCO2e/MWh	(0.62)	(0.86)	(1.09)
Reducción promedio	tCO2e/MWh	(1.06)	(1.29)	(1.52)
CAC USD/tCO_2e MIN	**USD/tCO_2e**	84.5	69.2	58.6
CAC USD/tCO_2e MAX	**USD/tCO_2e**	89.0	72.9	61.8
CAC USD/tCO_2e Avg	**USD/tCO_2e**	86.8	71.1	60.2

Source: Own elaboration partially based on Secretariat of Energy and Langholtz 2020.