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Trabajo Fin de Grado

Negative Emission Technologies Implementation in Spain to achieve CO_2 Neutrality by 2050

(Implementación de Tecnologías de Emisiones Negativas en España para alcanzar la Neutralidad en CO_2 para 2050)

Para acceder al Título de

Graduado/a en Ingeniería Química

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Definitions and Abbreviations

AR: Afforestation & Reforestation

BC: Biochar

BECCS: Bioenergy with Carbon Capture & Storage

CDRs : Carbon dioxide removal technologies

CO_2 : Carbon Dioxide

DAC: Direct Air Capture

EU: Europe Union

EW: Enhanced Weathering

FAO: Food and Agriculture Organization of the United Nations

GHG: Greenhouse Gases

INECP: Integrated National Energy and Climate Plan

LULUCF: Land Use, Land-Use Change and Forestry

NETs: Negative Emission Technologies

OF: Ocean Fertilisation

SCS: Soil Carbon Sequestration

REE: Red Eléctrica Española

Agroforestry:

“Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. Agroforestry can also be defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.” [FAO, 2015]

Carbon footprint:

“Sum of GHG emissions and GHG removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change.” [ISO, 2018]

Climate Change:

“Climate change is a change in the usual weather found in a place. This could be a change in how much rain a place usually gets in a year. Or it could be a change in a place's usual temperature for a month or season.

Climate change is also a change in Earth's climate. This could be a change in Earth's usual temperature. Or it could be a change in where rain and snow usually fall on Earth” [Stillmand & Green, 2014]

Environmentally friendly:

“It means earth-friendly or not harmful to the environment. Eco-friendly products also prevent contributions to air, water and land pollution.” [Holzer, 2018]

Green Energy:

“Energy that comes from natural sources such as sunlight, wind, rain, tides, plants, algae and geothermal heat. These energy resources are renewable, meaning they're naturally replenished.” [Rogers, 2012]

Grey Energy

“Grey energy is another word for polluting energy or non-renewable energy. In generating grey energy, fossil fuels are used such as coal or gas.” [MAVITEC Green Energy, 2019]

1. Introduction

For centuries, fossil fuel dependence has resulted in considerable emissions of CO_2 to the atmosphere and hence numerous effects to the planet, encompassed in the Climate Change term. To avoid climate change from becoming irreversible, greenhouse gas (GHG) emissions must cease. These gases are the reason why the heat of the sun is not released back into the space and, therefore, the global temperature is rising.

Environmental policies and ambitious goals for GHG emissions reduction have been established as the recent Paris Agreement that committed the world to limit Global Warming. Its main goal is to keep the average global temperature rise below 2ºC. Moreover, it aims to limit the increase to 1,5°C, since this would significantly reduce risks and the impacts of climate change. In order to achieve this goal, GHG emissions have to be reduced by at least 40% by 2030 compared to 1990, and by 95% by 2050 [European Commission, 2015]. To provide a coordinated international response to the climate change challenge the European Union (EU) mandated to each of its member states to develop an Energy and Climate Plan.

The main body of this report can be divided into six chapters. The first one is the introduction, which includes this brief information about the report structure and also an explanation of the National Clime and Energy Integration Plan for 2030 that will state the current status of the energy consumption in Spain and describe how some Negative Emission Technologies (NETs) work and how they could be implemented. In the second chapter, Objectives, it is described what is expected to achieve with this report. In chapter three, Methodology, it is explained the method used to obtain the results, which in this case is a box model with mass and energy balances.

The fourth chapter, called Results, includes different scenarios for CO_2 removal and costs for two years, 2030 and 2050. Furthermore, they include an extensive analysis about possible solutions to improve the situation.

The fifth chapter contains the conclusion of the whole report. In chapter sixth all the bibliography is listed. After the main body the Appendices can be found.

1.1 Integrated National Energy and Climate Plan for 2030

The Integrated National Energy and Climate (INECP) Plan is a ten-year integrated document mandated by the European Union to each of its member states in order for the EU to meet its overall Paris Agreement requirements to provide a coordinated international response to the climate change challenge [European Commission, 2018]. The Energy and Climate Plan addresses all five dimensions of the EU Energy Union: decarbonisation, energy efficiency, energy security, internal energy markets and research, innovation, and competitiveness. [Climate Change Laws of the World, 2020]

This Plan is considered to be a key element for Spain to adequately and responsibly fulfil the requirements arising from the Paris Agreement. The measures provided for in the INECP will allow the following results to be achieved in 2030 in Spain:

- 23% reduction in greenhouse gas (GHG) emissions compared to 1990.
- 42% share of renewables in energy end-use.
- 39,5% improvement in energy efficiency.
- 74% share of renewable energy in electricity generation. [INECP, 2020]

These results will enable progress to be made towards the longer-term objectives in the five dimensions:

1) to become a carbon-neutral country by 2050 by decreasing the gross total GHG emissions in the electricity, transport, and industry sectors.

2) to promote energy efficiency thanks to renewable energy in the final energy consumption, efficiency measures for the transport, industry and building sectors, and energy saving targets.

3) to ensure energy security by the diversification of the national energy mix, the use of indigenous sources and increase the flexibility of the national energy system.

4) interconnectivity, energy transmission infrastructure, and integration of the internal energy market.

5) to strengthen technology transfers, promote public-private partnership and business research and innovation, etc. [Climate Change Laws of the World, 2020]

Spain's INECP 2021-2030 is aimed at making progress with decarbonisation, especially of the energy system, since three out of every four tonnes of GHG gases originates in this system. In addition, the INECP is accompanied by the Just Transition Strategy [MITECO, 2019]: it will be essential to ensure continuous coordination between the General State Administration and the autonomous communities, as well as the active involvement of the autonomous communities, in order to ensure that the objectives of this Plan are achieved.

The implementation of this Plan will shift the energy system significantly towards greater self-sufficiency, based on efficiently exploiting existing renewable potential in our country, particularly solar and wind energy. This transformation will have a positive impact on national energy security by significantly reducing dependence on fossil fuel imports, which comes at a high economic cost and is subject to geopolitical factors and high price volatility.

In addition, because of the implementation of the Plan, in 2030 it is expected to have achieved a 42% share of energy end-use from renewables, due to the planned investment in renewable electric and thermal energy sources. This also includes a significant reduction in final energy consumption as a result of savings and efficiency programmes and measures in all sectors of the economy. [INECP, 2020]

Decarbonisation of the economy and progress in renewable energy

The long-term goal is to make Spain carbon neutral by 2050. To that end, the medium-term objective is to achieve a reduction in emissions of at least 20% in 2030 compared to 1990. According to the forecast made in the Plan, the measures that it includes will achieve a 23% reduction in emissions.

The path established for the achievement of the objectives set for 2030 is based on the principles of technological neutrality and cost efficiency. Although the energy system decarbonisation is the cornerstone on which the energy transition is based, the INECP also devotes a great deal of attention to measures to reduce GHG emissions in other sectors.

The sectors that will reduce their emissions the most in this period (2021-2030) are electricity generation and mobility and transport. The residential, commercial and institutional sector as well as industry (combustion) will also decrease their emissions. These sectors considered together represent 83% of the emission reductions in the 2021-2030 period.

1.1.1 Actual and Future Energy Consumption

The current distribution amongst renewable technologies each year between 2021 and 2030 will depend, in any case, on changes in their relative costs, as well as on the viability and flexibility of their implementation. Consequently, their relative weight may vary, within certain margins, with respect to Table 1 and Table 2 presented below.

Therefore, the Plan's forecasts regarding the decarbonisation of the electricity sector are that, as a consequence of the application of European Union market instruments, coal plants will cease to provide energy to the system by 2030 at the latest, since they will find it difficult to remain competitive due to high prices.

Renewable electricity generation in 2030 will represent 74% of the total value, consistent with a path towards a 100% renewable electricity sector in 2050. The Plan presents the reports that contain generation dispatch simulations carried out by Red Eléctrica de España (REE), both for the Baseline Scenario (Table 1) and for the Target Scenario (Table 2).

Table 1. Gross Electricity generation in the Baseline Scenario.

Gross Electricity generation in the Baseline Scenario (GWh)				
Years	**2015**	**2020**	**2025**	**2030**
Wind (onshore and offshore)	49325	60022	71522	83022
Solar photovoltaic	8302	16034	25032	34030
Solar thermoelectric	5557	5608	5608	5608
Hydroelectric power	28140	28288	27935	27581
Pumping	3228	4640	4640	4640
Biogas	743	813	829	1024
Geothermal energy		0	0	0
Marine energy		0	0	0
Coal	52281	32826	12549	10189
Combined Cycle	28187	31000	44133	51289
Coal cogeneration	395	78	0	0
Gas cogeneration	24311	22382	19148	9905
Petroleum products cogeneration	3458	2463	1767	982
Other	216	2563	2024	1838
Fuel and Fuel/Gas (NPT)	13783	10141	10141	10141
Renewables cogeneration	1127	988	1060	1151
Biomass	3126	4757	4750	4713
Cogeneration with waste	192	160	122	84
Municipal solid waste	1344	918	799	355
Nuclear	57196	58039	58039	58039
Total	280911	281720	290097	304593

Table 2. Gross Electricity generation in the Target Scenario.

Gross Electricity generation in the Target Scenario (GWh)				
Years	2015	2020	2025	2030
Wind (onshore and offshore)	49325	60670	92926	119520
Solar photovoltaic	8302	16304	39055	70491
Solar thermoelectric	5557	5608	14322	23170
Hydroelectric power	28140	28288	28323	28351
Pumping	3228	4594	5888	11960
Biogas	743	813	1009	1204
Geothermal energy		0	0	0
Marine energy		0	0	0
Coal	52281	33160	7777	0
Combined Cycle	28187	29291	23284	32725
Coal cogeneration	395	78	0	0
Gas cogeneration	24311	22382	17408	14197
Petroleum products cogeneration	3458	2463	1767	982
Other	216	2563	1872	1769
Fuel and Fuel/Gas (NPT)	13783	10141	7606	5071
Renewables cogeneration	1127	988	1058	1126
Biomass	3126	4757	6165	10031
Cogeneration with waste	192	160	122	84
Municipal solid waste	1344	918	799	355
Nuclear	57196	58039	58039	24952
Total	280911	281219	307570	346290

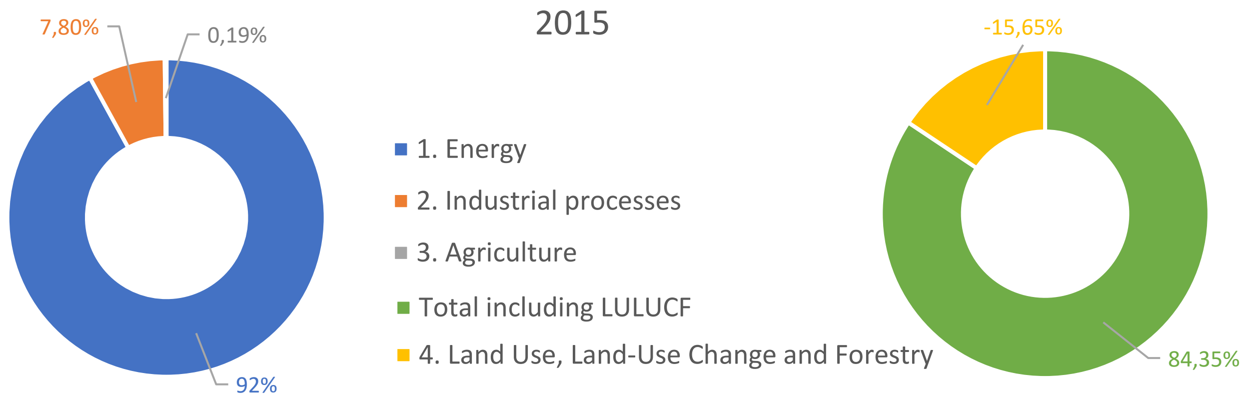
The baseline scenario data will be use for the 2030 calculations since it seems to be a more realistic approximation. The original goal was set on a 74% renewable energy generation by 2030, while in the baseline scenario only a 52% is achieved. Therefore, for the 2050 calculations it will be used the target scenario data for 2030, a 74% of renewable energy generation, since it is believed that, when the objective for 2030 is not achieved, neither will be the one for 2050.

1.1.2 Current CO_2 emissions

There are five sectors in which the emissions are grouped:

1. Energy
2. Industrial Processes
3. Agriculture
4. Land Use, Land-Use Change and Forestry
5. Waste

As stated previously, the main goal of the Spanish INECP is the decarbonisation of the electricity sector since it means up to a 92% of the total CO_2 emissions. The industrial processes have a very low impact in comparison, with a 7,8%. The Agriculture sector is hardly significant, with only a 0,19%, while the Waste impact is null. Regarding Land Use, Land-Use Change and Forestry (LULUCF), its impact is positive, which indicates that it can reduce the CO_2 emissions in a 15,65%, showing its potential to contribute to the goal of GHG emission mitigation. In the Figure 1it can be shown these percentages regarding the 2015 CO_2 emissions.



Total: 271727.2 kt CO_2

Total: 229210.44 kt CO_2

Figure 1. 2015 CO_2 Emissions.

The table with the CO_2 emissions data for 2015, 2030 and 2050 can be found in the in Appendix 1: Spain CO_2 Emissions Projections. Figure 2 and Figure 3 show the contribution of each sector for 2030 and 2050, respectively.

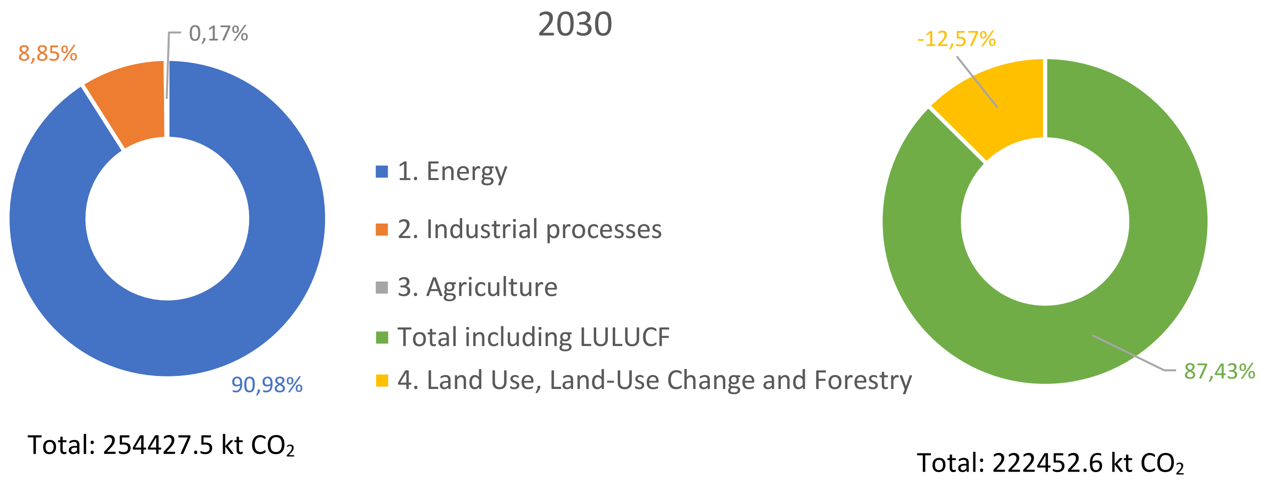


Figure 2. 2030 CO_2 Emissions.

The emissions from one year to another are reduced, by a 2,95% from 2015 to 2030 and a 16,49% from 2030 to 2050. Despite the CO_2 emissions reductions, the share of each sector hardly changes, being the Energy the cornerstone.

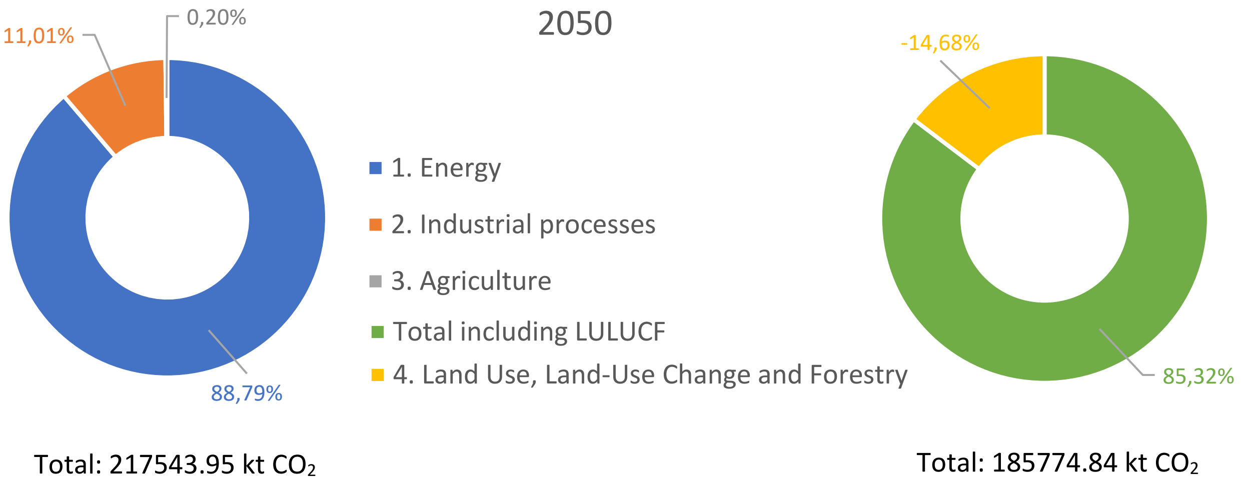


Figure 3. 2050 CO_2 Emissions.

Apart from actions in the energy field, the Plan addresses the need to tackle emissions in non-energy sectors, as well as to take advantage of the GHG absorption potential of natural sinks. Nonetheless, this last will not be enough to achieve the long-term plan, not even the short-term plan. It is crucial to look faraway and consider the possibility of implementing Negative Emission Technologies (NETs). [European Environment Agency, 2019]

1.2 Negative Emission Technologies (NETs)

Negative emission technologies (NTEs) are those based on CO_2 removal, which refers to the intentional removal of CO_2 from the atmosphere. A wide range of CO_2 removal technologies (CDRs) can be used in this effort (see Figure 4. CDR Technologies), but the current knowledge on CDRs is still diffuse and incomplete [CO_2 Removal, 2021]. For this assessment only five of the existing technologies will be considered: i) Afforestation & Reforestation (AR); ii) Soil Carbon Sequestration (SCS); iii) Bioenergy with Carbon Capture & Storage (BECCS); iv) Direct Air Capture (DAC); v) and Enhanced Weathering (EW). The other technologies categories are not applicable since there is not enough information regarding them. [CO_2 Removal, 2021]

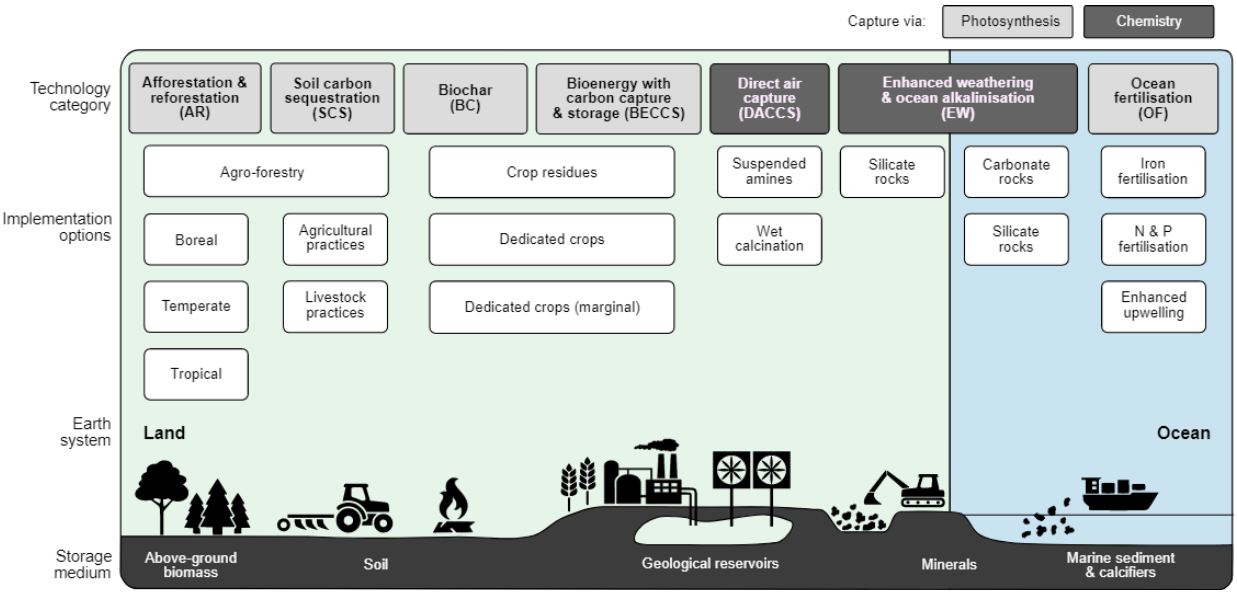


Figure 4. CDR Technologies. [CO_2 Removal, 2021]

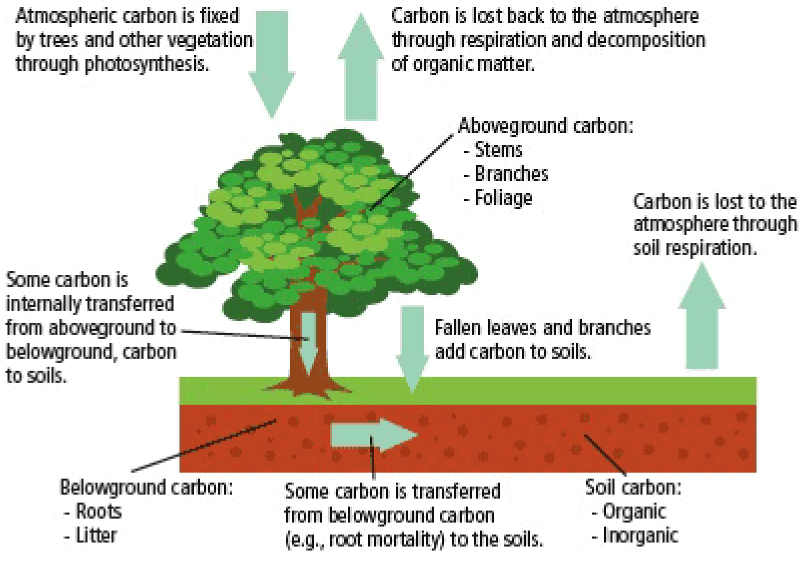
Figure 4 shows the different technology categories and how each of them could be implemented. Moreover, it also shows the earth system where it would be applicable and the carbon storage medium.

1.2.1LULUCF

The term LULUCF refers to the Land Use, Land-Use Change & Forestry. The role of these activities in the mitigation of climate change has long been recognized. In the context of CDRs, they can be identified as Afforestation & Reforestation (AR) and Soil Carbon Sequestration (SCS). However, the main drawback of LULUCF activities is their potential reversibility and non-permanence of carbon stocks as a result of human activities, natural disturbances or a combination of the two with loss of carbon stocks and release of GHG into the atmosphere as a result. [United Nations Climate Change, n.d.]

Afforestation & Reforestation (AR)

AR consists in increasing forest area by planting new forest or extending agroforestry on suitable land, and/or enhancing management of existing natural and plantation forests to maximise the carbon sink. [Shepherd et al., 2009]



Source: U.S. Environmental Protection Agency

Figure 5. Carbon Sequestration by trees.

In Figure 5 it is possible to see a scheme of how trees absorb atmospheric CO_2 via photosynthesis. Even though part of CO_2 is released again during that process while another fraction is storage in the soils underground.

Forests present a significant global carbon stock accumulated through growth of trees and an increase in soil carbon. Conversion of primary to managed forests, illegal logging and unsustainable forest management result in GHG emissions and can have additional physical effects on the regional climate including those arising from albedo shifts. Conversely, in areas of degraded forests, sustainable forest management can increase carbon stocks and biodiversity. In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks and carbon storage in long-lived wood products and reductions of emissions from use of wood products to substitute for emissions-intensive materials can also contribute to mitigation objectives. [United Nations Climate Change, n.d.]

Soil Carbon Sequestration (SCS)

Other terrestrial systems also play an important role. Most of the carbon stocks of croplands and grasslands are found in the below-ground plant organic matter and soil. Consequently, soil carbon sequestration in croplands and grasslands has a mitigation potential.

No-till agriculture to reduce the loss of carbon through oxidation when ploughing, thus enhancing the natural soil sink [Lal et al., 2004]. On the other hand, organic soil management, using manures and composts to increase the levels of soil organic content. [Azeez, 2009]

Soil can serve as a medium for carbon storage for techniques such as agroforestry, which is done by plants already explained in the point above, or agricultural practises, which can increase the amount of CO_2 that soil can absorb. Another technique is Circular Farming, which consist in an optimization of the use of resources to produce affordable, safe and healthy food that covers the demand. In turn, circular agriculture offers options to combat greenhouse gas emissions from agriculture to a far greater extent than the measures that are simply focused on making common agricultural processes more climate friendly. More about this topic can be found in Appendix 2: Circular Farming.

1.2.2 Direct Air Capture (DAC)

DAC technology consists in the adsorption of CO_2 directly from the atmosphere using amines in a solid form, suspended on a branched framework, through which air is pumped, or circulated by wind. The CO_2 is recovered by washing in vacuum, pressurised and injected into geological storage. [Lackner, 2009, Eisenberger et al., 2009]

The carbon removal plants capture atmospheric carbon with a filter. Air is drawn into the plant and the CO_2 within the air is chemically bound to the filter. Once the filter is saturated with CO_2 it is heated (using mainly low-grade heat as an energy source) to around 100 °C. The CO_2 is then released from the filter and collected as concentrated CO_2 gas, which can be used to supply customers or for negative emissions technologies. [Climeworks, 2021]

CO_2-free air is released back into the atmosphere. This continuous cycle is then ready to start again. The filter material is made of porous granulates modified with amines, which bind the CO_2 in conjunction with the moisture in the air. This bond is dissolved at temperatures of 100 °C. The filter is reused many times and lasts for several thousand cycles. In the Figure 6 it is possible to see how the grey particles (CO_2) are retained in the amine filter. [Climeworks, 2021]

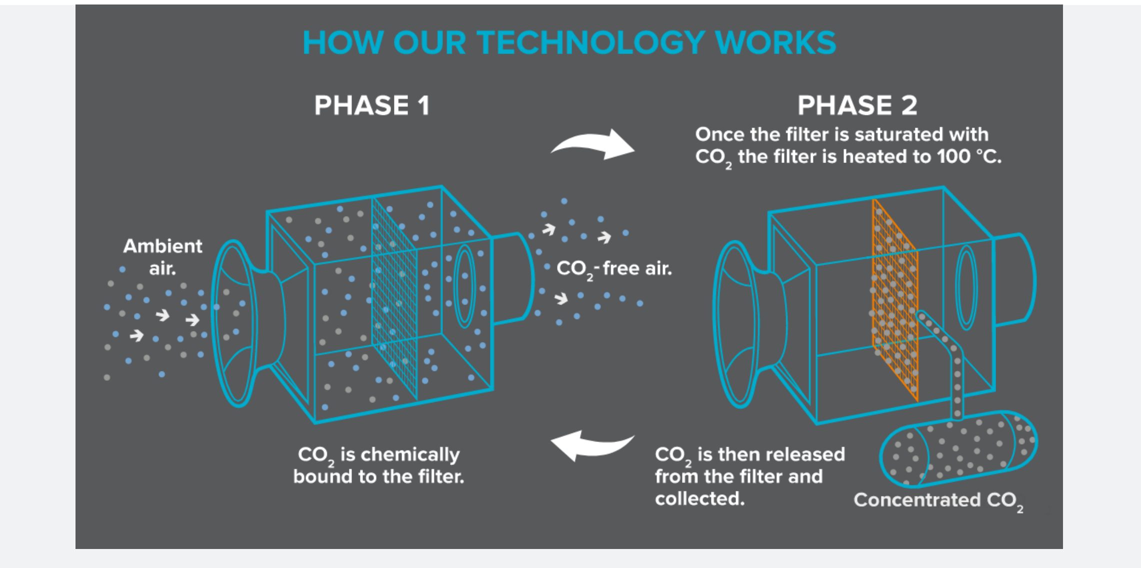


Figure 6. How DAC works. [Climeworks, 2021]

The main disadvantage of this technology is what to do with the concentrated CO_2. As mention before it can be used to supply customers which activities require CO_2 or for negative emission technologies. This last one consists in storing the CO_2 underground by injecting it into basaltic rocks that would conclude in the transformation of the CO_2 into carbonate minerals (see Figure 7). The conditions that make this process possible are diffuse. However, it still could be possible for Spain to acquire Climeworks technology and find a suitable customer to sell the CO_2 to.

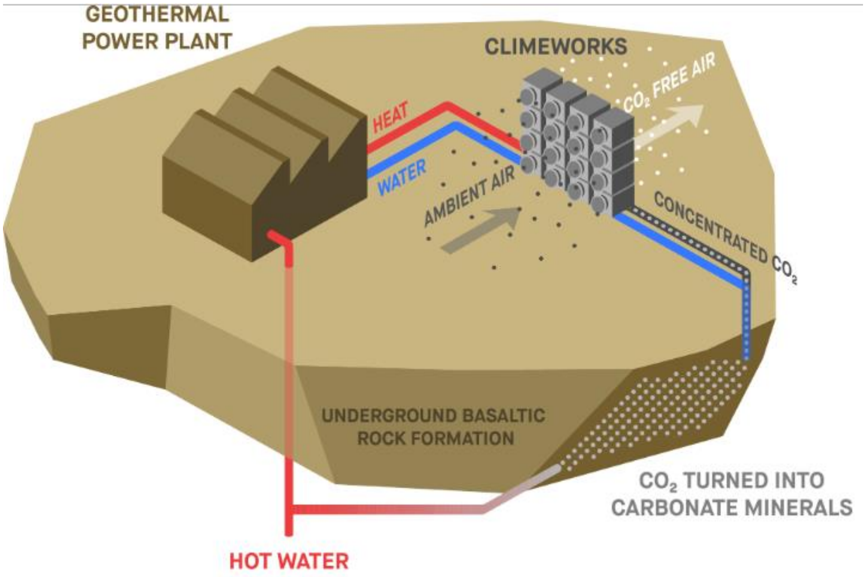


Figure 7 Process by which the CO_2 is storage underground. [Climeworks, 2021]

1.2.3 Bioenergy with Carbon Capture & Sequestration (BECCS)

BECCS can be deployed via a wide range of technologies. This paper will consider one of the two main existing routs: BECCS via biomass conversion to heat and power. Theoretically, BECCS permanently removes CO_2 from the atmosphere and provides reliable low-carbon energy, while displacing fossil-based fuel and power.

In a BECCS chain, CO_2 from the atmosphere is absorbed via photosynthesis into the biomass of plant materials. It is then burned or converted in power plants or industrial facilities equipped with technologies that capture the CO_2, preventing the gas from returning to the atmosphere. The captured CO_2 is then injected in deep geological formations. In the bioenergy to power route, all of the carbon fixed in the biomass is released as CO_2 during combustion, but in diluted form in the exhaust gas. Further separation and more energy use are required before compression and injection. This process results in a net transfer of CO_2 from the atmosphere to the ground, if emissions associated with supplying the biomass and capturing the CO_2 do not exceed the amount removed from the air by photosynthesis.

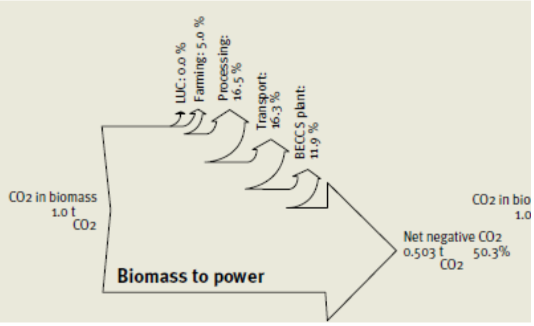


Figure 8. Carbon Efficiency Biomass to power.

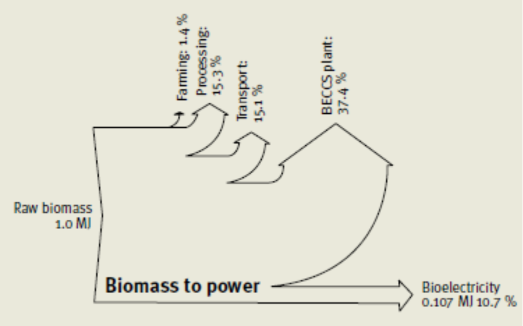


Figure 9. Energy Efficiency Biomass to power.

BECCS' performance can be measured by how much net carbon it captures (carbon efficiency, Figure 8) and how much net energy it produces (energy efficiency, Figure 9) along the whole supply chain.

The major risks of BECCS deployment are the energy and carbon costs of supplying Biomass. Supplying biomass will incur different energy costs and associated CO_2

emissions, depending on the feedstock and end process. The feedstock needs to be collected from a source, conditioned into a proper form for transport and transported to the biomass conversion facility. Each of these steps incurs an energy and CO_2 cost. [Fajardy, M.; Köberle, A.; Mac Dowell, N.; Fantuzzi, A., 2019]

For this report, the feedstock chosen was “Miscanthus”. It has a 47% of Carbon content, and in the BECCS process, it is possible to capture 90% of the CO_2 sequestered in the biomass. Regarding the energy, it produces energy with a factor of 0,107 of Energy produced/Energy demanded. Up to 30 tons of biomass can be obtained from one hectare, being the estimated cost around 60 €/ton biomass. The data used for the study can be found in Table 19, in the Appendix 3: CDRs Data.

1.2.4 Enhanced Weathering (EW)

EW consists in the distribution of crushed silicate and carbonate rocks on soil surfaces to absorb and bind CO_2 chemically. The rock material dissolves in the presence of water and CO_2 and dissolution products are transported via rivers towards the ocean.

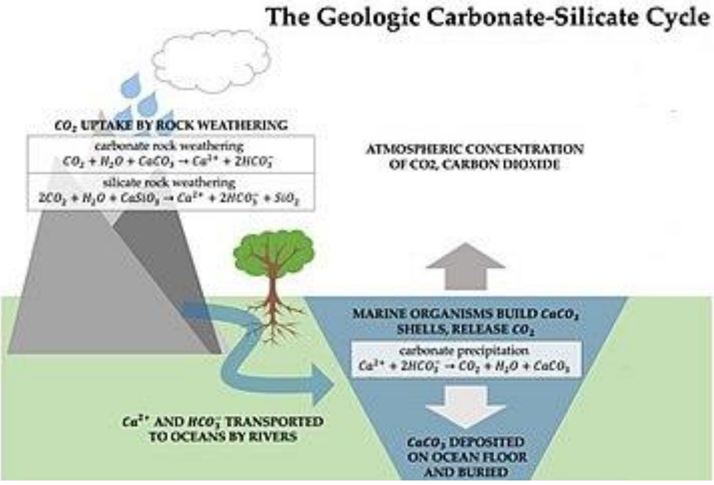


Figure 10. Geologic Carbonate and Silicate Cycle.

The weathering process by which Silicate and Carbonate rocks react with CO_2 and bind it chemically is shown in the Figure above. After the CO_2 is bonded, the new components travel through rivers until they reach the sea, where part of the CO_2 is in the component $CaCO_3$ that precipitates to the bottom of the sea, while the other part of the CO_2 is released again to the atmosphere. Studies suggest that the most suitable rocks for carbon dioxide sequestration are igneous rocks, which are chemically classified as acidic, intermediate, basic, and ultrabasic depending on their silica content. [Renforth, 2012]

The carbon capture potential of enhanced weathering is large, yet there are few data on the effectiveness or engineering feasibility of such process. The rock chosen was basalt, which has a potential of sequestering 0,125 tons of CO2 per ton of rock. It is a low performance; however, it does not need any more requirements, such us energy or water. The price estimated is of 150 €/ton CO_2, which considers the energy used for mining, crushing, and grinding the rock to the desired size.

1.2.5ERCD

The electrochemical reduction of carbon dioxide is the conversion of CO_2 to more reduced chemical species using electrical energy. The efficient conversion of CO2 to fuels and high-value-added chemicals can promote the development of the cyclic utilization of carbon resources and a reduction in CO_2 emissions.

Electrochemical reduction of carbon dioxide represents a possible means of producing chemicals or fuels, converting carbon dioxide (CO_2) to organic feedstocks such as formic acid (HCOOH), carbon monoxide (CO), ethylene (C_2H_4), ethanol (C_2H_5OH) and methane (CH_4). Among the more selective metallic catalysts in this field are tin for formic acid, silver for carbon monoxide and copper for ethylene, ethanol or methane. Propanol and 1-butanol have also been produced via CO_2 electrochemical reduction, albeit in small quantities.

Electrocatalysis

The electrochemical reduction of carbon dioxide to CO is usually described as:

$$CO_2 + 2\ H+ + 2\ e- \rightarrow CO + H_2O$$

The redox potential for this reaction is similar to that for hydrogen evolution in aqueous electrolytes, thus electrochemical reduction of CO2 is usually competitive with hydrogen evolution reaction.

Electrochemical methods have gained significant attention: 1) at ambient pressure and room temperature; 2) in connection with renewable energy sources; 3) competitive controllability, modularity and scale-up are relatively simple. The electrochemical reduction or electrocatalytic conversion of CO2 can produce value-added chemicals such methane, ethylene, ethane, etc., and the products are mainly dependent on the selected catalysts and operating potentials (applying reduction voltage).

A variety of homogeneous and heterogeneous catalysts have been evaluated. Many such processes are assumed to operate via the intermediary of metal carbon dioxide complexes. Many processes suffer from high overpotential, low current efficiency, low selectivity, slow kinetics, and/or poor catalyst stability. The composition of the electrolyte can be decisive. Gas-diffusion electrodes are beneficial. [Appel, 2013] [Du ; Li; Liu; Xin; Chen, 2020]

2. Objectives

The aim of this project is to make a study of the CO_2 emissions situation for two different scenarios: 2030 and 2050. Despite all the efforts for decarbonizing the energy sector, the predictions for these years assure that the Climate Change objectives will not be achieved, and more actions need to be taken. This study will focus on the implementation of different negative emission technologies and their feasibility. It will evaluate the CO_2 absorption potential, the energy and land requirements and the costs of each technology.

The final purpose is to obtain and evaluate the scenarios that could be achieved if all technologies are implemented, to stablish how far away the scenarios are from the Climate Change objectives and, in that case, to set what would be needed to achieve them.

3. Methodology

In this project, the first step was an examination of the INECP, to determine the CO2 emissions and stablish the sectors to approach. Afterwards, a deep literature research on the different existing technologies, their potentials and feasibility, was performed. In order to find a suitable way to achieve, or to get closer, to the Climate Change objectives, it is necessary a combination of the mentioned technologies.

In order to assess and determine the best scenarios, it was built a mathematical model. This model is based on mass and energy balances, which makes it possible to know the CO_2 reduction that each technology is able to achieve as well as the energy requirements. The figure below shows the overall flow diagram of the process, which is divided in four sections:

1. CO_2 sources suitable for capture, CO_2 sources unsuitable for capture, and LULUCF.
2. Extra renewable energy requirements.
3. CDRs: Enhanced Weathering, BECCS and Direct Air Capture.
4. ERCD and Natural Gas.

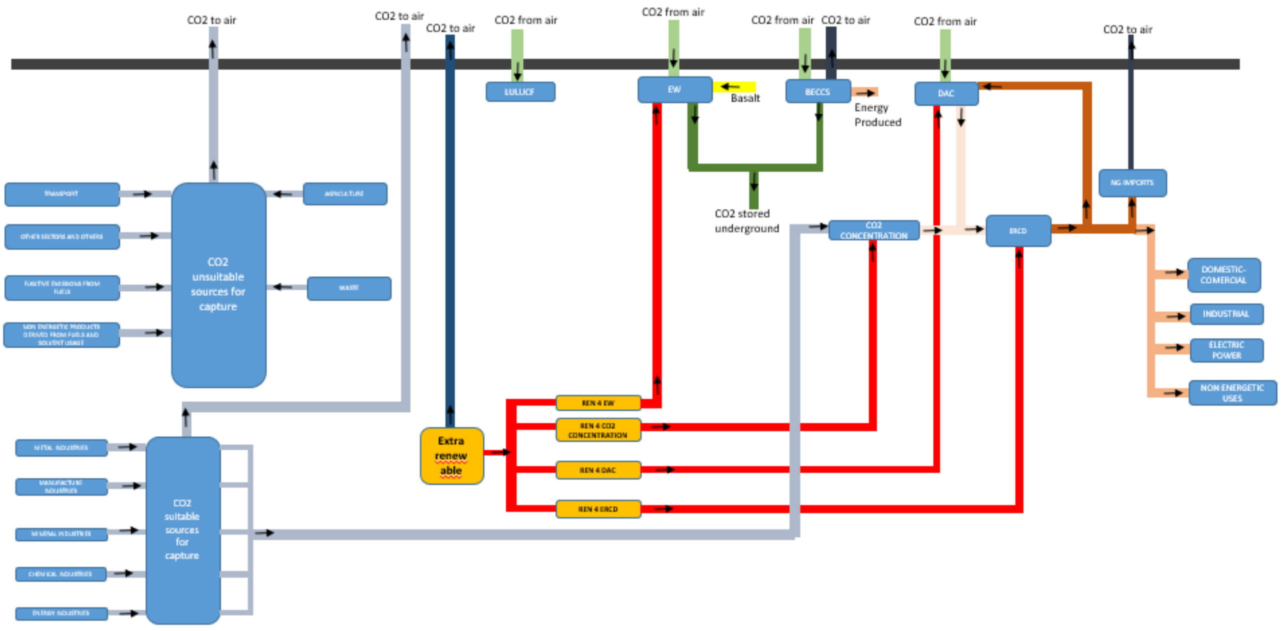


Figure 11. Flow Diagram.

1. CO_2 sources suitable for capture, CO_2 sources unsuitable for capture, and LULUCF.

These three blocks comprehend all the CO_2 emissions provided in the Appendix 1: Spain CO_2 Emissions Projections. The CO_2 sources that are suitable for capture (Figure 12) are those related with the industries that can be trapped during the activity. Later, they are purified, so afterwards the CO_2 can be treated, in this case, with ERCD.

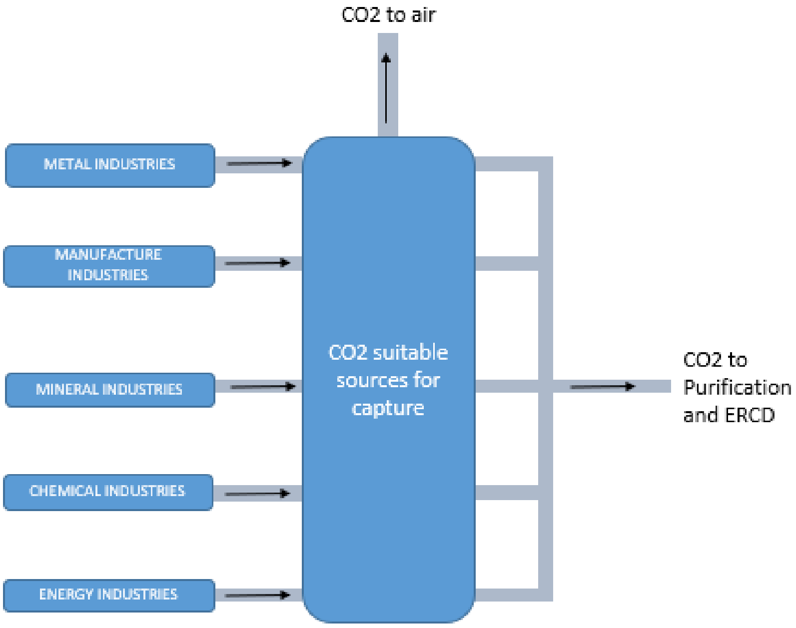


Figure 12. CO_2 Sources Suitable for Capture.

The CO_2 sources that are unsuitable for capture (Figure 13) are related to those sectors, such as transport and agriculture, whose emissions are inevitable. This means that, even though the emissions can be reduced, they will always be directly released to the atmosphere, thus, they will need to be capture by CDRs.

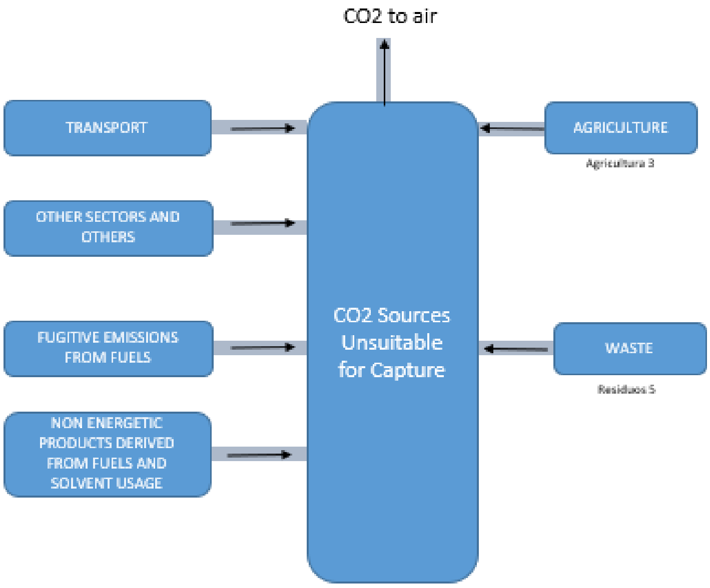


Figure 13. CO_2 Sources Unsuitable for Capture.

The last block, LULUCF, absorbs a certain amount of the CO_2 emissions that are released into the atmosphere, storing them in the earth.

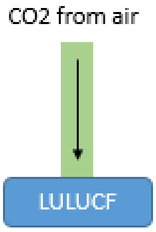


Figure 14. LULUCF.

2. Extra renewable energy requirements

The CDRs require energy to work, which is not considered in the energy predictions, hence it is an additional input of energy. In order to reduce the associated impact, the energy used should be renewable. Despite this, it will still have some CO_2 emissions associated, that will be added to the carbon footprint.

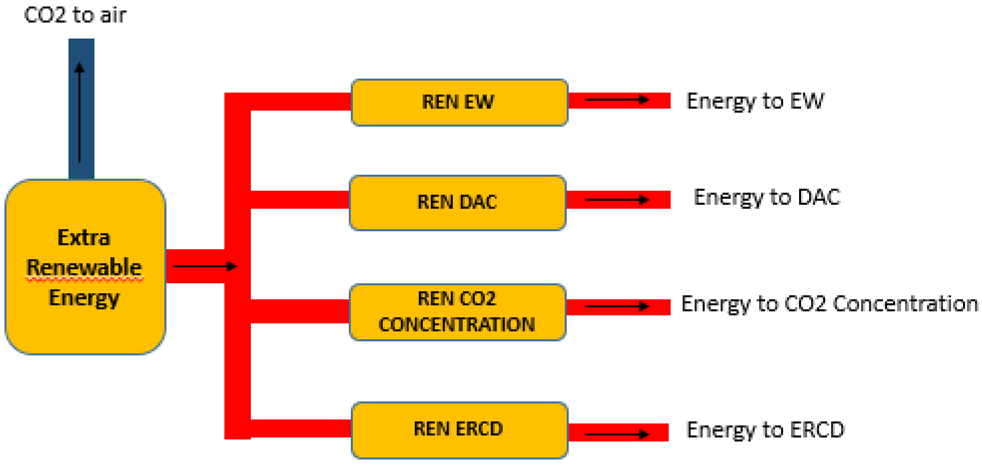


Figure 15. Extra renewable energy.

3. CDRs: Direct Air Capture, BECCS and Enhanced Weathering

The CDRs are based on black-box models, in which energy and mass balances are combined. In the first technology, DAC, a percentage of the CO_2 emissions are captured and produce 30% more of pure CO_2, which is treated with ERCD. For this mass conversion, energy and natural gas are needed. Figure 16 show the box model for DAC, which has three inputs: CO_2 from air, energy, and natural gas; and one output: pure CO_2.

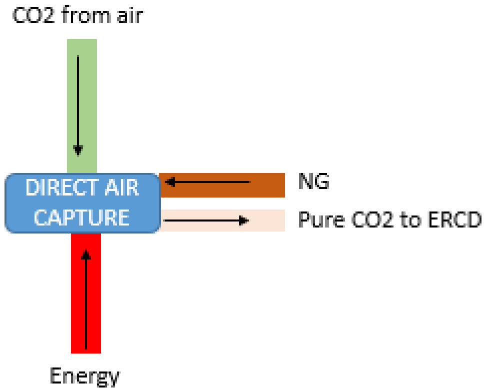


Figure 16. DAC box model.

Figure 17 shows the box model for BECCS. It has one input: CO_2 from air; and three outputs: CO_2 back to air, CO_2 sequestered and electricity. The technology requires energy, but since it also produces it, this technology is considered to be self-sufficient. Part of the CO_2 absorbed is storage in the earth and the rest is released back to air.

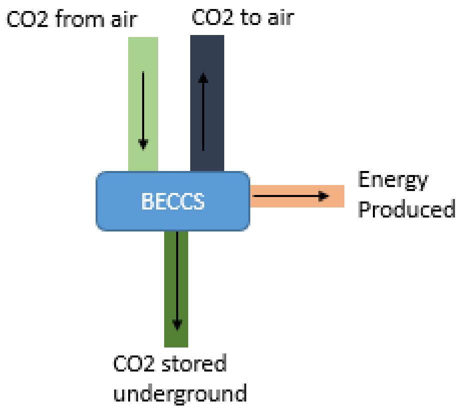


Figure 17. BECCS box model.

Regarding Enhanced weathering (EW), the box model in Figure 18 shows the inputs: CO_2 from air, basalt rocks and energy; and the outputs: CO_2 sequestered. The CO_2 sequestered will be stored in the earth, with the basalt rocks.

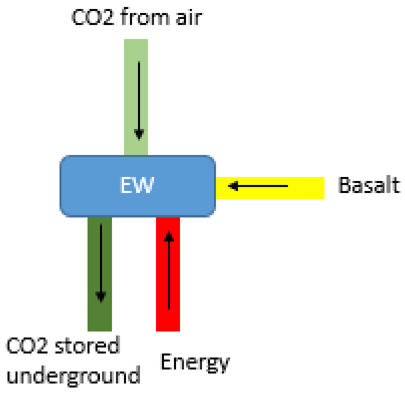


Figure 18. Enhanced Weathering box model.

4. ERCD and Natural Gas.

To the ERCD process there are two sources of CO_2 entering, one from the DAC and another from the CO_2 sources suitable for capture. Another input is the electricity that is necessary to turn the CO_2 into Natural Gas. Part of the NG produced is used for DAC, while the rest goes to the Natural Gas system.

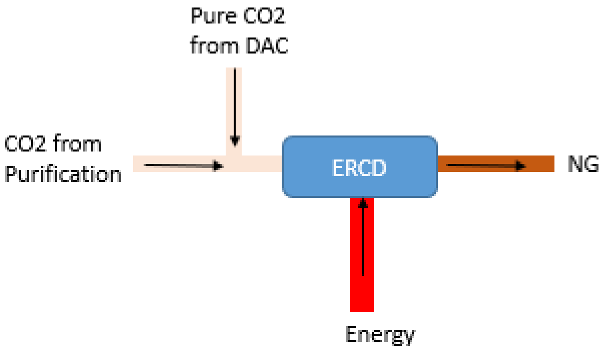


Figure 19. ERCD box model.

There are four NG consumers in Spain: Domestic-Commercial, Industrial, Electric Power and Non-Energetic Uses. The ERCD process produces more NG than the used for the DAC system and the consumed by the sectors mentioned above. Hence, it is possible to export NG, resulting in a decrease of the CO_2 emissions and money savings.

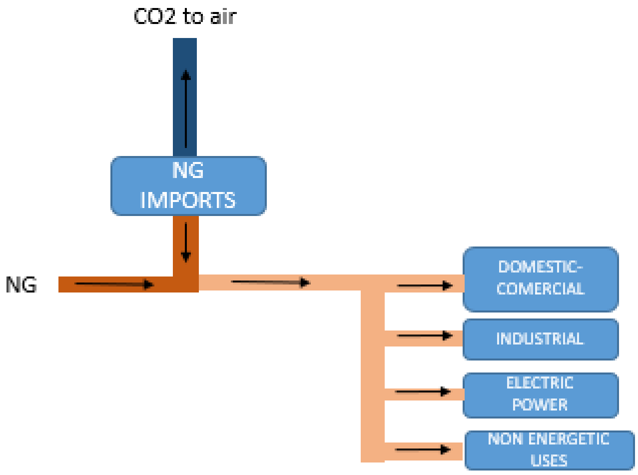


Figure 20. Natural Gas box model.

Land Use

Alongside with the mass and energy balances, it was assessed the land availability and requirements. Spain possesses 230.455 km^2, of which main use is agriculture, 46,2%. The land distribution is shown in Table 3. For this study two types of land are important: Agriculture and Non-Use. The first one will be used in combination with EW, while the 50% of the Non-Use land will be considered to be accessible for the implementation of the other technologies and the extra renewable energy. The information regarding the land that each technology and renewable energy will require can be found in Appendix 3, Table 22.

Table 3. Spanish Land Use. [MAPA, 2017]

	km^2	%
Total km^2	498504	100,00
Agriculture	230455	46,23
Farmland	106181	21,30
Forests, Shrubs and Grasslands	124274	24,93
Forest	108298	21,72
Inland Fishing	243	0,05
Non-Use	133980	26,88
Environmental Impact	15077	3,02
Services and Residential use	9678	1,94
Other Primary Production	806	0,16

4. Results

The amount of CO_2 removed by AFF and SCS is fixed in the LULUCF data. EW also has a limit, which comes set by the available land for this technology. To determine the amount of CO_2 that BECCS and DAC would remove, an optimization problem was run with GAMS, looking for the lower cost. Since the current ERCD energy demand is extremely high, the cost of the CO_2 removed from the atmosphere that it is later treated with this process involves a high increase on the cost related with that technology. Nonetheless, BECCS storages the CO_2 underground and is not realistic to consider that all the CO_2 could follow this path, as there is still unknowledge regarding the topic. Thus, although the ERCD path is more expensive it will be considered that most of the CO_2 will be absorb with DAC.

4.1 2030

The objective set for this year is a 40% reduction of the CO2 emissions compared to 1990 (see Table 4). In order to achieve that goal, Table 5 shows the CO_2 emissions % of 2030 removed by each CDR. It can be noticed that the emissions in 2030 are higher than in 1990, hence, to achieve the 40% reduction respect 1990, it would be necessary to reduce, or absorb, 60,31% the 2030 emissions.

Table 4. Comparison of CO_2 emission's objective 2030.

Year	Emissions (kt CO_2)	Reduction (%)	Final Emissions (kt CO_2)
1990	208356,22	40	125013,7
2030	254428	40,09	124831

Table 5. CO_2 Emissions % removed by each CDR 2030.

2030 CO_2 Emissions % Reduction				
DAC	BECCS	EW	LULUCF	TOTAL
24,96	19,54	3,24	12,57	60,31

Regarding the land that each technology would require to remove the amount of CO_2 mentioned above, considering the infrastructure and extra energy land requirements, it can be assured that it would not be a concern. EW will be assumed to use agriculture land, while the rest of the necessities will recur to land categorized as Non-Use, of which the 50% will be designate for CDRs infrastructure and extra renewable energy.

Table 6. Non-Use Land 2030.

50 % Non-Use Available		**66990000000 m^2**		
Tech		**m^2**	**%**	
BECCS	Biomass	10,68	1,59E-08	
DAC	Plants	8,26E+07	0,123	0,748
	Energy (Ren)	4,18E+08	0,625	
Extra Energy	ERCD	1,997E+10	29,82	30,44
	Purification	0	0	
	EW	42075	6,281E-05	
Total		2,047E+10	30,56	
Rest		4,65E+10	69,436	

Table 6 shows the percentage of land that BECCS, DAC and Extra Renewable Energy would require to reach the CO_2 reduction capacity mentioned in Table 5. The total land requirements would hardly surpass the 30% of the land considered to be useful. EW would only require a 14,32% of the available land in combination with agriculture (see Table 7).

Table 7. Agriculture Land 2030.

Available	**2,304E+11 m^2**	
Tech	**m^2**	**%**
EW	3,30E+10	14,319
Rest	1,97E+11	85,681

4.1.1Costs

Table 8 shows the cost of each process. Although DAC is the lowest contributor, only a 1,11% of the total cost, it would actually be the highest, since all the CO_2 captured via this technology goes to the ERCD process, which means more than half of the total cost. More NG would also need to be imported, which would also affect to the DAC real cost. BECCS has a very low impact in the economy, but it should be noticed that it is considered that all the CO_2 captured is storage underground, with no further cost. The energy associated to EW is minimum, and so it is the cost. On the other hand, the cost of the basalt is really expensive, making the technology very costly in comparison with the CO_2 reduction potential.

Table 8. 2030 Technologies Cost.

	Unit	**Unit cost (€)**	**Amount**	**Total cost (€)**	**% of Total Cost**
NG	MWh	69	2,24E+07	1,55E+09	5,31
DAC	MWh	14	2,32E+07	3,25E+08	1,11
BECCS	t Biomass	60	3,20E+07	1,92E+09	6,58
EW	t Basalt	150	6,60E+07	9,90E+09	33,86
	MWh	14,	2,34E+03	3,27E+04	0,00
ERCD	MWh	14	1,11E+09	1,55E+10	53,14

The total cost to achieve the 2030 objective is 30.789.720.932 €, of which more than the 50 % would be due to the energy increment.

Table 9. 2030 Total Cost.

Amount	**Cost (€)**	**%**
Energy	1,59E+10	51,51
Total	2,92E+10	100

4.2 2050

The objective set for this year is a 95% reduction of the CO_2 emissions compared to 1990 (see Table 10). In order to achieve that goal, Table 11Table 4. Comparison of CO_2 emission's objective 2030.

Year	Emissions (kt CO_2)	Reduction (%)	Final Emissions (kt CO_2)
1990	208356,22	40	125013,7
2030	254428	40,09	124831

Table 5 shows the CO_2 emissions % of 2050 removed by each CDR. It can be noticed that the emissions in 2050 are higher than in 1990, hence, to achieve the 95% reduction respect 1990, it would be necessary to reduce, or absorb, 102,11% the 2050 emissions.

Table 10. Comparison of CO_2 emission's objective 2050.

Year	Emissions (kt CO_2)	Reduction (%)	Final Emissions (kt CO_2)
1990	208356,22	95	10417,811
2050	219423	95,5	9367

Table 11. CO_2 Emissions % removed by each CDR 2050.

2050 CO_2 Emissions Reduction %				
DAC	BECCS	EW	LULUCF	TOTAL
42,16	31,37	14,01	14,57	102,11

Regarding the land that each technology would require to remove the amount of CO_2 mentioned above, considering the infrastructure and extra energy land requirements, it can be assured that it would not be a concern. EW will be assumed to use agriculture land, while the rest of the necessities will recur to land categorized as Non-Use, of which the 50% will be designate for CDRs infrastructure and extra renewable energy.

Table 12. Non-Use Land 2050.

50 % Non-Use Available		**66990000000 m^2**		
Tech		**m^2**	**%**	
BECCS	Biomass	14,79	2,21E-08	
DAC	Plants	1,20E+08	0,179	1,09
	Energy (Ren)	6,09E+08	0,91	
Extra Energy	ERCD	1,87E+10	27,92	28,829
	Purification	0	0	
	EW	1,57E+05	2,34E-04	
Total		1,94E+10	29,01	
Rest		4,75E+10	70,99	

Table 12 shows the percentage of land that BECCS, DAC and Extra Renewable Energy would require to reach the CO_2 reduction capacity mentioned in Table 11Table 5. The total land requirements would not even surpass the 30% of the land considered to be useful. EW would only require a 53,37% of the available land in combination with agriculture (see Table 13).

Table 13. Agriculture Land 2050.

Available	**2,304E+11 m^2**	
Tech	**m^2**	**%**
EW	1,23E+11	53,37
Rest	1,07E+11	46,63

4.2.1Costs

Table 14 shows the cost of each process. Although DAC is the lowest contributor, only a 0,62% of the total cost, it would actually be the second highest, since all the CO_2 captured via this technology goes to the ERCD process, which means a 20% the total cost. BECCS has a very low impact in the economy, but it should be noticed that it is considered that all the CO_2 captured is storage underground, with no further cost. The energy associated to EW is minimum, and so it is the cost. On the other hand, the cost of the basalt is really expensive, making the technology very costly (74,97%) in comparison with the CO_2 reduction potential. In this scenario, more NG than the required would be produced. Thus, it could be exported and result in a reduction by 20% of final cost.

Table 14. 2050 Technologies Cost.

	Unit	Unit cost (€)	Amount	Total cost (€)	% of Total Cost
NG	MWh	69	-1,41E+08	-9,78E+09	-19,87
DAC	MWh	9	3,39E+07	3,05E+08	0,62
BECCS	t Biomass	60	4,44E+07	2,66E+09	5,41
EW	t Basalt	150	2,46E+08	3,69E+10	74,97
	MWh	9,00	8,71E+03	7,84E+04	0,00
ERCD	MWh	9	1,04E+09	9,35E+10	19,00

The total cost to achieve the 2050 objective is 39.437.949.101 €, of which almost a 25 % would be due to the energy increment.

Table 15. 2050 Total Cost.

Amount	Cost (€)	%
Energy	9,66E+11	24,48
Total	3,94E+10	100

5. Conclusion

To reach the objectives of the Climate Change agreement, 40% and 95% CO_2 emissions reduction for 2030 and 2050 respectively, it would be necessary to reduce by a 60,31 % the 2030 expected emissions and by 102,11% the ones for 2050. DAC and BECCS are technologies that will contribute the most to this reduction, compared to EW and LULUCF.

Table 16. CO2 emissions reduction and cost for 2030 and 2050.

Tech	**CO_2 emissions % reduction**	
	2030	**2050**
DAC	24,96	42,16
BECCS	19,54	31,37
EW	3,24	14,01
LULUCF	12,57	14,57
TOTAL	60,31	102,11
Cost	30.789.720.932 €	39.437.949.101 €

Figure 21 show the contribution of each CDR to de cost for 2030 and 2050. For 2030 the highest impact comes from ERCD, and in consequence, DAC, followed by EW. For 2050 roles exchange, becoming EW the highest contributor, 75% followed by ERCD.

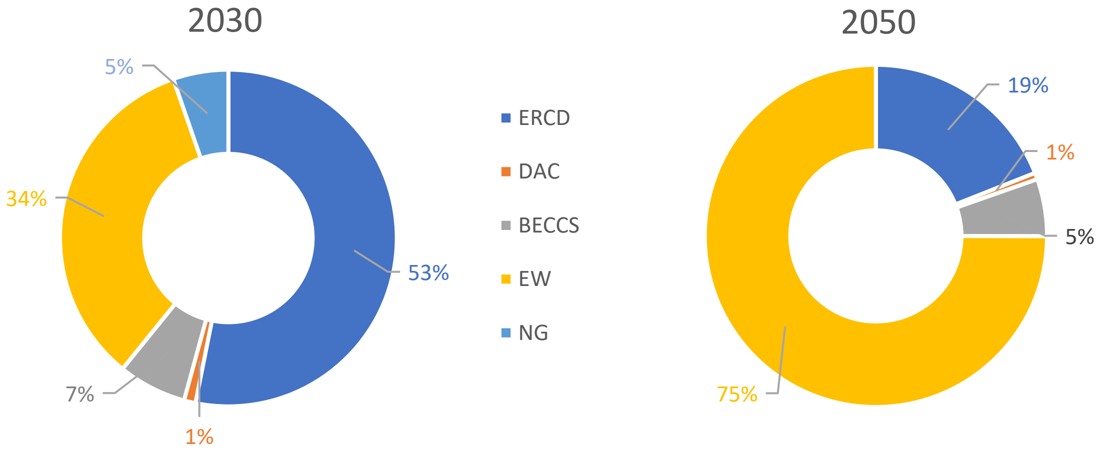


Figure 21. Cost contribution of each CDRs for 2030 and 2050.

The current ERCD energy demand is extremely high, the cost of the CO_2 removed from the atmosphere that it is later treated with this process involves a high increase on the cost related with that technology. Nonetheless, BECCS storages the CO_2 underground and is not realistic to consider that all the CO_2 could follow this path, as there is still unknowledge regarding the topic.

If the CDRs were to be implemented with the potential of Table 16, it would require increasing by four times the energy production vs the production estimation for 2030 and 2050. Even though this is unreasonable, the problem resides in the energetic consume of ERCD. In order for the plan to be feasible, ERCD must improve its energy efficiency or other technologies should be applied alternatively to ERCD or in combination with it.

In conclusion, despite the already planned efforts in reducing the CO_2 emissions form the different sectors and decarbonizing the energy sector, it will not be enough to achieve the Climate Change goal. It is crucial to implement Negative Emission Technologies, but for that more research in the topic must be done, since the prices are high and the energy efficiency too low.

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Appendix 1: Spain CO_2 Emissions Projections

Table 17. Spain CO_2 Emissions Projections for the Different Categories.

Category (1,3)	CO_2 (kt)				
Year	2015	2030	2040	%	2050
Total excluding LULUCF	271727,2	**254427,5**	235264	92,47	**217543,95**
Total including LULUCF	229210,44	**222452,6**	203288,2	91,38	**185774,84**
1. Energy	250039,227	231467,5	211586,2	91,41	193412,58
1.A. Fuel combustion	246316,59	227103,3	207076,2	91,18	188815,22
1.A.1. Energy industries	85739,538	54475,57	42175,91	77,42	32653,30
1.A.2. Manufacturing industries and construction	39481,903	40261,04	40366,92	100,26	40473,08
1.A.3. Transport	82265,757	90861,87	86475,84	95,17	82301,54
1.A.4. Other sectors	38312,813	40924,75	37432,21	91,47	34237,73
1.A.5. Other	516,57454	580,0625	625,3313	107,80	674,13
1.B. Fugitive emissions from fuels	3722,6407	4364,204	4510,005	103,34	4660,68
1.B.1. Solid fuels	28,646708	3,260267	3,134001	96,13	3,01
1.B.2. Oil and natural gas and other emissions from energy production	3693,994	4360,944	4506,871	103,35	4657,68
2. Industrial processes	21183,291	22528,14	23245,94	103,19	23986,62
2.A. Mineral Industry	12143,229	12824,86	13288,73	103,62	13769,38
2.B. Chemical industry	4018,2792	4331,378	4368,341	100,85	4405,62
2.C. Metal industry	4185,2983	4470,1	4620,723	103,37	4776,42
2.D. Non-energy products from fuels and solvent use	836,48409	901,7981	968,1492	107,36	1039,38
2.E. Electronics industry	NO	NO	NO	NO	NO
2.F. Product uses as substitutes for ODS(2)	NA	NA	NA	NA	NA
2.G. Other product manufacture and use	NO	NO	NO	NO	NO
3. Agriculture	504,68145	431,8702	431,8702	100,00	431,87
3.A. Enteric fermentation	NA	NA	NA	NA	NA
3.B. Manure management	NA	NA	NA	NA	NA
3.C. Rice cultivation	NA	NA	NA	NA	NA
3.D. Agricultural soils	NA	NA	NA	NA	NA

3.E. Prescribed burning of savannahs	NA	NA	NA	NA	NA
3.F. Field burning of agricultural residues	NA	NA	NA	NA	NA
3.G. Liming	39,037459	39,04631	39,04631	100,00	39,05
3.H. Urea application	465,64399	392,8239	392,8239	100,00	392,82
4. Land Use, Land-Use Change and Forestry	-42516,761	-31974,9	-31975,82	100,00	-31976,73
4.A. Forest land	-38240,617	-29734,75	-29513,82	99,26	-29294,54
4.B. Cropland	-2784,6532	-2539,409	-2753,292	108,42	-2985,19
4.C. Grassland	-359,71573	311,4065	347,1517	111,48	387,00
4.D. Wetlands	15,165975	40,85198	40,06541	98,07	39,29
4.E. Settlements	1147,0215	806,4308	559,9666	69,44	388,83
4.F. Other Land	54,383468	0	0	0,00	0,00
4.G. Harvested wood products	-2348,3458	-859,4337	-655,8866	76,32	-500,55
5. Waste	0	0	0	0	0
5.A. Solid Waste Disposal	NA	NA	NA	NA	NA
5.B. Biological treatment of solid waste	NA	NA	NA	NA	NA
5.C. Incineration and open burning of waste	NO	NO	NO	NO	NO
5.D. Wastewater treatment and discharge	NA	NA	NA	NA	NA

(1) IPCC categories pursuant to 2006 IPCC Guidelines for National Greenhouse Gas inventories and revised UNFCCC CRF tables for inventory reporting

(2) ODS - ozone-depleting substances.

(3) Use of notation keys: as regards the terms of use defined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (chapter 8: reporting guidance and tables), the notation keys of IE (included elsewhere), NO (not occurring), C (confidential) and NA (not applicable) may be used, as appropriate when projections do not yield data on a specific reporting level (see 2006 IPCC Guidelines).

Appendix 2: Circular Farming

Over the years during the half past century, big and efficient production for a low price with a reasonable income for the farmers were the main goals to reach on farming. However, it is not a guarantee for the future as the demand of agricultural products and resources only continues to grow. An optimization of the use of resources is required in order to produce affordable, safe and healthy food that covers the demand. Besides being a mental transition, which involves policy adjustments to reduce or even eliminate the waste of residual biomass, it is also the best way of optimization.

Circular agriculture is a solution that involves farmers, interested citizens, businesses, scientists and researchers in order to find the optimum combination of ecological principles with modern technology, new partnerships, new economic models, and credible social services.

The aim of the circular agrofood system is to ensure that cycles are closed at the whole range from local to national and international levels as much as possible. In other words, it aims to keep agricultural biomass and food processing residuals as renewable resources within the food system. Sparing much more scarce resources and wasting less biomass leads to needing fewer imports, such us chemical based fertilisers and remote livestock feedstocks. This means that the availability of circular resources will determine the production capacity and the resulting consumption options.

Future agriculture could base its activity in this new model, which would not be restrictive, but a new paradigm that provides the freedom for a wide range of company styles and earnings models. Furthermore, it will be adapted to the social and ecological environment depending on the availability of resources, markets, and buying options.

Circular agrofood system:

The steps to follow are the following:

1. **Crops**: Only 30% of the crops are suitable for human consumption
2. **Cattle**: Cattle and sheep can consume grass and herbs in pastures that are unsuitable for growing food as for example grasslands
3. **Manure**: It is also a valuable source of organic material that replenishes the soil and complete the circular agrofood system
4. **Land**: Manure from the animals contributes to a fertile healthy soil and improves crop yields

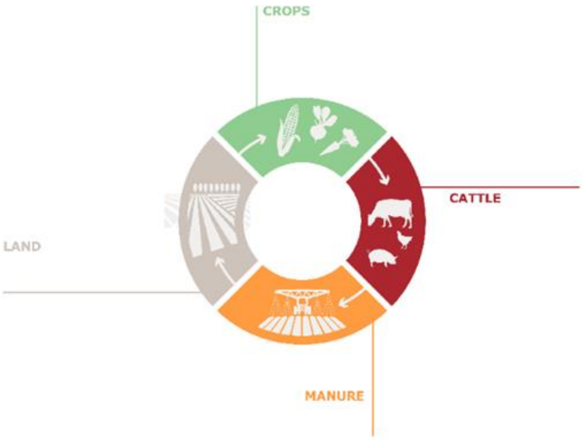

Figure 22. Circular Agrofood system.

Another important measure would be to optimize the use of waste streams, which should be done following the points below.

- Circular agriculture is that no more acreage or resources are used than are strictly necessary.
- Fields will primarily be used for the production of food crops. In order to use them optimally, successive crops will be sown, so that food will be growing in the field almost year-round.
- Mixed crops will be added to the rotation.
- Plants will serve dual purposes, primarily as food stocks, while the remains (leaves and stems) will be used as feedstock for livestock or biofertilizers to improve the soil.

Climate Benefits

The agricultural sector is extremely sensitive to the effects of climate change, which is why it must also contribute to mitigate its greenhouse gas emissions.

The key tenet of circular agriculture is to use agricultural biomass as often and efficiently as possible, which would be beneficial in the following aspects:

1. Avoiding the natural degradation of unused biomass (crop remnants, fertiliser) and the production of carbon dioxide, nitrous oxide and methane.
2. Less artificial fertiliser is necessary, so less CO_2 is released during production.
3. Natural fertiliser (manure, soil, compost) is a High-quality that increases the retention of carbon in the soil, which is in fact a natural way to combat climate change.

In turn, circular agriculture offers options to combat greenhouse gas emissions from agriculture to a far greater extent than the measures that are simply focused on making common agricultural processes more climate friendly. It is precisely through this combination that agriculture can really deliver big results for the climate.

Agricultural production depends on healthy and good structured soil. The health of the soil is largely determined by the quality of the organic material it contains, such us nitrogen, phosphorus, potassium, and a wide range of micronutrients.

Loss of nutrients leads to air, water, and ground pollution and a loss of biodiversity. It also exhausts limited resources, such as phosphate, which is then supplemented with mined fertilisers. Due to the crucial role of nutrients in the cycle, healthy soil is one of the most important foundations for circular agriculture. The next points are crucial on soil treatment:

1. Fertility and the quantity of organic material ensure crop yield.
2. Healthy fields with healthy soil life, leads to fewer illnesses and pests.

3. Increasing the level of organic materials is a natural way to absorb and contain CO_2 and other greenhouse gases.

In circular agriculture, soil life is optimally nourished using a resourceful combination of good quality animal-based fertiliser, preferably composted manure and crop remnants. Animal manure will no longer be stored in liquid form in the manure pit but will be separated at the farm into dry (faeces) and wet (urine).

Even when reuse is maximised, nutrient loss in the cycle is inevitable. Shortages can be supplemented by including nitrogen-fixing crops in the rotation. Thanks to new technology, the great advantage of precision fertilisation reduces loss to the environment.

Appendix 3: CDRs Data

Table 18. DAC Data. [Schneider & Schüwer, 2018]

CO_2 balance in DAC	Demand of energy for the capture of CO_2 from the atmosphere at 0.1 Mpa	Demand of electric energy for the capture of CO_2 from air	Demand of energy for the capture of CO_2 from the atmosphere	Heat for separation of CO_2 from diluted streams	Equivalent electric energy for CO_2 separation	Steam boiler efficiency
$kgCO_2$ sec/kg CO_2 captured	GJ/tCO_2	kWh/tCO_2	$kgCH_4/tCO_2$	KJ/mol CO_2	kWh/kg CO_2	
1,3	5,25	366	105	28	0,177	0,99

Table 19. BECCS. Miscanthus Data. [Himken; Lammel; Neukirchen; Czypionka-Krause; Olfs; 1997] [Green Energy Biomass, 2020]

CO_2 content in Biomass	CO_2 Balance in BECCS	Energy Produced	Area	Cost
(tCO_2 captured/ t Biomass)	(tCO_2 seq / t CO_2 captured)	(GJ produced / tCO_2 captured)	(t biomass/ ha)	(€/t biomass)
1,723	0,9	1,142	30	60

Table 20. EW. Basalt Data. [Ecoforce, 2020]

CO_2 Balance in Basalt	Energy for mining and crushing	Energy for grinding to 20 um	Spreading density	Cost
(tCO_2 sec/ t basalt)	(GJ / t basalt)	(GJ / t basalt)	(T basalt / hectare)	(€/tCO_2)
0,125	0,02	1	20	150

Table 21. ERCD Energy Data

Year	Energy consumption of the ERCD (kWh/kg)
2030	36,960
2050	23,760

Table 22. Land Tech Data.

Technology	Amount	Unit
Solar	5	m^2. year/GJ
Eolic	5	m^2. year/GJ
DAC	1000	$m^2/kt\ CO_2$
BECCS	0,000169308	m^2/GJ

Appendix 4: Natural Gas, and Energy Data

Table 23. Energy and NG use for 2030 and 2050. [Foro Nuclear, 2019]

Year	Current electric energy use (TWh)	Future electric energy use (TWh)	Current NG imports (TWh)	Current NG exports (TWh)	Future NG balance (TWh)
2030	286	1419	364	57	22
2050	281	1354	364	57	-141

Table 24. NG Data.

LC emissions from imports of NG	LC emissions of REN energy	NG density	Mass ratio CO_2/CH_4
0,738	0,020	0,752	2,750
$kgCO_2eq/kg\ CH_4$	$kgCO_2eq/kWh$	kg/m^3	$kg\ CO_2/kg\ GN\text{-}CH_4$

Table 25. Mass and Energy equivalences.

Equivalence between m^3 NG and energy	Equivalence between mass and energy	Equivalence between mass and energy
95300	71665600	19,91
m^3GN/GWh	kg GN/TWh	kg GN/GJ

Table 26. 2030 Energy Emissions.

	Emission Factor	Electrical Generation (Baseline Scenario)	Emissions
	t CO_2/MWh	GWh	Mt CO_2
Wind on-shore	0,00	83022	0
Wind off shore	0,00		0
PV solar	0,00	34030	0
Conc solar	0,00	5608	0
Hidro	0,00	27581	0
Storage	0,00	4640	0
Biogas	0,00	1024	0
Geothermal	0,00	0	0
Wave/Tidal	0,00	0	0
Coal	0,93	10189	9476
Combined cycle	0,37	51289	18977
Cogeneration coal	0,44	0	0
Cogeneration gas	0,44	9905	4358
Cogeneration oil	0,44	982	432
Others	0,00	1838	0
Oil/gas	0,74	10141	7504
Cogeneration renewable	0,00	1151	0
Biomass	0,00	4713	0
Cogeneration waste	0,00	84	0
Urban solid waste	0,25	355	89
Nuclear	0,00	58039	0
Bioenergy with CCS (90%)	0,00	17,5255638	0
NG with CCS	0,00	0	0
Hard coal with CCS	0,00	0	0
EMISSIONS OF CO2			40800

Table 27. 2030 Energy Generation and Demand (GWh).

TOTAL Brut Generation	304591
Consume in generation	-9488
TOTAL Nett generation	**295.103**
Consume in pumps	-6445
International Exchanges	-2342
DEMAND 2030	**286.316**

Table 28. 2050 Energy Emissions.

	Emission Factor	**Electrical Generation (Target Scenario)**	**Emissions**
	t CO_2/MWh	**GWh**	**Mt CO_2**
Wind on-shore	0,00	119520	0
Wind off shore	0,00		0
PV solar	0,00	70491	0
Conc solar	0,00	23170	0
Hidro	0,00	28351	0
Storage	0,00	11960	0
Biogas	0,00	1204	0
Geothermal	0,00	188	0
Wave/Tidal	0,00	113	0
Coal	0,93	0	0
Combined cycle	0,37	32725	12108
Cogeneration coal	0,44	0	0
Cogeneration gas	0,44	14197	6247
Cogeneration oil	0,44	982	432
Others	0,00	1769	0
Oil/gas	0,74	5071	3753

Cogeneration renewable	0,00	1126	0
Biomass	0,00	10031	0
Cogeneration waste	0,00	84	0
Urban solid waste	0,25	355	89
Nuclear	0,00	24952	0
Bioenergy with CCS (90%)	0,00	24,26857107	0
NG with CCS	0,00	0	0
Hard coal with CCS	0,00	0	0
EMISSIONS OF CO2			22600

Table 29. 2050 Energy Generation and Demand (GWh).

TOTAL Brut Generation	346289
Consume in generation	-10233
TOTAL Nett generation	336.056
Consume in pumps	-15262
International Exchanges	-40100
DEMAND 2030	**280.694**

Appendix 5: Results

Table 30. 2030 Emissions.

	Official balance (kt CO_2)	Official balance including DAC and CCS for ERCD (kt CO_2)	Official balance including DAC and CCS for ERCD and LC from NG and REN (kt CO_2)
Energy (1)	231468	231468	231468
1A1	54476	54476	54476
1A2	40261	40261	40261
1A3	90862	90862	90862
1A4	40925	41505	41505
1A5	580		0
1B	4364	4364	4364
Industrial processes and use of products (2)	22528	22528	22528
2A	12825	12825	12825
2B	4331	4331	4331
2C	4470	4470	4470
2D	902	902	902
Agriculture	432	432	432
LULUCF	-31975	-31975	-31975
Wastes		0	0
DAC		-63510	-63510
EW		-8250	-8250
BECCS		-49703	-49703
Extra Renewable Energy		22658	22658
Emission from NG			1183
Total	**222453**	**123647**	**124831**

Table 31. 2030 Official Balance including everything.

CO_2 Reduction	43,88 %
CO_2 Stored (of reduction)	59,37 %
Ratio future energy consumption vs current consumption	5,0
Increase total electric energy consumption	396 %
Import of NG	2,1

Table 32. 2050 Emissions.

	Official balance (kt CO_2)	**Official balance including DAC and CCS for ERCD (kt CO_2)**	**Official balance including DAC and CCS for ERCD and LC from NG and REN (kt CO_2)**
Energy (1)	195000	195000	195000
1A1	32653	32653	32653
1A2	40473	40473	40473
1A3	82302	82302	82302
1A4	34238	34912	34912
1A5	674		0
1B	4661	4661	4661
Industrial processes and use of products (2)	23991	23991	23991
2A	13769	13769	13769
2B	4406	4406	4406
2C	4776	4776	4776
2D	1039	1039	1039
Agriculture	432	432	432
LULUCF	-31977	-31977	-31977
Wastes		0	0

DAC		-92509	-92509
EW		-30750	-30750
BECCS		-68827	-68827
Extra Renewable Energy		21459	21459
Emission from NG			-7452
Total	**187446**	**16819**	**9367**

Table 33. 2050 Official Balance including everything.

CO_2 Reduction	95,00 %
CO_2 Stored (of reduction)	55,92 %
Ratio future energy consumption vs current consumption	4,8
Increase total electric energy consumption	382 %
Import of NG	-13,4