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COMPARISON OF GGR TECHNOLOGIES FOR CO2 CAPTURE FROM THE ATMOSPHERE: TECHNO-ECONOMIC ASSESSMENT

J.A Arewa

School of water, energy and environment Cranfield University, Cranfield, United Kingdom.

Abstract

CO_2 capture from the atmosphere has been extensively discussed as a good climate change mitigation option. Especially in meeting the 2015 Paris agreement of limiting future warming to below 1.5^0C. there are misconceptions about the technologies for capturing CO_2 from the atmosphere. The speculation on the long-term costs as well as energy, and mitigation potential. This could be a setback for GGR Technologies anticipated positive impact in greenhouse gases and energy system. This study set out to compare and determine the TRL, mitigation potential, CAPEX and OPEX of the following GGR technologies, Bioenergy with carbon capture and storage, Biochar, Artificial tree and Soda-lime technique. The method used for the techno-economic assessment was based on data obtained from various published literature and were analyzed through calculating their potential for over 30 years. The result of this assessment shows that these technologies can make a positive impact in achieving the 2015 Paris agreement. Even though most of these techniques require more investment financially and technically, this project work contributes to the recent historiographical debates concerning GGR technologies.

Keywords: Mitigation potential, CAPEX, OPEX and TRL.

1.0 Introduction

To reduce the negative impact of climate change on humanity and the planet. One hundred and ninety-four countries of the world plus the European Union in 2015 signed an agreement called the Paris agreement to limit future warming to a temperature less than 1.5^0C (Dowling and Venki, 2018). To achieve the 2015 Paris agreement, then it becomes necessary to remove CO_2 from the air. This introduced us to an acronym 'GGR' which mean greenhouse gas removal. It's a technology for recapturing an already emitted greenhouse gases from the atmosphere and ocean (Haszeldine *et al.*, 2019). GGR Technologies can play a useful role in meeting the 2015 Paris agreement of reducing the temperature to below 1.5^0C. There are several methods of GGR

Technologies which can be considered viable at large scale for CO_2 capture. Such as Afforestation, reforestation and forest management, Wetland, peatland and coastal habitat restoration, soil carbon sequestration, Biochar, Bioenergy with carbon capture and storage (BECCS), Ocean fertilization, building with biomass, Enhanced terrestrial weathering, Mineral carbonation, Ocean alkalinity and Direct air capture and carbon storage. This project work deals with the comparison of some GGR technologies for CO_2 capture from the atmosphere: Techno-economic assessment. The main objectives of the work are to use the work (Dowling and Venki, 2018) of literature and quantify the amount of CO_2 that can be capture from the atmosphere in the next 30 years by each of the selected GGR Technologies, to calculate the Capex and Opex cost of each technology for 30 years. The study is limited to four different GGR Technologies, which were chosen based on the technology readiness level (TRL) and exemplified alternative strategies for achieving harmful emissions (Santos, Gonçalves and Pires, 2019). The proposed GGR Technologies for this study are, Biomass energy with carbon capture and storage (BECCS), Artificial trees, The soda/lime process and Biochar. The techno-economic assessment is not based on original research but was done based on available data on literature survey combined with judgement and engineering calculations.

1.1 BECCS (Bioenergy with carbon capture and storage) technology

(Mitigation, 2019) Defines BECCS as the utilization of biomass for energy source and the capture and permanent storage of CO_2 generated during a biomass conversion for energy production. BECCS it is mostly used in two methods which are the utilization of the biomass-combustion and conversion, also in the conversion of biomass either through fermentation or digestion for the production of gaseous or liquid fuels (Mitigation, 2019).

(Restrepo-Valencia, S and Walter. A, 2019) reported a case study of techno-economic assessment of bio-energy with carbon capture and storage process in a typical sugarcane mill in Brazil. They used a method of computational simulation considering CO_2 arrest from fermentation and due to biomass combustion. The result obtained from both systems shows that CO_2 capture using BECCS technology in each order is feasible. It was discovered that CO_2 capture from combustion have a high impact on extra electricity and CO_2 capture from fermentation system was recommended as the best due to the low effect on the mill and the low cost on the ethanol carbon footprint. The cost of CO_2 avoided emissions on each system was approximately 62 €/ tCO_2.

1.2 Artificial tree technology

CO_2 capture from the air using an artificial tree: Is the process of directly capturing CO_2 from air using a chemical absorbent, depending principally on the wind to effect mass transport of air across an absorbent (Workman *et al.*, 2011)? (Santos, Gonçalves and Pires, 2019) reported a case study on artificial tree based on estimated data obtained from the literature that long term cost of an artificial tree of 500 m^2 area is approximately \$20,000 and each of the trees can capture 10.0 tCO_2/day which requires 15 days of annual maintenance. One major disadvantage of the artificial is that it requires a large area for installation (Santos, Gonçalves and Pires, 2019).

1.3 Biochar technology

Biochar: this is biomass that has been changed over to disintegration-resistant charcoal. Which is created when biomass is heated with small or no oxygen so as to drive off volatile gases and desert carbon. This is known as pyrolysis process. Whenever Biochar is added to the soil, it can sequester carbon for thousands of years (Belenky *et al.*, 2018). Mitigation potential of Biochar depends on the following factors: Temperature, feedstock used for pyrolysis, soil fertility and fuel type being offset (Belenky *et al.*, 2018). The mitigation potential and cost of production of Biochar are 6.6 Gt CO_2e/year and \$35-\$300/t CO_2 (Belenky *et al.*, 2018). These included the cost of feedstock collection, pyrolysis, transportation and handling for soil application. Resources demand the grow of Biochar are land and water source (Belenky *et al.*, 2018).

1.4 Soda-lime technology

This technique uses an dissolvable sodium hydroxide to capture CO_2 in the atmosphere in a conventional scrubbing column (Santos, Gonçalves and Pires, 2019). The soda-lime component is calcium hydroxide which is about 75%, Sodium hydroxide 4%, and water is approximately 20%. When air comes in contact with soda-lime, then CO_2 reacts with water and hydroxides on the granule surface (Wallace, 2005).

(Wallace, 2005) described the process of CO_2 capture using soda-lime by an equation.

$$CO_2 + H_2O = H_2CO_3 \quad (1.1)$$

$$2H_2CO + 2NaOH = Na_2CO_3 + 4H_2O + Heat \quad (1.2)$$

$$2Ca\,(OH)_2 + Na_2CO_3 = 2CaCO_3 + 2NaOH + Heat \quad (1.3)$$

(Santos, Gonçalves and Pires, 2019) Reported a case study of the energy requirement and cost of soda-lime technology for CO_2 direct air capture. They said that to achieve a benchmark of 0.1 ppm/year in CO_2 atmospheric reduction then the process will require 39.6 GWe of Work energy, 148.6 GW of heat energy and a total cost of approximately 155 \$/tCO_2e. Water lost from the scrubbing tower was noticed as a challenge in this technology as a result of humidification airflow, which may restrict the location where towers can be sited.

2.0 Methodology

The method used for the assessment was based on data obtained from published works of literature. The needed scale of GGR technologies contribution can be approximately predicted by comparing collective emissions budgets and output concentrations under practical frameworks (Raper, 2010) and calculated secured collective budgets or applications.

Data were obtained from repeated web searches, solely using Google scholar, giving an extensive literature catalogue, scoping search was done for the categorization of GGR technologies, which was then occupied with information (data) from the previous searches, communication was done through mails with other researchers in the field to get more knowledge and links for good information sources such as published literatures.

3.0 Why these four (BECCS, Biochar, Artificial trees, and Soda-lime) techniques?

These techniques were selected because they illustrate possible strategies for attaining harmful emissions (Santos, Gonçalves and Pires, 2019). In the case of Bioenergy with carbon capture and storage. There is an existing large-scale plant in Illinois USA (POST, 2017). Biochar technique can sequester CO_2 emissions by 12-84%, which is also advantageous by converting Bioenergy into the carbon-negative scenario (Mulabagal *et al.*, 2016). The soda-lime technique has the advantage of been regenerated at a lower temperature and with notable less power consumption compared chemical scrubbers. As such, this will help in reducing the cost of carbon capture (Williams *et al.*, 2019). In the case of an artificial tree, there is an existing laboratory plant in Arizona state University USA. Klaus Lackner predicted that artificial trees technique could sequester carbon dioxide 1,000 times faster than a natural tree does (Engelbrecht, 2007).

3.1 Assessment criteria and comments

1. Technology readiness level (TRL): The technology should be a bit theoretically proven, and leading into practical laboratory testing to obtain a right level of conviction regarding the technique achievement on the other standard identified.
2. Mitigation potential: The technology can make a remarkable contribution to the general degree of the needed harmful emission and does not go into several technical challenges.
3. CAPEX and OPEX: The technology should be affordable, easy to operate and maintain at a large-scale plant.

3.2 Technology Readiness Level (TRL)

3.2.1 Bioenergy with carbon capture and storage (BECCS)

The TRL of this GGR technology is 6. Knowing that Bioenergy from a biomass-based power plant is a developed technology. The combination of the two that's Bioenergy with Carbon capture and storage plant is still at the demonstration stage (Dowling and Venki, 2018)

3.2.2 Biochar Technology

The Technology Readiness Level (TRL) of Biochar for greenhouse gas removal is described based on the type of Biochar; Briquetting biochar is having 9, Gasification biochar 7-8 and Pyrolysis biochar is 5-6 TRL (Clare *et al.*, 2015).

3.2.3 Artificial tree Technology

This technology has a TRL of 3-5. It is still at the prototyping stage and requires More commercial and technical investment to enable the technology to grow for business operations (McLaren, 2011).

3.2.4 Soda-lime Technology

The TRL of this Technology is 3-4. This technology is still under study and requires further investigation for a large-scale operation (McLaren, 2012)

3.3 Mitigation potential, CAPEX and OPEX

Even though no works of literature specify the OPEX cost of the GGR technologies, but (Linde, 2016) presented a case study that the OPEX cost of for carbon capture technologies is 2.65/tCO_2 (2.98 USD/t CO_2). Therefore, it is assumed that the OPEX cost of these GGR techniques is the same as that presented by Linde above. Details of the expected OPEX cost can be check-in in Appendix A.

3.3.1 Bioenergy with carbon capture and storage (BECCS)

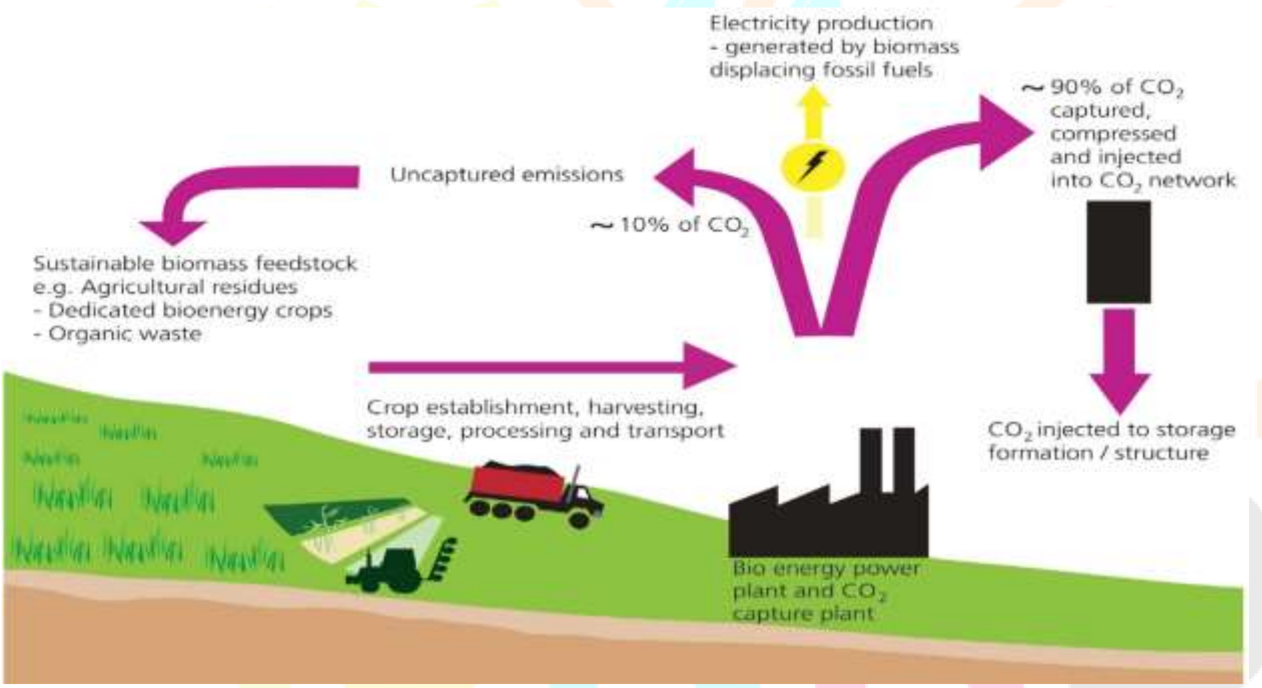

Figure 3. 1: Perception diagram of BECCS process from feedstock generation to combustion for electricity production and CO_2 sequestration obtained from (Santos, Gonçalves and Pires, 2019)

This technology has to do with the direct combustion or co-combustion of biomass in a conventional power plant that is fitted with carbon capture and storage, which may be in the form of solid, liquid or gaseous phase. When growing biomass such as plants and trees then, CO_2 is a capture from the atmosphere through a process called photosynthesis. This process involved the harvesting, storing, drying and transforming of the biomass into chips or pellet. The raw biomass (fuel) is transported to a biomass power plant, where it can be further processed for power generation. The energy generation plant may be likely to be entirely or partly burned with biomass as an energy source. This technology can create harmful emissions of CO_2 through net capture of carbon from the atmosphere. The technology is growing fast and gaining recognition by many agencies, more especially the United Kingdom Energy Institute picked interest in researching more on the subject. BECCS has gained a lot of attraction in capturing CO_2 from the air as a result of electricity generation from a biomass-fired power plant.

Table 3. 1 Mitigation potential, CAPEX and OPEX for BECCS technology

Technology	**Mitigation potential (Gt CO_2/year)**	**CAPEX (USD/t CO_2)**	**OPEX (USD/t CO_2)**	**Source**
BECCS	10	250	2.98	(Tamaryn Napp *et al.*, 2017) and (Linde, 2016)

3.3.2 Biochar Technology

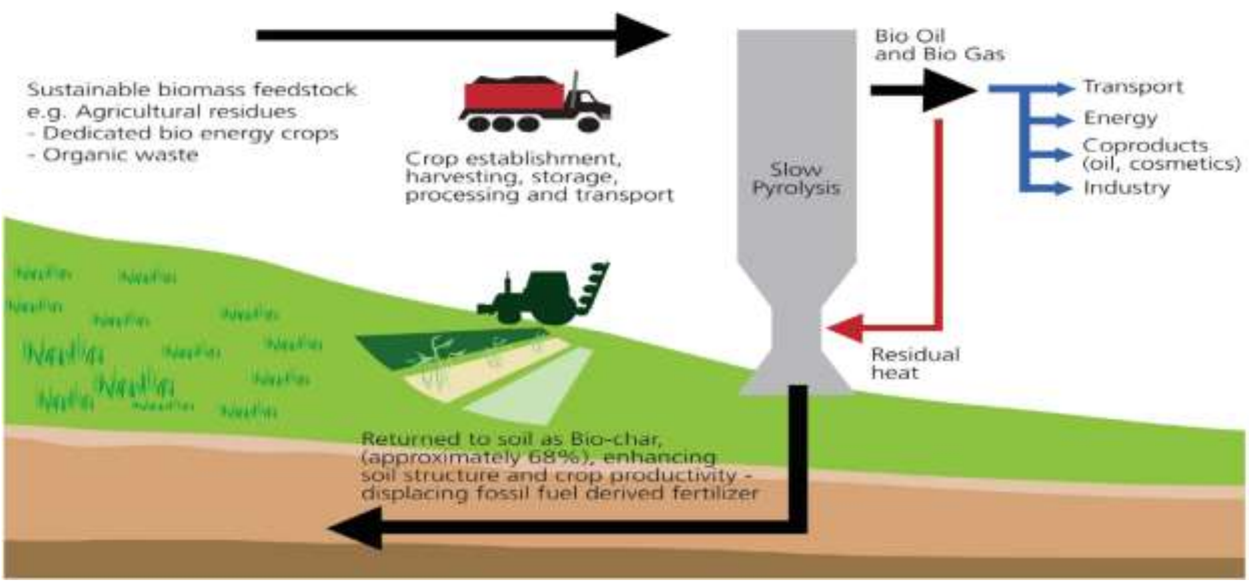

Figure 3. 2: Perception diagram of biochar process for CO_2 sequestration from feedstock manufacturing to low-temperature pyrolysis and the application of Biochar to soil to increase soil fertility obtained from (Santos, Gonçalves and Pires, 2019)

This technology is produced as a result of thermal decomposition of biomass where there is an absence of oxygen in the process. This is known as pyrolysis, which is turned into a stable, long-lived product as that of charcoal. This technology (Biochar) biomass carbon in the nature that is less resistant to disintegration (*Biochar for Environmental Management*, 2015) and can maintain organic matter attached to soil (Han Weng *et al.*, 2017). In this condition, carbon can be reserved in the soil for an expanded session, while at the same time provide a diverse soil fertility and soil grade mutual gains. Examples are upgrade water and nutrient reservation and excessive crop earnings (Jeffery *et al.*, 2017). Biochar is figured out to be steadier than soil organic matter, so should continue higher. Moreover, there are unpredictability's related to decomposition degree of various types of Biochar which mostly depends on the feedstock and temperature used during pyrolysis.

Table 3. 2 Mitigation potential, CAPEX and OPEX for biochar technology

Technology	**Mitigation potential (Gt CO_2/year)**	**CAPEX (USD/t CO_2)**	**OPEX (USD/year)**	**Source**
Biochar	3	300	2.98	(McLaren, 2012) and (Linde, 2016)

3.3.3 Artificial trees technology

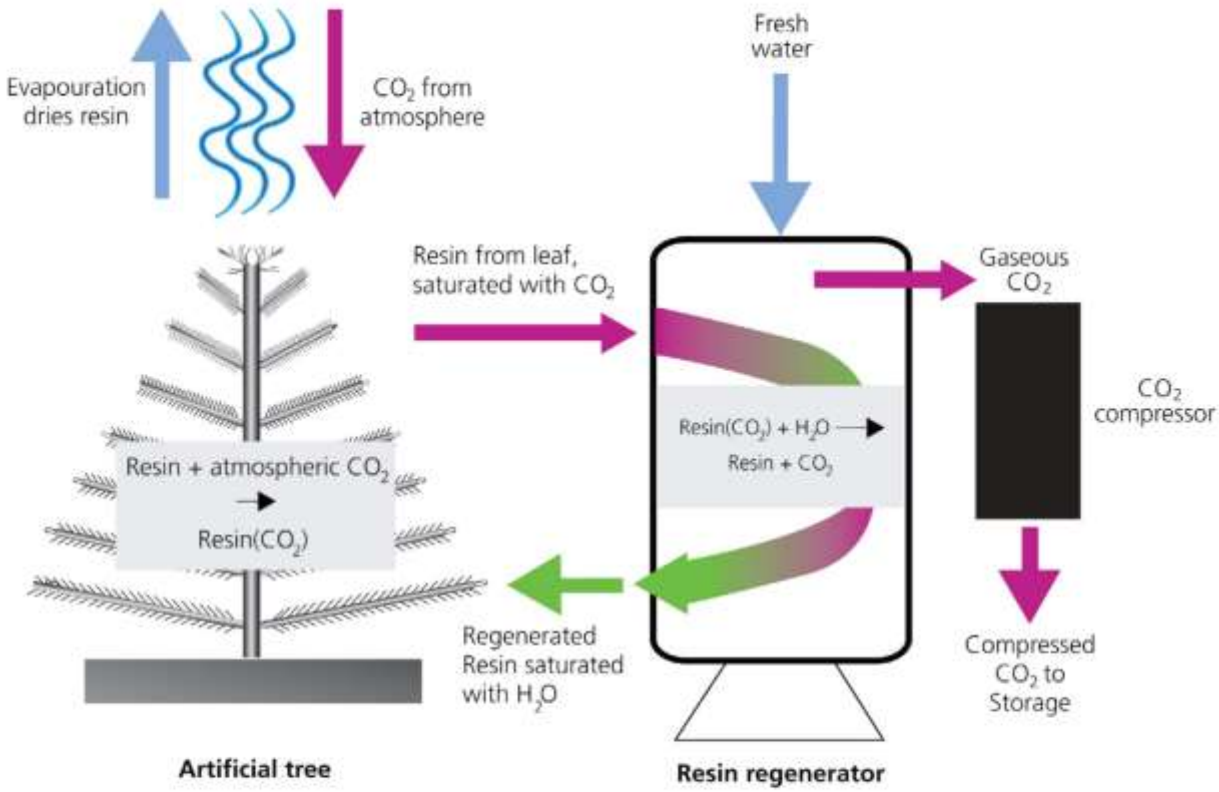

Figure 3. 3: A recommended arrangement of an artificial trees process obtained from (Santos, Gonçalves and Pires, 2019)

This technology is a group under pressurized, direct air capture (DAC). The surface assimilation (Adsorption) of CO_2 directly from the atmosphere with the use of amine in solid shape, hang on a branched substructure. The process is described as artificial trees. The CO_2 is retrieved from the amines by the washing in a vacuum cleaner, pressurized and force into the geological storehouse (Lackner, 2009). Artificial trees technology is considered to delivered theoretically multiple Gt CO_2 pa segregate by 2050. They are incredibly scalable. The product from the artificial tree is a flow of mostly natural CO_2 at high pressure set for sequestration. One hundred million units of Lackner's artificial trees each has the potential of capturing 1 Mt CO_2/day. Assuming 365 days of operation a year, then the mitigation potential will be 3.65e-7 Gt CO_2/year (Engelbrecht, 2007).

Table 3. 3. Mitigation potential, CAPEX and OPEX for artificial trees technology

Technology	**Mitigation potential (Gt CO_2/year)**	**CAPEX (USD/t CO_2)**	**OPEX (USD/year)**	**Source**
Artificial trees	3.65e-7	200	2.98	(Engelbrecht, 2007), (McLaren, 2011) and (Linde, 2016)

3.3.4 Soda-lime Technology

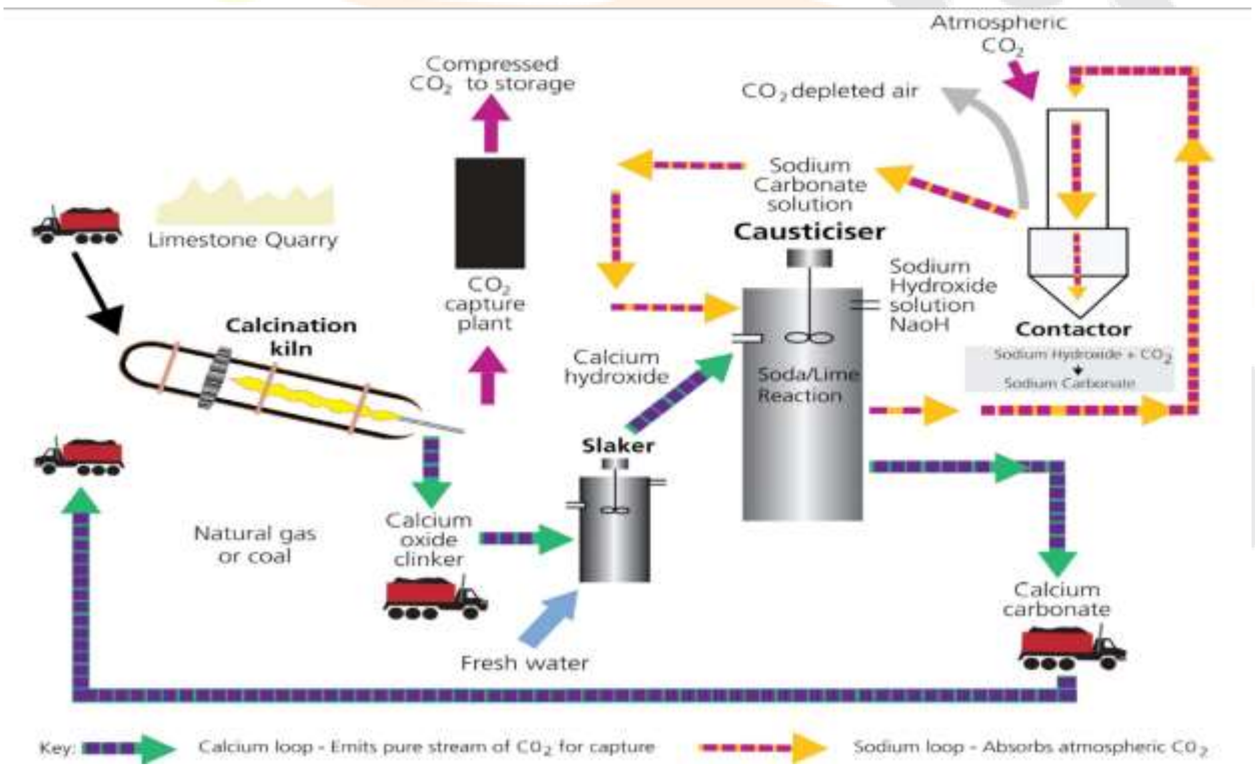

Figure 3. 4: Recommended arrangement for the soda-lime cycle which has to do with the conversion of Calcium carbonate to lime obtained from (Santos, Gonçalves and Pires, 2019)

This technology is similar to the artificial tree's process however uses functional (that's the energy required for CO_2 capture) slightly than passive CO_2 capture. Alkali absorbent-aqueous Sodium hydroxide transferred is exposed to the atmosphere through a standard scrubbing column arrangement (Socolow *et al.*, 2011). The emerging solution of sodium carbonate is then restored by reacting it with calcium oxide (lime) in a reaction called soda/lime. The calcium oxide may be generated in furnace-related to those used in a cement factory. The precipitates in the result are calcium carbonate, leaving an extract of sodium hydroxide solution. This process may be repeated for absorption in the washing columns. This process of cycling requires an energy input, majorly in the calcium oxide furnaces, for CO_2 compression to enable the transportation of the compress CO_2 in a pipeline. The tower product which is a carbonate/alkali solution moving with an absorbed CO_2, which may be reproduced in a two-step system.

This process looks a bit complicated. But the total effect is clearly to produce a concentrated CO_2 surge from the dilute CO_2 in the atmosphere.

Table 3. 4 Mitigation potential, CAPEX and OPEX for soda-lime technology

Technology	**Mitigation potential (Gt CO_2/year)**	**CAPEX (USD/t CO_2)**	**OPEX (USD/year)**	**Source**
Soda-lime	1	180	2.98	(McLaren, 2012) and (Linde, 2016)

1.5 Calculated Mitigation potential, CAPEX and OPEX cost for the GGR technologies.

Data obtained from literature were used to calculate the parameters in Table 3.5 for the period of 30 years at an interval of 5 years period starting from 2020 to 2050. The details of the calculation can be obtained in Appendix B1, Appendix B2, Appendix B3 and Appendix B4.

Table 3. 5. Calculated Mitigation potential, CAPEX and OPEX cost for the GGR technologies.

Bioenergy with carbon capture and storage (BECCS)

Year	Mitigation potential (Gt CO2/year)	CAPEX (USD)	OPEX (USD)
2020	10	2.5e+12	2.98e+10
2025	50	2.5e+12	1.49e+11
2030	100	2.5e+12	2.98e+11
2035	150	2.5e+12	4.47e+11
2040	200	2.5e+12	5.96e+11
2045	250	2.5e+12	7.45e+11
2050	300	2.5e+12	8.94e+11

Biochar Technology

Year	Mitigation potential (Gt CO2/year)	CAPEX (USD)	OPEX (USD)
2020	3	9.0e+11	8.94e+09
2025	15	9.0e+11	4.47e+10
2030	30	9.0e+11	8.94e+10
2035	45	9.0e+11	1.34e+11
2040	60	9.0e+11	1.79e+11
2045	75	9.0e+11	2.24e+11
2050	90	9.0e+11	2.68e+11

Artificial tree Technology

Year	Mitigation potential (Gt CO_2/year)	CAPEX (USD)	OPEX (USD)
2020	3.65e-7	7.30e+04	1.09e+03
2025	1.825e-6	7.30e+04	5.44e+03

2030	3.65e-6	7.30e+04	1.09e+04
2035	5.475e-6	7.30e+04	1.63e+04
2040	7.3e-6	7.30e+04	2.18e+04
2045	9.125e-6	7.30e+04	2.72e+04
2050	1.825e-5	7.30e+04	3.26e+04

Soda-lime Technology

Year	**Mitigation potential (Gt CO_2/year)**	**CAPEX (USD)**	**OPEX (USD)**
2020	1	1.8e+11	2.98e+09
2025	5	1.8e+11	1.49e+10
2030	10	1.8e+11	2.98e+10
2035	15	1.8e+11	4.47e+10
2040	20	1.8e+11	5.96e+10
2045	25	1.8e+11	7.45e+10
2050	30	1.8e+11	8.94e+10

4.0 Result

Table 4.1 and Figure 4.1,4.2, and 4.3 represent the discovery of the evaluation. Beneath, the primary findings of the assessment are set out, initial readiness level, mitigation potentials, Capex and Opex cost.

Table 4. 1. Technology Readiness Level of each technology.

Technology		**Technology Readiness Level (TRL)**
BECCS		6
Biochar	Gasification	7-8
	Pyrolysis	5-6
Artificial tree		3-5
Soda-lime		3-4

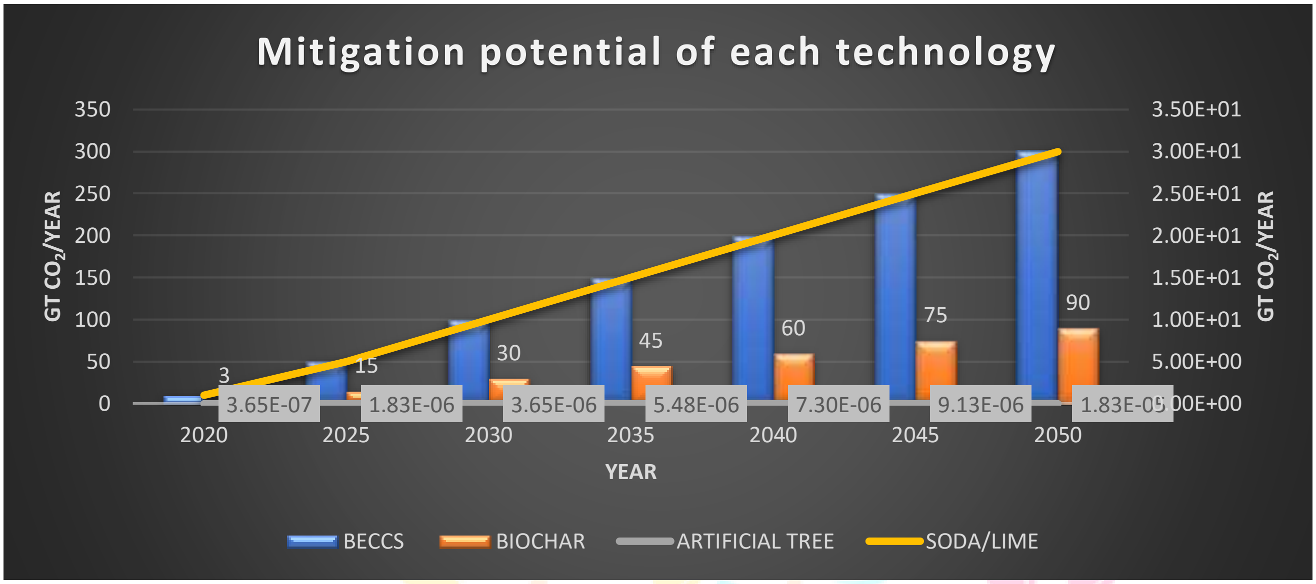

Figure 4. 1: Mitigation potential of each technology

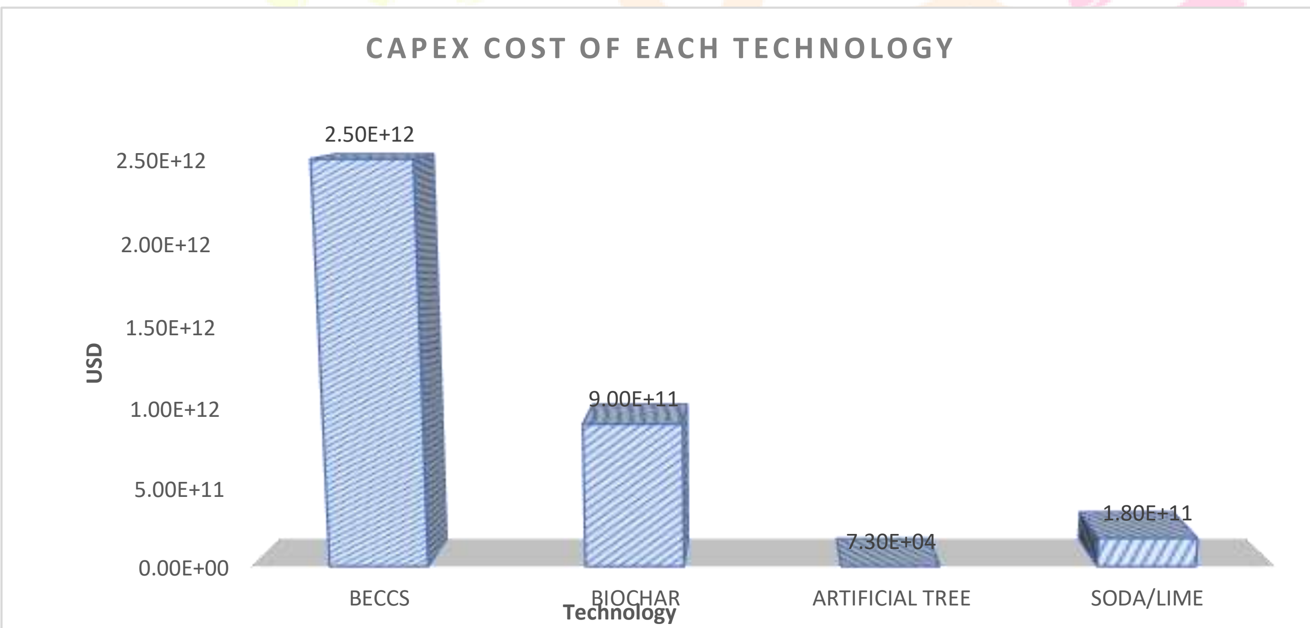

Figure 4. 2: CAPEX cost of each technology.

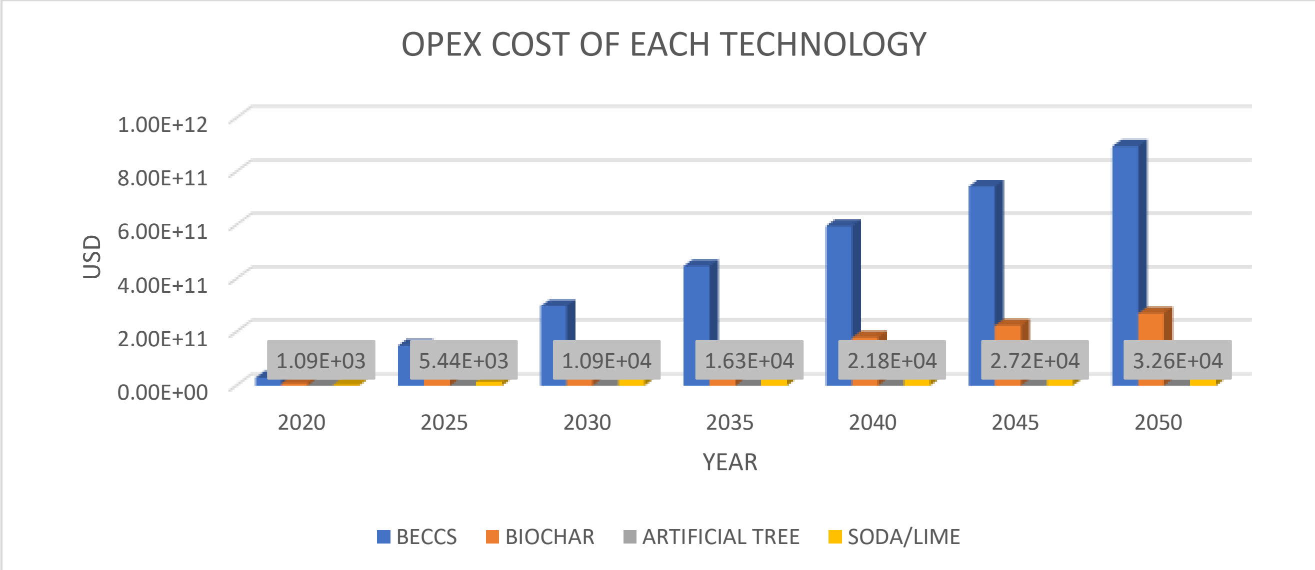

Figure 4. 3: OPEX cost of each technology

5.0 Discussion of Result

5.1 Technology Readiness Level (TRL)

5.1.1 Bioenergy with carbon capture and storage (BECCS).

From Table 4.1, this technique has a technology readiness level of 6.US Department of Defense (2008) describe TRL 6 as a process model manifestation in a suitable environment.

5.1.2 Biochar technology.

It was reported in Table 4.1 that biochar gasification and pyrolysis has TRL of 7-8 and 5-6. The data means that biochar gasification is a prototype illustration in the operating environment and the real process 'satisfied' through test and diagram. While biochar pyrolysis is in at the stage of radical acceptance in relevant environmental and process model manifestation in a suitable environment.

5.1.3 Artificial tree technology.

From Table 4.1, the TRL of this technique is 3-5. The data means that it is between the analytical and empirical critical function illustrated and the stage of radical acceptance in a relevant environment.

5.1.4 Soda-lime technology.

As reported from the findings in Table 4.1, this technique has a TRL of 3-4. The TRL of 3-4 means that it is at the stage of analytical and empirical critical function illustrated and element recognition in laboratory conditions.

5.2 Mitigation potential

Figure 4.1 shows the results of the mitigation potential of each GGR technology studied in this research work. The mitigation assessment is carried out for 30 years. From 2020-2050 and it was reported in 5 years period. The data on y-axes represent the mitigation potential in Gt CO_2/year, and the reading of the yellow line of best fit (Soda/lime) is on the y-axis at the right. The x-axis represents the year in 5 years.

5.2.1 Bioenergy with carbon capture and storage technology.

From Figure 4.1, this technique could deliver 10 Gt CO_2/year globally as described by researchers from the work of literature. Base on the assessment carried out in this research work, and it was discovered that the technique has the potential to sequester about 300 Gt CO_2 for 30 years using a plant capacity of 10 Gt CO_2/year globally. (McLaren, 2011) pointed out some limitation of this technique, such as the limitation in bio-feedstock supply and the fixed land for feedstock grow.

5.2.2 Biochar technology.

From Figure 4.1. Biochar technique has a mitigation potential of 3 Gt CO_2/year globally. The result of the findings in this research work showed that this technique has the potential to sequester up to 90 Gt CO_2 with 30 years globally. Some of the limitation of this technique as reported by (McLaren, 2011) is that the method may not meet the sequestration target of 36 Gt CO_2 emitted annually (Engelbrecht, 2007). This challenge is as a result of the limited sustainable biomass feedstocks, and Biochar may face opposition from other uses for feedstock, decreasing size below the conceptual uttermost (McLaren, 2011).

5.2.3 Artificial tree technology.

This technique currently is still at the laboratory stage. From the result, in Figure 4.1, each unit of this technique has the potential to sequester 3.65E-07 Gt CO_2/year globally. The result of the analysis obtained shows that each group of the method has the potential to sequester 1.83E-05 Gt CO_2 within 30 years globally. Lackner's reported that for this technique to meet up with the current target of 36 Gt CO_2 emitted annually at a global capacity. Then, there is a need to have 100 million units of this technique (Engelbrecht, 2007). Some of the limitations of this technique is the lack of enough sustainable geological storage for a processed CO_2 and the inefficient carbon power to operate the system (McLaren, 2011).

5.2.4 Soda-lime technology.

This technique has the potential of capturing 1 Gt CO_2/year and 30 Gt CO_2 within 30 years globally. The method requires enough investment technically to be more effective in sequestering the 36 Gt CO_2 emitted annually at a global capacity. The technique is faced with some challenges such as the limited availability of vessels and trans-shipment equipment's, limestone and the power source that will be used for the system (McLaren, 2011)

5.3 Capex cost

Figure 4.3 represents the result of the findings for the CAPEX cost of each technology studied. Bioenergy with carbon capture and storage technique has a CAPEX cost of 2.50E+12 USD for each 10 Gt CO_2/year. This technique has the highest CAPEX cost, which may be a result of the vast mitigation potential of 10 Gt CO_2/year.

Biochar technology has a CAPEX cost of 9.00E+11 USD, which is the second-highest CAPEX cost among all the techniques studied. This CAPEX cost could be as a result of the highest in mitigation potential that's after Bioenergy with carbon capture and storage technique.

Artificial tree technique has the lowest CAPEX cost of 7.30E+04 USD. The CAPEX cost maybe does to the level in mitigation potential of 3.65E-07 Gt CO_2/year.

The soda-lime technique has a CAPEX cost of 1.80E+11 USD. This technology may be highly effective in meeting or contributing to the Paris agreement target. But requires more in financial and technical investment.

5.4 Opex cost

Figure 4.3 showed the result of the OPEX cost for each of the four GGR technique studied. Bioenergy with carbon capture and storage plant capacity of 10 Gt CO_2/year have an annual OPEX cost of 2.98e +10 USD and a total OPEX cost of 8.94e +11 USD for the 30 years. 3 Gt CO_2/year biochar plant capacity has an annual OPEX cost of 8.94e +09 USD and an overall operation and maintenance cost of 2.68e +11 USD for the 30 years. Artificial tree plant capacity of 3.65e-07 Gt CO_2/year have an annual OPEX cost of 1.09e +03 USD and a total operation and maintenance cost of 3.26e +04 USD for the 30 years studied. Soda-lime technique plant capacity of 1 Gt CO_2/year plant capacity has an annual OPEX cost of 2.98e +09 USD and overall operation and maintenance cost of 8.94e +10 USD for the 30 years studied.

6.0 Conclusion

This study set out to compare and determine the mitigation potential, CAPEX and OPEX of the following GGR technologies, Bioenergy with carbon capture and storage, Biochar, Artificial tree and Soda-lime technique. The result of this assessment shows that these technologies can make a positive impact in achieving the 2015 Paris agreement. Even though most of these techniques require more investment financially and technically, this project work contributes to the recent historiographical debates concerning GGR technologies. It is now clear that GGR technologies have great potential in sequestering significant amounts of CO_2 from the atmosphere. The study is limited to mitigation potential, CAPEX and OPEX. The OPEX cost of GGR technologies is not available on the works of literature, and it was assumed the OPEX data obtained from the research for industrial process carbon capture storage in Appendix A. More information such as land use, water, energy and societal impact on GGR technologies would help to establish a higher degree of accuracy on these technologies.

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