An Explanatory Framework for the Implementation of Carbon Capture and Sequestration

By Artmiz Mahmoudzadeh, Nasser Rizk, Suaad Elmi, Pedro Cintron,

Bryce McCue, and Patrick Eaton

Abstract

Using current research and interviews with experts, our team created an explanatory framework describing how CCS technology would be implemented. We concluded that large scale implementation of CCS technology would be needlessly expensive and inefficient when compared to renewable energy.

Introduction

Climate change is a growing existential threat to humanity; The only way to stop it is to lower our emissions. To do that, we will have to adopt and implement new technologies, such as renewable energy and carbon capture. We will focus on carbon capture in this project, and how it will fit into a larger strategy to combat climate change and reduce emissions.

Capture Methods

Pre-combustion

Pre-combustion is a method that removes the carbon from the fuel source before power generation. It is an experimental technology with huge capital expenses (Wilberforce et. al. 2019). We will not focus on this method for this project because it is the least viable of the three methods

Post-combustion

Solvent

Post-combustion aims to remove carbon from flue gas. This capture method uses a chemical solvent. The solvent forms weak chemical bonds with CO2 in the flue gas. It is then heated to separate the CO2 (Raksajati et. al. 2018). The heat necessary for the reaction dictates the energy cost of this method.

Membrane

Other options for post-combustion carbon capture include membrane-based technology. This uses a membrane coated with enzymes to capture CO2 from exhaust gas. Unlike chemical absorption, membrane absorption does not involve a solvent. An enzyme coats the membrane and captures CO2 from flue gas. Limiting factors include thermal degradation at high temperatures, as well as high pH in flue gas rendering the membrane unusable (Yong et. al. 2017). Despite its limitations, this technology is promising for carbon capture at lower operating temperatures, such as separating CO2 from methane in biogas purification (Yong et. al. 2017) While other coatings such as zinc cyclin are viable catalysts for carbon capture at industrial temperatures (Floyd et. al. 2013).

Oxy combustion

The final method of carbon capture is oxy combustion. The process uses pure oxygen during combustion to remove nitrogen and ash from the flue gas stream, resulting in the flue gas composed of CO_2 and water (and some impurities) (Wilberforce et. al. 2019). While promising, oxyfuel capture introduces complications. Burning pure oxygen requires a higher temperature than air which complicates oxy-fueled boiler design (Wilberforce et. al. 2019).

Storage, Sequestration, and Utilization

Oceanic Sequestration

A popular method of carbon storage is Oceanic injection of a pure CO2 stream deep in the ocean. One technique pumps CO2 into a trench on the ocean floor, forming a CO2 lake. Liquefied CO2 injected at approximately 3000 m depth remains stable (O'Connor et al 2001). The oceanic sink capacity for CO2 sequestration is around 5000-10 000 Pg C (These units are peta-grams also as gigatons), larger than storage in depleted fossil fuel reservoirs (Herzog et al 1997, 2002). The cost of operating a project and the risk of CO2 leaking into the ocean causing devastating effects for marine life are serious problems with this method. It will require more research before large scale use.

Geological Sequestration

We can store carbon underground as well. This method requires the liquefaction of CO2 before pumping it into coal seams, old oil wells, stable rock sediment, or saline aquifers (Tsang et al 2002; Klara et al 2003; Baines & Worden 2004; Gale 2004). This method of storage involves less risk of leaking, since the carbon is stored under sedimentary rock and can react with the dissolved salts in water. This creates an aqueous solution, reducing the amount of carbon dioxide.

Biological

Biological storage is the most cost effective, environmentally safe, and least hazardous of the storage methods. One method, Soil carbon sequestration involves putting CO2 into the surface layer of soil: 0.5-1 m deep, where humification can take place. Humification is a process that occurs naturally in the soil, or in the production of compost, which make humus. Humus is a complex organic substance resulting from the breakdown of plant material. Maintaining this process requires integrated nutrient management, and it is essential to soil carbon sequestration (Himes 1998). An imbalance in Nitrogen and Carbon in the soil reduces the storage capacity (Paustian et al 1997). Evaluating the maintenance of soil carbon storage is a reason why industrial companies may turn away from the process. This process is not an immediate solution; it requires time for soil to convert the CO2.

Renewable and Non Renewable Energy

Wind

In 2019, wind turbines generated 24% of the United States' renewable energy, compared to 9% from solar power (Aggarwal, 2020). The main advantage wind has over solar is the ability to function 24 hours a day. Wind turbines must sit above obstacles that would block airflow to maximize their efficiency. Wind turbines are suited for the tops of smooth, rounded hills; open plains and water; and mountain gaps (U.S. Energy Information Administration, 2020). Offshore wind farms in coastal regions harness the wind in open water. With a variety of locations suitable for wind generation, many nations can utilize this technology as it becomes more accessible and efficient. In the United States, the cost of wind has fallen in the last decade: from $135/MWh in 2009 down to $43/MHw in 2018 (Barlett, 2020).

Solar

Solar has a promising future as an energy source. The location of solar collectors is more flexible than that of wind. The main factors in solar energy production are latitude, climate, and weather patterns (U.S. Energy Information Administration, 2020). Solar thermal-electric power plants require direct solar radiation, making them more suited for arid regions with few cloudy days. Flat-plate solar thermal, as well as photovoltaic (PV) collectors, use global solar radiation. This allows the collection of diffused as well as direct solar radiation (U.S. Energy Information Administration, 2020). A rule of thumb for solar is: its efficiency and total annual production increases closer to the equator. Seasonal variance is less at lower latitudes, leading to reliable year-round production. Similar to wind, solar energy has seen major decreases in LCOE (from $359/MWh in 2009 to $43/MWh in 2018), making it far more viable (Barlett, 2020). Solar energy works in residential areas, too. PV panels installed on roofs or on the ground reduce the energy homes draw from the grid. Inland Power & Light, a utility company in the northwestern US, installed both solar and wind technologies at their headquarters in Spokane, Washington. Over the course of 14 months, solar panels produced 5 times as much electricity as residential wind turbines (Aggarwal, 2020).

Hydro Power

Hydroelectric power is the leading renewable energy source because it is consistent and reliable. This form of renewable energy is a process that uses the power of water in motion to generate electricity. This occurs in dams with water held in artificial lakes. When water is released through the dam, it spins a turbine connected to a generator, producing electricity. The water returns to the river on the other side of the dam.

This technology is emission free and reliable , it will never run out unless water flow stops. Modern hydro turbines convert as much as 90% of the available energy into electricity. The best fossil fuel plants are only about 50% efficient(National Hydropower Association, 1996). In the U.S., hydropower produces an average of 0.85 cents per kilowatt-hour (kwh). This is about 50% the cost of nuclear, 40% the cost of fossil fuel, and 25% the cost of using natural gas. From 1985 to 1990 the cost of operating a hydropower plant grew at less than the rate of inflation(National Hydropower Association, 1996). These benefits expand into the job market, where hydropower is projected to create about 195,000 jobs by the year 2050.

The reduction of greenhouse gases is the main benefit of hydro power. If we use hydro power as a main source of electricity; there will be a reduction of 5.6 gigatonnes of CO_2 by the year 2050(Hydro Power Vision, 2016). The use of this clean energy will reduce millions of tons of CO_2 every year, making a near instant CO_2 emission reduction. The implementation process requires altering ecosystems, reducing biodiversity and changing the water quality. There are solutions to make them more sustainable such as: using fish-friendly turbines or lowering their height.

Natural gas

Natural gas is a reliable form of energy more consistent than renewable forms of energy like solar and wind. It is crucial to keep emissions low and natural gas is the perfect alternative for coal since it is very abundant and emits less carbon. According to the EIA the energy needed for production of natural gas is cheaper than coal (IEA, 2015). The most efficient gas-fired plant has investment costs of $1,100 per kilowatt, according to the IEA, compared with $3,700 for the most efficient coal-fired plant(IEA, 2015).

The United Arab Emirates

The United Arab Emirates is a young stable country, in the Middle East.According to the official data from the World Bank, the economy of UAE is the second largest in the Middle East with a Gross Domestic Product of 421 billion US dollars in 2019 (United Arab Emirates GDP, n.d.). The exploitation of natural resources and high energy demand due to the fast population growth has led to environmental challenges. Revenue from petroleum and natural gas play a major role in the economy of UAE, specifically in Abu Dhabi and Dubai (Kader, 2011). A long-term goal for the UAE is to implement sustainable technologies and to reduce its dependence on oil revenue. Evidence of this is in the artificial green city: Masdar. Their aim is to deploy clean energy and pioneer advanced sustainable developments (Hume, 2013).

Climate Change's Impact on The UAE

Loss of wildlife habitat in the deserts, climate change, limited agricultural land and air pollution are dire environmental issues that concern the UAE. According to the Ministry of Foreign Affairs and International Cooperation and the UAE Embassy in the US, UAE is among the countries to be impacted the most by climate change (2020). UAE has a central role in the global economy as a supplier of fossil fuels; therefore, it is focusing on long-term solutions for climate change and to reduce its impact in the future. The major impacts of global warming in UAE are water scarcity, contamination, aridity and rising sea levels.

In 2010, the Stockholm Environment Institute's US center conducted a report for Abu Dhabi; it examined the effects of climate change on: the ecosystem, infrastructure, economy and citizen health (Energy and Climate Change | UAE Embassy in Washington, DC, n.d). The results revealed the UAE can lose around 6 percent of its coastlines to rising sea levels by the end of the century. Furthermore, global warming fluctuates the balance of water supply and demand causing frequent flooding while other areas deal with droughts (Climate change, 2020). Higher temperatures affect agriculture and it increases harmful insect population. Crops will suffer from salt water. The biology department of the United Arab Emirates University investigated Dust storms and concluded that the reason for the noticeable shift in the frequency and strength of the dust storms are a consequence of climate change (Hamza, Enan, Al-Hassini, Stuut & Dirk de-Beer, 2011).

Renewable Energy and The UAE

The UAE aims to adopt the latest technologies to address carbon emissions and mitigation climate change. The UAE energy strategy 2050 intends to invest AED 600 billion to counter the growing energy demands and to have a 75 percent power output from clean energy. By the year 2021 UAE, Dubai aims to reduce Carbon emissions by 16 percent (Renewable energy shaping the future of sustainability, 2020).

Photovoltaic solar panels are UAE's main area of focus to reduce Carbon emissions as it has high radiation releases. In the Emirates News Agency article published by Salman, the implementation of new carbon capture, utilization and storage technologies reduce carbon emissions in the UAE. By the year 2030, they aim to capture five million tons of carbon dioxide (2020).

Our Research

Our research aims to identify the most suitable technology in UAE, to reduce carbon emissions. Economy, technology, environment and politics are important factors our team will consider. Our team will make an in-depth analysis and compare each technology considering its advantages and disadvantages. We will collect expert opinions in the fields of renewable energy sources and Carbon Capture and Sequestration technology from interviews. An important requirement for this research is to understand the power infrastructure, future plans and implementation of renewable energy within the Emirates. This research will make a new perspective on carbon emissions and the technologies to reduce it. It will also be beneficial in creating an awareness about the impacts of climate change and in building a culture to move towards carbon neutral technologies.

Methodology

The main objective of our project is to find out how carbon capture and sequestration (CCS) will fit into a larger strategy to reduce carbon emissions from the United Arab Emirates (UAE). To answer this question, we will need to build an understanding of CCS technology, renewable energy technology, and of the UAE. We are lucky to be working with students from the American University of Sharjah, who will provide in-depth knowledge of the UAE, and our sponsor, Art Foutzitsis, who has decades of experience working in the energy industry.

Data Collection

Our team will interview experts to collect data. We created a criterion for selecting experts. The criterion has three parts, each with a list of requirements. The first was engineering. We wanted to talk to experts who specialized in mechanical, environmental, or chemical engineering as these fields would have the most familiarity with the problems facing CCS implementation. The second part of the criteria was the economics of implementation. Besides the engineering issues, we wanted to learn more about how the cost would affect adoption, and possible ways to mitigate this cost. The last part of the criterion was the political and sociological part. We wanted to know how the UAE's politics affected the implementation, and what the government could to support the implementation of CCS. We then created an interview guide with a list of topics under each category of the criterion. We want the interviews to proceed organically, the guide serves as a loose framework to steer conversation. We will record each interview for transcription and later analysis.

Findings

It is important to discuss our data analysis to show how our team processed this information. This section includes how our team extracted themes from interview transcripts and how we used these themes to build a framework.

The Data Analysis Process

Our team used interviews to collect data. These interviews varied from multiple experts in the field of climate change. Each interviewee provided a different perspective on what the best plan to reduce emissions was, as well as how they fit in our current society. The process of gathering the specific themes required using the software NVivo to make annotations clear and organized. Our team classified themes as codes and sub codes to elaborate on broader terms. Our findings resulted in an explanatory framework describing the implementation of CCS.

Explanatory Framework

After we gathered all of the codes from the transcripts, we built a framework around the resulting data. This framework describes how to implement carbon capture and sequestration based on expert opinion. It consists of two aspects, the social and political aspect, the technical aspect, and two global contextual factors that affect the whole of implementation..

The social and political aspects contain the codes awareness, adaption, and government support. Awareness encompasses the general knowledge of the technologies and of climate change. This is one of our most common codes, appearing in some way in every transcript. We coded text, such as “I think, as I said, an important aspect that probably in your communities you can do is to try to engage the SoC to engage the community,” as awareness because the main topic was increasing the general knowledge on the subject. We also coded text, for example “Creating a passion for having a greener planet has always been a difficulty for all governments. For humans. I'm sorry to say this, but not many people are very passionate about keeping our planet green,” because it follows the awareness theme.

Adaption represents the changes we need to make as a society to address climate change. This theme shares some overlap with awareness; it is, however, distinct enough to be a separate code. We coded any text regarding changing lifestyle, business, or other practices as adaption. The following quote represents a good example: “part of the whole story of sustainability would be how each one of us in future generations will behave now and in the future.” This line appeared in a larger section we coded as both awareness and adoption, awareness because the topic is about teaching future generations about climate change, adoption because it is about teaching *future* generations about climate change and sustainability.

Government support is self explanatory. It describes how governmental support affects the implementation of carbon capture. This is another common one. We coded any text regarding: regulations, subsidies, taxes, laws, or policies as government support. The following is a good example: “Yes, definitely policies should be there and quite strict policies in order to reduce this carbon emission.” We coded it as government support because it discusses policies aimed at reducing emissions.

The technical aspect consists of four parts: efficiency, inefficiency, new technology, sustainability and new technology. We used efficiency or inefficiency to code any text about the technical capabilities of carbon capture or renewable energy systems. We used new technology to code anytime the interview described or discussed any new technology. We focused on codes for new technology aimed at addressing inefficiencies. Sustainability was another very common theme. Every expert stressed that any carbon capture system must be sustainable.

The last two cost and synchronization are global themes affecting each aspect of the implementation. We coded any text as cost if it referenced any form of price, such as energy, financial, or material. Synchronization represents that carbon capture will always be a smaller part of a much larger strategy, and it will have to cooperate with renewables. This code was emphatically stated by one of our experts: “what's the answer to climate change like there's no silver bullet. There's a lot of silver buckshot.”

Overall, this framework means a few things. For one, carbon capture is not ready for wide scale use. There are too many inefficiencies, and the new technology to address them is in development. The current method of carbon capture just does not scale well. On the other hand, renewables are market ready, efficient, and in widespread use. This is not to say we should not use carbon capture and sequestration. Humanity has to do everything possible to lower carbon emissions. Carbon capture is still useful, but renewable energy should be the bulk of our power generation. A way to implement carbon capture would be to use it on “peakers.” These are generators used to make up for peaks and falls in electricity generation. This would address the largest problem with renewables. Solar and wind are intermittent. There are times when the sun is not shining or the wind slows. “Peakers” would then activate and make up for the decrease in power generation. These “peakers” could burn a low carbon fuel, such as methane, and use a carbon capture system to further lower emissions.

Discussion

Political and Sociological

After conducting several interviews, our findings illustrate the constraints of Carbon Capture and Sequestration technology. Through the research, our team found different solutions more suitable than Carbon Capture. The main replacement is renewable energy. A question our team raised during the interviews was the extent to which the use of Carbon Capture should be reduced or replaced. There were some controversies present.

One of the interviewees argued that carbon capture should be used in parallel with renewable energy due to environments, socio economic and political factors. The controversial claim was that Carbon Capture is expensive and there is not much benefit to progress the technology in that field. Instead, research has to go towards renewable energies such as Solar and Wind while the use of fossil fuels should stop. Both arguments hold advantages and disadvantages that we cannot disregard. Therefore, in this section the controversial claims are discussed alongside with their economic, political and environmental constraints and benefits. In addition to that, our findings provide an analysis and relation to the limitations and possible progressions that UAE can implement to reduce its Carbon emissions.

One of the major drawbacks of renewable energy in the UAE is the governmental and public sector's support in different areas of the UAE. In Dubai, there are rapid progressions taking place to enhance the use of renewable energies. Dubai supports Renewable energy companies and Solar panels are sold for private use. However, a less developed city such as Sharjah, is less supportive of new implementation and research in renewable energy. Additionally, Dubai Electricity and Water Authority is a public service infrastructure company in the UAE that charges a large amount for electricity and water services. Therefore, such monopolistic companies constrain the mass usage of renewable energies for their profit benefits. However, building an awareness between people in a society can increase the usage of renewable energies such as Solar to operate their electrical usage. Also, it is important to raise this awareness to build a culture within a society to shift towards renewable energy over time.

Moreover, research and development in renewable energy technologies are progressing rapidly and it is a highly competitive field as new improvements and innovation occur, specifically for solar energy systems. Solar is the more efficient option in comparison to wind energy. The implementation of solar panels is simple; they are installed on rooftops or on the surface of buildings. However, wind requires a vast amount of land and dangers the wildlife. While wind turbines require a high maintenance, solar panels do not. With the emergence of modern technology, nano coating on solar panels, reduces maintenance, and robots can be used to clean the panels. A reason to shift towards solar energy is not subsidizing energy. For example, in Iran, energy and electricity is subsidized. producing electricity in a country like Iran costs more than they are being offered to the customers. Therefore, the government is paying for it. A common use in the solar industry is now mostly Silicon based. Solar has its downsides, for example, Silicon is still a very expensive material. However, a panel gives a minimum 25 years 20 years guarantee. The rate of return of projects, depending on the location of the project, could span from one year and a half to a maximum of five years, making it an economically feasible solution.

If counties have the potential to generate electricity using solar solutions, they could supply the countries around them. This could be an income source for governments. A limitation the government of UAE faces is that it needs to implement regulations on renewable energies.

Even though cities such as Dubai and Abu Dhabi have a beneficial regulatory environment for sustainable and renewable energy, while in Sharjah, it is more difficult to progress because it lacks a beneficial regulatory environment. A strong governmental institute is required to implement renewable technologies in Sharjah, private companies and corporations are constrained to develop the solar industry. Permission from the government is required to go solar and it is expensive. Enhanced regulations are needed in the UAE to urge or motivate people to move towards solar energies for their daily electricity use. Also, electricity prices are very high in UAE, so such implementation will be beneficial to the society. A possible solution for this is that electricity bill should go towards the budget of making a greener society.

The Kyoto Protocol of the United Nations framework convention on climate change has been in effect since 1998. It obliges the parties to combat climate change through relevant requirements, such as the increase of the use of renewable forms of energy and carbon carbon capture technologies. Another convention is the London Convention since 1972. It's an international agreement that prohibits the dumping of wastes at sea. Dumping refers to deliberate disposal of waste at sea. An amendment in 2006, permitted permanent carbon carbon capture under the seabed. A barrier to investment for companies that could be involved with such procedures was removed. Therefore, proceeding with CCS is less narrow now, reflecting the global interest in reaching such solutions.

Carbon Capture and Sequestration (CCS) technology is costly. Governments will need to support it. Usually in the form of either tax breaks or providing grants. From a legal perspective, there are concerns about the leakage of carbon dioxide during transportation. The risk of leakage of carbon dioxide is civil liability leading to litigation by a third party. In addition to that, environmental laws breaches if a leakage occurs. Therefore, a major risk that CCS operators must consider, as in theory the liability would be unlimited. This also poses a great risk for countries that are trying to submit to climate change activities and to proactively reduce the effects of carbon dioxide on global warming.

An alternative to the costly CCS technology is investing in renewable energy for a safer and cleaner energy. However, it will be difficult to convince developing countries and the Middle East since itself is rich in oil and gas. After the Paris agreement to combat the effects of climate change, countries have focused on finding cost-effective and efficient methods to eliminate greenhouse gas emissions. Two countries that have followed the convention by using Carbon Capture are Norway and Canada. In Norway, plants capture CO_2 from gas productions. This project is financed by the Norwegian government (Moe, 2019). Similarly, Canadas has a full-scale plant connected to a coal-fired power plant. In Canada, 90% of emitted carbon dioxide is captured successfully (Bruce. 2018). A major drawback of CCS is the pricing of the transport, capture and storage of carbon dioxide. The European price for carbon dioxide emission is more than EUR 20 per ton. In Norway, this price is 15-25 times higher than in Europe, making it financially unprofitable. However, Norway envisions that in the long-term these prices will be reduced once large-scale operations and reproduction of plants is succeeded. Norway aims to reduce its CO_2 emissions 50% by 2020 and 95% by 2035.

Technical

The framework we developed was a powerful tool to further provide results regarding the sentiment of CCS technology among experts. Overall the feasibility of furthering the research into carbon capture has become unreachable since the benefits of renewable energy shadow the benefits of carbon capture. Our framework depicts that CCS is not ready for wide scale use. The lack of development has created a risk for companies that emit greenhouse gases since there are multiple cost and energy factors to consider. It is not viable for these plants to operate with this technology when they already need to meet demands, especially for a country that relies on fossil fuels for energy.

When it comes to renewables, our framework showed that it is a more developed technology. Although the production of fossil fuels has a great impact for the UAE economy, it is good to reduce reliance on fossil fuel energy. Cleaner energy can benefit the country since the cost of operation is better than setting up a carbon capture and sequestration schematics. The fact that renewable energy is proven to work also plays a big role in furthering which technology is more likely to be adopted. Today, many countries have also begun to phase out fossil fuels and adopt clean energy. These countries are more than enough proof that renewable energy is cost efficient technology and available for wide scale use. Only two plants in the world have successfully converted to CCS as a way to reduce their plant emissions and they are very different in terms of their geological location.

Furthering on why CCS is unproven to work is due to the new technology that is required. As new and better options to cut emissions have risen throughout the years most research and technology for CCS has been stagnant beyond laboratory experiments. This is crucial for the goal of adoption since the challenge to stop climate change is an ongoing problem which will be irreversible within a few years. In the current state of technology, companies will need something that doesn't require the need to wait multiple years of testing. Without widespread awareness of new technology it is just another reason to add on why carbon capture is not viable. Not only is new technology required for the capturing of carbon in plants but also the sequestration. The challenge that unfolds is when considering how storage can work in a country majorly covered in desert land. While geological storage is a method that can work, it is not feasible to do extensive geological research in order to find the best method of storage in an untested geological storage environment.

It is very important to consider storage since it is also the main goal of CCS. The need for a storage site stems from the first challenge of geological research. With geological research though, there needs to be an operating site with constant maintenance. An operation of this size has the potential to become a liability. If CO2 were to depressurize and leak, or is pumped improperly the environment will face major repercussions. Not only that, the company will need to pay for damages that occur at the site on top of the already expensive process to implement sequestration for the captured carbon. When observing these risks, a site for CCS can result in reconsideration of the technology, since there is not enough geological research.

Contextual Factors

The contextual aspect of the framework is made up of two themes: cost and parallel. These are constants. They affect every part of CCS implementation, and they describe how CCS will fit into a larger emission reduction strategy. As we have discussed, there are technical problems which make CCS ineffective. This means CCS will have to work with some form of renewables. This is the meaning behind our theme parallel. The broader meaning is renewables are necessary. CCS on its own is too weak to support our energy needs. It requires too much additional overhead to be effective.

Cost is the main deciding factor regarding the use of carbon capture. This is a very complicated subject. There are very few examples of CCS in use, and it is very difficult to predict how new technology will affect the future use. However, There is one certainty: renewables are viable now. CCS is a good idea, and some methods look promising, but renewables are ready now. Deciding between using renewables or CCS is a false choice. Investing in CCS is a gamble. It might be viable in a few years. It might work at scale. New technology might make it more effective. Renewables are effective, profitable, and work at scale, now.

Carbon capture and sequestration is not viable. However, It could have a possible place. One of the largest issues with solar and wind is intermittency. CCS can help address this on peaker plants. Peakers are special power plants designed to turn on quickly. They address dips in energy generation or increased demand, supplementing the grid with additional power. Installing CCS on these support plants would further decrease carbon emissions.

Conclusion

Reflections

Our team began with the idea regarding how to influence the UAE to adopt CCS as well as what the cost to implement CCS in the UAE. This proved to be an imperfect route as we interviewed experts. We later found out that focusing on just CCS was not going to be the best solution to reduce emissions and renewables like solar and wind would yield a better result. For these reasons our question focused on the broader perspective. Instead of focusing on how the adoption of the technology would occur it was better to consider the current research done and apply it .Our interview questions being about the importance of CCS adoption they shifted towards the practicality of CCS and the different ways renewables are a better investment. Alongside these questions it was also valuable information learning about the parallel nature that could arise when both technologies work together.

Our methodology was useful for creating interview guides and finding which experts we wanted to interview. By asking experts questions regarding this, we found the best route for the UAE. The interviews we transcribed helped us see the patterns related to renewable energy and CCS as technologies used together as tools.

The methodology resulted in discovering the truth about how CCS is not a viable technology. When using NVIVO the common codes that related to carbon capture was the inefficiencies and overall cost to operate this type of technology. It is a very expensive and intricate process. Experts leaned towards renewables more often.

Final Thoughts

Our findings indicate investing in renewables is, overall, better than investing into carbon capture and sequestration. CCS technology is not ready for wide scale use, while renewables are in use at various sites around the world. This makes sense. CCS requires much more support to be viable, and it does not scale. Compare CCS to solar; solar panels can power a house, or a whole city. CCS only works at the powerplant level. It needs a long term carbon storage site, and all of the additional logistical hurdles that entails: transport, maintenance, and staffing. Of course, that is only if conditions for such a site exist.

Renewables work better as the main work-horse. However, carbon capture is not useless. CCS works well in a supporting role. Intermittency is a large issue for solar and wind power. A promising way to address it is with "peaker plants." These would burn a form of natural gas to make up for dips in energy production from renewables. Installing CCS on these plants, if able to, would further lower emissions.

One last point to end with, Humanity has to do something now. Sooner is better than later. We need to do everything possible to reduce emissions. Renewables and carbon capture will play a role. Climate change is an existential threat, we need to stop it.

Bibliography

References

Aggarwal, V. (2020, September 17). *Solar vs. Wind Energy: What's Better in 2020?*. EnergySage. Retrieved December 11, 2020, from https://news.energysage.com/solar-vs-wind-energy-right-home/

Aliabadi, D. E. (2020). Decarbonizing existing coal-fired power stations considering endogenous technology learning: A Turkish case study. *Journal of Cleaner Production*, *261*. https://doi.org/10.1016/j.jclepro.2020.121100

Bartlett, J. (2019, October 8). *What Are the Costs and Values of Wind and Solar Power? How Are They Changing?*. Resources Magazine. Retrieved December 11, 2020, from https://www.resourcesmag.org/common-resources/what-are-costs-and-values-wind-and-solar-power-how-are-they-changing/

Bruce, C. (2018, May 23). *Clean Energy and Low Emissions Link Norway and Canada "*. International CCS Knowledge Centre. https://ccsknowledge.com/blog/clean-energy-and-low-emissions-link-norway-and-canada.

Dubai Media Office. (2020, January 5). *Renewable Energy Shaping the Future of Sustainability.*

Emirates 24/7. https://www.emirates247.com/news/emirates/renewable-energy-shaping-the-future-of-sustainability-2020-01-05-1.691242#:~:text=The%20UAE%20Energy%20Strategy%202050,the%20sustainable%20growth%20of%20economy

Energy and Climate Change. (n.d.). UAE Embassy in Washington, D.C. Retrieved December 11, 2020, from https://www.uae-embassy.org/about-uae/energy/energy-and-climate-change

Floyd, W. C., Baker, S. E., Valdez, C. A., Stolaroff, J. K., Bearinger, J. P., Satcher, J. H., & Aines, R. D. (2013). Evaluation of a Carbonic Anhydrase Mimic for Industrial Carbon Capture. *Environmental Science & Technology, 47(17)*, 10049–10055. https://doi.org/10.1021/es401336f

Gramig, B. (2012). Some Unaddressed Issues in Proposed Cap-and-Trade Legislation Involving Agricultural Soil Carbon Sequestration. *American Journal of Agricultural Economics, 94*(2), 360-367. Retrieved September 18, 2020, from http://www.jstor.org/stable/41331259

Gulf Cooperation Council. (2020, October 19). *United Arab Emirates' Economic Update — October 2020.* The World Bank. https://www.worldbank.org/en/country/gcc/publication/economic-update-october-2020-uae

Lal, R. (2008). Carbon Sequestration. *Philosophical Transactions: Biological*

Sciences, 363(1492), 815-830. Retrieved September 18, 2020, from http://www.jstor.org/stable/20208469.

Liang, Z. H., Rongwong, W., Liu, H., Fu, K., Gao, H., Cao, F., Zhang, R., Sema, T., Henni, A., Sumon, K., Nath, D., Gelowitz, D., Srisang, W., Saiwan, C., Benamor, A., Al-Marri, M., Shi, H., Supap, T., Chan, C., … Tontiwachwuthikul, P. PT. (2015). Recent progress and new developments in post-combustion carbon-capture technology with amine based solvents. *International Journal of Greenhouse Gas Control, 40,* 26–54. https://doi.org/10.1016/j.ijggc.2015.06.017

Moe, O. (2019, May 6). Carbon capture may solve the climate crisis but how do we get there. Retrieved December 16, 2020, from https://www.cowi.com/insights/carbon-capture-may-solve-the-climate-crisis-but-how-do-we-get-there

The Official Portal of the UAE Government. (2020, July 19). *Climate Change.* U.AE. https://u.ae/en/information-and-services/environment-and-energy/climate-change/climate-change

Otitoju, O., Oko, E., & Wang, M. (2020). A new method for scale-up of solvent-based post-combustion carbon capture process with packed columns. *International Journal of Greenhouse Gas Control*, *93*, 102900. https://doi.org/10.1016/j.ijggc.2019.102900

Raksajati, A., Ho, M., & Wiley, D. (2018). Solvent Development for Post-Combustion CO2 Capture: Recent Development and Opportunities. *MATEC Web of Conferences, 156*(The 24th Regional Symposium on Chemical Engineering), 03015. https://doi.org/10.1051/matecconf/201815603015

Rochelle, G. (2009). Amine Scrubbing for $C0_2$ Capture. *Science, 325*(5948), 1652-1654. Retrieved September 18, 2020, from http://www.jstor.org/stable/40301873

Salman, N. (2020, January 11). *Carbon capture, technology transfer successful energy transition mechanisms in UAE, say experts.* Emirates News Agency. https://wam.ae/en/details/1395302815278

Shavalieva, G., Kazepidis, P., Papadopoulos, A. I., Seferlis, P., & Papadokonstantakis, S. (2020). Environmental, health and safety assessment of post-combustion CO2 capture processes with phase-change solvents. *Sustainable Production and Consumption*, *25*, 60–76. https://doi.org/10.1016/j.spc.2020.07.015

Siemens, J., Pacholski, A., Heiduk, K., Giesemann, A., Schulte, U., Dechow, R., Kaupenjohan, M., Weigel, H. J. (2012). Elevated air carbon dioxide concentrations increase dissolved carbon leaching from a cropland soil. *Biogeochemistry, 108*(1/3), 135-148. Retrieved September 18, 2020, from http://www.jstor.org/stable/41410587

Sohngen, B. (2018). An Analysis of Forestry Carbon Sequestration as a Response to Climate

Change. *Copenhagen Consensus Center*. Retrieved September 18, 2020, from http://www.jstor.org/stable/resrep16325.6

Trading Economics. (2019). *United Arab Emirates GDP.* Trading Economics. https://tradingeconomics.com/united-arab-emirates/gdp#:~:text=GDP%20in%20the%20United%20Arab%20Emirates%20is%20expected%20to%20reach,macro%20models%20and%20analysts%20expectations

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2020, April 2). Retrieved December 11, 2020, from https://www.eia.gov/energyexplained/solar/where-solar-is-found.php

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2020, March 24). Retrieved December 11, 2020, from https://www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php

Wang, Q., Liu, Y. (2020). India's renewable energy: New insights from multi-regional input output and structural decomposition analysis. Journal of Cleaner Production, 124230. https://doi.org/10.1016/j.jclepro.2020.124230

Wilberforce, T., Baroutaji, A., Soudan, B., Al-Alami, A. H., & Olabi, A. G. (2019). Outlook of carbon capture technology and challenges. *Science of The Total Environment, 657*, 56–72. https://doi.org/10.1016/j.scitotenv.2018.11.424

Yong, J. K. J., Stevens, G. W., Caruso, F., & Kentish, S. E. (2017). The resilience of carbonic anhydrase enzyme for membrane-based carbon capture applications. *International Journal of Greenhouse Gas Control, 62,* 122–129. https://doi.org/10.1016/j.ijggc.2017.04.006

Zhang, H., & Desideri, U. (2020). Techno-economic optimization of power-to-methanol with co-electrolysis of CO2 and H2O in solid-oxide electrolyzers. *Energy, 199,* 117498. https://doi.org/10.1016/j.energy.2020.117498

Zhang, S., Zhuang, Y., Tao, R., Liu, L., Zhang, L., & Du, J. (2020). Multi-objective optimization for the deployment of carbon capture utilization and storage supply chain considering economic and environmental performance. *Journal of Cleaner Production*, *270*. https://doi.org/10.1016/j.jclepro.2020.122481