BUYING A GREEN CONSCIENCE:
THE DEVELOPMENT AND STABILIZATION OF CARBON OFFSETS

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Bachelor of Science in Systems Engineering

By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Climate change presents a systemic risk to all citizens on Earth. It threatens the basic elements of life: access to food and water, health, land use, and physical and natural resources. According to Nasa's Climate Change division (n.d.), "the Intergovernmental Panel on Climate Change (IPCC), which includes more than 1,300 scientists from the United States and other countries, forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century" (para. 2). This once seemingly premature scientific field of study now breaches into the lives of all individuals, as citizens of all countries start to see its consequences. Diverging weather patterns eliminate natural habitats as glaciers shrink and hurricanes strengthen, the Earth further deviates from its natural ambient levels that threaten future living conditions (Brennan, 2020; Lin, Emanuel, Oppenheimer, & Vanmarcke, 2012). As predicted by Houérou in 1996, Meehl and Tebaldi in 2004, and again by Sierro in 2009, intense heat waves, extended droughts, and accelerated rising sea levels reveal the Earth's riot against increasing greenhouse gas levels (Houérou, 1996; Meehl & Tebaldi, 2004; Sierro et al., 2009). Citizens of the Earth experience firsthand the interplay of science and technology with society.

Environmental punishments impede on human well-being, and society must now project forward to minimize carbon emissions. In response, UVa assembled a network of students, professors, and third-party players across multiple fields to develop a plan to achieve carbon-neutrality by 2030, and eventually fossil independence by 2050. Further, this technical project will expand the scope to the State of Virginia to consult the Department of Mines, Minerals and Energy (DMME) on crafting a separate plan with the similar end goal. Alongside the technical aspect of the project, the Science, Technology and Society (STS) Research Project will narrow the focus to a major agent in sustainable finance by looking at the inconsistency of carbon offsets and the network that stabilized the innovation. As the market for offsets grows, a critical lens must be applied to this accepted process to analyze its environmental effectiveness. With more institutions pledging carbon neutrality, now more than ever both the government and its citizens must hold corporations and communities financially and environmentally accountable for their public promises. The loosely coupled topics will help paint a clarifying picture on different environmental strategies that aim to achieve the same goal. However, the different methods behind both processes may highlight the key motivations of attaining such goals.

Eight members compose the technical group. System engineers Thomas Anderson, Daniel Collins, Chloe Fauvel, and Bailey Thran, team with environmental-track civil engineers Harrison Hurst and Nina Mellin to provide an array of knowledge across multiple concentrations: economics, computer science, and environmental sustainability. Systems Engineer Arthur Small and Environmental Engineer Andres Clarens advise the project with their extensive knowledge in environmental economics and anthropogenic carbon flows. Small received his Ph.D. in Agricultural and Resource Economics from the University of California at Berkeley and currently holds a senior research position in the Department of Economic Policies Studies at the University of Virginia. As an economist and decision scientist, Small offers specialized knowledge in issues regarding energy, climate, and environment (Small, n.d.). As a professor in the Department of Civil and Environmental Engineering, Andres Clarens concentrates in carbon capture and sequestration and researches strategies surrounding negative emissions (Clarens, n.d.). In addition to applying the advisors' environmental expertise, the team uses graduate student Roger Zhu to provide the analytical tool TEMOA in the team's evaluation of energy sources. To supplement the group's efforts, many department leaders within the University of Virginia provide project statuses and insight on required areas of research. A final report was presented on April 29, 2021 at the IEEE Systems and Information Engineering Design Symposium.

FONTAINE RESEARCH PARK CASE STUDY: DEVELOPING CARBON-NEUTRAL MODELS FOR THE UVA AND THE COMMONWEALTH

According to the US Energy Information Administration's (EIA) Annual Energy Outlook (2020), economic growth is the primary contributor of energy demand and related CO_2 emissions (p. 19). Further, the Outlook noted that "energy-related CO_2 emissions in all [2020 Annual Energy Outlook] cases decrease early in the projection period before increasing in the later years through 2050 as economic growth and increasing energy demand outweigh improvements in efficiency" (p. 146), as summarized in Figure 1. As conduits for economic growth, corporations and institutions largely influence environmental outcomes, thus such groups should be held partially responsible for their environmental contributions.

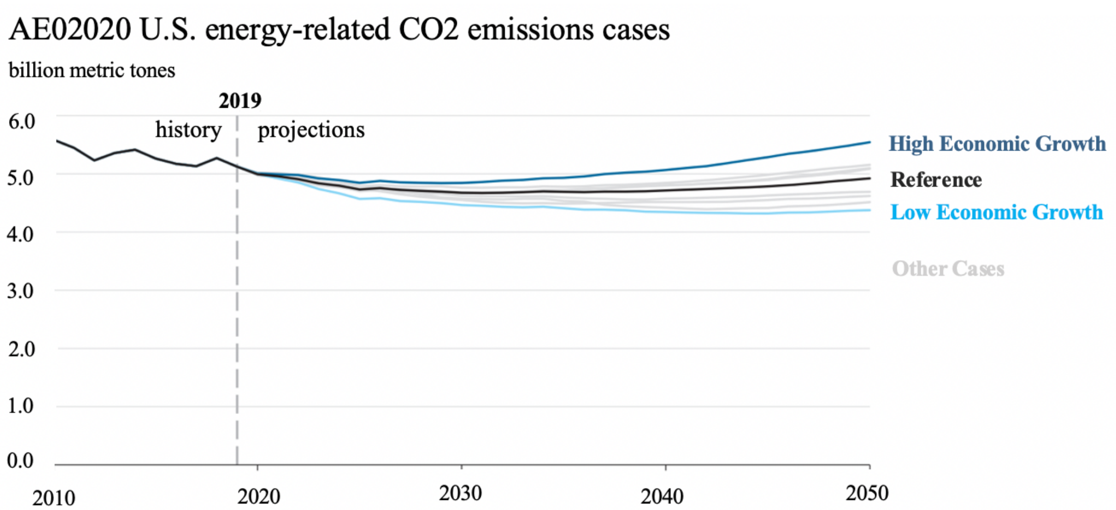

Figure 1. U.S. Energy-Related CO_2 Emission Cases. The graph shows that economic growth is a main driver for CO_2 emissions and that emissions are projected to increase. Adapted by Thran (2020) from U.S. Energy Information Administration (2020).

Over the past several months, a large number of businesses pledged commitments to decarbonize their operations. Companies such as Microsoft, Delta, and Shell, as well as states like California and Virginia, promise to cut their carbon emissions to zero over the coming decades. However, in many cases, these institutions do not yet have detailed plans outlining the path toward achieving these goals. The technical group will team with UVa and the Commonwealth to design two plans, one for decarbonizing the University and one for decarbonizing the Commonwealth. Throughout the process, the team will work with stakeholders within both institutions and use modeling tools to identify activities that will cumulatively enable goals.

In order to achieve this goal, the University deployed a network of department leaders and experts to implement the strategy. The technical team will assist in breaking down relevant information and scoping the project to a specific area of study. Carbon-neutrality umbrellas multiple dimensions of emission reductions: renewable resources, loading balancing initiatives, transportation reduction, and so on. After identifying subjects requiring further research, the team decided to analyze how innovative load-shifting technologies can be used by large institutions like the University of Virginia to shift load and support statewide efforts to decarbonize. To do this, the technical team focused on the University's plans for expansion of the Fontaine Research Park, which is a good model for understanding how these technologies could distribute energy load behind the meter. In the past few years, the University assembled a group to expand the Fontaine site by renovating previous landscape and adding new research buildings. The technical team decided to utilize the site’s early design phase to target the greatest impact at the University.

FORMING OBJECTIVES

One of the principal challenges associated with decarbonization is the temporal variability of renewable energy generation, which is creating the need to better balance load on the grid by shaving peak demand. After determining the issue, the goals were identified. Three main objectives have centralized the team's focus. First: develop a case study. As a large institution, understanding the interplay of different agents and actors within the network remains difficult and can quickly become disordered. The project aims to use Fontaine as a case study in order to expand the University's understanding of distributed energy on campus, especially in the context of developing new buildings and retrofitting existing ones as both are main aspects of the current design. Second: create a model. As of 2020, the Virginia Clean Economy Act now mandates Dominion Energy by law to implement 100% renewable energies by 2045 (Yarmosky, 2020). The University of Virginia, as one of the largest energy consumers in the state, plays a crucial role in reaching state emission goals. In addition to achieving the University's own goals, the team questions how the institution could influence other organizations to pursue similar distributed energy projects by serving as a model, leading into the final objective. Third: Use the model to expand load-shifting development across the state. By sharing the study's findings, state-wide application of such technologies could be achieved.

To develop the three main objectives, the team had to research the school's and state's energy statuses to provide context for the project's capacity. Research conducted from the University shows that electricity proves to be the primary driver in greenhouse emissions, as presented in Figure 2. Electricity use has shown a steady decline, however drastic methods must be implemented to achieve the 2030 goal. Conversations with key stakeholders such as Cheryl Gomez, the Director of Facilities Management at the University, Jesse Warren, the Sustainability

Program Manager for Buildings and Operations, and Sathish Anabathula, the Associate Director of Power and Light, shared background for different dimensions of electricity use on campus. Discussing areas which lacked thoughtful information and research helped guide the team to focus on distributed generation at the Fontaine Research Park site.

Figure 2. Carbon Reduction Progress. The chart shows electricity to be the main contributor of greenhouse gas emissions and demonstrates a decline in electricity-correlated emissions. (Adapted by Thran (2020) from University of Virginia (n.d.)).

METHODS AND OUTCOMES

Different analytical tools will structure the evaluation of the plans. Energy modeling programs such as TEMOA and R Studio, coupled with Excel, will formalize raw data across multiple variables to bring insight for future plans. The team aims to determine the extent of which to implement different renewable energies, load balancing technologies, and other resources to optimize emissions reductions in both the micro-grid and the Commonwealth. Carbon-neutral plans typically involve large systems with many working components. Building a model for other institutions and states may accelerate both the national and global emission reductions by helping provide solutions for intertwined systems. The study may allow for greater resource allocation on research and development initiatives that will shift marginal abatement cost curves and eventually produce greater reduction outcomes. The team will have the Rivanna supercomputer at its disposal to help process large data files that run on our programs. Finally, in 2021, the research and work will be presented in a technical paper. With the research, the team anticipates to publish a document for UVa's Carbon-neutral plan with specific designs and technologies that will be put in place on grounds. The published paper hopes to encourage other institutions to develop models by using the technical report as a framework.

STS RESEARCH

In the fight to reduce carbon emissions, multiple policy mechanisms emerged to enforce reductions, one being an accounting tool known as a carbon offset. In simple terms, institutions, companies, states, and individuals use carbon offsets as an accounting mechanism to balance their own pollution with third party reduction credits, however typically larger entities use these credits to meet environmental standards. For example, if US airline A were to emit 100,000 tones of carbon equivalent emissions through gas combustion, US airline A could compensate their emissions by purchasing 100,000 carbon tons of equivalent offsets from a forest sequestration project in Brazil; if recorded properly, the internal books would essentially balance to net zero emissions. Two types of offsets exist: compliance and voluntary. Compliance schemes, such as the United Nations Framework Convention on Climate Change, Kytoto Protocol, and the European Union Emission Trading Scheme allows carbon offsets to be bought and sold to achieve certain targets (World Bank, 2015). Additionally, many different states and governments have implemented cap-and-trade programs that set thresholds on the total amount of carbon dioxide they are allowed to emit per year. The program sets a certain level of acceptable emissions and every business that emits carbon has to get permission from the jurisdiction or they will be fined. Instead of purchasing permits or incurring abatement costs to reduce emissions, it is often cheaper for organizations to meet such legally binding caps by purchasing offsets. On the other hand, voluntary offsets can be purchased at consumer's own discretion. Certification programs such as the Verified Carbon Standard, the Gold Standard, and the Climate Action Reserve establish requirements and register offsets so parties can engage in the voluntary carbon market and trade credits (World Bank, 2015). However, researchers in the field pose serious issues with the certification and verification of such offsets, which results in over-estimating reductions and in some instances have led to an increase in emissions.

The recent environmental movement has led many organizations to monopolize on consumer ethics by making corporate campaigns to decrease emissions. As of 2020, Shell alone have bought $300 million on forest plantations to reduce its carbon footprint by 2 to 3 percent on their internal books. However, many forestation projects cut down well established older forests to plant faster growing plants, such as the eucalyptus tree. Not only counter intuitive, the mass implementation of monocrops also exceeds environmental consequences by breaching into the ethical domain. The highly corporate organizations monitoring the sequestration projects prevent locals from accessing the forests. Many locals can no longer feed themselves with the diverse ecosystem destroyed and physical security blocking their entry. Alain Karsenty, researcher at the French Agricultural Research Centre for International Development (CIRAD), notes that offsets are a "cop-out that risks dissuading society collectively from making greater effort and investing in costlier technologies" (Donadieu, 2019).

As of May 2020, German bank Berenberg projected that the value of the global market for carbon offsets could total $200 billion by the year 2050 (Watson, 2020). If research suggest offset schemes result in ineffective outcomes, then why do countries continue to legitimize this innovation? This paper aims to apply Bijker and Pinch's (1984) Social Construction of Technology as a framework to analyze the dimensions of the artifact's development and stabilization in order to answer this question. Their idea of interpretative flexibility will play a key role in understanding the motives that influence the establishment of carbon offsets and how the innovation has molded to fit these multiple goals. As environmental laws mandate new business compliances and more institutions pledge carbon neutrality, understanding how the environmental inefficiencies of this innovation emerged proves crucial for instilling a better solution. To craft efficient legislations, the government and offset-issuing programs must achieve a better understanding of past failures. However, in order to analyze the stabilization of the artifact, a developed understanding of the formation must be applied.

THE KYOTO PROTOCOL: THE DEVELOPMENT OF THE OFFSET

In December of 1997, 192 parties came together and signed the Kyoto Protocol, a cooperating commitment to limit and reduce greenhouse gas emissions by setting agreed individual targets for different parties to match. In order to achieve such reductions, the agreement created the Clean Development Mechanism (CDM) to facilitate offset purchases by industrialized countries from low- and middle-income countries. To ensure this accounting tool achieves nation reduction objectives, the CDM consists of a validation and verification process to ensure authentic benefits that deliver real and *additional* reductions. (United Nations Climate Change, n.d).

According in World Banks report, Overview of Carbon Offset Programs (2015), there are four basic criteria to validate an offset under CDM as shown in Figure 1: Additionality, Baseline and Measurement, Permanence, and Leakage. Additionality is the most important prerequisite to proving the effectiveness of an offset. It asks whether the project would occur even without the investment raised by selling carbon offset credits. For example, if a power plant uses a non-additional offset rather than reducing its own emissions to meet its reduction commitments, global emissions would be higher than the counterfactual. Second, in order to determine the amount of carbon reduction gained from an offset, programs must calculate a baseline to determine the number of potential emissions in the absence of a proposed project and determine how the emissions are going to be measured. Third, a program must consider the permeance of a project. In other words, are some reductions reversible? A common example calls into question the state of forestation projects as fires can often burn trees and therefore decrease the actual amount of carbon sequestered. Lastly, leakage seeks to ensure that crediting the project does not cause higher emissions outside the project boundary.

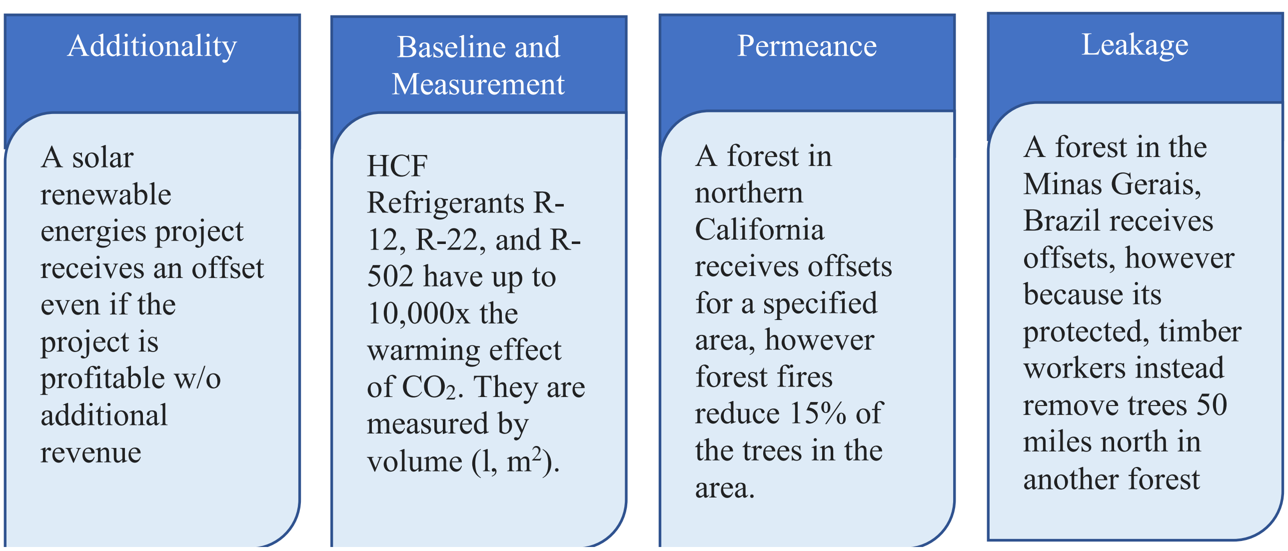

Figure 1. The Key Criteria for Carbon Offset Validation. The figure outlines additionality, baseline and measurement, permeance, and leakage as the four main aspects of offset validation within the CDM and provides an example. (Thran, 2020)

IDENTIFYING LEGACY FLAWS

Since the creation of the accounting tool, the offset crediting market has seen consistent growth. A 2020 S&P article reports that the offset market has more than tripled over the past three years (Watson, 2020). However, many studies have analyzed the effectiveness of offsets under the CDM and argue that such credits frequently over-estimate reductions. A study conducted by Cames, Harthan, Füssler, Lazarus, Lee, Erickson, and Spalding-Fecher explore the additionality of offsets verified under the CDM by looking at a random sample of around 800 CDM certified projects. They presented their research to Directorate-General for Climate Action (2016) and found that "85% of the projects covered in this analysis and 73% of the potential 2013-2020 Certified Emissions Reduction (CER) supply have a low likelihood that emission reductions are additional and are not over-estimated." (p. 11).

FORMING VARIETY: THE STABILIZATION OF THE OFFSET

Over the past decade, a wide variety of programs have emerged that certify offsets, each with different methods, practices, and standards. Though such short-comings existed with the CDM's verification of offsets, their protocols still lay the foundation for nearly all compliance and voluntary programs. As a result, its legacy carried over, thus reinforcing the idea of stabilization as policy makers failed to re-invent the technology and rather simply mended the innovation. As noted by Cames, Harthan, Füssler, Lazarus, Lee, Erickson, and Spalding-Fecher, the "CDM certainly forms an important basis for the elaboration and design of future international crediting mechanisms" (p. 12).

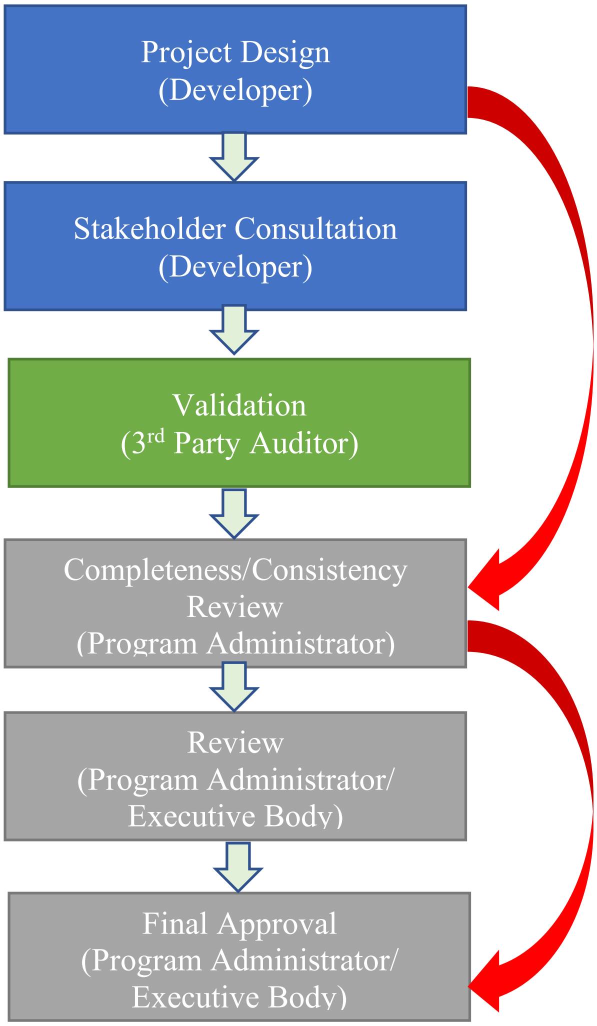

Figure 2. The Process to Issue Carbon Offsets. The global process shows inconsistencies in phase completions across multiple programs. (Thran, 2020)

Today, the process of issuing carbon offsets poses many challenges, two of which include the quantification of carbon benefits, i.e. the reduction of emissions, and the verification that offsets achieve such reductions (Wara, 2007). In 2005, the World Bank analyzed eleven main programs used to issue carbon credits and compared the different aspects of each one. As shown in Figure 2, an offset must complete six different phases, however their research showed some programs skipped certain steps.

Sohngen's (2010) study explores the development of a forestry offset and outlines the difficulties in monitoring and verifying low- cost forestry offsets. He explains that a "forestry carbon sequestration or emission reduction program can only work if a valid system of measuring, monitoring and verifying (MMV) carbon credits on the landscape can be developed and implemented cost-effectively" (p. 6). Poor policy designs could essentially make many low-cost offsets misleading, and potentially harmful. Jardine (2009), Sohngen (2010), and Wara (2007) have addressed inconsistencies with offset calculations and note that poorly designed offsets schemes could undercut the efficiency of emission limits. Professor Kevin Anderson, the deputy director University of Manchester's Center for Climate Change Research, also points out the issues of sending misleading price signals to the market, which in turn decreases emission reduction incentives.

> The promise of offsetting triggers a rebound away from meaningful mitigation and towards the development of further high-carbon infrastructures. The UK government's purchase of offsets through the CDM and its simultaneous drive towards both additional airport capacity and the exploitation of UK shale-gas reserves are just two such examples (Anderson, 2012, p. 1).

MOTIVATION IS KEY: SCOT THEORY APPLIED

In order to determine how carbon offset have fallen short of efficient standards, an analysis of an offset's interpretative flexibility can be applied. Moreover, looking at different consumer and producer motives can help shed light on inefficiencies. To explore this idea, the paper will give an example of an offset based on identical products, however results in polar effectives due to diverging user motives. As such, different social groups interpret technology and their uses through radically diverse modes, thus Bijker and Pinch claim technology has interpretive flexibility.

TWO SIDES OF A COIN: TRADEWATER VS GUJARAT FLUORO CHEMICALS LIMITED

In 2016, Tim Brown and Gabe Plotkin developed a business called TradeWater to collect and properly destroy potent gases before they leak into the atmosphere. Their mission aims to "improve our environment and create economic opportunity through the collection, control, and destruction of potent, high impact greenhouse gases." (TradeWater, n.d.). In short, their team collects R-12 refrigerants and other types of refrigerants, like R-22, and R-502, from outdated refrigerant tanks scattered around the country. Refrigerants such as R-12, R-22, and R-502 keep things cold, therefore they are found in many technologies such as refrigerators and AC units. However, these refrigerants have up to 10,000 times the warming effect of regular old carbon dioxide, and as a result, TradeWater receives offset credits to support their business that would otherwise not be profitable. In other words, the offsets granted to TradeWater prove additional as the refrigerants they're collecting would not have been destroyed otherwise. Such an offset proves effective as their motives align with the artifact's intended use.

Across the world in India, a coolant plant named Gujarat Fluorochemicals Limited received certified offsets for pursing a similar business model of destroying the refrigerant HFC-23s. However, rather than seeking environmental integrity, Gujarat Fluorochemicals Limited's sole motive involves maximizing profits. Noticing the lucrative potential with offsets, many Chinese and Indian corporations without national refrigerant restrictions began producing HFC-23s with the sole intention of destroying them to receive about $30 million in carbon offsets annually (Lehren, A. & Rosenthal, E., 2012). Since 2005, 19 plants have adopted such business models. As with an incentive program, unintended consequences can be expected. Thus, the high revenue gained from destroying HFC refrigerants in the end created an incentive to recreate more emissions from an artificially high baseline. This idea circles make to the four main criteria for certifying an offset.

Thus, though the offsets were used similarly, TradeWater and Gujarat Fluorochemicals Limited interpreted the artifact differently due to dissimilar motives. In theory, an offset scheme should allow firms to maximize flexibility to achieve environmental objectives (Field & Field, p. 257), rather than putting restrictive requirements that would increase compliance costs. However, this flexibility often fails to provide desired results as portrayed with TradeWater and Gujarat Fluorochemicals Limited.

INTERPRETATIVE FLEXABILITY: MAIN MOTIVES

According to an Ecosystem Market Place study (2009) "suppliers indicated that "Corporate Social Responsibility" and "Public Relations/Branding" were by far the primary motivations behind voluntary market transactions, as companies sought to offset emissions for goodwill, both of the general public and their investors" (p. 96). Today more and more companies, institutions, and municipalities pledge carbon neutral goals to in order to gain safeguard reputation, ethics, and corporate social responsibility (CSR). According to the International Institute of Sustainable Development (IISD) (2019), more than 170 companies in December of 2019 have pledged carbon neutrality by 2050; of those 170 companies include giants such as Microsoft, Google, and even Delta Airlines. However as discussed, offsets are vulnerable to manipulation. James Bushnell, an economics professor at the University of California Davis analyzes: "there's always going to be an incentive problem when you pay someone not to do something as opposed to charging them to do something […] And that's kind of the offset scheme where instead of charging people to emit carbon for example, we are paying them to not admit carbon." As Bijer and Pinch theorized, such social factors and forces shaped technological development as policy makers amended such offsets to eliminate this loop whole.

LOOKING FORWARD: REFINE AND REBUILD

That remains clear negative implications of adverse interpretations of offsets. Inefficiencies within the production, verification and purchasing of offsets. In order to achieve long term goals, the artifact needs to be reconstructed rather than mended as its stabilization has shown to have harmful consequences. In order to achieve long term reduction, society must look toward other technologies to actively remove carbon from the atmosphere, as well technologies that limit the amount of carbon released. However, this cannot be achieved overnight. Rather than using credits as a sustained program, offsets should be utilized to buy society time to transition to low-carbon and sequestration technologies. Further, the industry should re-invest the money saved from offsets into research and development to find such innovations. However, in the meantime, the current system must be improved.

FUTURE CONTRACTS: MISMANTLING THE BLACK BOX

There have been initiatives to restructure the current offset market, as private transactions only reinforce the profit maximizing incentives by keeping transactions, and products, behind doors. CME Group aims to restructure the offset market by making the market more transparent. As an exchange operator, CME Group Inc plans to tap into the expanding market of offsets as companies rush to make up for their emissions by launching trading in voluntary carbon-offset futures. As Dezember notes in this article, *Carbon offsets that companies are gobbling up get a futures contract (2021)*, California has seen success with their Cap-N-Trade program and have seen fairly transparent valuations of offset credits. The offset trading platform will dismantle the black box of privately exchanged offset trades. CME's global head of energy, Peter Keavey, notes that, "Ultimately [we] need to develop a more global benchmark and viewpoint to harmonize the valuation and trading of offsets." Future Contracts demonstrate great potential because they will "also allow companies to lock in prices for carbon credits created down the road and to hedge against declines in the value of those they already own." CME aims to standardize offsets by requiring offsets to be verified by a choice of three certified carbon registries. Based on supply and demand, offset transactions on the Xpansiv CBL Holding Group platform will uncover price. By making the market more transparent, exchanged offsets can now be viewed by the public and hopefully increase efficiency of carbon reductions. Yet, there still lies issue in the verification of offsets.

Many offsets are merely a façade that allow entities to dismantle their guilty and to keep costs low in order to continue practices as before. Indeed, many organizations create offsets with motives that align perfectly with the offset's original intention, as seen with TradeWater. However, many do not. Though offsets have not scientifically fulfilled their goals, they have helped increase environmental awareness by its bringing attention to many individuals. In a sense, offsets provide a bridge that connect corporations with environmental action; it has helped transition corporations, individuals, and governments into thinking environmentally by forcing entities to start putting a price tag on environmental values. Down the road, offsets are not the solution to reducing emissions, however they've helped transition the thought process to be more environmentally oriented. Many jurisdictions keep corporations legally and financially accountable, however entities will need to start paying abatement costs and investing in further technologies in order to create real change.

WORK CITED

Anderson, K (2012). The inconvenient truth of carbon offsets. *Nature, 484*, 7. doi:10.1038/484007a

Bijker, W., & Pinch, T. (1984). The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. *Social Studies of Science, 14*, 399-441. doi: 10.1177/030631284014003004

Brennan, P. (2020, August). *Stunning forecast: A century of ice loss for nearly 100,000 glaciers*. Retrieved from Nasa's website: https://climate.nasa.gov/news/3008/stunning-forecast-a-century-of-ice-loss-for-nearly-100000-glaciers/century-of-ice-loss-for-nearly-100000-glaciers/

Cames, M., Erickson, P., Füssler, J., Harthan, R., Lazarus, M., Lee, C., & Spalding-Fecher, R. (2016, March). *How additional is the Clean Development Mechanism?* Paper presented at the GM CLIMA Conference, Berlin, Germany.

Donadieu, P. (2019, September). *Tree-planting to offset carbon emissions: no cure-all.* Retrieved from Phys Organization website: https://phys.org/news/2019-09-tree-planting-offset-carbon-emissions-cure-all.html

Field, B., & Field, M. (2016). *Environmental economics: An introduction* (7TH ed.). New York, NY: McGraw-Hill Companies.

Houérou, H. N. (1996). Climate change, drought and desertification. *Journal of Arid Environments, 34*, 133-185. Doi: 10.1006/jare.1996.0099

Lansing, D. (2012). Performing Carbon's Materiality: The Production of Carbon Offsets and the Framing of Exchange. *Environment and Planning A, 44,* 204-220. doi: 10.1068/a44112

Lehren, A. & Rosenthal, E. (2012, August 8). Profits on carbon credits drive output of a harmful gas. New York Times. Retrieved from https://www.nytimes.com/2012/08/09/world/asia/incentive -to-slow-climate-change-drives-output-of-harmful-gases.html?auth=login-google

Lin, N., Emanuel, K., Oppenheimer, M., & Vanmarcke, E. (2012). Physically based assessment of hurricane surge threat under climate change. *Nature Climate Change, 2*, 462–467. doi:10.1038/nclimate1389

Meehl, G. A., & Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science, 305*, 994-997. Doi: 10.1126/science.1098704

NASA Global Climate Change. (n.d.). The effects of climate change. In *Facts*. Retrieved from https://climate.nasa.gov/effects/

Rogers, M. E., Singhal, A., & Quinlan, M. M. (1962). *Diffusion of Innovations*. New York, NY: Free Press of Glencoe.

Sohngen, B. (2010). Carbon Offsets in Forest and Land Use. Holmes, K (Ed.). *Modeling the Economics of Greenhouse Gases*. Retrieved from https://www.nap.edu/read/13023/chapter/18

Thran, B. (2020). The Key Criteria for Carbon Offset Validation. [Figure 1]. *STS Thesis* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Thran, B. (2020). The process to issue carbon offsets. [Figure 3]. *STS Thesis* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

United Nations Climate Change. (n.d.). What is the Kyoto Protocol. In *Process and meetings.* Retrieved from United Nations Climate Change website:https://unfccc.int/kyoto_protocol

Wara, M. (2007). Is the Global Carbon Market Working? *Nature, 445,* 595-596. doi: 10.1038/445595a

Watson, F. (2020, May). Global Carbon Offsets Market Could Be Worth $200 billion by 2050: Berenberg. Retrieved from S&P Global website: https://www.spglobal.com/platts/ en/market-insights /latest-news/natural-gas/051320-global-carbon-offsets-market-could-be-worth-200-bil-by-2050-berenberg

World Bank. (2015, January). *Overview of Carbon Offset Programs: Similarities and Differences*. Retrieved from http://documents1.worldbank.org/curated/en/891711468309 365201/ pdf/939450WP0201500ers0385391B00PUBLIC0.pdf