Responsible Ownership Fostering Green Tech Innovation

Jonsdottir, Gudrun Erla; Mitchell, Jordan ; Sigurjonsson, Olaf; Alavi, Ahmad Rahnema

Document Version
Accepted author manuscript

Published in:
Sustainable Energy Technologies and Assessments

DOI:
10.1016/j.seta.2022.102923

Publication date:
2023

Responsible Ownership fostering Green Tech Innovation

Abstract

Carbfix, an Icelandic green tech pioneer, has attracted worldwide attention for its novel solution to fight climate change by capturing and storing CO_2 safely in basalt rock and eliminating it from the atmosphere. This study explores how responsible ownership can drive innovative solutions to deal with climate change and foster a sustainable future. An exploratory case study using archival data was applied, which provided evidence of relationship between responsible ownership and sustainable technology commercialization. The results show that an effective ownership strategy strengthens a focus on the SDGs on climate action. The results demonstrate as well how responsible ownership produces an innovative green tech solution throughout a long-time horizon to address CO_2 reduction and commercialization. This study's originality is that it delves into the business facets of a green pioneer by exploring the relationship between owners and green tech innovation The theoretical contribution is on advancing the literature on responsible ownership in innovation and technology for the transition to a sustainable future. Using grounded theory methodology to analyze the empirical data, it is concluded that owners practicing responsible ownership can overcome many of the barriers to bringing innovative green tech solutions to market.

Highlights

- Responsible ownership is a driver of companies in focusing on sustainability.
- Ownership strategy is an essential part of responsible ownership.
- Owners practicing responsible ownership can overcome common barriers in green tech innovation.

Keywords: Renewable Energy, Climate Action, SDGs, Sustainability, Innovation, Green tech, Responsible ownership

List of abbreviations

UN, United Nations; SDGs, Sustainable development goals; $CO_{2,}$ Carbon dioxide; R&D, Research and development; CCS, Carbon capture and storage; SMEs, Small and medium enterprises; EU ETS, European Union Emission Trading Scheme.

1. Introduction

In 2021, the UN's Intergovernmental Panel on Climate Change (IPCC) released a "Code Red" for humanity, stating: "The alarm bells are deafening, and the evidence is irrefutable: greenhouse-gas emissions from fossil-fuel burning and deforestation are choking our planet and putting billions of people at immediate risk." [1]

However, the question remains: How to fight it? The IPCC highlighted the importance of decarbonizing the energy economy by developing modern technologies and generating environmentally clean electrical energy [2]. While many companies create new technologies to promote sustainability, the next steps are tough. Often, commercializing the technologies is challenging [3] and there are myriads of gaps in driving innovation, managing regulatory policy, aligning stakeholders, developing successful buyer-supplier partnerships and ensuring financial health [4,5,6,7]. These gaps raise the question of the best path forward to "achieve a better and more sustainable future" [8] and deliver on the dual goals of reducing carbon and building a financially feasible entity. In this study, we use the Icelandic green tech start-up, Carbfix, to explore this significant challenge.

The Carbfix concept was sparked in 2005, as a way to advance carbon capture & storage (CCS) and meet Iceland's commitment to reduce CO_2 emissions, via sequestration. A couple of years later, the initiative evolved into a joint academic-industrial program. The decarbonization solution involves safely storing carbon dioxide (CO_2) as a solidified mineral in basalt rock and permanently eliminating it from the earth's atmosphere.

The company was born out of the culmination of more than 15 years of work by universities and its parent organization, Reykjavik Energy. Given that international cooperation is often required to address climate change [2], Reykjavik Energy formalized Carbfix as a separate legal entity in 2020, with the mandate to commercialize the CO_2 storage system in Iceland and internationally. When compared with other carbon capturing and storage processes, Carbfix's solution of storing carbon safely in basaltic rocks offers a global storage potential that exceeds anthropogenic emissions [9]. The company's technology has been widely cited in academic journals and the international press as a viable solution.

From a financial point of view, Carbfix has the potential to generate revenue for its potential clients through the European Union Emission Trading Scheme (EU ETS) "cap and trade" mechanism, which permits carbon units to be bought and sold to meet CO_2 reduction targets. A sharp increase in the market price of the EU ETS in recent years – from €4.26 (US$4.81) in 2017 to €99.22 (US$99.87) in 2022 – has led to greater financial viability for Carbfix [10].

However, despite a seemingly technologically-sound solution and path to generate revenues, we wondered if Carbfix was truly on a path to the successful diffusion of "green tech" by overcoming the main barriers of technology uncertainty, regulatory dependency and a disadvantaged cost position [4,5]. Additionally, we were curious if the firm could confront further challenges from interactions between policymakers, industry partners, and end-users for technology commercialization [3]. Could the company's present and future buyer-supplier partnerships perhaps drive innovation forward [6,7,11,12]?

When we surveyed the research, we found gaps in understanding how responsible ownership [13,14] and in the collective actions [15] by owners, led to the advancement of the UN's Sustainable Development Goals (SDGs), particularly for SDG 13 on climate action.

In this study, we set out to answer the key research question: What is the relationship between responsible ownership and innovative green tech solutions? In addressing the question, we first review academic studies on sustainability, green tech innovation, barriers firms face in bringing technology to the market and the relationship between sustainability and responsible ownership. We then delve into the Carbfix case study to show how responsible ownership and the company's ownership strategy is helping it surmount common green tech innovation barriers through a complete explanation of the firm's history and three main commercialization options in its dual pursuit of carbon reduction and profits. The novelty of our study – an empirical research example using grounded theory methodology – lies in showing how responsible ownership can be a driver to green tech innovation.

2. Literature review

The literature review offered in the next subsection includes the call for radical actions to accelerate the stuttering implementation of the SDGs. Focusing on greenhouse gas reduction, attention is turned to literature on breakthrough technology commercialization and the barriers for bringing green tech to market. We explore new theoretical ideas on responsible ownership and the collective actions of owners as means to foster green tech innovation and overcoming the barriers.

2.1 Sustainability and Green Tech Innovation

The UN established the SDGs to encourage the international community to accelerate sustainability [16]. The SDGs are a "blueprint to achieve a better and more sustainable future for all" [8]. The UN has called for radical action to protect the environment and climate, but progress is slow [17]. This begs the questions: Why is the progress slow? What solutions can accelerate change?

Incremental investment required for the global energy transition to net-zero emissions by 2050 is estimated at $50 trillion [18]. Greenhouse gas reduction will rely not only on energy efficiency but on breakthrough technologies such as bioenergy and carbon capture/storage solutions, which are currently at their early stages of development. And while innovation is important to remain competitive [19], full project development and validated business models require a significant amount of capital. Also, organizations must define how they wish to invest in innovation [20]. While investing in early-stage green tech is desirable to transition to greater sustainability and create more diversity in financial markets [21], the investment in these capital-intensive projects is highly risky, which results in difficulties for many firms to secure financing [22].

Organizations, facing a variety of new technological challenges, simultaneously create business opportunities [23,24]. Most green tech companies are start-ups and SMEs, which tend to cluster in large urban areas where they can access capital [25]. As mentioned in the introduction, the three main barriers for bringing green tech to market are: technological uncertainty with fresh solutions; high regulatory dependency; and a disadvantaged cost position due to lack of scale and newness [21]. Negro et al. considered even a broader number of factors such as market structure, infrastructure, institutional forms, interactions between market players and capability gaps as to why renewable energy innovation is slow to diffuse [26].

There are broad suggestions to bring any new technology to market, such as a three-pronged approach of starting with the front-line users, selecting the right early adopters and mitigating the money barrier [27]. Specifically for green tech firms, Pakura [28] stresses the importance of “open innovation” whereby firms cooperate with universities, suppliers, and networks, versus more traditional innovation that relies on financing and marketing. Supporting this, Vincenzi and da Cunha [20] reported organizations amenable to innovation score higher in performance improvement, especially regarding the breadth of open innovation.

Innovations in energy technology are generally a result of a single company’s research and development efforts [29,30,31]. However, radical innovations are more often the result of collaboration [29]. As mentioned earlier, Nowotny et al. [2] argue climate change solutions require international cooperation.

There is a growing body of research on how buyer-supplier relationships can contribute to innovation especially in terms of new product development in other industries as illustrated by Johnsen [32], Sillanpää et al. [33] and Moradlou et al. [34], however most of the research to date has focused on information technology products and services. Awan [6] considers how relational governance – the degree to which formal and informal norms, processes and systems that govern a relationship – are a major contributing factor to innovation between buyers and suppliers.

Meijer et al.’s [3] research suggests business models can assist small and medium enterprises (SMEs) to remove certain barriers and calls for more research on sustainable technology commercialization and business model design [35,36]. The research encourages further exploration of how an organization’s structure can be arranged to best alleviate barriers. Successful business models should align company activities to the goals of the business [37]. Others such as Awan [6] recommend a strong system of relational governance between the buyers and suppliers to remove facilitate innovation.

Accordingly, we focused on how the organizational structure – including ownership – plays a role in sustainability.

2.2 Sustainability and Responsible Ownership

In addition to the challenges of bringing green tech to market, a firm's compliance with SDGs may result in lower financial returns for shareholders or owners, resulting in a transfer of wealth from shareholders to other stakeholders [28,38]. While this may be a reason "why" change is slow, the importance of "how" needs to be addressed to advance the SDGs. Joshi, Hughes and Sisk [29, 39] argued that "virtuous feedback loops" in SDG governance can improve sustainability. An ownership strategy as part of responsible ownership has been seen credited with creating such a loop for Reykjavik Energy [30,40]. As such, it might be seen as a driver to advancing sustainability. However, the challenge remains to pursue a dual objective of advancing SDGs and profits.

Contemporary studies indicate that ownership is important for a sustainable and responsible business [40]. Responsible ownership is active and positive when it seeks to maximize shareholder value. Shareholders require unifying themes around responsible ownership [41]; an effective ownership strategy fills this need by documenting the will of owners. An ownership strategy differs from a shareholder agreement in that its focus is uniting the owners around a set of principles [41] rather than shareholders' rights [42]. Owners' significant influence [43] can directly impact SDGs implementation [30]. Collaboration, which is important for sustainability governance [44,45], also creates important bonds among stakeholders [41].

Having theoretical ideas about responsible ownership and ownership strategies structured the inquiry to the subject matter, as we had an opportunity to explore the empirical example of Carbfix's novel CO_2 storage system technology amid commercialization. As such the research is empirically-driven, interrelated to theory. See Figure (1).

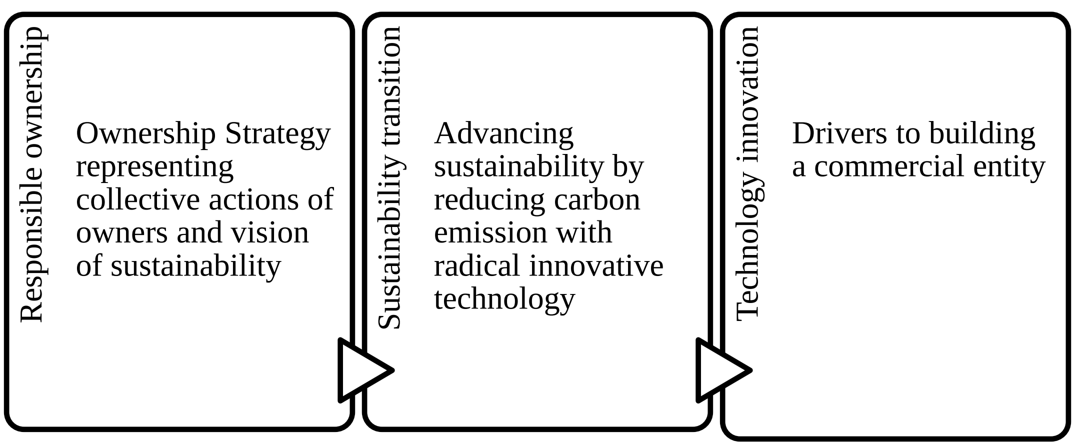

Fig. 1. Theoretical ideas structuring the inquiry to the empirically driven research on identifying a driver in accelerating change towards sustainability.

Considering that responsible ownership, solidified through an ownership strategy, represents a common long-term vision and the collective actions of owners, we should ask what is the relationship between responsible ownership and sustainable technology commercialization? With the ground-breaking CO_2 storage system technology in mind, our research question was born:

> ***What is the relationship between responsible ownership and innovative green tech solutions?***

Before diving into the case material and results, we should describe our research design and methods.

3. Research design and methods

The empirical study rests on the qualitative method, using a single-case research design [46] and an information-rich case company [47,48,49]. Identifying potential subjects [47] that were both interested and available [49] narrowed the selection. The research was inductive, drawing general conclusions from the data. The research process is depicted in the following diagram, figure (2).

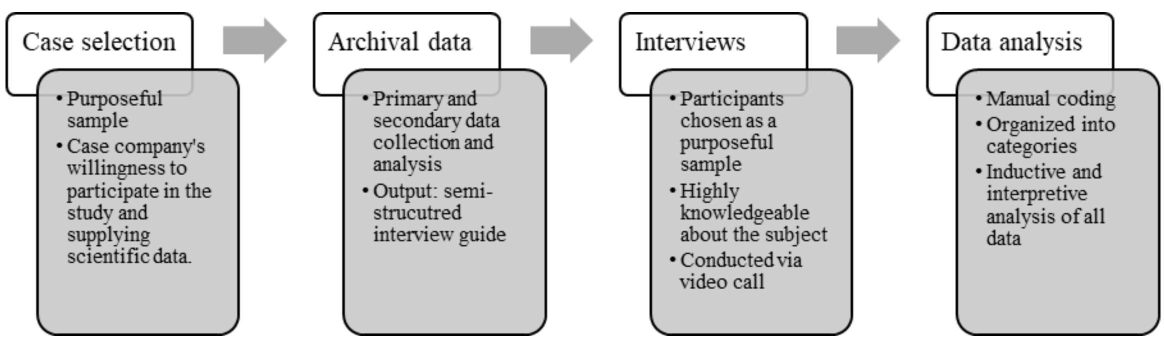

Fig. 2. Diagram of the research process.

Each subsection refers to the steps in the research process.

3.1. Institutional context and case selection

The case company, Carbfix, was chosen as a purposeful sample [51], based on the objective of the study. It is a subsidiary of one of Iceland's main electricity generators and distributors and water utilities, Reykjavik Energy. Reykjavik Energy's operations include two geothermal plants, a hydropower station, hot and cold water supply, and an open fiber network. Reykjavik Energy is fully-owned by three municipalities and aims to "enhance the quality of life, guided by the principles of social responsibility". The company's three main values – "*foresight, efficiency, and integrity"* – are emphasized across all its subsidiaries [52]. One of the company's most fundamental tenets is its ownership strategy, which was formulated with the municipalities' participation in 2012. (The ownership strategy is described in detail in Section 4 of this paper).

The precursor to Carbfix began in 2005 as an idea to permanently store CO_2 in basalt rock in order to reduce Iceland's CO_2 emissions and meet its Kyoto protocol commitments [53]. In 2007, Carbfix was formalized as a joint research program between the University of Iceland, Reykjavik Energy, the Earth Institute at Columbia University (U.S.) and the CNRS, National Scientific Research group (Toulouse, France) [53]. The project involved a team of geoscientists, students, engineers and Reykjavik Energy employees who conducted experiments in laboratories and at Reykjavik Energy's Hellisheidi geothermal plant.

Carbfix was formally established in January 2020, with a dual mandate of CO_2 reduction and commercialization. Financing has come from a mix of its parent company and EU project funding and grants; the idea is that through commercialization, the entity will eventually operate as a stand-alone business. As of 2022, the company was actively working on three main commercialization initiatives for meeting its objectives: licensing its technology to CO_2 emitters; developing its collaboration on a direct air CO_2 capture and storage system; and, building a storage hub to import CO_2 for permanent storage in Iceland. The company's main source of revenues would be licensing fees as well as the sale of European Union Emission Trading Scheme (EU ETS) "cap and trade" carbon units. Since the company's establishment as a separate legal entity in 2020, the EU ETS market price had grown from a low of €15.43 (US$18.35) in March 2020 to more than €99.22 ($99.87) by August 2022 [10].

3.2. Archival data

Archival data was collected from October 2019 through March 2021 and involved information contributed by Carbfix and Reykjavik Energy. Secondary data included numerous publications, since Carbfix had been featured extensively in the international press, e.g., the BBC, NBC, *Newsweek*, and *The Economist*, and featured in many documentaries such as David Attenborough's *Climate Change-The Facts*. Also, from the outset of the project, scientists involved with Carbfix published more than 80 academic papers largely focused on the scientific characteristics of the project.

3.3. Interviews

Interviews were applicable in this case study as they allowed us to dive deeply into the subject and gain understanding from the interviewees' point of view. Five interviewees held executive positions at the case company. All interviews were semi-structured, as per a guide developed following archival data analysis [51]. The questions were open-ended and aimed at gaining an in-depth understanding of the opinions of the respondents [51]. Interviewees were selected as a purposeful sample, based on being highly knowledgeable about the subject and their expected contribution to the research [48]. Table (1) lists the interviewees.

Interviewees‘ position at Carbfix	Gender	Interview method and date
Carbfix‘s CEO	Female	Video call. January 15, 2021.
Head of CO2 Capture and Injection	Male	Video call. January 15, 2021.
Head of Business Development	Male	Video call. March 5, 2021.
Head of Research and Innovation	Male	Video call. December 23, 2020.
Head of Storage	Female	Video call, January 15, 2021.

Table 1 A list of interviewees.

All interviews were conducted one-on-one via video call between December 2020 and March 2021. Each interview lasted for about one hour.

*3.4***.** *Data analysis*

Archival data relating to the research question was gathered, coded and categorized. Interpretations of the data was inductive, based on grounded theory methodology [51]. Categories were further refined, and results were then summarized and analyzed. A semi-structured interview guide was created. Interviews were manually coded and ordered into categories from the first step. Categories were *Project History*, *Commercialization*, *R&D*, *Technology*, *Financing*, and *Owners*.

4. Results and Findings

*4.1***.** *Carbfix's innovation to permanently store CO_2*

The Carbfix storage technology involves injecting CO_2 gas into a small tower while water is pumped at the top; the scientists at Carbfix describe the operation as a giant "Soda Stream machine". After the CO_2 is dissolved in the water, the mixture is pumped into a well between 500m and 2,000m below the earth's surface and then into basalt rock. The CO_2 essentially fills the porous basalt rock; within two years, a solid calcite is formed, effectively locking the CO_2 away forever. Basalt rock is common in volcanic areas; due to its reactive and porous composition it is recognized as a suitable option for storing CO_2.

CO_2 and basalt react with one another throughout the natural world; however, it is usually a process spanning thousands of years. Carbfix's solution accelerates the process to two years. By accelerating the process, there is the possibility of creating mini earthquakes and increased seismicity, which is constantly evaluated and monitored by the Carbfix team. See figure (3) for a diagram of the Carbfix storage system.

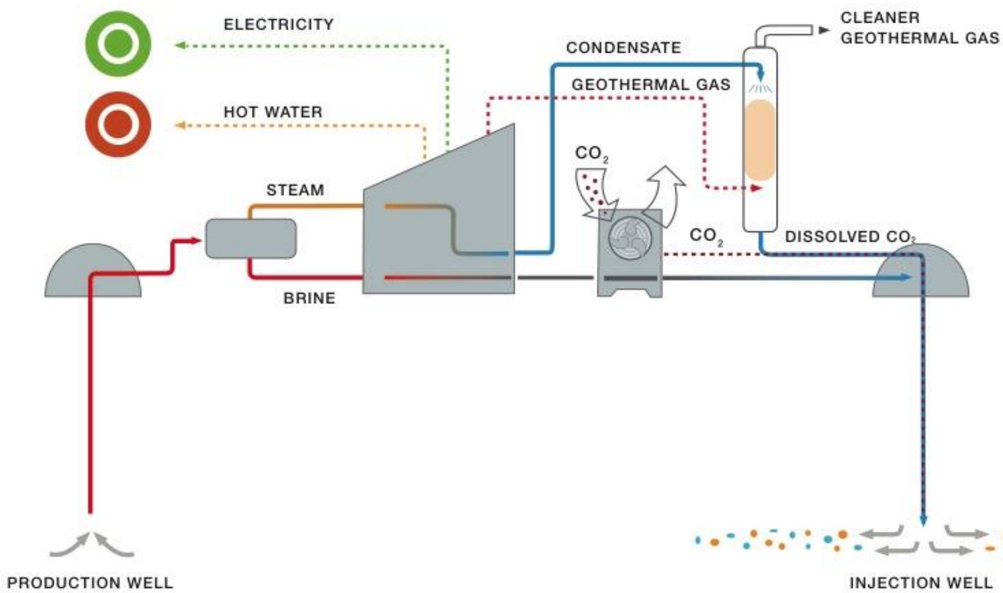

Fig. 3. Diagram of Carbfix Storage solution. Source: Company Files.

A key element of Carbfix's solution is that it can be built using standardized equipment such as pipes, pumps and compressors. The innovative aspects of the solution are seen by the Carbfix team to be the unique configuration of the uniform components, monitoring processes and software that has been developed with scientific "know-how" throughout the organization's evolution.

4.2. Carbfix's Evolution prior to Commercialization

Prior to their commercialization efforts, the Carbfix team moved through three main stages to ensure the solution could scale.

Preparation Stage (2007-2011): Scientists relied first upon lab experimentation, design, field studies, modeling, and monitoring to ensure the technology and equipment worked for the intended purpose of permanently storing CO_2. Throughout this period, the team presented the concept to appropriate local and national parties and acquired the appropriate licensing to expand to a pilot [54].

Pilot Stage (2011-2014): Carbfix1 The first iteration of Carbfix began at Reykjavik Energy's subsidiary ON Power's Hellisheidi plant. Since public pressure had been growing over the smell and health implications of Hydrogen Sulfide (H_2S) in the atmosphere, the pilot program experimented with injecting a mix of CO_2 and H_2S as well as pure CO_2 [55]. Over the first quarter of 2012, the project injected 175 tons of pure CO_2 at 500 meters of depth and later in the year, injected another 73 tons of a mix of CO_2 and H_2S [55]. By 2014, the team measured that 95% of the injected CO_2 and H_2S had mineralized successfully in less than two years [54]. The findings were published in the academic-reviewed journal "Science" [56] emphasizing that the two-year mineralization process was significantly shorter than the 10-year computer modeling predictions prior to the pilot [57].

Industrialization Stage (2014-2020): Carbfix2 The next phase looked to substantially increase volumes in an industrialized setting at the Hellisheidi geothermal plant. Carbfix's Head of Storage commented:

> *"Hydrogen sulfide continued as a big problem and if it wasn't addressed in some way then Reykjavik Energy would have had challenges with the public. Luckily, the scientists working on Carbfix and Sulfix said 'we have a solution' and that gave a push to industrialize*."

Connecting to two of Hellisheidi's six geothermal high-pressure turbines, Carbfix essentially had a full-scale carbon capture plant, permitting the injection of 10% and 22% of the plant's CO_2 and H_2S emissions [58,59]. By continually adjusting the configurations including water flow, the operation grew to represent 34% and 68% of the plant's CO_2 and H_2S emissions by 2017 [59,60]. The complete cost of capture and storage was estimated at US$24.80/ton [54]; the trading price of the European Union Emission Trading Scheme (EU ETS) often exceeded Carbfix's fully loaded cost [10].

With the confidence of being able to store higher quantities of $CO_{2,}$ the team looked for alternatives to capture CO_2 and initiated a partnership with Switzerland's Climeworks to capture CO_2 directly from ambient air. Climeworks installed their direct air capture (DAC) solution at the Hellisheidi plant to capture 50 tons of CO_2 per year [59,60]. The team believed the direct air capture coupled with Carbfix's storage method was a compelling innovation, since it allowed the solution to be installed at any global basalt-rich site.

In 2018, Carbfix received a €3.2 million (US$3.7 million) grant as part of a larger €16 million (US$18.5 million) pool of funding to apply Carbfix's solution at four different sites throughout Europe, i.e., an Icelandic basalt reservoir, an Italian gneiss reservoir, a Turkish volcano-clastic reservoir, and a German sedimentary reservoir [60].

4.4. Carbfix's Road to Commercialization

After improving the solution and demonstrating its capability to be implemented in an industrial setting, Carbfix began pursuing three commercialization options to expand their green tech innovation.

Option 1: Onsite Licensing The first option involves finding CO_2 emitters located in basalt-rich areas to complement the implementation of Carbfix's storage method onsite. The team has identified approximately one million suitable sites for small deployments representing a potential to capture approximately 4 trillion tons of CO_2 in Europe and 7.5 trillion tons in the U.S. [61]. The cost is estimated at approximately $30 per ton of CO_2.

Given the quantity of potential basalt sites, the team has focused on jurisdictions where CO_2 incentives exist, such as Sweden, Norway, Canada and the U.S. Because of Carbfix's press coverage in the international media, many emitters have inquired as to the solution. Accordingly, Carbfix has started "proactive prospecting" to find suitable partnerships. Carbfix's CEO talked about the onsite licensing option:

> *''The pros are that it's the lowest cost provided the site does not have to transport CO_2 for long distances and is in a favorable area with basalt. Most are fairly straightforward projects with readily available equipment. The major con is that everyone wants to reduce their emissions, but no one wants to pay for it.''*

Option 2: Direct Air Capture The second main option looks to take advantage of the company's relationship with Climeworks to install the combined direct air capture technology with Carbfix's storage capability. Air is first drawn in through a collector and, by increasing the temperature, concentrated CO_2 can be effectively captured [62]. The potential is much greater since a site does not necessarily need to be close to a CO_2 emitter. However, the direct air capture method is still in its infancy and the sites are much smaller, capturing between 3,000 and 5,000 tons of CO_2 annually. While the aviation and automotive industries are seen as potential partners, the cost is estimated to be much higher, at approximately $600 per ton of CO_2. Despite the high cost, partners had come forward to develop test sites to prove out the concept and potential scalability.

Carbfix's Head of Storage expanded about the pros and cons:

> *"CO_2 is very diluted in the atmosphere and requires a lot of energy to capture the CO_2 and because it's very energy intensive, it's very expensive. The positive side is that you can put it anywhere and line up and couple it with other activities and wastewater. Almost all climate scenarios require Direct Air Capture to remove CO_2 from the atmosphere. Trees can do this, but it takes a long time and a lot of space. More technological advances will be needed as it will take time to scale up this option."*

Option 3: Developing a Storage Hub in Iceland The third option involves importing and storing the CO_2 in Iceland at a large-scale site. Neighboring countries such as Norway, Sweden, Denmark, and the UK have been identified as potential partners. As a first demonstration site, the team plans to build a facility capable of storing 100,000 to 300,000 tons of CO_2. They would like to expand it to as much as 3 million tons within 10 years. The team believes there is the potential to develop several storage hubs throughout Iceland and has experimented with an offshore seawater hub. Potential customers from the neighboring countries are carbon-intensive industries like cement, chemicals, metals and power plants that could capture their CO_2 and ship it to Iceland. While the storage cost is estimated to be as low as $10 to $15 per ton, the total cost would need to include the capture and transportation costs, which could be up to $80 per ton.

Carbfix's CEO expanded on the pros and cons:

> *"The main pro is that we can reach scale and make the infrastructure very efficient. We can focus our efforts on fewer projects with a bigger impact from a human resource perspective. One of the biggest cons is the cost of transport can be high, but perhaps once more hubs are developed, the storage cost would come down further making it more attractive to transport. We feel we have a much cheaper way to store CO_2 when we look at the other major CCS projects occurring in Northern Europe.*
>
> *The biggest risk to a project like this is seismicity and because Iceland has natural earthquakes, we have to be careful to not trigger some of them earlier than expected. Some people might also say 'we don't want to become the waste disposal site of the earth' but as I look at it, we only have one atmosphere, and we must select the best options to make the greatest impact on climate change. We are creating value of our bedrock and creating new jobs and a new industry that is climate friendly*."

Evaluating Options: In building out its path to commercialization, Carbfix weighed the development of its options against three main considerations:

1. Time to market – the team looks at how long it will take to deliver the initiative from initial prospecting through to final implementation.
2. Financial benefit – the team evaluates each opportunity on the revenue, cost, and up-front investment.
3. Environmental benefit – the team considers the overall reduction of CO_2 including the environmental impact of additional carbon emissions such as traveling around the world for Option 1 or the transportation of CO_2, as in Option 3.

Carbfix's Head of Business Development talked about the importance of the EU's ETS carbon credits:

> *"For all options, we always need to consider ETS carbon credits. However, with the Government of Iceland extending the deduction of CO_2 injected into injection sites such as ours, this would allow any company in the EU to claim credits even if they inject the CO_2 in Iceland.*
>
> *The importance of carbon credits cannot be underestimated. Even if we look around the world at other companies, we see how big of a role they play. For example, the automotive manufacturer Tesla derives a significant portion of its profitability by selling regulatory credits."*

At the core of evaluating the options against the above criteria, we observed something much deeper – the reason the company had been so "patient" in the development of the solution. We found the answer in the company's responsible ownership vis a vis the parent company's ownership strategy since it explicitly lays out the parallel importance of respecting the natural environment and the pursuit of profits.

4.4. Carbfix and Reykjavik Energy's responsible ownership

In order to fully explore the linkage between responsible ownership and Carbfix's green tech innovation of permanently storing CO_2, a brief recent history of Carbfix's parent company, Reykjavik Energy, may be useful:

Reykjavik Energy came close to bankruptcy after the global financial crash of 2008; the company credited the ownership strategy as a major contributing factor to the company's resuscitation. The non-binding ownership strategy outlined the firm's guiding vision, role in society, essential activities, location, board of directors' decision-making privileges, financial objectives, risk assessment, environmental impact goals, terms of employment, communication and reporting, and decisions subject to owners' consent.

Reykjavik Energy demonstrated its willingness to place respect for the environment on an equal footing with profits [40] by participating in the UN's SDGs using an ESG methodology. The advancement of SDG 13 on Climate Action, which involves "taking urgent action to combat climate change and its impacts" [1] was fully in line with the vision of the ownership strategy and it drove Reykjavik Energy executives, board and owners to support the establishment of Carbfix as a separate entity in January 2020.

The connection to responsible ownership and the ownership strategy is paramount in Reykjavik Energy's decision to establish Carbfix as a separate entity to address SDG 13. First, Reykjavik Energy's owners were confident in Carbfix's technology to advance Climate Action, since the Carbfix system demonstrated on an industrial scale that it could reduce CO_2 with measurable results. Second, the owners believed the solution had applicability throughout the world, given the abundance of basalt rock around the world and the need to reduce CO_2 globally. Third, the owners had a long-term time horizon given that they had supported the project for over 15 years, without the immediate expectation of commercialization and profits. Tied to responsible ownership and the ownership strategy, Reykjavik Energy's three main values of foresight, efficiency, and integrity were at the forefront of supporting Carbfix as an ongoing concern.

Establishing Carbfix as a wholly owned subsidiary required the owners' consent as per the ownership strategy. In supporting Carbfix, Reykjavik Energy's ownership strategy was challenged in two main sections, i.e., "core activities" and "areas of operation." Reykjavik Energy's management and owners overcame these challenges due to the company's guiding vision of "respecting the environment, responsible use of natural resources, and responsible utilization of capital." [36]. The goals were established to further the reach of the technology to reduce CO_2 while ensuring that Carbfix activities would not interfere with the core activities of the parent company. In a press release in late 2019, Reykjavik Energy representatives wrote [63]:

> *"Carbfix has received global attention in recent months and years, especially concerning its applicability to reducing emissions from various power and industrial processes. However, investing in climate projects comes with a potential risk. Therefore, one of the goals of establishing the new subsidiary around Carbfix is to limit the financial risk of Reykjavik Energy with new Carbfix projects while continuing Carbfix development and scale-up in Iceland and abroad*."

5. Conclusion

Studies suggest that complying with the United Nations SDGs result in a lower financial return for shareholders [38], which might be one reason the adaptation of the SDGs is so slow. Radical actions are needed, but the challenge remains on how to enable the transition to sustainable energy systems and commercialize new technologies [3]. Barriers to bringing novel green tech solutions to the market often revolve around technological uncertainty, regulatory dependency, and a disadvantaged cost position, amongst others [5,26].

In the Carbfix case, we saw an innovative approach to carbon storage that configured existing technology in an innovative way to expedite the process of storing CO_2 in basalt rock. The team was then able to prove the solution at an industrial scale and, by doing so, deliver a solution at a significant cost advantage. Furthermore, they set the stage for eventual commercialization by engaging with local and national governments and witness positive regulatory changes, namely, the Icelandic government embracing the EU's ETS carbon credits from other countries.

The question remains, does responsible ownership foster sustainability and commercialize recent technology? While recent literature suggests that a sense of ownership is required to build a sustainable and responsible business, it also suggests that collaboration is important in governance for sustainability [41]. This led us to look at how the ownership might have contributed to the innovative solution.

One of the key tenets of Reykjavik Energy's ownership arrangement is the ownership strategy that acts as a consistent compass in the company's decisions. The ownership strategy clearly places sustainability on equal footing with profits and strengthens strategic decision making and the execution of strategic decisions. Since we established earlier that many green techs are stand-alone start-ups, they may not have the financial wherewithal to fully develop the solution and wait for the right market conditions before commercialization [25]. However, Carbfix's chain of ownership [63] – Reykjavik Energy and in turn, the three municipalities – all have a long-term vision, as codified in the ownership strategy. This allowed the initiative to develop through pilot to industrialized phases for more than 15 years before developing viable commercialization options.

Throughout that period, they were able to confront the common barriers in technological uncertainty, including regulatory dependency and a disadvantaged cost position. Reykjavik Energy's value of foresight seems to be particularly apt to understanding that climate solutions would become increasingly urgent.

While the results of the study suggest that owners practicing responsible ownership can advance green tech innovation by placing sustainability on an equal footing with profits, there are limitations to the study given the geographic context and the composition of the owners as municipalities. While the sample size is a limitation to generalize more broadly, we suggest future studies to first understand how green tech companies have overcome the main challenges in bringing technology to the market. We recommend further investigation to the extent that buyer-supplier relationships can spur on innovation and reduce barriers to green tech diffusion. Finally, we suggest looking at the linkages between responsible ownership, SDGs, and the long-term commitment to implementing vital climate change solutions.

6. Discussion

As of the time of this research, Carbfix is in the midst of commercialization; the company appears to be well-positioned to confront the all-too-common barriers of bringing green tech to the market. The implication this study has for policymakers and practitioners is to focus on ownership and documenting the "will" of owners to propel climate change solutions. For researchers and future research, we believe there are ample areas to continue exploration – namely: How can we collectively remove barriers to address crucial environmental challenges?

Author contribution

Gudrun Erla Jonsdottir: Conceptualization, Methodology, Writing – original draft. Jordan Mitchell: Data curation, Investigation, Reviewing and Editing. Throstur Olaf Sigurjonsson: Supervision, Validation. Ahmad Rahnema Alavi: Validation, Investigation.

Data availability

Data, excluding primary data, will be available by a direct request from the corresponding author.

Declaration of competing interest

One of the authors is employed by the parent of the case company and another author participated in a separately funded research project with the parent company.

Acknowledgments

We thank Carbfix and Reykjavik Energy for their willingness to participate in this study and for its scientific support.

References

[1] United Nations, IPCC. (2021, August 9). Secretary-General Calls Latest IPCC Climate Report 'Code Red for Humanity', Stressing 'Irrefutable' Evidence of Human Influence, https://press.un.org/en/2021/sgsm20847.doc.htm, Accessed November 21, 2021.

[2] Nowotny, J., Dodson, J., Fiechter, S., Gür, T. M., Kennedy, B., Macyk, W., Bak, T., Sigmund, W., Yamawaki, M., Rahman, K. A. (2018). Towards global sustainability: Education on environmentally clean energy technologies. Renewable and Sustainable Energy Reviews, 81: 2541-2551. http://dx.doi.org/10.1016/j.rser.2017.06.060

[3] Meijer, L.L.J., Huijben, J.C.C.M., van Boxstael, A., Romme, A.G.L. (2019). Barriers and drivers for technology commercialization by SMEs in the Dutch sustainable energy sector. Renewable and Sustainable Energy Reviews, 112: 114-126. https://doi.org/10.1016/j.rser.2019.05.050

[4] Foxon, T., Pearson, P. (2008). Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime, Journal of Cleaner Production, Volume 16, Issue 1, Supplement 1, Pages S148-S161, https://doi.org/10.1016/j.jclepro.2007.10.011.

[5] Polzin, F., von Flotow, P., Klerkx, L. (2016). Addressing barriers to eco-innovation: Exploring the finance mobilisation functions of institutional innovation intermediaries, Technological Forecasting and Social Change, Volume 103, Pages 34-46, https://doi.org/10.1016/j.techfore.2015.10.001.

[6] Awan, U. (2019). Effects of buyer-supplier relationship on social performance improvement and innovation performance improvement. International Journal of Applied Management Science. Vol. 11, No. 1 pp 21-35, https://doi.org/10.1504/IJAMS.2019.096657

[7] Awan, U., Kraslawski, A., Huiskonen, J. (2018). Buyer-supplier relationship on social sustainability: moderation analysis of cultural intelligence. Cogent Business and Management, Cogent, Vol. 5, No. 1, p. 1429346.

[8] United Nations. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. UN report.

[9] Snæbjörnsdóttir, S.Ó., Sigfússon, B., Marieni, C. et al. Carbon dioxide storage through mineral carbonation. Nat Rev Earth Environ 1, 90–102 (2020). https://doi.org/10.1038/s43017-019-0011-8

[10] EUA Futures, Ice Futures Europe (2021). Available at: https://www.theice.com/products/197/EUA-Futures/data?marketId=5693906&span=3, Accessed March 10, 2021.

[11] Cao, Z., Lumineau, F. (2015). Revisiting the interplay between contractual and relational governance: a qualitative and meta-analytic investigation. Journal of Operations Management, Elsevier, Vol. 33, pp. 15-42.

[12] Liu, Y., Lui, Y., Liu, T. (2009). Governing buyer-supplier relationships through transactional and relational mechanisms: Evidence from China. Journal of Operations Management, Vol. 27, No. 4, pp. 294-309.

[13] Mayer, C. (2013). Firm Commitment. Oxford: Oxford University Press.

[14] Mayer, C. (2018). Prosperity. Oxford: Oxford University Press.

[15] Olson, M. (1965). The logic of collective action: Public goods and the theory of groups. Cambridge MA: Harvard University Press.

[16] Future Earth 2025 Vision. (2013). Future Earth Interim Secretariat (Report of the transition team). Paris: International Council for Science; 2013. ISB 978-0-9330357-95-5

[17] United Nations. (2019). Report of the Secretary-General on SDG Progress 2019. UN Report, https://sustainabledevelopment.un.org/content/documents/24978Report_of_the_SG_on_SDG_Progress_2019.pdf

[18] Energy Transitions Commission. (2020). “Making Mission Possible: Delivering a Net-Zero Economy”.

[19] Fernandes Rodrigues Alves, M., Vasconcelos Ribeiro Galina, S., Dobelin, S. (2018). Literature on organizational innovation: past and future. Innovation & Management Review, 15(1): 2-19. https://doi.org/10.1108/INMR-01-2018-001

[20] Vincenzi, T.B.D., da Cunha, J.C. (2021). Open innovation and performance in the service sector. Innovation & Management Review, 18(4): 382-399. DOI 10.1108/INMR-01-2020-0004

[21] Polzin F., Sanders M., Stavlöt U. (2018). Mobilizing Early-Stage Investments for an Innovation-Led Sustainability Transition. In: Walker T., Kibsey S.D., Crichton R. (eds) Designing a Sustainable Financial System. Palgrave Studies in Sustainable Business In Association with Future Earth. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-319-66387-6_13

[22] Khaykin, I, Colas, J. T., Aks, M. (2021). How to finance industry’s net-zero transition, MarshMcLennan, Available at: https://www.marshmclennan.com/insights/publications/2021/february/how-to-finance-industrys-net-zero-transition.html Accessed October 15, 2021.

[23] Schiavi, G. S. & Behr, A. (2018). Emerging technologies and new business models: a review on disruptive business models. Innovation & Management Review, 15(4): 338-355. https://doi.org/10.1108/INMR-03-2018-0013

[24] Tongur, S. & Engwall, M. (2014). The business model dilemma of technology shifts. Technovation, 34(9): 525-535

[25] Marra, A., Antonelli, P., Pozzi, C. (2017). Emerging green-tech specializations and clusters – A network analysis on technological innovation at the metropolitan level. Renewable and Sustainable Energy Reviews, 67, 2017, Pages 1037-1046, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2016.09.086

[26] Negro, S.O., Alkemade, Floortje., Hekkert, M.P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. Renewable and Sustainable Energy Reviews. 16. 3836–3846. 10.1016/j.rser.2012.03.043

[27] Stadler, C., Helfat, C.E., Verona, G. (2021). 3 Strategies for Rolling Out New Tech Within Your Company. Harvard Business Review, August 25, 2021. https://hbr.org/2021/08/3-strategies-for-rolling-out-new-tech-within-your-company

[28] Pakura, S. (2020). Open innovation as a driver for new organisations: A qualitative analysis of green-tech start-ups. International Journal of Entrepreneurial Venturing, 12(1): 109-142.

[29] Greco, M., Locatelli, G., Lisi, S. (2017). Open innovation in the power & energy sector: Bringing together government policies, companies' interests, and academic essence. Energy Policy: 104, 316-324. https://doi.org/10.1016/j.enpol.2017.01.049

[30] Noailly, J.,Ryfisch, D. (2015). Multinational firms and the internationalization of green R&D: A review of the evidence and policy implications. Energy Policy, 83: 218-228. https://doi.org/10.1016/j.enpol.2015.03.002

[31] Bers, J.A., Dismukes, J.P., Mehserle, D., Rowe, C. (2012). Extending the stage-gate model to radical innovation-the accelerated radical innovation model. J. Knowl. Econ. 5:1-29. https://doi.org/10.1007/s13132-012-0131-6

[32] Johnsen, T.E. (2009) 'Supplier involvement in new product development and innovation: taking stock and looking to the future', Journal of Purchasing and Supply Management, Vol. 15, No. 3, pp.187–197.

[33] Sillanpää, I., Shahzad, K., Sillanpää, E. (2015). Supplier development and buyer-supplier relationship strategies - a literature review. International Journal of Procurement Management. 8. 227 - 250. https://doi.org/10.1504/IJPM.2015.066283.

[34] Moradlou, H., Roscoe, S., Ghadge, A. (2020). Buyer-supplier collaboration during emerging technology development. Production Planning and Control. 33. https://doi.org/10.1080/09537287.2020.1810759.

[35] Meijer, LLJ, Schipper F, Huijben, JCCM. (2017). The roles of business models in sustainability transitions: car sharing in Sydney. In: Zinek RJ, Baumgartner AL, KiesnereRauter R, editors. Exploring a changing view on organizing value creation. Graz: Institute of Systems Science, Innovation and Sustainability: 72–6.

[36] Huijben, JCCM, Verbong, GPJ, Podoynitsyna, KS. (2016). Mainstreaming solar: stretching the regulatory regime through business model innovation. Environmental Innovation and Societal Transitions, September, 1(20): 1–15. https://doi.org/10.1016/j.eist.2015.12.002

[37] Hernández-Chea, R., Jain, A., Bocken, N.M.P., Gurtoo, A. (2021). The Business Model in Sustainability Transitions: A Conceptualization. Sustainability, 13: 5763. https://doi.org/10.3390/su13115763

[38] Villalonga, B. (2018). The Impact of Ownership on Building Sustainable and Responsible Business. Journal of the British Academy, 6(1): 375-403. https://doi.org/10.5871/jba/006s1.375

[39] Joshi, D.K., Hughes, B.B., Sisk, T.D. (2015). Improving governance for the post-2015 Sustainable Development Goals: Scenario forecasting the next 50 years. World Development, 70: 286-302. https://doi.org/10.1016/j.worlddev.2015.01.013

[40] Jonsdottir, G. E., Sigurjonsson, T. O., Rahnema Alavi, A., Mitchell, J. (2021). Applying Responsible Ownership to Advance SDGs and the ESG Framework, Resulting in the Issuance of Green Bonds. Sustainability, 13(13): 7331. MDPI AG. http://dx.doi.org/10.3390/su13137331

[41] Jonsdottir, G. E., Sigurjonsson, T. O., Poulsen, T. (2020). Ownership strategy: A governance mechanism for collective action and responsible ownership. Corporate Ownership & Control, 17(3): 34-45. http://doi.org/10.22495/cocv17i3art3

[42] Carvalhal, A. (2012). Do shareholder agreements affect market valuation? Evidence from Brazilian listed firms. Journal of Corporate Finance, 18: 919–933. http://dx.doi.org/10.1016/j.jcorpfin.2012.04.003

[43] Villalonga, B., Amit, R. (2009). How are U.S. family firms controlled? The Review of Financial Studies, 22: 3047–3091. https://doi.org/10.1093/rfs/hhn080

[44] Schoon, M., Cox, M.E. (2018). Collaboration, Adaptation, and Scaling: Perspectives on Environmental Governance for Sustainability. Sustainability, 10: 679. https://doi.org/10.3390/su10030679

[45] van Tulder, R. (2018). Business & The Sustainable Development Goals: A Framework for Effective Corporate Involvement; Erasmus University: Rotterdam, The Netherlands.

[46] Siggelkow, N. (2007). Persuasion with case studies. Academy of Management Journal, 50(1), 20-24. DOI: 10.5465/AMJ.2007.24160882

[47] Eisenhardt, K. M. (1989). Building Theories from Case Study Research. Academy of Management Review, 14: 532-550. https://doi.org/10.5465/amr.1989.4308385

[48] Eisendhardt, K. M., Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. Academy of Management Journal, 50(1): 25-32. https://doi.org/10.5465/amj.2007.24160888

[49] Patton, M.Q. (2002). Qualitative research and evaluation methods. 3rd Sage Publications; Thousand Oaks, CA.

[50] Saunders, M., Lewis, P., Thornhill, A. (2016). Research Methods for Business Students, 7th ed. Pearson Education Limited: Essex, UK, 2016.

[51] Yin, R.K. (2014). Case Study Research: Design and Methods, 5th ed.; Sage Publications: Thousand Oaks, CA, USA, 2014.

[52] Reykjavik Energy Website (2021). Available at: https://www.or.is/en/about-or/operations/values/, Accessed January 23, 2021.

[53] Gislason, S. R., (2018). "Acceptance of the 2018 C.C. Patterson Award to Sigurdur R. Gislason." Geochimica et Cosmochimica Acta, 246: 591–593.

[54] Carbfix Website, Our Story, Available at: https://www.Carbfix.com/our-story, Accessed January 23, 2021.

[55] Olafsdottir, S., Gardarsson, S.M., Andradottir, H.O. (2014). Natural near field sinks of hydrogen sulfide from two geothermal power plants in Iceland. Atmospheric Environment, 96: 236-244. http://dx.doi.org/10.1016/j.atmosenv.2014.07.039

[56] Matter, J. M, Martin, S., Snæbjörnsdottir, S. Ó., Oelkers, E. H., Gislason, S.R., Aradottir, E.S., Sigfusson, B., Gunnarsson, I., Sigurdardottir, H., Gunnlaugsson, E., Axelsson, G., Alfredsson, H.A., Wolff-Boenisch, D., Mesfin, K., Taya, Fernandez de la Reguera, Hall, J., Dideriksen, K., Broecker, W.S. (2016). Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions. Science, 352(6291): 1312-1314, https://doi.org/10.1126/science.aad8132

[57] Kintisch, E. (2016, June 10). Underground injections turn carbon dioxide into stone. Science website, Available at https://www.sciencemag.org/news/2016/06/underground-injections-turn-carbon-dioxide-stone, Accessed January 30, 2021.

[58] Sigfússon, B., Arnarson, M.Þ., Snæbjörnsdóttir, S.Ó., Karlsdóttir, M.R., Aradóttir, E.S. & Gunnarsson. (2018). I. Reducing emissions of carbon dioxide and hydrogen sulfide at Hellisheidi power plant in 2014-2017 and the role of Carbfix in The 15th International Symposium on District Heating and Cooling Hellisheidi power plant in 2014-2017 and the role of Carbfix in achieving the 2040 Iceland climate goals. Energy Procedia, 146: 135-145. https://doi.org/10.1016/j.egypro.2018.07.018.

[59] Smith, M. (2017, October 20). Climeworks captures CO2 from the air, turns it to rock in the world first. JWN Energy website, https://www.jwnenergy.com/article/2017/10/20/climeworks-captures-co2-air-turns-it-rock-world-fi/, Accessed January 31, 2021.

[60] Richter, A. (2018, October 1). Carbfix project in Iceland wins EUR 16m EU Geothermal Emissions Control funding. Think Geoenergy, available at: https://www.thinkgeoenergy.com/Carbfix-project-in-iceland-wins-eur-16m-eu-geothermal-emissions-control-funding/, Accessed January 31, 2021.

[61] Carbfix Website, Where does it work?, https://www.Carbfix.com/Carbfix-atlas, Accessed February 6, 2021.

[62] Climeworks, CO2 Removal, Available at: https://climeworks.com/co2-removal, Accessed February 6, 2021.

[63] Carbfix Website, (2019, November 27). Carbfix as a subsidiary, Available at, https://www.Carbfix.com/Carbfix-as-a-subsidiary, Accessed January 31, 2021.