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Sustainability Unleashed: Pioneering Carbon Removal Solutions for a Net-Zero Future

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ABSTRACT

Purpose- Countries are urged to submit aggressive emissions reduction plans for 2030 to achieve net-zero emissions by 2050. Carbon removal solutions have become the focus of discussion by various scholars to adapt to global climate change and the goal of carbon neutrality. The paper aims to fill the knowledge gap by evaluating sustainable carbon removal solutions; nature-based, technological and hybrid solutions in terms of capturing, processing, transporting and storing CO_2 from the atmosphere.

Design/methodology/approach- To keep global warming at sustainable levels will require carbon removal technologies to scale up. The carbon removal methods vary in terms of capturing, processing, transporting, and storing CO_2 from the atmosphere. We evaluated and classified these solutions on the parameter of net carbon absorption from capturing, processing, transporting, and storing.

Findings- The paper establishes that technological and hybrid solutions hold the future of carbon removal solutions, and strategic interventions such as regulating carbon removal services and carbon pricing could catalyse decarbonization.

Practical Implications- The paper outlines a well-designed strategic intervention for policymakers to enforce regulations in light of the current status and accelerate the adoption of proven net-zero technologies. The paper offers a pool of business opportunities for an entrepreneur.

Originality/value- We are flooded with climate change talks on multiple platforms with CO_2 emissions targets thrown without feasible solutions or know-how. This paper breaks the clutter and fills the knowledge gap by evaluating sustainable carbon removal solutions in terms of capturing, processing, transporting and storing CO_2 from the atmosphere.

Keywords- Net Zero, Climate Change, Greenwashing, Carbon Removal

1. Introduction

Amidst the chaos, negotiations and counter-protests surrounding United Nations climate negotiations (United Nations, 2021) in Glasgow in November 2021 arose the promise to be better in terms of emissions and environmental destruction. Hundreds of countries pledged to halt deforestation by 2030, while leaders across the world vowed to reach net zero emission targets by specific dates. In the case of India, Prime Minister Modi addressed the gathering with an ambitious pledge to achieve net zero emissions by 2070. While the UK has championed a net zero plan by 2050, and the list of net zero targets goes on. But there is a problem - net zero emissions can mean infinitely different schemes depending on the context. Theoretically, India, the UK or even fossil fuel giants have stated that net zero emission targets can continue inspite of emitting greenhouse gases, claiming that future carbon capture technologies will compensate for all of their emissions (Okeke, 2021). Until now, countries have compensated emissions under "reduce and offset" outlined by Clean Development Mechanism (CDM) under the Kyoto Protocol (Lovell & Liverman, 2010). However, climate change calls for compensating emissions under "reduce and remove" to meet the requirements of net zero targets.

Sustainability is now a key performance indicator for managers. Sustainability management has become a full-time job to manage the asset portfolio, implement new initiatives to deliver better sustainability results and keep up with the legislative and regulatory changes. Often, facility manager takes the lead in promoting sustainable and eco-friendly practices (Zameer et al., 2021), but now Chief Sustainability Officer (CSO) roles are created in light of the emphasis on "net-zero". "Rather than just being a social responsibility, corporate sustainability is now being treated as an economic necessity" (Sonawane, 2020). The Chief Marketing Officer (CMO) needs to work in tandem with CSO in promoting sustainability concepts, shifting consumer expectations and weaving sustainability in the value proposition to encourage consumers to make sustainable purchase decisions (Breatnach, 2022). With this perspective in mind, the paper contributes in filling the knowledge gap by evaluating sustainable carbon removal solutions. It establishes the reality of the net-zero concept and aids in combating a company's carbon footprint, which is in no way a small feat. Each section of the paper makes a substantial contribution for an entrepreneur to have a business case.

Carbon removal solutions, particularly sustainable technological solutions, have become the focus of discussion by various scholars to adapt to global climate change and the goal of carbon neutrality. The significance of our study is in bridging the action gap through strategic interventions. The underlying objective of the paper is to address the key research questions- (1) What are the implications of net zero pledges? (2) What is greenwashing in the context of net-zero emissions? (3) What are the types of emissions under scope 1, 2, and 3 & their importance in net-zero? (4) What are the strategic interventions & sustainable solutions to decarbonize?

We have evaluated sustainable carbon removal solutions on the parameter of net carbon absorption, right from capturing, processing, transporting, to storing. The paper seeks to help managers in designing a strategy to realize the net-zero targets going forward. The paper also seeks to outline a well-designed strategic intervention by policymakers to help them avert the likely climate crisis.

2. The concept behind "Net Zero"

A decade ago, an idea was brewing - one that was meant to encapsulate the dual mission of reducing emissions while also capturing greenhouse gases from the atmosphere. The concept of net zero climate targets took root quickly during the Paris Climate negotiations (Bataille, 2019). "Net Zero" became the new climate buzz term for political and corporate leaders alike. Theoretically, a net zero strategy is a promising advancement when addressed appropriately. According to Alsaifi et al. (2020), a government or company must first identify and disclose all emissions it is accountable for, to reach net zero emissions, and then reduce them as much as possible. If there are still emissions, it should take initiatives that either prevent carbon emissions in another place or remove carbon out of the air resulting in a net zero balance on paper. In short, the ideal approach to achieving the net zero target is to prioritize carbon emission reductions. Then, as a last resort, carbon sequestration techniques can be adopted if all other possibilities for reduction have been exhausted. However, the problem with net zero goals is that there are no standards defined for the same. One company may not even reduce its emissions and rely on future carbon capture technologies, while the other might heavily reduce greenhouse gas output and only supplement with carbon negative options in the end (Statista, 2021). In most cases, however, net zero climate targets are used as buzz phrases for procrastinating until the last second because "Net Zero" may refer to various things. Countries and corporations may use these targets to continue polluting and turning a profit on the bet that some massive carbon capture infrastructure will suck up their emissions at the 11th hour (Coen et al., 2022). Simply put, Net Zero might be another procrastination strategy.

3. Greenwashing in the context of net zero emissions

Let us try and understand the problem of greenwashing in the context of net zero emissions by taking the case of some fossil fuel giants. As COVID-19 began to shake the globe in February 2020, BP's CEO announced that BP would reach net zero emissions by 2050. This felt strikingly similar, as if it were two decades ago when BP greenwashed beyond petroleum campaign in the early 2000s, where the major oil firm planned to phase out fossil fuels (Munir & Mohan, 2022). Looking back, one can see that the oil company's new eco-centric slogans and green graphics depict that very little has changed in their business practices.

To begin with, BP’s net zero claims appear to be limited to direct emissions resulting from oil and gas drilling and processing rather than consumer side emissions of their product such as automobile exhaust. This means that BP could claim zero emissions by completely reducing its operational emissions without even considering the carbon emissions of its fuel or natural gas. Furthermore, BP is not cutting emissions from its refineries and infrastructure (Barrage et al., 2020). The case falls under the "deceptive manipulation" of greenwashing (Siano et al., 2017). In theory, BP can continue emitting under the label of net zero as long as it offsets those emissions with massive tree-planting operations that often come with complications or some future carbon sequestration technology that is yet to be tested at scale.

What is more likely, however, is that when 2049 hits, BP might push the target further into the future. To make matters worse is BP's pledge "excludes more than 40 percent of its oil and 15 percent of its gas production" (Roberts, 2020). However, this would only cut the emissions intensity of their products by less than 30 percent. Emissions intensity is not the same as emissions. In short, net zero emissions do not actually mean zero emissions.

In recent years, a lot of capital has been invested into sustainability marketed funds and other ESG funds, increasing the incentives for firms to highlight environmental performance even when the facts do not back it up. Another challenge is that there is limited enforcement of greenwashing laws. This discussion highlights the need for future theory building by addressing the conventional understanding of CSR communication and greenwashing. It presents a substantial problem for management research, particularly in terms of how organizations can reduce their irresponsible actions and the associated negative repercussions.

4. Types of emissions

Companies should consider their sustainability strategy and business models to achieve net zero emissions by 2050 or perhaps sooner. To understand any individual firm's commitments to reach net zero, we need to be sure that we are talking about the same emissions. There are three different scopes of emissions that need to be addressed, as shown in figure 1. Scope 1 emissions are those direct on-site emissions from sources controlled by the entity itself. Primarily, this could include on-site vehicle fleets or production processes on site. Scope 2 emissions are indirect greenhouse gas emissions that arise from purchased electricity, heat, or steam by the entity. The emissions are off-site, but they are within the control of the entity. The third type of emissions are Scope 3 emissions, and these are the most distant and indirect from an organization. These are greenhouse gas emissions that arise from sources that are not controlled by the entity but relate to the upstream or downstream activities of the entity. For example, if an employee of a firm flies on a plane for business-related travel, the firm does not own the aircraft, it does not operate the aircraft, but it sends the employee on that business trip. The emissions from that business-related travel are the Scope 3 emissions of the firm. And while many companies attempt to get away with merely measuring scope 1 and 2, which is their energy usage or if they own fleets of vehicles, scope 3 accounts for the lion's share of a tech company's emissions, i.e. more than 80 percent. Hence, scope 3 is critical for measuring carbon footprint (Coniam, 2022).

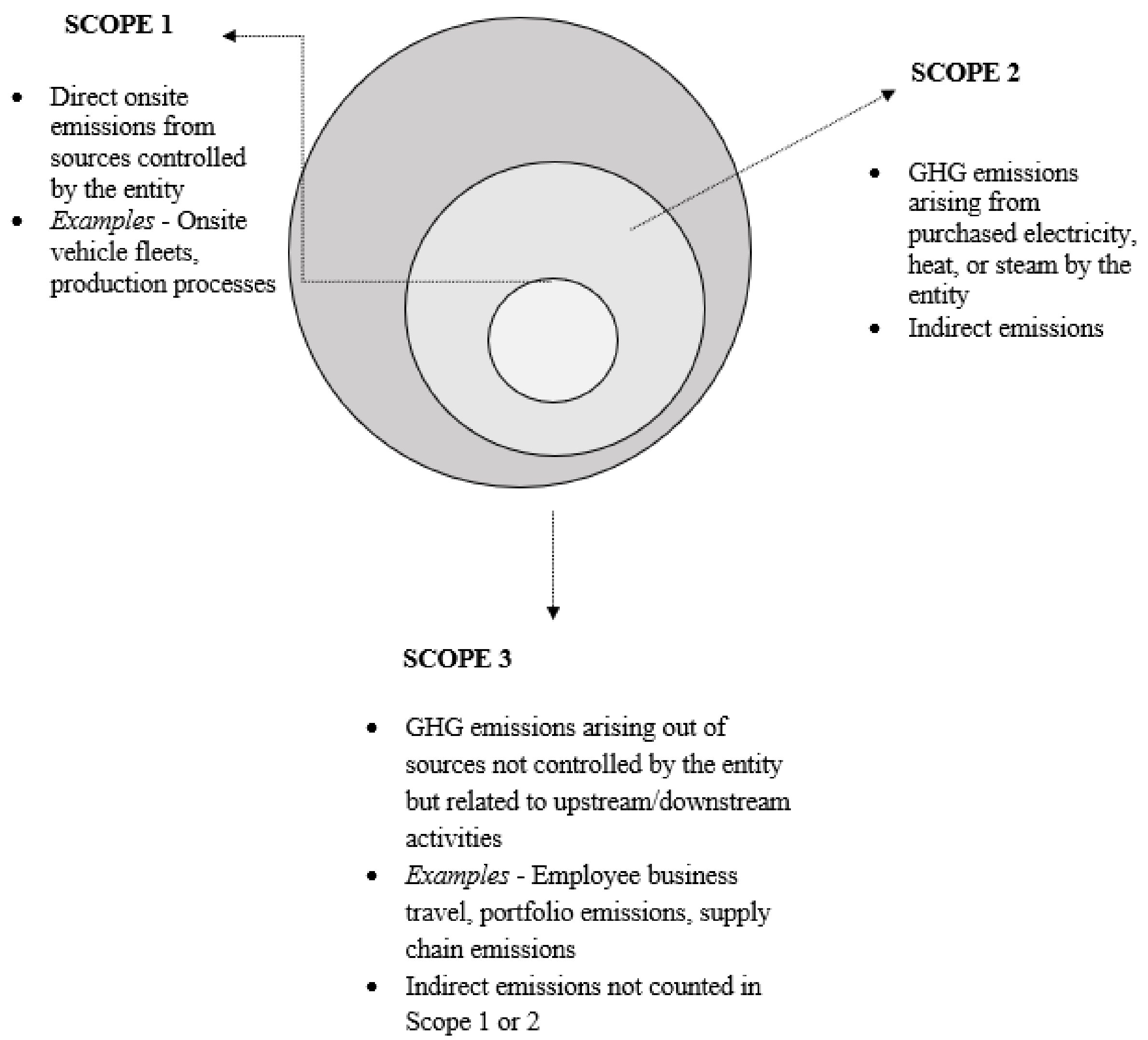

Figure 1: Classification of greenhouse gas emissions (Ryan & Tiller, 2022)

5. Solutions to decarbonize

Zero emissions are a long way off, as there is a continuous rise in carbon emissions globally even after numerous efforts to transition towards a low-carbon economy. The road toward full decarbonization in specific industries is decades away. As a result, balancing residual emissions and reversing previous emissions until and after 2050 will necessitate billions of tonnes of negative emissions and carbon removal technologies to scale up. The carbon removal methods vary in terms of capturing, processing, transporting, and storing CO_2 from the atmosphere. These are referred to as Negative Emissions Technologies (NETs) (Honegger & Reiner, 2018). However, not all of them depend on technological processes. As shown in figure 2, there are three classifications of sustainable carbon removal solutions. These solutions are evaluated on the parameter of net carbon absorption from capturing, processing, transporting, and storing in the following section.

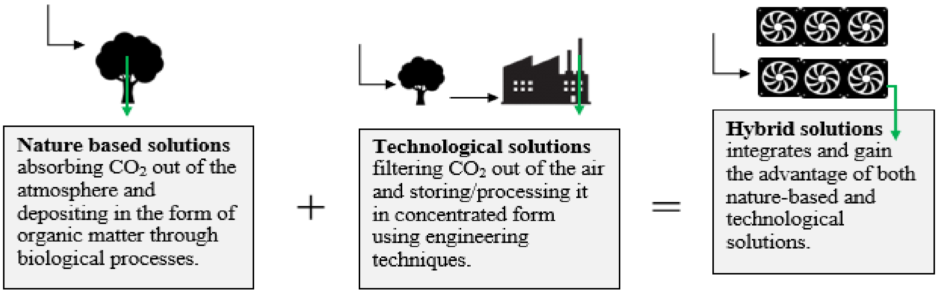

Figure 2: Carbon removal solutions

Scientists believe that we cannot limit global warming below 2° C with a single solution of carbon removal techniques (IPCC, 2005). Hence, a portfolio strategy is necessary with other climate change mitigation strategies to cater to the varying needs of communities, landscapes, economic feasibility and risk appetite.

5.1. Nature-based solutions

In such solutions, plants absorb CO_2 from the atmosphere by photosynthesis and use it to make biomass, i.e.,

leaves, roots, and woods, where the carbon is stored for the duration of the plant's life. Some carbon is released into the atmosphere as dead biomass decomposes, while others are metamorphosed into humus or peat.

Most nature-based solutions, such as afforestation and soil carbon sequestration strategies – are economical and prevalent (Fuss et al., 2018). Additional forms of carbon removal from nature, such as blue carbon, have received less attention (Herr et al., 2015). Nature-based solutions have far-reaching benefits, apart from carbon sequestration – it helps in flood protection and drought resilience. Moreover, it aids in biodiversity conservation which plays a significant role in preserving essential ecosystem functions.

On the other hand, nature-based solutions demand the use of land and water. The shared usability of land with agricultural activities, fodder production, and other human engagements; increases economic constraints and limits scalability (Smith, 2016). Furthermore, the time horizon to create negative emissions is not immediate: growing a forest or accumulating humus takes decades (Adeleke et al., 2021). Another concern is the long-term viability of storage owing to environmental and human factors. The capacity of trees and plants to absorb carbon is hampered by global warming and changing precipitation, and wildfires or any change brought to land management will result in an abrupt reversal of carbon in the atmosphere. There are three types of sustainable nature-based solutions (1) afforestation and enhanced forest management, (2) soil carbon sequestration, and (3) blue carbon

5.1.1. Afforestation and enhanced forest management

The phenomenon of planting trees in the previously unforested area is defined as afforestation. Better forest management aims to boost existing forests' carbon stock (Hou et al., 2020).

Capturing	Through the process of photosynthesis; vegetation absorbs CO_2 from the air
Processing	No emission
Transporting	Transportation of seedlings/saplings to their specified sowing location
Storing	In the form of growing and full-grown forests. Additionally, CO_2 is deposited in live biomass and the soil of forests (Vasudev, 2022) – it is worth noting that woody biomass may be collected and transformed into lifelong building materials, like mass timber, lasting for decades and store carbon

5.1.2. Soil carbon sequestration

In a regenerative farming method, soil collects organic matter into subsurface humus and biomass. The process of soil carbon sequestration directly increases carbon input into soils through numerous practices, such as cover crops growing close to the ground to enhance the soil quality (Ramesh et al., 2019), crop rotation restores a variety of soil nutrients (Alhameid et al., 2017), composting enhances the high quality of organic fertilization to the soil (Greff et al., 2022), improved grazing management, and reduced or no-tillage farming also decreases carbon loss from soils (Paustian et al., 2019).

Capturing	Atmospheric CO_2 ends up in soils as a result of plant biomass development and breakdown
Processing	No emission
Transporting	No emission
Storing	The organic matter gets transformed into soil

5.1.3. Blue carbon

Coastal wetlands and freshwater peatlands consisting of mangroves, seagrass meadows, salt marshes, and macroalgae can trap carbon greater than any other ecosystem (Macreadie et al., 2019). Still, there is a wide gap in our knowledge of sequestration rates and the way people might impact them positively (or adversely).

Capturing	Atmospheric CO_2 accumulates in wetland habitats as plant biomass grows and decomposes
Processing	No emission
Transporting	Transportation of seedlings/saplings to their specified sowing location
Storing	CO_2 gets stored in the soil, living biomass, peat, and deposits that mount up in wetlands

5.2. Technological solutions

In technological solutions, removal of atmospheric CO_2 for capturing, storage or both happens with industrial processes. This solution is energy-intensive as it relies on machinery, processing, and storage to transport captured concentrated CO_2 products. Hence, to avoid adding new CO_2 to the environment while eliminating what is already there, it is imperative that the energy consumed should come from renewable sources. For example, capturing a single tonne of CO_2 straight from the air requires 2300 kWh of energy by current filter technologies, which is similar to energy-matter in 0.2 tonnes of oil (IEA, 2021). When it undergoes the process of production, transportation and burning, oil generation emits 0.6 tonnes of CO_2 from 0.2 tonnes of oil. Hence, if we have to capture 1 tonne of CO_2 from the atmosphere with the energy derived from oil, it would result in merely 0.4 tonnes of CO_2 captured as the net benefit (IEA, 2021). Technological solutions are in the developmental and implementation stages because nature-based solutions are economical and have less operating expense. However, other advantages like employment generation, reusing abandoned oil wells/facilities, and innovation spillover are limited (Minx et al., 2018). Due to the lack of mandatory carbon pricing and involuntary purchases of carbon removal, there is hardly any commercial incentive to develop expensive technology. On the flip side, the land requirements are minimal compared to biological storage systems, and chemical or geological storage techniques are more lasting. The primary technological solutions are (1) direct air capture and storage and (2) enhanced weathering.

5.2.1. Direct air capture and storage (DACS)

In the DACS process, filtration of CO_2 takes place directly from the atmosphere, then compressing and later infusing deeply underground in geological structures for storing in the long run (Cobo et al., 2022).

Capturing	Chemical air filters installed in the processing units capture CO_2 at a concentration of 0.04 percent in the air and then bring it to a concentration of approximately 100 percent in the resultant gas product. This separation job necessitates the use of electricity (10–20 percent of total energy) to move adequate volumes of air through the unit, as well as heat (80–90 percent of total energy) to regenerate the filters (IEA, 2021).
Processing	After capturing the concentrated CO_2, it is gushed in compressors at >65 bar at room temperature for liquefaction (Deutz & Bardow, 2021).
Transporting	To enable air capture everywhere and not just at the CO_2 point source, air capture units are placed at the source of renewable energy, or at a storage location, or both; resulting in a small amount of CO_2 transport infrastructure requirement, for instance, long-distance pipes (Al-Qahtani et al., 2020).
Storing	The compressed – liquid CO_2 is injected into geological strata at a depth of about 800 to 2500 meters. When injected at a higher pressure than reservoir pressure, biochemical reactions stabilize CO_2 (IPCC, 2005). The advantage of storing CO_2 geologically is that the old infrastructure of exhausted oil and gas fields can be restocked. However, the methanation of CO_2 can be a viable alternative to geological storage (Tregambi et al., 2022).

There is not even a business model for simply extracting carbon from the atmosphere or investing a lot of money and not selling the carbon dioxide for some purpose. Hence, we have to sell the CO_2. What is the best use of CO_2 currently? It is to pump the CO_2 into an oil well and make the oil less dense. As a result, it will float to the top and make the oil more productive. This is called Enhanced Oil Recovery. The oil companies prefer this because it allows them to take the CO_2 and utilize it to increase their oil production, which also means we will be burning even more CO_2, burning even more oil for transportation and other purposes, resulting in even more pollution and global warming (Olabi et al., 2022).

Another alternative is to use the CO_2 collected as a feedstock and combine it with hydrogen to make synthetic fuels (Olabi et al., 2022). Gasoline and diesel vehicles, even planes that are challenging to electrify, can be powered by these fuels. Carbon engineering claims that this process produces carbon-neutral fuel because, even though the synthetic fuel emits CO_2 when burned, the carbon used to make it was removed from the environment before it was created. Since 2017, carbon engineers have started experimenting with synthetic fuel synthesis. However, the company is unable to market its fuels due to a lack of incentives that would make the fuel more competitive. Hence, in the United States, the federal government has a renewable fuel standard that incentivizes the production of sustainable fuels, but the air is not included as a feedstock (CNBC, 2021). As a result, competitors that generate fuel from corn, palm oil, or renewable municipal garbage have a significant government subsidy advantage when a company competes in the US market.

The future carbon engineering business model looks at selling carbon credits, which corporations would buy to offset their own emissions. Shopify has already expressed interest in becoming a customer (Shopify, 2022). Members of Virgin red loyalty programme may also spend their points to have carbon engineering remove carbon molecules from the air and eliminate their requirements (Virgin, 2021).

5.2.2. Enhanced weathering

The process of chemical weathering occurs naturally when CO_2 dissolved in water from the atmosphere damages the surface of a rock. This process can be enhanced by increasing and exposing the surface of appropriate rocks to rainwater/ocean water as much as possible (Schuiling & Krijgsman, 2006).

Capturing	Alkaline rock is mined and finely grounded to improve surface area before being placed uniformly over soil or beaches. CO_2 in water reacts with the rock grains to generate carbonic acid, which attacks and dissolves them, resulting in a constant mineral or a bicarbonate solution. The process of weathering can also be performed in an engineered reactor, provided pressure, pH and temperature are adjusted to speed up the processes, such as mineral carbonation or mineralization (Lackner et al., 1995).
Processing	Grinding and mining rock
Transporting	Trucks, trains, and ships transport materials from the mine/grinder to the weathering locations
Storing	It is stored in the form of bicarbonate solution, which is fixed in the pores or the surface of ocean water, and ultimately leads to mineral carbonation (Rinder & von Hagke, 2021).

5.3. Hybrid solutions

It aims to blend and profit from the prime features of both nature-based and technological solutions. Nature marvels at photosynthesis, which is air capture fuelled by the sun. Furthermore, technology is superior in converting CO_2 into long-term storage.

5.3.1. Bioenergy with carbon capture and storage (BECCS)

In a power plant, biomass is converted into heat and power, whereas turned into energy carriers such as ethanol, methanol or biogas in an industrial facility; as a result of this conversion, which is extracted from off-gas, using traditional point source carbon technologies, a biogenic CO_2 is produced (Hanssen et al., 2020). Concentrated CO_2 can be transported or converted for geological storage or into products with a long shelf life.

Capturing	Initial stage - Capturing CO_2 from the air through the process of photosynthesis
Processing	Firstly, plant biomass is collected, burnt, and processed into biofuels and other compounds. Secondly, the resultant biogenic CO_2 is removed from the exhaust gas using traditional carbon capture technologies (e.g., amine scrubbing). Lastly, the concentrated CO_2 is subsequently compressed and transported to a storage facility (Azar et al., 2010).
Transporting	It is a two-stepped process: 1. Transportation of biomass from forest/field to processing units. 2. Transportation of compressed/liquified CO_2 to a storage facility through pipelines or trucks/trains, or ships. Ideally, biomass sources and storage sites should be closer to reduce transportation costs (IPCC, 2005).
Storing	The storage possibilities are identical to those of DACS

5.3.2. Biochar

Biochar is produced by heating biomass in the absence of oxygen, such as in pyrolysis. It is a more permanent carbon storage solution than biomass as it comprises carbon black, which breaks down at a slower rate in natural conditions. It is mainly used to restore soil fertility in deteriorated topsoil (Smith, 2016).

Capturing	CO_2 is captured from the atmosphere by plant growth through photosynthesis.
Processing	In pyrolysis plants, biochar is processed from plant biomass. It generates off-gas (synthesis gas), i.e. methane and hydrogen-rich, which can strengthen the pyrolysis process or convert it into synthetic bio-fuels (Nan et al., 2020).
Transporting	Transporting biomass and biochar from the forest/field to the pyrolysis plant and the pyrolysis plant to the final destination, respectively (Tripathi et al., 2016).
Storing	CO_2 is stored in the form of carbon black – that can be used for soil amelioration and also used as building blocks in the chemical industries or construction, maintaining its stability over the decades (Ennis et al., 2012).

5.4. Regulating carbon removal services

A resilient net-zero approach for operational emissions is built on two distinct targets: 1) reducing emissions strictly, and 2) unavoidable emissions should be balanced by an equal amount of negative emissions through carbon removal. The former should take precedence in this approach. Quick attempts by companies to cut emissions; and also avoid the need for potentially expensive emissions, wherever feasible. However, most corporate net-zero pledge implementation plans prefer nature-based solution certifications because they are less costly and accessible (Seddon et al., 2021). Corporate purchasers of carbon removal services also prefer forest projects over soil carbon sequestration and blue carbon projects (IUCN, 2022). However, new forest clash over added land usage such as farming or habitat conservation is a challenge. Minx et al. (2018) assessed the carbon removal capability of the forest project. They discovered that "existing and new forests will be able to store 135 billion tonnes of CO_2 by the end of the century". The annual potential of removal was estimated to be between 0.5 and 3.6 billion tonnes, with the constraint of not employing any other land use-based removal option simultaneously. The rates mentioned above will last only until 2050. Such limitations highlight the need for corporates to support the expansion and deployment of less established, more costly, but more scalable technological solutions in addition to investing in nature-based solutions.

Another concern is what kind of removals should be used to counteract specific sources of residual emissions. What if climate innovators currently invest all of their CO_2 compensation funds only in forest and agriculture initiatives, they would effectively acquire all of the lands that are now accessible. Then, when land becomes scarce, prices will increase, making carbon removal more expensive for everyone, including developing markets and businesses with difficult-to-abate footprints. On the other hand, if companies announce their readiness to invest in more scalable but expensive solutions (hybrid and technological) at the first-mover price, the market will respond by increasing supply. Prices will begin to fall as the immature hybrid and technological solutions scale (Harvard Business Review, 2022). Technologies, in general, are quite expensive, and when we purchase more of them, they become gradually cheaper, not due to economies of scale but due to learning effects. The individuals who provide the technology grow more efficient at what they do, and unit costs begin to fall. You buy expensive today so that we can all buy them cheaply in a few years. Tech CEOs are early adopters of these removal technologies because they understand rights, laws, scaling, cost curves, and placing a bet on early technologies. This will lower the average cost of carbon removal certificates for everyone. Ideally, it will arrive just in time when the demand would be in tonnes.

The growth of the carbon removal industry to operate at the requisite scale is only possible through demand creation. It requires voluntary buyers who can take action quickly and incur the first mover cost and policymakers who enforce compliance globally at the correct price point in the marketplaces. The latter appears to be less plausible than the former. The anticipation is how well-funded private sector organizations, like banks and insurers, can interact and drive demand in the most effective way possible (Johannsdottir et al., 2014). In most circumstances, buyers of carbon removal services demand a certificate as evidence of their agreements. The market for traditional carbon offsets is well-established at a price ranging between 1 to 20 dollars per tonne of CO_2. Similarly, the market for carbon removal certificates also needs to be developed. Although the first marketplace attempts have emerged, the few corporate purchases of major removal services have included a prolonged procedure of proposing, selection and contracting (e.g., Stripe, Microsoft and Shopify) (Honegger et al., 2021). Broadly, it is challenging to find removals with international standardization at a price lower than carbon offsets. "Prices range from 5–10 dollars per tonne of CO_2 for specific existing projects in the realm of nature-based solutions to hundreds of dollars per tonne for less developed, technological alternatives" (Honegger et al., 2021). "The world's first certificates for DACS are presently available in Iceland for more than 1000 dollars per tonne of CO_2 (Climeworks, 2022) and wholesale for around 700–800 dollars" (Orbuch, 2020). Businesses need to set up separate targets for carbon removal with short-term milestones - critical to address the free-rider issue. However, waiting till 2049 to remove inevitable emissions in the expectation for the prices to fall in carbon removal technology will create a shortage of capacity, expertise and affordability of removal services in 2050.

5.5. Carbon pricing

The most significant impediment to carbon removal deployment is the lack of a business case. Globally, societies are disposing of carbon into the atmosphere as per their own choice, in the absence of carbon price. Currently, a carbon price is applied to a little over a fifth of worldwide greenhouse gas emissions, either through a tax or by requiring polluters to purchase tradable emissions permits (Fankhauser, 2021). Till date, businesses paid for necessary emissions by traditional carbon offset certificates (The Economist, 2020). As shown in Figure 3, a transaction occurs between an emitter and a third party to steer clear of an equivalent amount of emissions that the emitter is unable to prevent. This sort of CO_2 compensation certifies these operations as "climate neutral" (Zhang et al., 2022). It fails to fulfil the conditions to achieve a target of net zero, where an emitter is required to get a certificate from the carbon removal project, demonstrating that unavoidable emissions are offset by an equal amount of negative emissions.

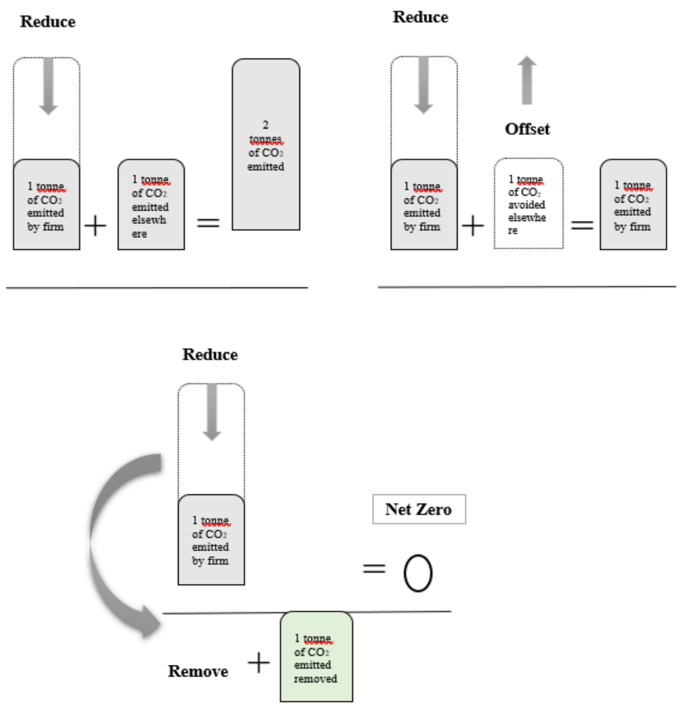

Figure 3: Difference between carbon offset and carbon removal

Carbon pricing has a lot of room for improvement. The United Nations Global Compact encourages businesses to set an internal carbon pricing of at least $100 per tonne on emissions (UN, 2022) because the bulk of carbon pricing is still much below that level. Furthermore, fines for exceeding permissible levels are ineffective even if carbon is appropriately priced. In the E.U., a fine for an excess tonne can be as low as €100 (Fang et al., 2018). It is barely a deterrent, given that it is approximately the cost of a permit. In theory, regulators enforce carbon prices and permits, but it can be challenging in practice due to carbon emissions scope 1, 2 and 3 measurements. In most markets around the world, enforcement is lax, and punishment is negligible and even if some markets adopt effective deterrents, the ones next door may not.

Globally, there are rules, systems and enforcement mechanisms to deal with the problem. A multinational corporation with divisions making the same product the same way will face a patchwork of different rules and regulations, causing carbon leakage between these markets (Wu et al., 2022). A company may relocate from an area with strict environmental regulations to one with less stringent standards, allowing it to avoid paying for its carbon emissions. However, regulation plays an essential role in this scenario since no one would pay for carbon emissions or face a penalty without it (Albitar et al., 2022). As a result, the government is essentially required to create the market, set the rules, enforce fines and impose a carbon cap. Border carbon adjustments are one short-term solution for preventing carbon leakage (Evans et al., 2020). The E.U. recently proposed a carbon market tax on carbon emitted by goods manufactured outside the E.U. importers would be required to pay the same tariff as if the goods were manufactured in the E.U. Hence, sourcing goods from a less regulated region will not be cheaper. As we are gaining momentum in addressing climate change in the following years, we will need to accomplish a global carbon price and economic harmonization (Ben-Amar et al., 2022). The big kahuna is China, an industrial powerhouse and carbon-intensive. It is required to take action and collaborate with other economies to harmonize carbon pricing and trading systems; otherwise, most of the world's efforts will be undermined by the fact that countries like China are producing heavily carbon-intensive goods, and multinationals will shift production to those countries even more than they have done in the past (Zhang et al., 2017).

As climate change has moved up the political agenda, governments are beginning to improve how their carbon markets function. Since 2019, the E.U. has been taking steps to reduce the number of permits issued, which has resulted in carbon prices in the E.U. reaching record highs of €97.50 per tonne (Reuters, 2022; Gerlagh et al., 2022). Carbon prices in other markets are also rising as regulators seek measures to improve their effectiveness. Other countries will create their own markets if it appears that money can be earned. Carbon markets have hit the mainstream in the last 12 to 18 months. For those who believe there is a good marriage between public policy and regulators, this is a golden opportunity for innovators. If prices remain high enough, supported by pledges from governments and regulators, carbon markets may begin to achieve their original goal of helping to decarbonize the world.

6. Implications and Directions for Future Research

6.1 Implications for Managers

The net-zero transition cannot be accomplished by governments alone. Leaders in the private sector have an opportunity to be role models in achieving net-zero transition goals. In this context, the current section elaborates implications for the organization.

First, each section of the paper offers a pool of business opportunities for an entrepreneur to apply our evaluation of sustainable technological solutions that can avert climate crises.

Second, the paper highlights the opportunities for the broader ecosystem that needs to be built around low-emissions products. For instance, markets for an entirely new set of raw materials and minerals will be needed for the transition, and new supply chains need to be established.

The paper elaborates that pledging funds are insufficient. Our solutions shall help managers in designing a credible strategy across organizational functions and supply chains to realize the net-zero targets. It is challenging for businesses to understand where action must be focused and prioritized to address the issue of decarbonization. We suggest that managers should realize and be open to the environmental consulting services while designing their strategies going forward.

Finally, the paper also highlights how greenwashing can cause significant reputational risk to a company. Research has supported that environmentally conscious consumers are capable of figuring out the actual green claims or products from the greenwashing ones (Vollero, 2022; Zhang et al., 2018). However, our underlying objective is to help marketing professionals understand how climate concerns can translate into carbon pricing and carbon removal decisions instead of unsustainable practices.

6.2 Implications for Policymakers

In the light of climate crises, a more active role of policymakers would be required. We lay down the following implications for the policymakers.

The paper outlines a well-designed strategic intervention for decarbonization for benefit of the consumers and society at large. This might be helpful to the policymakers to design and enforce regulations in light of the current status and to best avert the likely climate crises.

Our paper also suggests policymakers to put a price on carbon emissions and regulate carbon certificates.

We also recommend leveraging government subsidies and creating financial incentives to accelerate the adoption of proven net-zero technologies, particularly in the areas of energy efficiency and renewable energy generation.

6.3 Future Research

Future research could develop metrics for ascertaining carbon removal solutions and explore more use cases of carbon. Additionally, more research is required on carbon capture and storage (CCS), carbon capture utilization (CCU) and carbon capture utilization and storage (CCUS).

Future research could also consider finding solutions for reducing Scope 3 emissions that happen during the consumption stage. This would enable marketers to comprehend what influences a product's lifecycle carbon footprint, for instance, if we start disclosing the carbon emissions count on the label of a hamburger or a laptop of its lifecycle. However, we are far from making a purchase decision based on that. The intriguing feature of Scope 3 emissions is that it is driven by consumer behaviour, which the company finds difficult to influence.

Lessons from history indicate that net-zero transition, when combined with technological innovation, will not necessarily lead to inclusive growth (Rydge et al., 2018). However, future research requires robust institutional frameworks and policy mechanisms to deliver sustainable and more inclusive growth.

7. Conclusion

Scaling up of carbon removal depends on the implementation and enforcement of extremely rigid climate policies, which is presently lacking in most countries. The private sector can play a significant role in leveraging and expediting the scaling up of the carbon removal industry. Asset management and investor side of insurance do not enter the carbon removal market due to certain predicaments like market immaturity, lack of insurance offerings and institutional support, which could help ward off some investment risks. It is highly uncertain that a potential insurer or an investor would render into the carbon removal market alone; instead, they look for opportunities as sidecar investments, such as oil and gas majors investing in the transition to net-zero. This will help to smoothen out initial fears about the maturity of the market. Nonetheless, sooner or later, an increase in the momentum of shareholder pressure, investors' own net-zero commitments, technological advancement in carbon removal solutions and tightening climate policies should attract investors to this sector. Still, posing the question of "how soon?"

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