How do Voluntary Carbon Markets Aid Green Transition & Sustainability?

- What can strengthening the effectiveness of them?
- What drives firms to purchase carbon credits?
- How can AI assist the verification process of carbon credits and Blockchain facilitate their transactions?

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- *EDHEC Business School does not express approval or disapproval concerning the opinions given in this paper which are the sole responsibility of the author.*

Dedication

In the loving memory of my father who "sailed" for another world in December 2023.

Thank you for everything.

Executive Summary

The global climate crisis has elevated the importance of mechanisms that allow organizations to reduce their carbon footprints. Voluntary Carbon Markets (VCMs) have emerged as critical platforms for companies and individuals to purchase carbon credits that support projects aimed at reducing or removing greenhouse gases (GHGs) from the atmosphere. Unlike compliance markets, VCMs operate on a voluntary basis, driven by corporate social responsibility, stakeholder expectations, and the need to meet sustainability goals.

This research examines the role of VCMs in facilitating the green transition, the drivers for firms to purchase carbon credits, and how technologies such as Artificial Intelligence (AI) and blockchain can enhance the transparency and verification of these markets. The findings show that VCMs have significant potential to contribute to global climate goals, but face challenges related to market volatility, inconsistent quality of carbon credits, and the need for robust verification standards.

Firms are motivated to purchase carbon credits for various reasons, including compliance with anticipated regulations, corporate social responsibility, risk management, and enhancing their public image. As carbon markets grow, high-quality carbon credits that deliver real, measurable environmental benefits are becoming increasingly important.

Emerging technologies such as AI and blockchain offer solutions to address the credibility and transparency issues within VCMs. AI can automate the measurement, reporting, and verification (MRV) processes, while blockchain can facilitate secure and transparent transactions, reducing fraud and enhancing market confidence.

In conclusion, while VCMs play a significant role in global efforts to combat climate change, their long-term success depends on improving market transparency, standardization of carbon credit quality, and leveraging advanced technologies. With these enhancements, VCMs can make a meaningful contribution to sustainability and the green transition, helping businesses and governments meet their climate commitments.

Keywords

#VoluntaryCarbonMarkets (VCMs)

#CarbonCredits

#Sustainability

#ArtificialIntelligence (AI)

#Blockchain

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Abbreviations

Abbreviation	Full Form
ACR	American Carbon Registry
AI	Artificial Intelligence
BVCM	Beyond Value Chain Mitigation
CAR	Climate Action Reserve
CCB	Climate, Community, and Biodiversity
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CO2e	Carbon Dioxide Equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	Direct Air Capture
EM	Environmental Markets
ESG	Environmental, Social, and Governance
GHG	Greenhouse Gas
ICVCM	Integrity Council for the Voluntary Carbon Market
IFM	Improved Forest Management
IoT	Internet of Things
ISO	International Organization for Standardization
MRV	Measurement, Reporting, and Verification
NBS	Nature-Based Solutions
NDC	Nationally Determined Contribution
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDG	Sustainable Development Goals
TSVCM	Taskforce on Scaling Voluntary Carbon Markets
VCM	Voluntary Carbon Market
VCMI	Voluntary Carbon Markets Integrity Initiative
VCS	Verified Carbon Standard
WTP	Willingness to Pay

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Introduction

The global climate crisis has intensified the demand for innovative solutions to reduce greenhouse gas (GHG) emissions. Among the mechanisms that have gained prominence are Voluntary Carbon Markets (VCMs), which enable companies and individuals to purchase carbon credits generated from projects that reduce or remove carbon from the atmosphere. These markets are increasingly recognized as vital tools for facilitating the green transition, empowering organizations to take proactive steps toward sustainability while meeting their carbon offset goals.

Unlike compliance markets, which are regulated and mandatory, VCMs operate on a voluntary basis. Participation is driven by corporate social responsibility, stakeholder expectations, and the desire to demonstrate leadership in climate action. As VCMs expand, they present both opportunities and challenges, particularly concerning the credibility and quality of carbon credits, market volatility, and the need for robust verification processes.

The central focus of this research is to explore the role of VCMs in supporting sustainability and the green transition. Key questions include: How can the effectiveness of VCMs be enhanced? What motivates firms to purchase carbon credits? And how can advanced technologies like Artificial Intelligence (AI) and Blockchain improve the verification and transaction processes of carbon credits?

The volatility in carbon pricing and concerns about the integrity of carbon credits underscore the importance of this research. By investigating these key dynamics, the study aims to provide a clearer understanding of how VCMs can contribute to sustainability goals while identifying areas where further improvements are needed for the markets to deliver real, measurable benefits.

This paper begins with an overview of carbon pricing and its influence on market participation and project development, followed by an analysis of the different types of carbon credits, their valuation, and the role of standards organizations. The empirical findings then explore how firms engage with VCMs, what drives their participation, and how emerging technologies such as AI and blockchain are shaping the future of carbon credit verification and transactions.

Understanding Carbon Prices in Voluntary Carbon Markets

Carbon pricing is a fundamental mechanism in both voluntary and compliance carbon markets, designed to internalize the external costs of carbon emissions by assigning a monetary value to each ton of carbon dioxide equivalent (CO_2e) reduced or removed from the atmosphere. This pricing mechanism is crucial for driving investments in low-carbon technologies and projects, as it creates financial incentives for companies and governments to reduce their emissions or to purchase carbon credits as offsets.

Carbon pricing within voluntary carbon markets (VCMs) is a complex and evolving mechanism that plays a significant role in global efforts to reduce greenhouse gas emissions. The pricing of carbon credits is influenced by various factors, including the type of project generating the credits, market confidence in the integrity of those credits, and broader regulatory and economic contexts.

The Role of Carbon Prices in Voluntary Carbon Markets

Voluntary carbon markets (VCMs) have seen significant evolution since their inception in the early 1990s. These markets allow companies to purchase carbon credits on a voluntary basis, often to meet corporate social responsibility goals or to preempt regulatory requirements. The price of carbon credits within these markets is influenced by several factors, including the type of carbon reduction project, its location, and the additional benefits it provides, such as contributions to biodiversity or community development.

However, one of the key challenges in VCMs is the fragmentation and variability in carbon prices. Unlike compliance markets, where carbon prices are often determined by government regulations or cap-and-trade systems, VCMs operate with less regulatory oversight, resulting in a wide range of prices for carbon credits. This variability is largely due to the diversity of carbon projects and the lack of standardized pricing mechanisms (Dawes, McGeady, & Majkut, 2023).

Historical and Recent Trends in Carbon Prices

Historically, carbon prices in voluntary markets have been subject to significant fluctuations. For instance, in 2023, the average price of carbon credits in the voluntary market dropped to $6.53 per ton of CO_2e, reflecting a broader contraction in the market due to factors such as increased scrutiny over the quality of carbon offsets and reduced buyer confidence (Procton, 2023). This price drop contrasts sharply with the higher prices seen in 2022, highlighting the inherent volatility in these markets (Favasuli & Sebastian, 2021).

The type of carbon credits also plays a significant role in pricing dynamics. Projects that generate these credits vary widely, from nature-based solutions (NBS) like reforestation to technology-driven approaches such as carbon capture and storage. Nature-based solutions (NBS), such as afforestation and reforestation projects, tend to command higher prices due to their perceived co-benefits. However, concerns about the accuracy of emissions reductions

and the permanence of these projects have also contributed to price volatility (Dawes, McGeady, & Majkut, 2023).

For example, nature-based credits saw a significant price drop in 2023 after a report challenged the credibility of many REDD+ credits (credits from reducing emissions from deforestation and forest degradation), which shook market confidence (Choudhury et al., 2024).

Moreover, the broader market sentiment and concerns about the integrity of carbon credits also significantly impact their pricing. In 2023, the market for carbon credits was severely affected by revelations regarding the questionable quality of certain credits, particularly those issued by well-known standards like Verra. This situation led to a dramatic decrease in prices, with nature-based credits experiencing some of the steepest declines.

The Platts CNC, a standardized contract for nature-based credits, saw its price plummet by over 95% in 2023, reflecting a broader skepticism about the efficacy and authenticity of these credits (Edwardes-Evans, 2020). This market volatility underscores the importance of maintaining high standards and transparency within the VCMs to preserve market integrity and stabilize prices.

In addition to these factors, the mechanisms of the market itself—such as the development of standardized contracts and the role of trading platforms—have a significant contribution in determining carbon prices. Efforts to standardize and increase transparency within the market aim to reduce price volatility by making it easier for buyers to understand what they are purchasing.

However, despite these efforts, the market remains fragmented, with prices heavily influenced by the specific risks associated with different types of projects. For example, the significant price drop of standardized contracts in 2023, as mentioned prior, where prices for some contracts hit record lows, highlights the challenges the market faces in achieving stability (Choudhury et al., 2024).

As we move further into 2024, the outlook for carbon pricing in VCMs remains uncertain, though there is cautious optimism that prices may recover as the market addresses integrity issues and regulatory frameworks become clearer. The slow recovery of prices from their 2023 lows suggests that while the market is resilient, it is still highly susceptible to shocks related to credibility and regulatory uncertainty. For the market to thrive, ongoing efforts to improve the transparency, verification, and standardization of carbon credits will be crucial (Procton, 2023).

Figure 1: Total Volume & Value of VCM, and Average Price of Carbon Credit (Procton, 2023)

2022			2023			Percent Chang		
Volume ($MtCO_2e$)	Value (USD)	Price (USD)	Volume ($MtCO_2e$)	Value (USD)	Price (USD)	Volume	Value	Price
253.8	$1.87 B	$7.37	110.8	$723 M	$6.53	-56%	-61%	-11%

Impact of Carbon Prices on Market Participation & Project Development

Carbon pricing within voluntary markets is a key determinant of both market participation and the development of carbon projects. Higher carbon prices can incentivize the development of new projects by enhancing their financial viability, particularly in sectors where emissions reductions are expensive. Conversely, lower carbon prices can undermine the financial feasibility of these projects, particularly those that depend heavily on carbon credit revenues to cover operational costs (Procton, 2023).

The lack of transparency and the fragmentation of carbon pricing have been significant barriers to the growth of voluntary markets. The absence of centralized pricing mechanisms and the reliance on over-the-counter trades complicate the process for buyers to assess the quality and value of carbon credits, leading to potential underpricing and reduced investment in high-quality projects (Dawes, McGeady, & Majkut, 2023).

The Future of Carbon Prices in Voluntary Markets

Looking forward, the future of carbon prices in voluntary markets will likely be shaped by several factors, including the implementation of **Article 6 of the Paris Agreement**, which aims to create a more standardized global carbon market. If successfully implemented, Article 6 could help stabilize carbon prices by providing a consistent framework for the certification and trading of carbon credits across borders, thereby enhancing market transparency and increasing the confidence of both buyers and sellers (Procton, 2023).

The pricing of carbon credits in voluntary carbon markets is influenced by a myriad of factors, including the type of credits, market sentiment, regulatory environments, and the mechanisms of the market itself. These factors combine to create a complex and dynamic pricing environment that stakeholders must navigate carefully. Understanding these dynamics is essential for anyone involved in carbon markets, whether they are policymakers, investors, or companies looking to offset their carbon emissions.

Detailed Definition of Carbon Credits Types & Projects

Carbon credits are tradable certificates representing the reduction or removal of one metric ton of carbon dioxide (CO2) or its equivalent in other greenhouse gases from the atmosphere. These credits play a pivotal role in both compliance and voluntary carbon markets, enabling organizations to offset their emissions by investing in projects that reduce or remove greenhouse gases.

The types of carbon credits are primarily classified into two categories: Removal Credits and Avoidance Credits. Each type is associated with specific project types that contribute to the global effort of mitigating climate change.

Removal Credits

Removal credits are awarded for projects that physically remove carbon dioxide from the atmosphere. These projects focus on sequestering carbon through natural or technological processes, ensuring that CO2 is captured and stored over a long period.

Direct Air Capture (DAC) is a technology that involves capturing CO2 directly from the air using chemical processes and then storing it underground or utilizing it in industrial applications.

Reforestation and afforestation projects involve planting trees in deforested areas or creating new forests in previously non-forested lands. Trees absorb CO2 during photosynthesis, sequestering carbon in biomass and soils.

Biochar production, which involves converting organic materials into biochar, helps in sequestering carbon in the soil. The carbon in biochar remains stable in the soil for hundreds to thousands of years, thus providing long-term carbon sequestration (Dawes et al., 2023).

Avoidance Credits

Avoidance credits are generated by projects that prevent the emission of CO2 or other greenhouse gases that would have otherwise occurred. These credits are typically associated with actions that reduce or avoid emissions compared to a baseline scenario.

Renewable energy projects, for example, replace fossil fuel-based power generation with renewable sources such as wind, solar, or hydroelectric power. By generating energy from renewable sources, these projects avoid the emissions associated with burning fossil fuels.

Forestry and Land Use projects, particularly those under the *REDD+* (Reducing Emissions from Deforestation and Forest Degradation) framework, prevent deforestation and promote sustainable land use practices. By protecting forests that would otherwise be logged or degraded, these projects avoid the release of stored carbon in trees and soil (*What Are the Different Carbon Reduction Projects Types?*, 2024).

Additionally, projects that distribute **energy-efficient** cookstoves to communities help reduce the amount of biomass needed for cooking, thereby reducing the emissions produced from less efficient traditional stoves (Dawes et al., 2023)).

Hybrid Projects

Some projects encompass elements of both removal and avoidance, contributing to reducing emissions while also enhancing carbon sequestration.

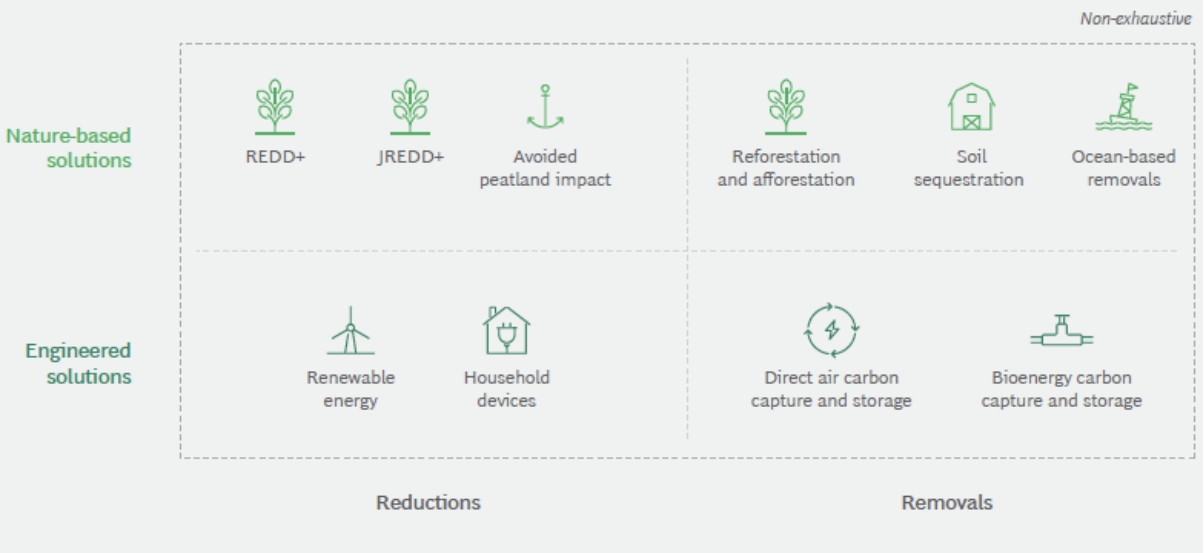
Blue carbon projects, for instance, focus on the restoration and conservation of coastal and marine ecosystems such as mangroves, seagrasses, and salt marshes. These ecosystems act as significant carbon sinks, absorbing CO2 while also protecting against the release of stored carbon through habitat destruction (ClimateSeed, 2024).

Agricultural land management projects implement sustainable agricultural practices, such as no-till farming or planting cover crops, which help sequester carbon in the soil while also reducing emissions from agricultural activities (ClimateSeed, 2024).

Understanding the types of carbon credits and the projects associated with them is crucial for stakeholders in the carbon market. Removal credits focus on sequestering carbon from the atmosphere, while avoidance credits aim to prevent emissions. Hybrid projects, such as blue carbon and sustainable agriculture, offer dual benefits of emission reductions and carbon sequestration.

These distinctions are essential for ensuring the effectiveness and integrity of carbon credit systems, as they directly impact the ability of companies and governments to meet their climate goals.

Figure 2: Carbon Credit Types & Projects (Baridó et al., 2023)



The CORSIA Eligibility Criterion

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) has played a significant role in driving demand for carbon credits during its pilot phase from 2021 to 2023. During this phase, airlines were able to voluntarily purchase eligible carbon credits from specific standards and project types to offset their carbon emissions from international flights. Initially, CORSIA was perceived by some as a "de facto" quality standard for the voluntary carbon market (VCM), particularly before the introduction of the Integrity Council for the Voluntary Carbon Market (ICVCM) Core Carbon Principles.

Throughout the pilot phase, credits from 11 different standards were deemed eligible for CORSIA, although most forestry projects from these standards were excluded due to their higher risk of reversal. In 2022, there was a reported 30 percent premium on transactions involving CORSIA-eligible credits to the Environmental Markets (EM), but this premium had dissipated by 2023.

The first implementation phase of CORSIA is set to begin in 2024, with only two project standards approved for offsetting at the time of writing. It remains uncertain which standards will be included in this next phase and how the project requirements may evolve from those in the pilot phase *(Procton, 2023)*.

The Voluntary Carbon Markets

In the contemporary landscape of voluntary carbon markets, several key platforms have emerged as central to the trading of carbon credits. These markets are critical for enabling companies and individuals to voluntarily purchase carbon credits, often as part of their strategies to offset emissions or meet sustainability goals.

One of the largest and most active voluntary carbon markets today is the **Xpansiv Carbon Benefits Ledger (CBL)**. Located in New York, Xpansiv CBL provides a platform where carbon credits from a wide array of projects, including renewable energy and forestry, are traded. The market has developed standardized products such as the Nature-based Global Emission Offset (N-GEO) to ensure consistent quality and facilitate trading, making it a significant player in the global carbon market (*CBL - Home*, n.d.).

Another major platform is the **AirCarbon Exchange (ACX)**, based in Singapore. ACX operates as a fully digital exchange, allowing carbon credits to be traded in real-time. It has introduced innovative products like the Global Nature Token, which standardizes nature-based carbon credits, thereby enhancing the ease and accessibility of trading for a broader audience of buyers and sellers (*Products - ACX*, 2023).

The **Climate Action Reserve (CAR)**, while primarily recognized as a standards organization, also plays a significant role in the voluntary carbon market, particularly in North America. CAR supports the trading of high-quality carbon credits generated from projects that meet its rigorous standards, with a strong presence in sectors such as forestry, agriculture, and waste management (*Carbon Market Directory*, n.d.).

In addition, **Verra**, the organization responsible for the Verified Carbon Standard (VCS), operates the **Verra Registry**, which supports the trading of carbon credits from VCS-certified projects. The Verra Registry is a vital part of the voluntary carbon market, offering transparency and ensuring that all credits listed are real, additional, and permanent, thereby upholding the credibility of the market (*Verra Registry*, n.d.).

The **Gold Standard**, known for its stringent environmental and social criteria, also facilitates a voluntary carbon market where credits from Gold Standard-certified projects are available for purchase. This marketplace is particularly attractive to buyers who prioritize credits that contribute to sustainable development goals (SDGs) alongside carbon reduction, adding a layer of social and environmental value to their carbon offset activities (*The Gold Standard Marketplace*, n.d.).

The **American Carbon Registry (ACR)** operates in a similar capacity, functioning both as a standards organization and a voluntary carbon market. ACR is well-regarded for its focus on high-quality, rigorously verified carbon credits, supporting projects across various sectors, including forestry, agriculture, and carbon capture and storage (CCS) (*American Carbon Registry*, n.d.).

Lastly, **Puro.earth** represents a more specialized voluntary carbon market focused on carbon removal credits, and specific CO2 Removal Certificates (CORCs). Based in Finland, Puro.earth emphasizes projects that actively remove carbon dioxide from the atmosphere, such as biochar production and carbonated building materials, positioning itself as an innovator in the market by focusing on long-term carbon sequestration (*How to Buy CORCs Carbon Credits*, n.d.).

These voluntary carbon markets provide essential infrastructure for the trading of carbon credits, playing a crucial role in global efforts to mitigate climate change. Each market offers unique strengths, whether through geographic focus, the types of projects supported, or the standards of verification, collectively contributing to the growth and dynamism of the voluntary carbon market sector.

Moreover, it is noticable that almost all of the market places that have been identified in this chapter are also the standards organizations that will be listed later on, however, a more centralized common trading platform like **CBL** and **ACX** could be the most appropriate method for ensuring the robustness of carbon credits quality, transparency and comparability of listings, and raise of public interest. Thus, achieving the primary purpose of carbon credits to contribute significantly to tackling climate change and to mitigate its consequences.

The Participants of the VCM

The carbon markets are driven by the collaborative efforts of five main participants, each playing a distinct role in the ecosystem. The first key player is the **project developers**. They operate at the upstream end of the market, initiating and managing projects that generate carbon credits. These projects vary widely, ranging from large-scale industrial endeavors, such as high-volume hydroelectric plants, to smaller, community-based initiatives like clean cookstoves.

The projects are diverse, addressing direct emissions from industrial processes through methods like fugitive emissions management and ozone capture, as well as engaging in nature-based solutions such as REDD+ (Reduced Emissions from Deforestation and Forest Degradation) and soil sequestration. Each carbon credit issued by these projects is characterized by its vintage, the year of issuance, and its delivery date, indicating when it becomes available on the market. Beyond their primary function of reducing greenhouse gases (GHGs), these projects often contribute additional benefits, aligning with the United Nations' Sustainable Development Goals (SDGs), such as improving local welfare, enhancing water quality, or reducing economic inequality.

The **end buyers** represent the downstream market, comprising companies and even individual consumers who purchase carbon credits to offset some or all their GHG emissions. Historically, early adopters in this category included tech giants like Apple and Google, airlines, and oil and gas majors.

However, more sectors, including finance, are entering the market as they establish net-zero targets or seek to mitigate the financial risks associated with the energy transition. The implementation of *Article 6 of the Paris Agreement* has further expanded this market by setting the rules for a crediting mechanism that allows the 193 parties to the Paris Agreement to purchase voluntary carbon credits, provided they adhere to Article 6's regulations.

The **retail traders** serve as the intermediaries between supply and demand, akin to brokers in other commodity markets. They purchase large volumes of carbon credits from suppliers, aggregate them into portfolios, and then sell these bundles to end buyers, typically for a commission.

While many transactions currently occur through private negotiations, the emergence of exchanges such as the **New York-based Xpansiv CBL** and **Singapore-based AirCarbon Exchange (ACX)** mentioned prior is beginning to streamline the trade of carbon credits. These exchanges have developed standard products, like *CBL's Nature-based Global Emission Offset (N-GEO)* and *ACX's Global Nature Token*, which help to simplify the complex trade process by ensuring that certain specifications are met.

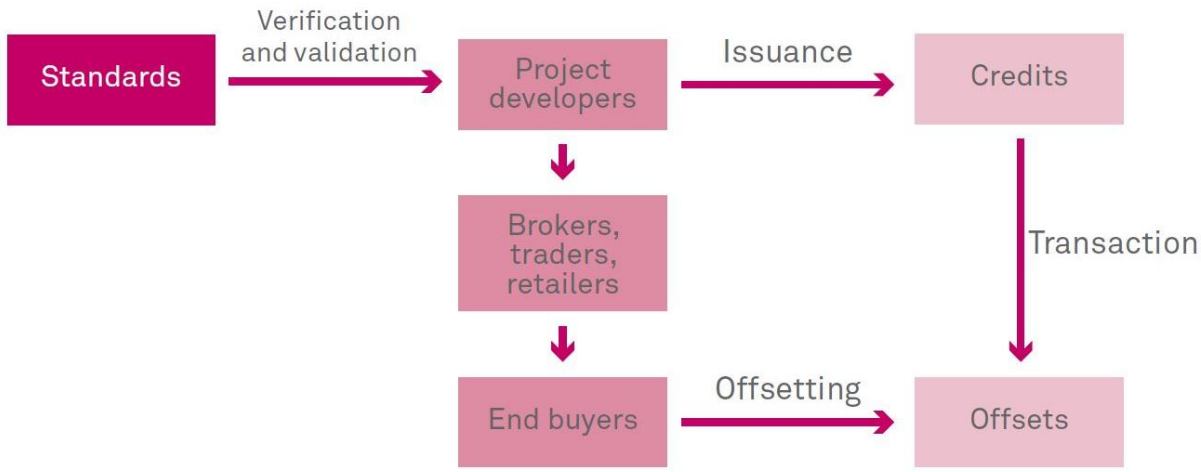
Nevertheless, non-standardized products are often preferred by end buyers, who prioritize the specific characteristics of each underlying project to ensure the quality of the credits and protect themselves from accusations of greenwashing.

Brokers play a critical role in the market by purchasing carbon credits from retail traders and marketing them to end buyers, typically charging a commission for their services. They help to facilitate the flow of credits between traders and buyers, thereby supporting the overall functioning of the market.

Lastly, the **standards organizations**, usually non-governmental organizations (NGOs), are unique to the carbon markets. These entities certify that carbon credit projects meet their stated objectives and accurately quantify the emissions reductions they claim to achieve. Each type of project, whether it be reforestation or renewable energy, follows specific methodologies to calculate the number of carbon credits it generates, ensuring that the credits have integrity and are credible within the market (Favasuli & Sebastian, 2021).

These five players—project developers, end buyers, retail traders, brokers, and standards—collectively form the backbone of carbon markets, driving the development, trading, and regulation of carbon credits, which are essential tools in the global effort to combat climate change.

Figure 3: The Participants of the VCM (Favasuli & Sebastian, 2021)



Regarding standards organizations and carbon credits verifiers, beyond them, and the process of rankings, there will be a careful examination in the following chapter.

Standards Organizations and Verifiers

In the carbon credit market, several key standards organizations and verifiers are instrumental in ensuring the credibility, transparency, and integrity of carbon credits. These organizations establish the rules and methodologies that projects must follow to generate carbon credits, ensuring that the claimed emissions reductions or removals are real, measurable, and additional.

One of the most prominent standards is the **Verified Carbon Standard (VCS)**, managed by Verra. VCS is one of the largest and most widely used carbon credit standards globally, covering a broad range of project types, including forestry, agriculture, energy efficiency, and renewable energy. VCS projects undergo rigorous verification by independent third-party auditors, making it a highly trusted standard in the market (*Verified Carbon Standard*, n.d.).

Another significant standard is the **Gold Standard**, which was initially established by the World Wildlife Fund (WWF) and other international NGOs. The Gold Standard is known for its stringent environmental and social impact criteria, certifying projects that contribute to sustainable development goals such as clean energy and community-based initiatives. This standard is particularly valued for its focus on projects that generate co-benefits beyond carbon reduction, such as improving local livelihoods and enhancing biodiversity (*Gold Standard for the Global Goals*, n.d.).

In North America, the **Climate Action Reserve (CAR)** plays a critical role, particularly in the United States and Mexico. CAR provides standardized protocols for various types of carbon offset projects, including forestry, agriculture, and waste management. It is recognized for its rigorous verification processes and strong emphasis on transparency, ensuring that the credits generated are reliable and of high quality (*Verification*, n.d.).

Similarly, the **American Carbon Registry (ACR)**, operated by Winrock International, is another leading standard in North America. Altough ACR is only a registry and does not offer verification services, however, it provides a detailed guide "*ACR Validation and Verification Standard*" disclosed in May 2018, that outlines general validation and verification requirements for project-based GHG emission reductions and removals, applicable to a wide range of project types.

The **Plan Vivo** standard supports small-scale, community-based projects, primarily in developing countries. Plan Vivo emphasizes sustainable land management and ecosystem restoration, with projects certified under this standard often generating significant social and environmental co-benefits, particularly for rural and indigenous communities (*What Are Plan Vivo Certificates?*, 2020).

Historically, the **Clean Development Mechanism (CDM)**, established under the Kyoto Protocol, has been a significant player. The CDM allowed industrialized countries to invest in emission reduction projects in developing countries and earn *Certified Emission Reductions*

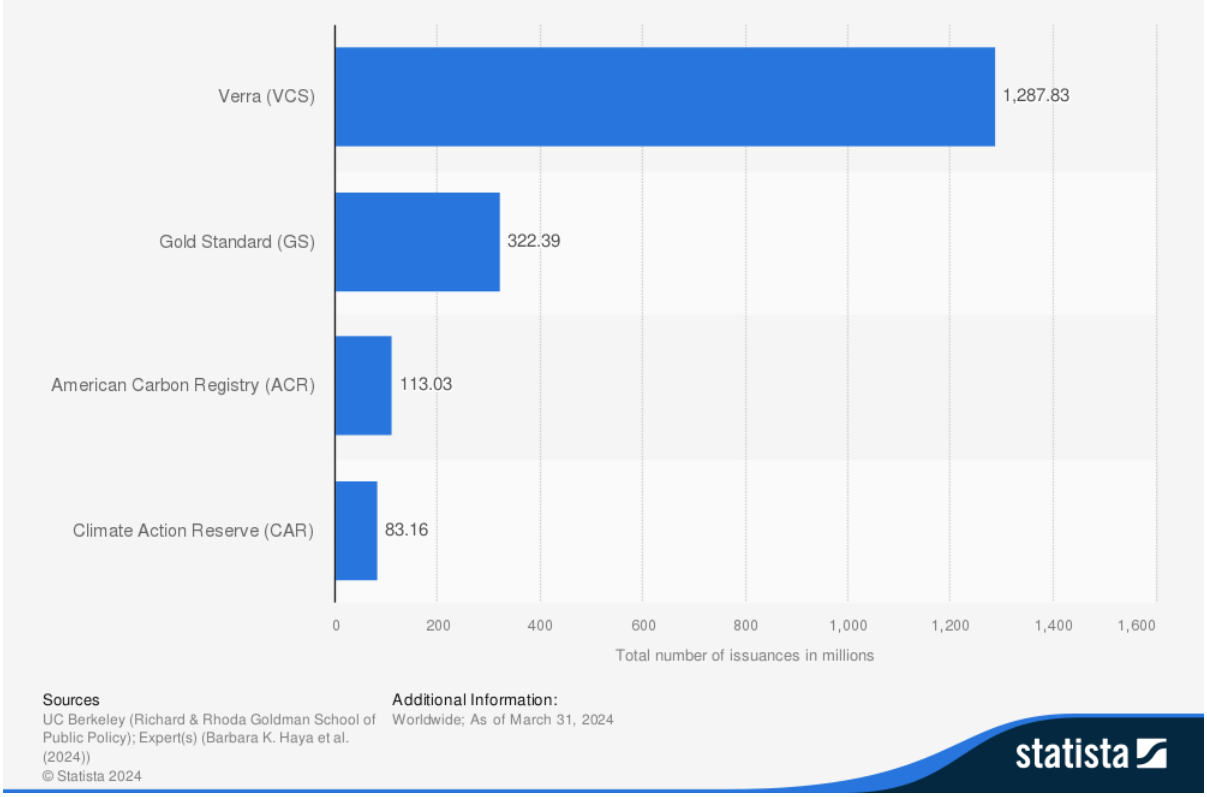
(CERs). Although the use of CDM has declined with the evolution of carbon markets, it remains an important framework in the historical context of carbon credit verification (*CDM: About CDM*, n.d.).

Additionally, **Social Carbon** is a standard that emphasizes the social and environmental co-benefits of carbon offset projects. Often used in conjunction with other standards like the VCS, Social Carbon focuses on assessing factors such as community engagement, biodiversity, and cultural preservation, thereby enhancing the overall impact of carbon credit projects (*Why SocialCarbon*, n.d.).

Finally, the **ISO 14064** standards, developed by the International Organization for Standardization (ISO), provide a framework for quantifying, monitoring, and reporting greenhouse gas emissions and removals. While ISO 14064 is not a certification standard in the same vein as VCS or Gold Standard, it offers a *robust framework* that can be used alongside other standards to ensure the accurate verification of carbon credits (*ISO 14064-01*, n.d.).

These standards organizations and verifiers are essential in maintaining the integrity of carbon credits by ensuring that projects adhere to rigorous environmental and social criteria. Their verification processes build trust in carbon markets, ensuring that the credits traded represent genuine, additional, and permanent reductions in greenhouse gas emissions.

Figure 4: Issuance of Carbon Credits per Leading Standard Organization (Tiseo, 2024)



Beyond Standards Organizations

Moreover, in the continiously evolving landscape of voluntary carbon markets, beyond standards organizations mentioned above, several innovative tools have emerged that focus on enhancing transparency, quality assessment, and informed decision-making. These platforms play a crucial role in ensuring that carbon credits are credible and effective in contributing to global climate goals.

BeZero Carbon is an independent rating system designed to evaluate the quality of carbon credits. Unlike traditional standards organizations that primarily focus on verifying projects, BeZero Carbon offers an innovative approach by providing transparency and insights into the potential risks and benefits associated with different carbon credits.

The platform's comprehensive methodology assesses various factors such as project type, location, governance, and environmental impact. By offering detailed ratings, BeZero Carbon enables buyers and stakeholders to make more informed decisions, thereby enhancing trust and credibility within the carbon markets (BeZero Carbon, n.d.).

Sylvera, another key player in this space, provides data-driven insights and independent ratings for carbon credits. Utilizing advanced technologies such as satellite imagery, machine learning, and remote sensing, Sylvera offers a comprehensive evaluation of carbon offset projects.

The platform monitors and verifies the actual impact of projects, such as reforestation efforts, over time. By combining quantitative data with qualitative assessments, Sylvera delivers a holistic view of each project's effectiveness. This transparency helps buyers, investors, and other stakeholders navigate the complexities of the carbon markets and make decisions that are both credible and impactful, reducing the risk of greenwashing (*Carbon Credits Are the 'Net' in Net Zero*, n.d.).

Calyx Global also contributes to the enhancement of carbon markets through its independent rating system, which focuses on the environmental integrity and co-benefits of carbon projects. Calyx Global's ratings evaluate key criteria such as *additionality*, *permanence*, and *leakage*, offering a clear and rigorous assessment of the quality of carbon credits.

The platform's emphasis on environmental integrity ensures that the emissions reductions or removals claimed by a project are genuinely additional and would not have occurred otherwise. Furthermore, Calyx Global considers the broader social and environmental impacts of projects, including benefits related to biodiversity and community engagement. This holistic approach helps stakeholders to distinguish high-quality carbon credits and align their offset purchases with broader sustainability goals (*Approach - Calyx Global*, n.d.).

Lastly, the **Offset Guide** provides a comprehensive framework for evaluating and selecting carbon credits. Developed by experts in carbon markets and environmental policy, the Offset Guide offers tools and guidance to help buyers assess the quality of carbon offsets.

The framework includes criteria such as **additionality**, **permanence**, **leakage**, and **monitoring**, all those will be discussed extensively in the next chapter, which are essential for ensuring that carbon credits deliver the intended environmental benefits. The Offset Guide is particularly useful for companies, policymakers, and individuals who seek to navigate the complexities of carbon markets and make informed decisions about their carbon offset strategies (*Carbon Offset Guide*, n.d.).

These tools—BeZero Carbon, Sylvera, Calyx Global, Offset Guide, and many more nowadays—are integral to the functioning of voluntary carbon markets. By providing independent assessments, ratings, and comprehensive frameworks, they help to build trust and transparency, enabling stakeholders to make informed decisions and ensuring that investments in carbon credits are both effective and credible.

The Rankings of the Carbon Credits

The evaluation and ranking of carbon credits in the voluntary carbon market (VCM) have become increasingly sophisticated as market actors seek to prioritize quality over cost. Buyers are shifting towards carbon credits from projects that provide demonstrable climate benefits, particularly those with measurable greenhouse gas (GHG) reductions and additional environmental and social co-benefits.

Key factors such as project transparency, the type of project, and its location significantly influence the ranking of credits, with removal projects like reforestation and direct air capture (DAC) receiving higher value. The market is also seeing a growing demand for credits verified by third-party standards, ensuring that emissions reductions are real, quantifiable, and permanent.

Although the demand for high-quality credits continues to rise, the willingness of buyers to pay premiums for these credits highlights the market's focus on credibility, long-term impact, and broader environmental contributions.

Quality Factors

The ranking of carbon credits in the voluntary carbon market is determined by several quality factors. One of the primary determinants is the **demonstrable reduction** or removal of greenhouse gases (GHGs), with **additionality**, **permanence**, and **robust measurement practices** (Carbon Accounting) being critical. This focus on GHG impact ensures that high-quality carbon credits genuinely contribute to climate mitigation goals.

Moreover, the **type of project** and its **location** significantly influence the ranking, with carbon removal projects, such as reforestation or direct air capture (DAC), being rated higher than emission reduction projects like renewable energy initiatives. Buyers also tend to prioritize credits from projects that are geographically closer to their operations or supply chains (*VCMI Claims Code of Practice*, 2023).

Verification by trusted third-party agencies such as Verra, Gold Standard, and the American Carbon Registry, already referred prior, plays a pivotal role in the ranking process, as these certifications provide confidence in the reliability of the credits.

Projects that offer broader **environmental** or **social benefits**, known as *co-benefits*, also rank higher, particularly when they contribute to biodiversity preservation or support local communities. Transparency in project reporting and verification processes is another critical aspect of ranking, as buyers value clear and comprehensive data on the credits they purchase (Procton, 2023).

Additionality, Measurement (Carbon Accounting), Permanence, & Leakage

Additionality is a core principle in the ranking of carbon credits, ensuring that the emission reductions would not have occurred without the implementation of the carbon project. For a

project to be considered additional, it must demonstrate that it goes beyond business-as-usual scenarios and is not financially viable without the revenue from carbon credit sales.

For example, renewable energy projects in regions where fossil fuels dominate the energy mix are often considered additional because they displace high-emission sources of energy. By contrast, credits from renewable energy projects in areas where clean energy is already common may rank lower because they do not provide significant incremental benefits (Dawes et al., n.d.).

Robust *carbon accounting* and *measurement* practices are essential for maintaining the credibility of carbon credits, as they ensure accurate tracking, reporting, and verification of emission reductions or removals. This transparency and accuracy prevent over-claiming or misrepresentation of climate benefits. Third-party verification organizations play a key role by enforcing stringent *monitoring*, *reporting*, and *verification* (**MRV**) protocols, which guarantee that projects accurately measure their GHG impacts.

Carbon credits that undergo these robust MRV processes are ranked higher because they inspire confidence that the reported reductions or removals are real, measurable, and permanent.

To determine how many credits a project can issue, developers must first establish a **baseline scenario** that estimates emissions in the absence of the project. The project is then credited for the difference between actual emissions and this baseline. However, if the baseline is exaggerated, as in cases where expected forest loss is overstated, the project risks over-crediting. While many projects rely on conservative historical data, over-crediting can occur when estimates are based on probabilistic models that overlook historical rates (*How Do You Know If Carbon Credits Are Living up to Their Promises?*, 2024).

According to the *VCMI Claims Code of Practice*, high-quality carbon credits must have a clear, transparent, and detailed accounting methodology that includes baseline measurements, tracking of emissions, and an ongoing reporting mechanism. This ensures that buyers can trust the numbers associated with their purchases and that the credits represent a real reduction or removal of emissions.

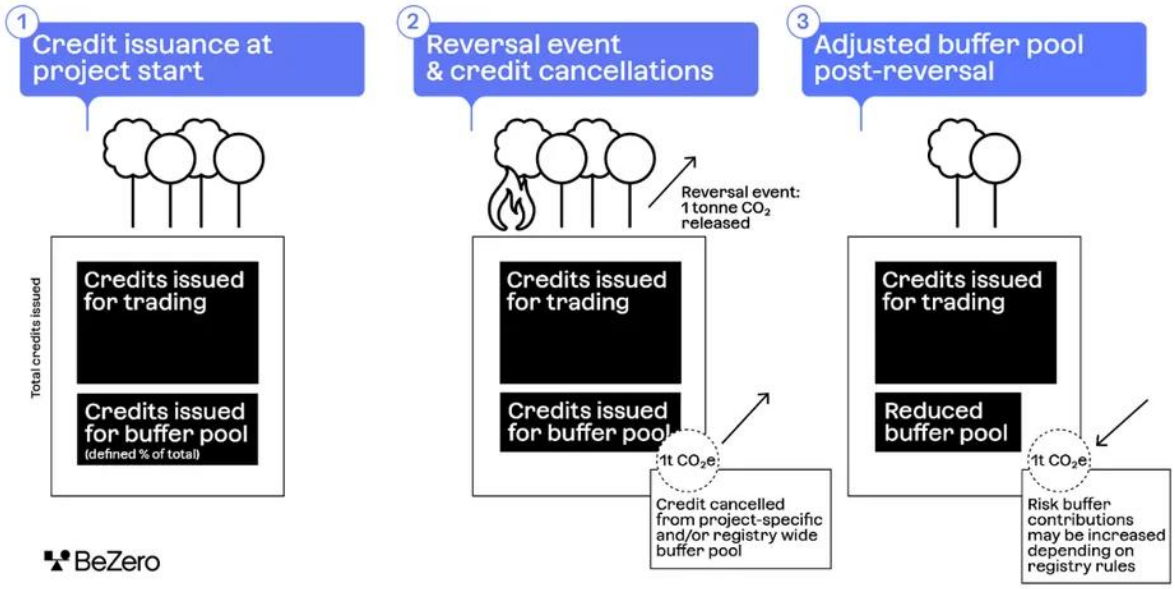
Additionally, such practices help mitigate the risk of *double counting*, where the same reduction might be sold to multiple buyers—a concern often raised in less regulated markets .

Permanence refers to the duration that the carbon is sequestered or the emissions are avoided. High-quality carbon credits must ensure that the carbon removed from the atmosphere will stay sequestered for a long period, typically 100 years or more. This is particularly important in projects like afforestation and reforestation, where there is a risk of reversal if the forest is destroyed by natural events such as fires or pests.

Credits from engineered solutions, such as DAC and carbon capture and storage (CCS), generally score higher on permanence because they provide a more stable and long-term sequestration method compared to nature-based solutions. DAC technology, for example, captures CO_2 directly from the air and stores it in underground geological formations, where it can remain for thousands of years. Such engineered removals tend to command a premium in the market due to their reliability in ensuring long-term carbon storage (*The State of Carbon Credits 2023*, n.d.).

For projects that face potential risks to permanence, such as forestry projects, buyers expect robust risk mitigation strategies. One example is the creation of **buffer pools** (Figure 4), which are reserves of credits that can be used to compensate for any potential reversal of carbon sequestration. This provides additional assurance to buyers that the climate benefits of their credits are maintained over time.

Figure 5: Illustration of a Buffer Pool Mechanism (BeZero)



Finally, when a carbon crediting project or program does not fully eliminate emissions, but instead shifts those emission-generating activities to areas outside the project boundary, this phenomenon is known as *leakage* (*VCMI Claims Code of Practice*, 2023). One key concern is ensuring that activities such as deforestation, which are halted within the project area, do not simply move to other regions. To address this, many evaluators employ advanced geospatial and Earth observation tools to monitor forest cover changes both within and outside project boundaries. This analysis is supplemented by considering economic factors that may contribute to the risk of leakage.

Interestingly, leakage can sometimes have positive effects. In certain afforestation projects in Uganda, for example, farmers near project sites have adopted agroforestry practices after observing the benefits, such as enhanced tree shade and improved soil fertility. This

replication can lead to increased carbon storage in soils outside the project area (*How Do You Know If Carbon Credits Are Living up to Their Promises?*, 2024).

Whether leakage results in positive or negative outcomes, it is vital to account for it in the carbon crediting process to ensure the integrity and accuracy of carbon accounting.

Co-benefits & SDGs

Carbon credits that provide additional environmental and social benefits, such as biodiversity conservation or improvements to local communities, are ranked higher in the market. Buyers are increasingly looking for projects that not only contribute to emissions reductions but also promote broader sustainability goals, including the UN Sustainable Development Goals (SDGs). For example, afforestation projects that also enhance biodiversity or provide jobs to local communities are often favored by buyers seeking to maximize their social and environmental impact (*VCMI Claims Code of Practice*, 2023).

In 2023, the voluntary carbon market (VCM) increasingly focused on carbon credits from higher-quality projects, particularly those demonstrating "**beyond carbon**" environmental and social co-benefits such as biodiversity preservation, water security, or support for sustainable local economies. Projects that provide these co-benefits can achieve certifications like Verra's Climate, Community, and Biodiversity (CCB), SD VISta, and the Social Carbon Standard.

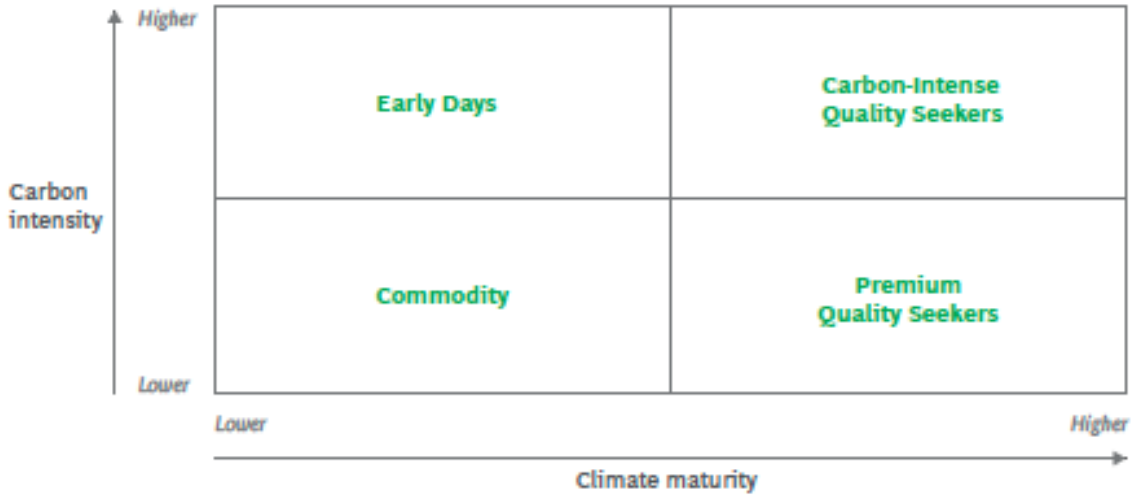
Additionally, many projects align with the UN Sustainable Development Goals (SDGs), with standards like Gold Standard requiring contributions to at least three SDGs and Plan Vivo requiring contributions to six. Despite the growing share of VCM transactions involving projects with co-benefit certifications (28 percent in 2023, up from 22 percent in 2022), and projects with SDG certifications (26 percent in 2023, up from 18 percent in 2022), the price premiums for these credits declined significantly.

The average price for credits with co-benefits fell by 23 percent, and those with SDGs by 31 percent, reflecting an increased supply in 2023, especially from projects like Cookstove Distribution in the Household/Community Devices category. While credits with co-benefits and SDG certifications still command higher prices, the premium dropped to 37 percent and 34 percent, respectively, down from much higher premiums in 2022 (Procton, 2023).

Buyer Segments and Preferences

Different buyer segments have varying preferences when it comes to carbon credits. **Commodity buyers** typically seek lower-cost credits that meet basic certification standards, while more **Carbon-intense industries**, such as oil, gas, and aviation, look for **high-quality** credits to improve their public image and meet stricter scrutiny. The **Early Days Segment** includes buyers with higher carbon intensity but lower climate maturity, who seek higher-quality credits due to increased scrutiny, while gradually improving their quality-assessment processes. **Premium-quality** buyers, who often come from less carbon-intensive industries, are willing to pay a premium for the highest-quality credits available. This segmentation of buyers drives different pricing dynamics within the market.

Figure 6: The Segmentation of Carbon Credits Buyers (BCG Analysis)



Across all segments, the **GHG Impact Score** is a top priority, followed by the type of project or program. Buyers also place significant value on projects with co-benefits, particularly biodiversity. Additionally, there is a willingness to pay a premium for credits from projects located near their value chains. While price is considered, it is not the primary driver, and although benefit sharing and safeguards are important, there is generally a lower willingness to pay for these attributes compared to others. (Baridó et al., 2023)

Global Market Initiatives & Standards

Several global initiatives are playing a crucial role in standardizing the voluntary carbon market and ensuring the quality of carbon credits. The Voluntary Carbon Markets Integrity Initiative (**VCMI**) introduced the *2023 Claims Code of Practice*, which promotes credible claims and ensures high-integrity participation in the market. This code aligns with net-zero goals and the UN Sustainable Development Goals (SDGs), offering guidance for companies to follow.

Article 6 of the **Paris Agreement** provides a global framework that contributes to standardizing carbon credits and ensuring that they are used towards countries' *Nationally Determined Contributions* (NDCs). Additionally, the Taskforce on Scaling Voluntary Carbon Markets (**TSVCM**) emphasizes the need for transparency and quality in the carbon market, particularly by introducing intermediaries to support these objectives (Dawes et al., 2023).

Challenges in Ranking & Quality

Despite the growing emphasis on quality, the market still faces challenges. The global voluntary carbon market remains fragmented, with various standards and certifications making it difficult for buyers to discern the quality of credits. This fragmentation increases the risk of greenwashing, where low-quality credits fail to provide substantial GHG impact or additionality, thereby threatening the credibility of the market.

In response, there is an emerging trend towards higher pricing for high-quality removal credits, particularly those from DAC and other engineered solutions. Governments are also playing a more active role in centralizing and regulating voluntary carbon markets, as seen with initiatives like the Australian Carbon Exchange and Japan's GX League. (Dawes et al., 2023)

It is acknowledged that companies may find it difficult to confidently offset emissions in the current market landscape; however, inaction will not advance progress toward climate goals. Transparency about the measures taken to create impact, both within their value chain and beyond, should be commended rather than criticized. Companies and organizations that invest in and pursue multiple approaches to climate action, while prioritizing the highest-quality credits, are deserving of recognition (*The State of Quality in the VCM 2024*, 2024).

Conclusion for Carbon Credits' Ranking

In conclusion, carbon credits are increasingly ranked based on *GHG impact*, project *transparency*, *co-benefits*, and *alignment* with global standards such as the VCMI Claims Code of Practice. Premium buyers are willing to pay higher prices for credits that are verified, transparent, and aligned with broader environmental goals, reflecting a market shift towards quality over quantity (*VCMI Claims Code of Practice*, 2023).

Having provided an extensive **research context**, the next step is to examine and review the existing literature in relation to the specific research questions of this paper. This involves a focused analysis of how voluntary carbon markets (VCMs) **aid the green transition** and sustainability, what can be done to **strengthen their effectiveness**, **what motivates firms** to purchase carbon credits, and **how technology** can enhance the reliability and transparency of carbon credit verification and transactions.

By **correlating** the available literature with these research questions, a deeper understanding of the role of VCMs in global climate efforts will be established, as well as the challenges and opportunities for further improving the market's efficiency and credibility.

Traditional Literature Review

Voluntary Carbon Markets (VCMs) are a relatively new industry, yet a growing body of reliable literature provides a strong foundation for understanding how they can aid the green transition and sustainability. On the primary research question of how VCMs can support these efforts, several reports provide valuable insights.

For instance, the report "*Promoting Transformational Change Through Carbon Markets*" by Olsen et al. explores how VCMs can align with **Article 6 of the Paris Agreement** to help countries achieve their Nationally Determined Contributions (**NDCs**) and assist companies in fulfilling their Sustainable Development Goals (**SDGs**). This report emphasizes the potential of VCMs to promote transformational change that goes beyond merely offsetting emissions.

Similarly, the report "*Above and Beyond: An SBTi Report on the Design and Implementation of Beyond Value Chain Mitigation (BVCM)*" by Bensin et al., and the "*VCMI Claims Code of Practice*" highlight the importance of improving the effectiveness of VCMs by focusing on co-benefits and social safeguards. These reports stress the need to move **beyond GHG** integrity to generate broader social and environmental benefits through verified high-quality carbon credits, which are crucial in the global effort to mitigate climate change.

Regarding the second sub-question on the drivers that motivate firms to purchase carbon credits, literature from BeZero, in the article "*6 Ways Companies Benefit from Using Carbon Credits*" outlines six distinct reasons why companies choose to buy voluntary offset credits. This analysis is supported by the detailed segmentation of buyers provided by Baridó et al. in the report "*In the Voluntary Carbon Market, Buyers Will Pay for Quality*" by Boston Consulting Group (BCG) and the Environmental Defense Fund. This segmentation discloses the **motivations** of firms and their **preferences** regarding the types of projects they choose to support, offering a more granular understanding of why organizations engage in VCMs.

In addition to these insights, Statista in a report published by Tiseo provides an overview of the primary initiatives that drove global demand for voluntary carbon credits in 2023, classifying them into seven categories (*Annex 1*). However, there remains significant scope for further research in identifying the core motivators for organizations seeking to include carbon credits in their portfolios. This suggests that while some understanding of these drivers exists, there is still much to explore and analyze.

On the more technical side of the research concerning cutting-edge technology, there is ongoing progress in leveraging innovations to enhance the verification process of carbon credits and facilitate transactions. Swinkels, in his paper "*Trading Carbon Credit Tokens on the Blockchain*" published by the International Review of Economics and Finance, describes how carbon credits can be **tokenized** and traded on a **blockchain-based exchange**. This model offers a transparent and efficient way to manage carbon credits, but further work is required to refine the application of this technology.

Adigun et al., in "*Enhancing Carbon Markets with Fintech Innovations: The Role of Artificial Intelligence and Blockchain*" scrutinize how artificial intelligence (**AI**) and **blockchain** technologies can address key challenges such as transparency, inefficiency, and fraud in carbon trading systems. These innovations are positioned as crucial tools for enhancing the **reliability** of carbon credit markets, though more research is needed to fully realize their potential.

Additionally, the **Social Carbon Foundation** and **Wilder Earth** provide an overview of blockchain technology in the context of carbon markets, highlighting how blockchain can secure transactions and ensure transparency. **Sylvera**, in their work on using machine learning (**ML**) and satellite data to analyze carbon projects, provides detailed insights into how AI can evaluate carbon credit **performance** and provide more reliable **ratings** (*How Sylvera Uses Machine Learning (ML)*, n.d.). Despite these advancements, the practical implementation of these technologies still requires further development to achieve their full potential in VCMs.

In conclusion, while there is substantial literature that addresses how VCMs contribute to the green transition, improve sustainability, and utilize advanced technology, significant gaps remain. Further research is necessary to better understand the core drivers of corporate participation in VCMs and to fully harness the potential of emerging technologies like AI and blockchain in enhancing transparency, verification, and the overall effectiveness of these markets.

Methodology

For the purposes of this research paper, which seeks to answer the main research question of *how Voluntary Carbon Markets (VCMs) aid the green transition and sustainability*, a **qualitative** study on **secondary** data was chosen as the primary methodology.

This method is particularly suitable for addressing this research question, as it allows for an in-depth exploration of existing literature, reports, and relevant industry data. By employing **content analysis** to interpret the data, the research can draw comprehensive conclusions about the current state and potential of VCMs. The use of qualitative secondary data enables a broad understanding of how these markets function, their role in sustainability, and the benefits they bring to global climate efforts.

Strengthening the Effectiveness of Voluntary Carbon Markets

To address the first sub-question—*how the effectiveness of VCMs can be strengthened*—the same **qualitative approach** based on **secondary** data and **content analysis** was employed. Reports from key organizations, such as the "VCMI Claims Code of Practice" and studies by Olsen et al., were utilized to examine strategies that can improve VCMs, including the generation of co-benefits, the introduction of social safeguards, and the promotion of high-quality carbon credits.

The qualitative nature of the study provided a framework to evaluate how these improvements align with international climate goals, such as those outlined in Article 6 of the Paris Agreement, and how they can drive transformational change in carbon markets. Content analysis was instrumental in identifying recurring themes and patterns in the data, allowing for a critical assessment of the recommendations from existing literature.

Drivers for Firms to Purchase Carbon Credits

For the second sub-question—*what drives firms to purchase carbon credits*—the methodology combined a **qualitative** study of **secondary** data with exploratory interviews. The secondary data provided insights into the broader market trends and motivations, drawing from reports such as BeZero's "*6 Ways Companies Benefit from Using Carbon Credits*" and the buyer segmentation outlined by Baridó et al. in the Boston Consulting Group (BCG) report. These sources outlined key motivations such as corporate social responsibility, regulatory compliance, and public relations benefits.

However, to gain a more nuanced understanding of corporate motivations, a series of **exploratory interviews** were conducted with decision-makers from firms that actively purchase carbon credits. These interviews provided qualitative, first-hand insights into the true motivations behind investing in carbon credits, revealing not only the market-driven reasons but also the strategic and ethical considerations that influence such decisions. The

combination of secondary data and interview findings allowed the study to bridge theoretical concepts with practical business motivations.

The Role of Technology in Enhancing Carbon Credit Verification and Transparency

For the third sub-question—*how can technology improve the reliability of carbon credit verification process and enhance transaction transparency*—a **qualitative research** methodology was applied to both **primary** and **secondary** data. While the initial aim was to collect comprehensive primary data through a survey targeting industry professionals specializing in blockchain, AI, and carbon market innovations, the response rate was relatively low due to the highly specialized nature of the subject. Nonetheless, the survey provided valuable insights into current technological applications and future prospects.

To supplement the limited primary data, secondary data from relevant studies such as Swinkels' "*Trading Carbon Credit Tokens on the Blockchain*" and Adigun et al.'s "*Enhancing Carbon Markets with Fintech Innovations*" were used. These sources explore the integration of blockchain and AI into VCMs and how these technologies can address key challenges such as transparency, verification reliability, and fraud reduction. **Content analysis** was once again applied to synthesize the primary and secondary data, allowing the study to present a comprehensive understanding of how technological advancements can enhance the credibility of carbon markets.

Conclusion for Methodology

In conclusion, this research paper employed a qualitative methodology rooted in secondary data analysis, complemented by primary data from interviews and surveys where applicable. By using content analysis as the primary tool for data interpretation, the study was able to comprehensively address the research questions regarding how VCMs aid the green transition and sustainability, what drives firms to invest in carbon credits, and how technology can enhance market transparency and reliability.

The methodology ensures a thorough examination of the literature and empirical data, providing a solid foundation for future research and practical applications in the field of voluntary carbon markets.

Empirical Study

The empirical study for this research paper primarily involved the systematic collection and analysis of qualitative data, both primary and secondary. For each research question, the secondary data served as the foundation for understanding the current state of VCMs, their effectiveness, and the role of technology. The content analysis of these sources enabled the extraction of relevant themes, which were then contextualized within the broader framework of climate policy and market dynamics.

The exploratory interviews, conducted as part of the empirical study for the second sub-question, played a crucial role in providing deeper, context-specific insights into firm behavior. These interviews were semi-structured, allowing interviewees to express their motivations and decision-making processes in their own words while providing the researcher with flexibility to probe into key areas of interest. The findings from these interviews were then integrated with secondary data to form a well-rounded analysis of corporate motivations.

For the third sub-question, the empirical study also incorporated survey data, although the response rate was lower than expected. The survey was designed to gather insights from professionals working at the intersection of carbon markets and emerging technologies, with a focus on how blockchain, AI, and other fintech innovations could address existing inefficiencies. The survey findings, although limited, provided useful qualitative data that were combined with the broader content analysis to offer a detailed exploration of how technology can improve the reliability and transparency of carbon credit verification.

How do Voluntary Carbon Markets Aid Green Transition & Sustainability?

The research question set in this paper "*How do voluntary carbon markets aid green transition and sustainability?*" explores the role of Voluntary Carbon Markets (VCMs) in promoting the global shift toward **sustainable** and **low-carbon** economies. Voluntary Carbon Markets, driven by organizations' **voluntary commitments** to offset emissions, provide a platform for the exchange of carbon credits generated from projects that reduce or remove greenhouse gases.

These markets help create **financial incentives** for industries to engage in emissions reduction and sequestration projects, which contribute significantly to the green transition. By supporting projects like renewable energy, reforestation, and energy efficiency, VCMs play a pivotal role in funding the shift away from fossil fuel dependence, particularly in sectors that are difficult to decarbonize. This process enables industries to invest in sustainability while they work to lower their operational emissions (*VCMI Claims Code of Practice*, 2023).

Additionally, VCMs align with the *United Nations Sustainable Development Goals* **(SDGs)**, particularly those that focus on **climate action**, **poverty alleviation**, and **biodiversity conservation**. Many projects funded by VCMs not only reduce emissions, **GHG integrity,** but also provide co-benefits such as improving community livelihoods and protecting ecosystems,

SDG impact (*The State of Quality in the VCM 2024*, 2024). These projects contribute to the broader sustainability agenda by addressing social and environmental goals alongside emissions reductions (State of the Voluntary Carbon Markets, 2024).

Companies that engage in VCMs demonstrate **corporate responsibility** and leadership in climate action, often setting ambitious climate targets and contributing to long-term sustainability strategies. VCMs **encourage innovation** by allowing companies to integrate carbon offsetting with their efforts to improve transparency and accountability in their climate commitments.

However, VCMs are not without challenges. Issues such as *greenwashing*, the risk of over-claiming emissions reductions, and concerns over the quality of carbon credits can hinder their effectiveness. These markets can also face problems such as double counting and inconsistencies in verification processes. Addressing these concerns is essential to enhancing the credibility and impact of VCMs in promoting sustainable practices.

Furthermore, VCMs provide essential **funding** for emerging technologies like direct air capture **(DAC)** and carbon capture and storage **(CCS)**, which are critical for achieving long-term emissions reductions and advancing sustainable industries (Dawes et al., 2023).

Finally, VCMs complement national and international **climate policies** by enabling private sector contributions to emissions reductions, thus helping bridge the gap between government-led efforts and broader global climate goals. These markets are particularly relevant to the **Paris Agreement's Article 6**, which encourages the use of carbon credits to meet national climate commitments.

In summary, VCMs aid the *green transition* by supporting emissions reduction projects, fostering sustainability, and driving corporate climate leadership, while also facing challenges that require continuous improvement to ensure their effectiveness in combating climate change.

What can Strengthening the Effectiveness of Voluntary Carbon Markets?

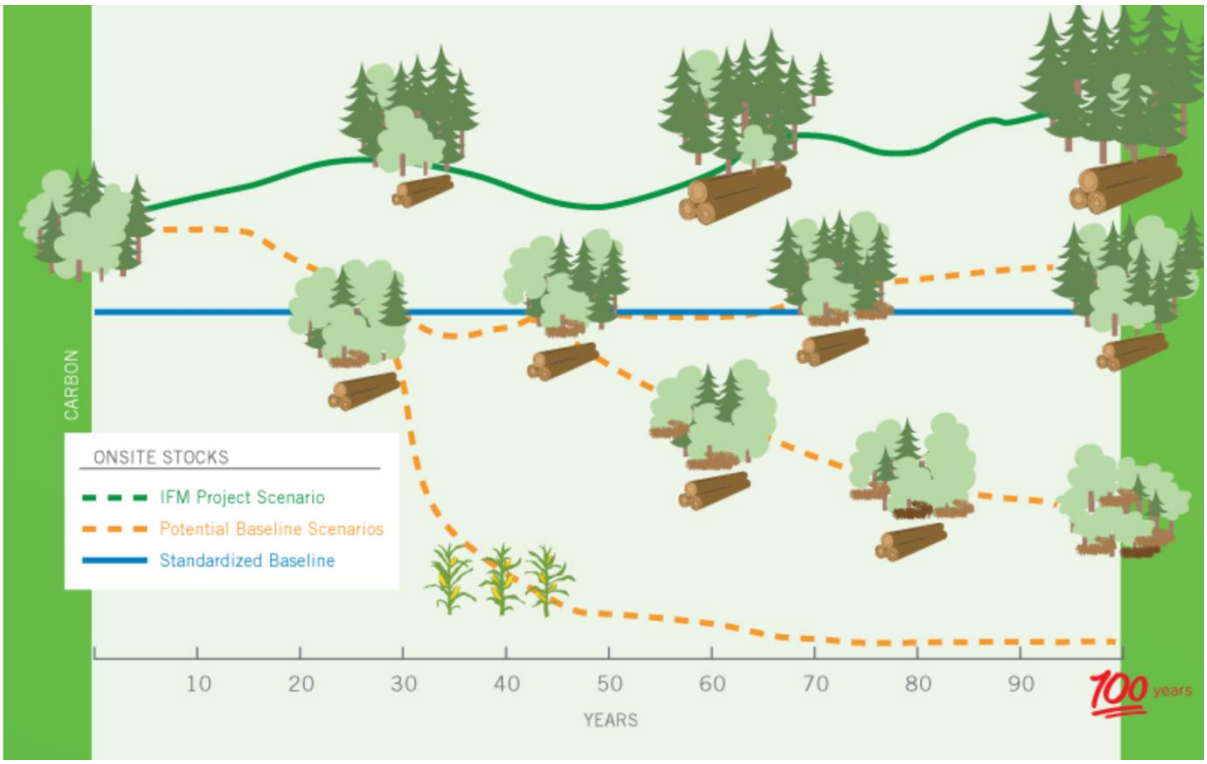
To strengthen the effectiveness of Voluntary Carbon Markets (VCMs) in advancing the green transition and promoting sustainability, several improvements can be made across different dimensions. One key area is the need for **improved standardization** and **regulation**. Establishing more uniform and stringent standards for carbon credits across the global market can enhance the credibility of VCMs, reducing market fragmentation caused by differing verification methods (*Taskforce on Scaling Voluntary Carbon Markets Final Report*, 2021). Organizations such as Verra and the Gold Standard are already working to create robust certification frameworks, but more harmonization is needed to ensure consistency across markets.

Transparency and accountability are also critical in addressing issues like greenwashing and over-crediting. Projects involved in VCMs need to adopt transparent reporting mechanisms, including **publicly available data** on emissions reductions and detailed methodologies for calculating baselines (*ICROA Code of Best Practice*, 2024). Third-party audits and certifications should become mandatory to maintain the credibility of carbon credits and prevent double-counting of emissions reductions (World Bank, 2024).

Addressing the **permanence** and **additionality** of carbon credits is another crucial factor in improving VCMs (*Verified Carbon Standard*, n.d.). Ensuring that emissions reductions or removals last for the **long term**, typically at least *100 years*, and that the projects funded are genuinely additional is essential (*Forest Carbon Accounting for IFM Projects*, n.d.). This can be achieved through more **conservative baseline-setting** approaches and **risk mitigation measures**, such as creating *buffer pools* to safeguard against potential reversals of carbon sequestration, particularly in nature-based projects like reforestation (*Nature Based Solutions*, 2023).

In this attempt, Improved Forest Management (**IFM**) projects are well-known to generate carbon credits by sequestering **additional** carbon beyond a *standardized baseline* through sustainable practices. There are 3 key methods of receiving credits within these projects: avoiding emissions by **reducing** *harvests*, enhancing sequestration through **improved** *forest practices*, and **utilizing** *long-lasting wood* products. IFM projects must commit to a **100-year timeline** to ensure the *permanence* of carbon storage.

Figure 7: Potential & Standardized Baselines in IFM Project Scenarios (Climate Action Reserve)



Investing more in **high-quality** projects, especially those offering additional environmental and social **co-benefits**, would further improve the impact of VCMs. Projects that contribute to biodiversity conservation, community development, and the Sustainable Development Goals (SDGs) are increasingly attracting premium investments. However, creating incentives for the purchase of such high-quality credits, possibly through higher price premiums or **government-backed subsidies**, could enhance their market share (Procton, 2023).

In addition, supporting emerging carbon removal technologies, such as direct air capture (**DAC**) and carbon capture and storage (**CCS**), is key to achieving *long-term climate goals*. VCMs can channel significant investments into these innovative technologies, helping to **scale** their development and deployment. By providing financial incentives or reducing investment risks, VCMs can play a pivotal role in advancing cutting-edge carbon sequestration solutions (Mannion et al., 2023).

Another important improvement involves better **integration** of VCMs with *national and international climate policies*, particularly the Paris Agreement. By linking voluntary carbon credits with Nationally Determined Contributions (**NDCs**), VCMs can complement government-led initiatives and ensure that the private sector's efforts contribute to broader global climate targets (Overholt et al., 2024). Mechanisms to prevent double-counting of credits between voluntary and compliance markets are also essential for improving the integrity of these markets (*CAD Trust - IETA*, 2023).

Educating stakeholders about the functioning of VCMs and the importance of investing in high-quality credits is critical. Many companies and investors, especially smaller entities, may not fully understand the benefits and operational mechanisms of carbon credits. Creating **educational resources** and **campaigns** can empower more stakeholders to make informed decisions that align with their sustainability goals (Baridó et al., 2023).

Finally, ensuring **equity** and **inclusion** in VCM projects, particularly those involving *local* and *indigenous communities*, would maximize their social impact. By engaging these communities in decision-making processes and ensuring the equitable sharing of benefits, VCMs can promote both *environmental sustainability* and *social justice*. Projects that align with the UNDP's guidelines on inclusive climate action are more likely to deliver meaningful outcomes in terms of poverty reduction and community development (*Inclusion*, n.d.).

In summary, strengthening voluntary carbon markets requires a multifaceted approach that includes improving standardization, enhancing transparency, ensuring permanence and additionality, increasing investment in high-quality projects, supporting new technologies, integrating with climate policies, educating stakeholders, and promoting equity. By addressing these areas, VCMs can more effectively contribute to the green transition and long-term sustainability.

What drives firms to purchase carbon credits?

In the context of the growing urgency to mitigate climate change, many firms are increasingly investing in Voluntary Carbon Markets (VCMs) as part of their broader sustainability and climate strategies. The decision to purchase carbon credits is driven by a combination of regulatory pressure, corporate social responsibility, stakeholder expectations, risk management, and economic opportunities. This section elaborates on the key drivers motivating firms to purchase carbon credits, supported by existing literature and industry insights.

Regulatory Compliance and Anticipating Future Legislation

One of the primary drivers for firms to purchase carbon credits is the need to comply with existing or anticipated **climate regulations**. While voluntary carbon markets are not bound by legal requirements, companies operating in sectors with stringent emissions regulations, such as energy, aviation, and manufacturing, often purchase carbon credits to meet compliance obligations in parallel markets like the European Union Emissions Trading System (**EU ETS**) or the Carbon Offsetting and Reduction Scheme for International Aviation (**CORSIA**) (Procton, 2023).

In addition, businesses often use voluntary offsets to **hedge** against *future regulatory changes*, anticipating that governments will impose stricter emission reduction targets as part of global efforts to meet the Paris Agreement targets (*Carbon Credits and Climate Regulation*, 2024)

Voluntary carbon credits serve as a flexible tool for companies, enabling them to take proactive action on emissions reduction while preparing for potential future mandates.

One interviewee from a large manufacturing company emphasized that their firm uses carbon credits to "*get ahead of the curve*" regarding future climate regulations. "*We know that regulations will only become more stringent, so purchasing carbon credits now not only prepares us for future requirements but also allows us to demonstrate our commitment to sustainability in the interim*" he said.

By investing early in carbon offsets, firms demonstrate **climate leadership**, reduce compliance costs in the long run, and gain the expertise needed to navigate evolving regulatory frameworks (*6 Ways Companies Benefit From Using Carbon Credits*, 2024).

Corporate Social Responsibility and Sustainability Commitments

A second significant motivator is the desire to meet corporate social responsibility (**CSR**) objectives and align with sustainability commitments. Many firms are setting ambitious climate goals, such as achieving *net-zero emissions*, as part of broader environmental, social, and governance (ESG) initiatives. Carbon credits provide a mechanism for companies to offset their unavoidable emissions while working on long-term decarbonization strategies. As noted in the report by Ecosystem Marketplace, carbon credits allow companies to contribute to

global **emission reductions** and generate environmental and social **co-benefits**, such as *biodiversity conservation* and *community development* (Procton, 2023).

For firms with large carbon footprints, especially those in *carbon-intensive industries*, voluntary carbon credits help demonstrate their **commitment** to sustainability and corporate responsibility. Purchasing high-quality carbon credits aligns with their public sustainability pledges and enhances their reputation among stakeholders, including customers, investors, and the general public (Baridó et al., 2023).

Stakeholder and Investor Expectations

As environmental awareness grows, companies are increasingly accountable to a wide range of stakeholders, including customers, investors, regulators, and employees. These stakeholders expect businesses to adopt more sustainable practices, reduce their environmental impact, and demonstrate a commitment to combating climate change. In **response** to these *expectations*, firms often purchase carbon credits to enhance transparency and demonstrate progress toward sustainability targets (*Taskforce on Scaling Voluntary Carbon Markets Final Report*, 2021).

Sustainability-focused investors, in particular, are driving demand for carbon credits. Many institutional investors, such as pension funds and mutual funds, now incorporate ESG criteria into their investment decisions. Companies that are **proactive** in *reducing their emissions* and **investing** in *carbon credits* are more likely to **attract** such investments. The "*In the Voluntary Carbon Market, Buyers Will Pay for Quality*" report from Boston Consulting Group (BCG) and Environmental Defense Fund emphasizes that firms seeking to enhance their ESG profiles are willing to pay (**WTP**) a premium for high-quality, verified carbon credits that align with their sustainability goals.

The interviewees confirmed that **stakeholder expectations** play a major role in corporate decisions to *buy carbon credits*. One of the sustainability officers remarked, "*Our investors are particularly focused on our ESG metrics. The ability to show that we are reducing our carbon footprint by purchasing verified, high-quality credits is key to maintaining investor confidence*".

Risk Management and Mitigating Reputational Risks

Carbon credits also serve as a tool for risk management, helping firms mitigate potential reputational risks associated with their environmental impact. Companies that fail to take meaningful action on climate change face growing scrutiny from the public, media, and advocacy groups. Such scrutiny can result in reputational damage, loss of market share, and diminished brand value (Blaufelder et al., 2021). Firms that are perceived as failing to address their carbon footprints risk being labeled as greenwashing—promoting an environmentally friendly image without substantive action (Procton, 2023).

One interviewee noted that "*Reputation is everything. We cannot afford to be accused of inaction or greenwashing, especially when it comes to our environmental commitments*".

By purchasing carbon credits, especially those associated with verified, high-quality projects, companies can **mitigate** these *risks* by showing they are actively addressing their emissions. This is particularly important for multinational corporations that are subject to varying levels of environmental scrutiny across different markets. Offsetting emissions through credible carbon credits helps businesses protect their brand image and maintain positive relationships with key stakeholders.

Economic Opportunities and Market Access

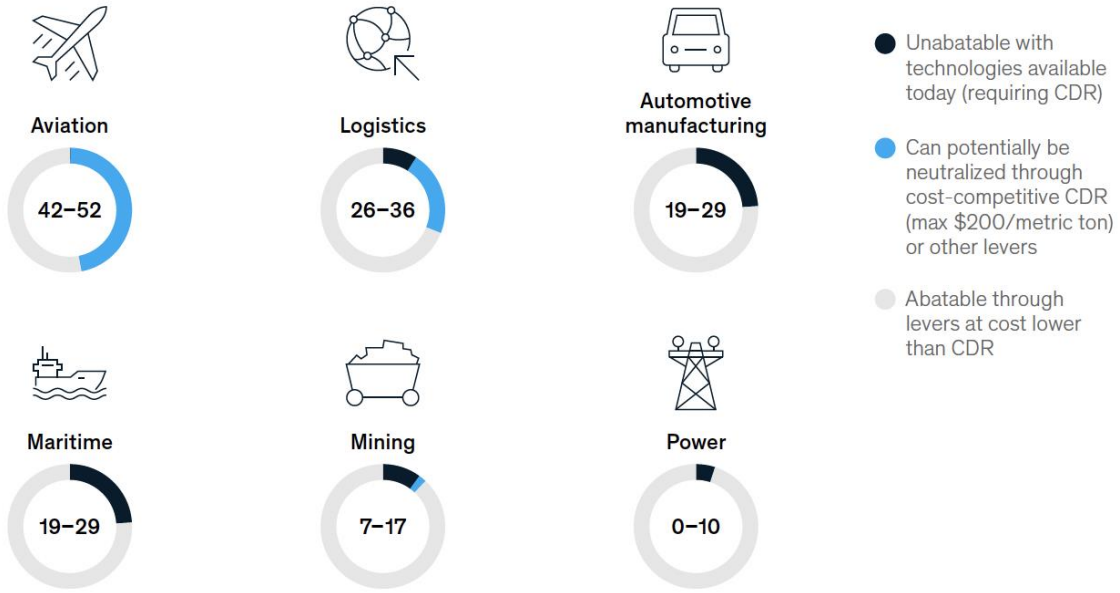
For some companies, purchasing carbon credits presents **economic opportunities**, particularly as part of broader market strategies. In certain sectors, carbon credits can provide a competitive advantage, enabling companies to enter new markets or gain preferential treatment from investors and customers who *prioritize sustainability*. For instance, firms that demonstrate a commitment to reducing emissions may benefit from *preferential contracts*, *certifications*, or *partnerships* with sustainability-conscious businesses.

Additionally, carbon credits can enhance **access** to *capital*. Many investors now favor companies with strong sustainability profiles, and firms that invest in carbon credits may attract *green financing* or *sustainability-linked loans*, where interest rates are tied to ESG performance. This creates a financial incentive for firms to purchase carbon credits and demonstrate their climate leadership (*6 Ways Companies Benefit From Using Carbon Credits*, 2024).

Achieving Long-term Net-zero Goals

Many firms, especially those with carbon-intensive operations, recognize that achieving net-zero emissions will take years, if not decades, of sustained effort and significant investment in technology. While companies work to decarbonize their operations through renewable energy adoption, process optimization, and other initiatives, carbon credits offer an interim solution to **offset emissions** that *cannot be eliminated* in the short term. Carbon credits, therefore, act as a bridge, allowing companies to achieve short-term carbon neutrality while they develop long-term strategies to reduce their direct emissions (Blaufelder et al., 2021).

Figure 8: Percentage of CO2 Emissions that could be Neutralized by CDR per Industry (McKinsey Sustainability Report)



High-quality carbon credits, particularly those from projects that focus on **carbon dioxide removal (CDR)** technologies such as *reforestation* or *direct air capture*, are viewed as essential to achieving net-zero goals (Mannion et al., 2023). These credits not only offset emissions but also contribute to *long-term environmental benefits*, which align with the net-zero ambitions of many corporations (*Annex 2*).

Conclusion on What Drives Firms to Purchase Carbon Credits

In summary, firms are driven to purchase carbon credits by a mix of regulatory requirements, corporate social responsibility, stakeholder expectations, reputational risk management, and economic opportunities. By investing in carbon credits, companies can proactively address their carbon footprint, enhance their sustainability profiles, and align with global climate goals. As the voluntary carbon market evolves, firms that lead in purchasing high-quality, verified carbon credits will gain competitive advantages, attract sustainability-conscious investors, and reinforce their positions as responsible corporate citizens.

How can AI assist the verification process of carbon credits and Blockchain facilitate their transactions?

To address the third sub-question of this research paper, "How can AI assist the verification process of carbon credits and Blockchain facilitate their transactions?", a comprehensive analysis reveals how emerging technologies like artificial intelligence (AI) and blockchain are transforming carbon markets. These technologies address key challenges, such as improving accuracy and transparency, reducing fraud, and facilitating efficient transactions. By integrating AI for automated data analysis and blockchain for secure and transparent record-keeping, carbon markets can be made more reliable, scalable, and accessible.

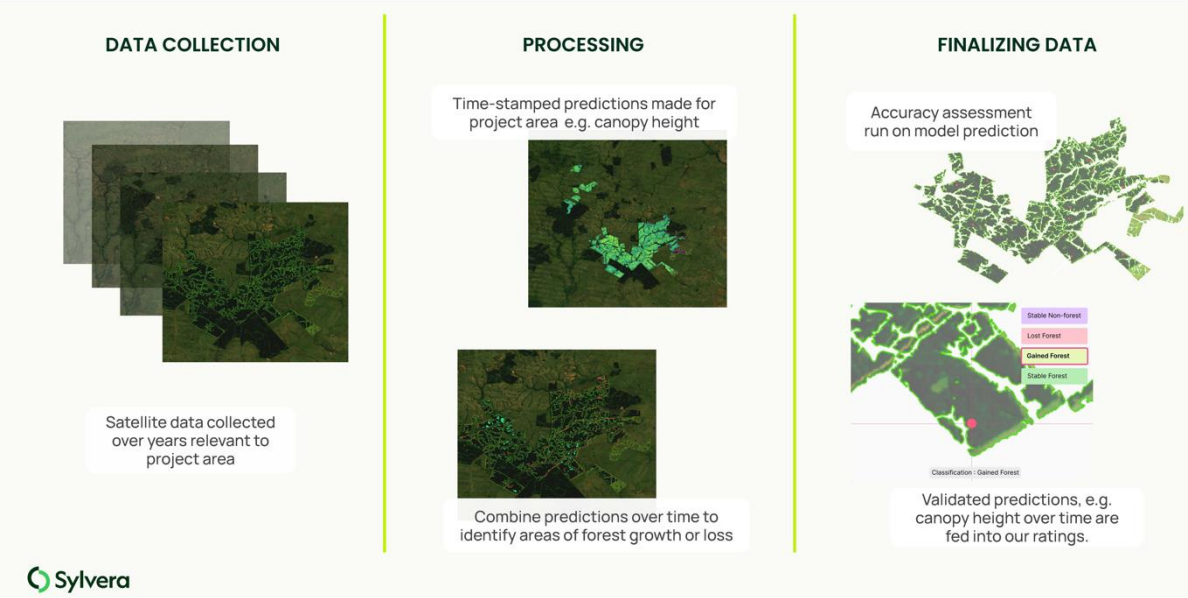
How AI Can Assist the Verification Process of Carbon Credits

Artificial Intelligence is playing a transformative role in improving the verification of carbon credits by automating and streamlining the measurement, reporting, and verification (**MRV**) process, which is typically labor-intensive and prone to human error. On the other hand, AI technologies offer the ability to handle large datasets in real-time, allowing for more accurate and efficient monitoring of carbon emissions and sequestration, and have several key advantages:

Automated Monitoring: AI-powered tools can analyze satellite imagery and data from IoT devices to continuously monitor carbon sequestration projects, such as reforestation efforts. This allows for **real-time tracking** of key environmental indicators like *biomass*, *land use*, and *forest canopy cover*, making it easier to verify carbon sequestration without manual field inspections. AI automates data collection and processing, providing precise verification data faster and more efficiently than traditional methods (Adigun et al., 2024).

Improved Accuracy: Machine learning models help verify carbon credits by analyzing historical and current data to predict trends in carbon sequestration. These models can **cross-check various data** sources to ensure that reported emissions reductions align with *real-world outcomes*. For example, the document on *How Sylvera Uses Machine Learning* describes how AI helps validate carbon credits in projects like REDD+ by detecting deforestation and degradation through *deep learning algorithms*. AI-based systems are able to detect discrepancies, improving data accuracy and trust in carbon markets.

Figure 9: Implementation of Artificial Intelligence into Sylvera Predictions Models (*How Sylvera Uses Machine Learning (ML)*, n.d.)



Fraud Detection: AI tools also play a crucial role in fraud detection by **cross-referencing environmental data** with project reports to spot *inconsistencies*, such as over-reported carbon savings. This helps ensure that carbon credits are only issued for verifiable emissions reductions, reducing the risk of fraud in the carbon markets (Adigun et al., 2024).

Standardizing Verification: By implementing standardized AI-driven MRV systems across different carbon credit projects, stakeholders can create **consistent methods** for verification. This reduces discrepancies and brings *uniformity* across diverse regions and project types.

How Blockchain Can Facilitate the Transactions of Carbon Credits

Blockchain technology is essential in addressing transparency, security, and efficiency challenges in carbon credit transactions. Through its decentralized and immutable ledger, blockchain ensures that every transaction is recorded and verifiable, reducing the risk of fraud and improving trust among market participants.

Immutable Record-Keeping: Blockchain creates a decentralized, permanent ledger that securely records every carbon credit transaction, preventing unauthorized modifications or deletions. This ensures that carbon credits are **accurately tracked** from issuance to retirement, **reducing the risk** of *double-counting* and *fraud*. *Blockchain and the Carbon Markets* precisely explains how tokenized carbon credits on blockchain platforms offer transparent ownership tracking.

Smart Contracts for Automating Transactions: Blockchain enables smart contracts, which automatically execute carbon credit transactions based on predefined conditions. For example, when AI verifies emissions reductions, a smart contract can automatically issue or retire carbon credits, **reducing the need** for *intermediaries*. This feature also builds trust, as transactions are guaranteed to occur only when conditions are met (Schletz et al., 2020).

Reduced Transaction Costs: By removing intermediaries, blockchain allows **peer-to-peer transactions** between buyers and sellers, which *reduces transaction costs* and makes carbon markets *more accessible* to smaller participants. According to Swinkels in *Trading Carbon Credit Tokens on the Blockchain*, blockchain's decentralized nature enables cost-effective trading of carbon credits without the need for brokers or auditors.

Global Market Integration: Blockchain facilitates the seamless integration of regional carbon markets into a global system. By creating a **universal platform** for verifying and trading carbon credits, blockchain promotes *liquidity* and *cross-border* carbon credit transactions. This is particularly highlighted in the paper of Pan et al. "*Application of Blockchain in Carbon Trading*", where the authors discuss blockchain's potential to link various national carbon markets together, ensuring real-time updates and secure cross-border trading.

Figure 10: Benefits of Blockchain Technology in the VCMs (*Blockchain and the Carbon Markets*, 2023)

Synergy Between AI and Blockchain in Voluntary Carbon Markets

The combination of AI and blockchain creates a **powerful solution** for voluntary carbon markets, as each technology *complements* the other. While AI ensures that carbon credits are verified with a high degree of accuracy based on real-time environmental data, blockchain secures the integrity of these verified credits by facilitating transparent and secure transactions.

For example, AI-driven satellite monitoring can provide detailed insights into carbon sequestration and emissions reductions in real-time. This data can then be recorded on a blockchain, ensuring that the verification process is transparent and immutable. Moreover, blockchain's smart contracts can automate the trading of these AI-verified credits, reducing human involvement and the potential for error. In this way, AI and blockchain together create a more efficient, trustworthy, and scalable carbon market system.

In summary, AI enhances the verification of carbon credits by automating the monitoring and reporting processes, increasing accuracy, and reducing human error. Blockchain, on the other hand, ensures that these verified credits are securely transacted, reducing the risk of fraud, double counting, and inefficiencies. Together, these technologies address many of the *longstanding challenges* faced by carbon markets and are instrumental in creating more effective climate mitigation strategies.

Survey Insights and Recommendations

Insights from the survey conducted (Annex 3) provide a practical perspective on how AI and blockchain can enhance carbon credit verification and transactions, that aligns with the current literature on the subject. Respondents strongly emphasized the need for **standardization in verification processes**. They pointed out that a lack of *global consistency* in how carbon credits are measured, reported, and verified creates confusion and diminishes trust in carbon markets.

AI and blockchain were seen as critical tools for creating a **unified framework** for verification, which would ensure that carbon credits are validated under *consistent global standards*, regardless of their origin.

AI's role in **automating** the ***MRV process*** was also *highlighted*, with respondents noting that AI could reduce reliance on costly manual audits and third-party verifiers. By automating data collection and analysis, AI improves both the accuracy and speed of the verification process. This is particularly relevant for projects involving land-use changes, such as reforestation, where continuous monitoring is essential for accurate reporting.

On the subject of **Blockchain**, survey participants stressed its potential to enhance *transparency* and *security* in carbon credit transactions. By using blockchain to track carbon credits from issuance to retirement, market participants can ensure that credits are **not double-counted** or **fraudulently altered**. Additionally, blockchain's ability to facilitate peer-to-peer transactions was seen as a major advantage, particularly for smaller entities that typically face high transaction costs in traditional markets.

Recommendations for **policymakers** included the need to develop **clear** and **consistent** *regulatory frameworks* that support the integration of AI and blockchain in carbon markets. Respondents also called for **increased investment** in *technological infrastructure* to ensure that these tools are scalable and accessible to all market participants.

Finally, they highlighted the importance of **international cooperation** in creating a unified global carbon market that leverages AI and blockchain for greater efficiency and transparency.

Conclusion on how AI and Blockchain can assist the VCM

AI and blockchain technologies offer transformative solutions to the challenges currently plaguing carbon credit verification and transactions. AI enhances the verification process through real-time monitoring, predictive analytics, and automated MRV, while blockchain

ensures transparency, security, and efficiency in transactions through its immutable ledger and smart contract capabilities.

Together, these technologies address the critical issues of standardization, fraud prevention, and transaction costs, making carbon markets more reliable, transparent, and accessible to a wider range of participants.

Policymakers and industry leaders must focus on developing clear regulatory frameworks and investing in the necessary infrastructure to fully harness the potential of these technologies.

Discussion of Findings

This research set out to explore the role of Voluntary Carbon Markets (VCMs) in aiding the green transition and promoting sustainability, identifying the motivations behind firms' participation in these markets, and investigating how technology can enhance transparency and the reliability of carbon credit verification. Through the analysis of secondary data, empirical studies, and interviews with industry participants, several key findings have emerged, offering both a deeper understanding of the current landscape and potential areas for improvement in the VCM ecosystem.

Voluntary Carbon Markets as Catalysts for Green Transition

Voluntary Carbon Markets have demonstrated their potential to drive sustainability by facilitating investments in projects that reduce or remove carbon emissions. The findings reaffirm that VCMs offer companies a **flexible mechanism** for offsetting emissions while working towards *long-term decarbonization*. Carbon credits generated from renewable energy, reforestation, and carbon capture projects are integral to industries that face significant decarbonization challenges.

However, despite the promising role of VCMs in aiding the green transition, the research also highlights the *market's volatility*, especially around carbon pricing. As observed in the price drops of nature-based credits in 2023 due to questions about the credibility of REDD+ projects, the *lack of standardization* and credibility remains a critical barrier to market confidence. Buyers often grapple with fluctuating prices and concerns over the integrity of certain credits. To strengthen their effectiveness, VCMs must address these credibility issues by adopting more **stringent verification** processes and improving transparency around the *additionality*, *permanence*, and *leakage* of carbon projects.

Moreover, while VCMs contribute to reducing emissions, their fragmented nature, characterized by *varied pricing models*, standards, and regulations across regions, hinders their overall impact. A more **harmonized approach**, possibly facilitated by *global frameworks* such as Article 6 of the Paris Agreement, is essential for the maturation of these markets. Such an approach could enhance confidence in the market, standardize pricing mechanisms, and facilitate broader participation by both buyers and sellers.

Drivers for Firms to Participate in VCMs

The motivations driving firms to purchase carbon credits are multifaceted, combining regulatory anticipation, corporate social responsibility, and economic incentives. Companies often view carbon credits as a method to **mitigate** *reputational risk* and **align** with their *sustainability goals*, especially as stakeholders increasingly scrutinize their environmental impact. Firms operating in *carbon-intensive industries* such as energy and aviation are under growing pressure to decarbonize, and VCMs provide a pathway to offset emissions while these industries transition towards cleaner technologies.

Additionally, **stakeholder expectations**, particularly from investors focused on Environmental, Social, and Governance (**ESG**) metrics, play a significant role in firms' decision to participate in VCMs. Companies that proactively manage their carbon footprints by purchasing high-quality credits often gain **competitive advantages** by attracting *sustainability-conscious investors* and *customers*. The findings suggest that firms are willing to pay a premium for verified carbon credits that not only reduce emissions but also provide social and environmental **co-benefits**, such as *biodiversity* preservation and *community development*.

However, the research also indicates that firms face challenges in navigating the **complexities** of the voluntary carbon market. The *quality* and *ranking* of carbon credits remain major concerns, with firms seeking greater transparency and assurance that the credits they purchase are credible and contribute meaningfully to climate mitigation. This highlights the need for **enhanced** *market mechanisms* that prioritize the quality and credibility of credits, making it easier for companies to differentiate between low- and high-quality projects.

Technology as a Catalyst for Improving Transparency and Verification

Emerging technologies, particularly artificial intelligence (AI) and blockchain, present significant opportunities for improving the verification and transparency of carbon credits. The findings show that AI can play a transformative role in **automating** the *measurement*, *reporting*, and *verification* (**MRV**) processes. AI's ability to process vast amounts of data from sources such as satellite imagery and Internet of Things (IoT) devices offers more **accurate** and **real-time** *monitoring* of projects, reducing the risk of human error and fraud in the verification process.

Blockchain technology, with its decentralized and immutable ledger, also holds promise for improving the transparency of carbon credit transactions. By **tokenizing** carbon credits and **recording** all transactions on a secure, tamper-proof platform, blockchain can address some of the major challenges of the market, such as *double-counting* and *fraud*. Smart contracts, which **automatically execute** transactions based on pre-set conditions, further enhance the efficiency of these markets, reducing the *reliance on intermediaries* and lowering *transaction costs*.

However, while both AI and blockchain offer promising solutions, the practical implementation of these technologies in VCMs is still in its infancy. There are challenges related to **scalability**, **integration** with existing market systems, and the **high cost** of deployment. For instance, AI-driven MRV systems may require significant investment in *infrastructure* and *data acquisition*. Similarly, blockchain solutions need to overcome concerns about the *energy consumption* of decentralized networks and the *complexity* of integrating different blockchain platforms globally.

Challenges and Opportunities in Strengthening VCMs

Despite the valuable role of VCMs, this research has identified several challenges that need to be addressed to strengthen their effectiveness. **Market fragmentation**, **concerns** over the *quality* of carbon credits, and the **risk** of *greenwashing* are persistent issues. Furthermore, the **pricing volatility** observed in 2023 demonstrates that buyer confidence remains fragile, particularly in the face of market uncertainty regarding credit quality.

Nevertheless, there are clear opportunities for improvement. The development of **global standards** and **frameworks** such as *Article 6* of the *Paris Agreement* offers the potential to create more consistent and transparent carbon markets. By **integrating** voluntary markets with *compliance mechanisms* and *national climate policies*, VCMs can ensure greater alignment with global climate goals and build confidence among market participants.

Additionally, the increasing focus on **co-benefits** and the role of carbon credits in achieving Sustainable Development Goals (**SDGs**) offers a unique opportunity for firms to enhance their social impact while contributing to emissions reductions. Firms are increasingly willing to invest in projects that provide broader environmental and social benefits, signaling a shift towards quality-driven carbon markets.

Conclusion of the Findings

The findings of this research confirm that Voluntary Carbon Markets play a critical role in facilitating the green transition and enabling firms to meet their sustainability goals. However, to fully realize their potential, VCMs must address issues related to market fragmentation, credibility, and transparency. Technologies such as AI and blockchain have the potential to enhance the efficiency and reliability of carbon markets, but their widespread adoption will require overcoming practical challenges related to implementation and scalability.

Ultimately, the future success of VCMs will depend on continued efforts to standardize the market, improve transparency, and prioritize high-quality carbon credits that contribute meaningfully to global climate goals. Firms that lead in adopting these practices will not only enhance their sustainability profiles but also gain competitive advantages in an increasingly climate-conscious market.

Conclusion

Voluntary Carbon Markets (VCMs) represent a crucial mechanism in the global fight against climate change, providing a flexible framework for businesses and individuals to offset their carbon emissions. This research has demonstrated that VCMs are not only tools for immediate emissions reduction but also catalysts for long-term sustainability efforts and the green transition. By supporting projects that reduce or remove greenhouse gases, VCMs contribute to the achievement of both corporate climate goals and broader global environmental objectives.

However, the effectiveness of VCMs hinges on several factors. Ensuring the quality and credibility of carbon credits remains a primary challenge, as market volatility and inconsistent verification standards can undermine trust. Firms are motivated to purchase carbon credits for a variety of reasons, including regulatory compliance, corporate social responsibility, and the desire to enhance stakeholder confidence. Yet, the success of VCMs requires ongoing efforts to strengthen transparency, standardization, and the integration of emerging technologies.

Technologies such as Artificial Intelligence (AI) and Blockchain offer promising solutions to enhance the accuracy of carbon credit verification and the transparency of transactions. AI can automate and improve the measurement, reporting, and verification (MRV) processes, while blockchain can provide secure, tamper-proof records of carbon credit trades, ensuring greater market confidence.

In conclusion, while VCMs hold significant potential in the global green transition, their future success will depend on improving the integrity of carbon credits, increasing market transparency, and leveraging technological advancements. With the right improvements, VCMs can play an even more impactful role in achieving the world’s climate goals.

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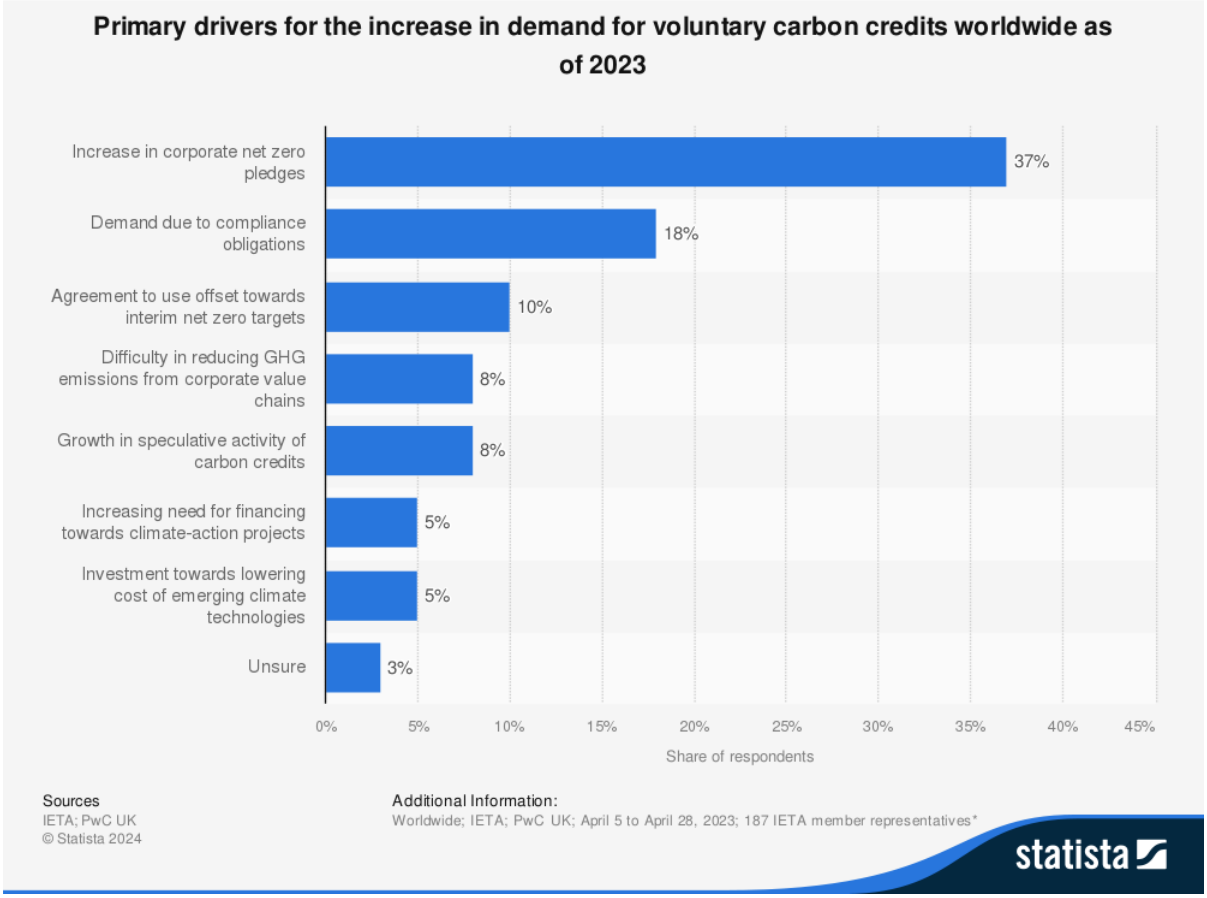
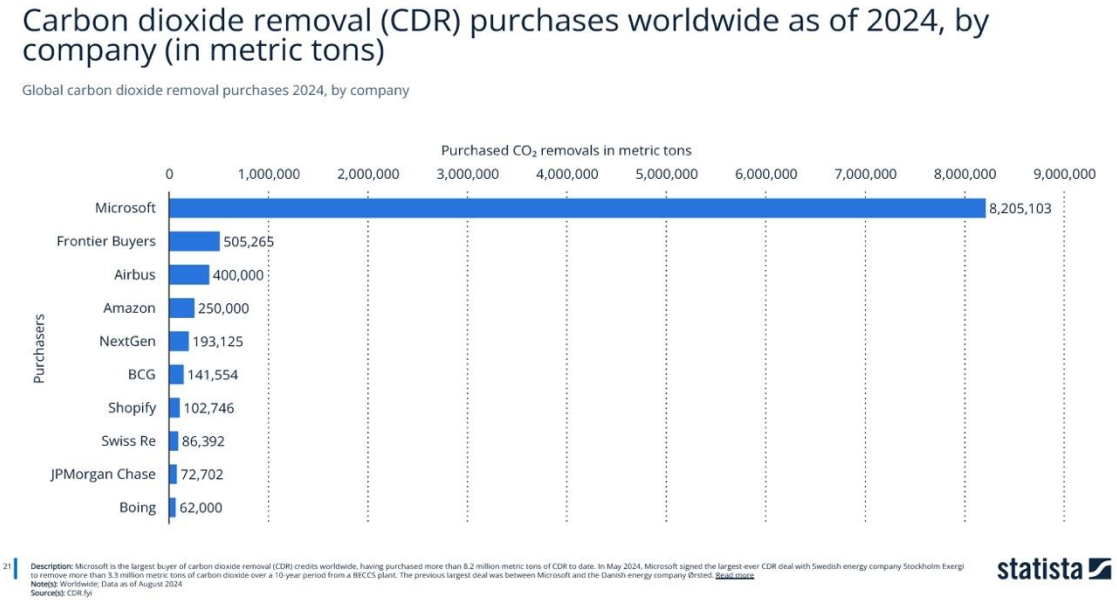
Appendices

Annex 1



Annex 2



Annex 3 (Survey: Exploring AI & Blockchain Technology in Carbon Credit Verification and Transaction Process)

Exploring AI & Blockchain Technology in Carbon Credit Verification and Transaction Process

6. How familiar are you with the use of AI in the verification of carbon credits?

7. In your experience, what are the primary challenges in the current methods of verifying carbon credits?

11
Responses

Latest Responses
"It will be based on data Base and feeding. Anomalies may be missed"
"Standardisation of methods Proper and trustworthy verification"

4 respondents (**36%**) answered **verification** for this question.

8. How do you perceive the potential of AI to enhance the reliability of carbon credit verification?

9. What specific AI technologies do you believe could be most effective in improving the verification process?

10. What challenges do you foresee in the implementation of AI for verifying carbon credits?

Page 3 of 6

11. What opportunities can AI bring to the verification process that are currently unmet by traditional methods?

11
Responses

Latest Responses

"- more traceability - more verification "

"Excess to open source data easily, thus time efficient as first layer filter"

"The potential to verify a larger quantity at a given time"

12. How familiar are you with the use of blockchain technology in carbon credit transactions?

13. What are the key transparency and speed-related challenges in the current carbon credit transaction process?

7
Responses

Latest Responses

14. In your opinion, how effective can blockchain be in addressing these challenges?

Exploring AI & Blockchain Technology in Carbon Credit Verification and Transaction Process

15. Which aspects of blockchain technology do you think are most critical for improving transparency in carbon credit transactions?

Decentralisation	3
Immutable record-keeping	9
Smart contracts	2
Traceability of credits	6
Other	1

16. What potential obstacles do you anticipate in the adoption of blockchain for carbon credit transactions?

Regulatory compliance	8
Integration with legacy systems	7
Technical complexity	5
Scalability	4
Cost implications	5
Other	0

17. How could blockchain technology enhance the speed and efficiency of carbon credit transactions?

5
Responses

Latest Responses

3 respondents (**60%**) answered **Real-Time** for this question.

Exploring AI & Blockchain Technology in Carbon Credit Verification and Transaction Process

18. What future trends do you anticipate in the use of AI and blockchain in carbon credit markets?

9
Responses

Latest Responses
"It could be a first layer filter but not a decision maker"

19. What recommendations would you provide to policymakers or industry leaders to encourage the adoption of AI and blockchain in carbon credit verification and transactions?

8
Responses

Latest Responses
"Embrace technology and the help but not dependent on it"

20. Would you like to participate in further research on this topic?

21. Any additional comments or insights you would like to share?

2
Responses

Latest Responses