A Work Project, presented as part of the requirements for the Award of a Master's degree in Business Analytics from the Nova School Of Business and Economics.

Challenges and opportunities in the voluntary carbon market: How can emerging regulatory frameworks and blockchain technology enhance transparency and credibility in the market.

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Abstract:

This work project presents a comprehensive analysis of the voluntary carbon market, exploring dynamics and frameworks while emphasising the transformative impact of blockchain technology in enhancing transparency and credibility. Conducted in partnership with Celfocus, the research delves into the challenges and potential opportunities within the market, offering novel insights for stakeholder perspectives. Detailing qualitative and quantitative data on the historical market context, the study underscores the market's critical importance in reducing carbon emissions. The findings offer valuable contributions to understanding market mechanisms, associated costs, and possible investment outlooks and opportunities in Europe, Africa, and South America.

Keywords: Voluntary Carbon Market, Blockchain, Carbon Credits, GHG emissions, Carbon market

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1 Introduction

1.1 Field Lab Specification

This Field lab project focuses on the in-depth study of one of the mechanisms built to combat climate change and to reduce the emission of Greenhouse Gases (GHG), the voluntary carbon market. The project fits within the scope of the BLOCKCHAIN.PT initiative, which forms a part of the "Decentralize Portugal with Blockchain" agenda, is backed by funding from the European Union's NextGenerationEU program. This project's genesis lies in forming a consortium which successfully secured acceptance into Portugal's resilience recovery plan (RRP). Among various collaborators, Nova has joined this consortium and opened the opportunity for master's students to participate. In collaboration with Celfocus, the project team has been assigned to investigate and develop a blockchain-driven platform explicitly designed to facilitate the voluntary carbon market and the transaction of carbon credits.

This undertaking coincides with Portugal's legislative initiatives to establish a Voluntary Carbon Market (VCM). Minister of Environment and Climate Action Duarte Cordeiro has emphasised the imperative of achieving carbon neutrality by stating, "To attain carbon neutrality, we must not only address emissions but also enhance the capacity of the country's carbon sinks." This national VCM initiative, including this specific project, will contribute to devising strategies and frameworks to attain the goal of carbon neutrality by 2050 (Duarte Cordeiro, 2023).

1.2 Climate Change: the global challenge that needs to be tackled

Climate change is a current global problem, and its control started in the seventies when environmental law began to appear, such as the Clean Air Act in the United States of America, followed by the first reports on the importance of climate change in the early nineties. It was not until 1997 that the world saw a collective effort by countries to mitigate climate change in an initiative known as the Kyoto Protocol (United Nations, Dec. 10, 1997). Countries under this protocol must meet targets for greenhouse gas emissions, primarily through national measures;

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otherwise, countries will be exposed to a "carbon tax" if they exceed emissions. To that end, three market-based solutions emerged: the International Emissions Trading System (ETS), the Clean Development Mechanism (CDM), and Joint Implementation (JI), known as Compliance Carbon Markets. These solutions led countries to invest in carbon removal or avoidance projects, which would count towards their nationally determined contributions (NDCs). However, the surplus of emissions removed or avoided was transformed into what today is called carbon credits and traded in market-based solutions.

In recent years, the solutions brought by the Kyoto Protocol have been re-evaluated in the Paris Agreement (United Nations, Dec. 12, 2015) to provide financing to developing countries to mitigate climate change, strengthen resilience, and enhance the ability to adapt to climate impacts. The Paris Agreement brought new global targets, including cutting all GHG emissions by 2050 (net zero) and limiting the global temperature variation below 1.5 degrees Celsius. Article 6 of the Paris Agreement was essential, as it allowed the voluntary cooperation of countries on the international trade of credits, which enabled the scale of the Voluntary Carbon Market. This market emerged in conjunction with the compliance market. However, intending to be a non-obligatory market, the VCM was initially low due to a lack of initiative by private entities. Many corporations have unveiled commitments to invest in forest carbon financing in recent years. Microsoft pledges to be carbon-negative by 2030, while Walmart and Amazon pledge carbon neutrality by 2040 (“A Green Growth Spurt | Ecosystem Marketplace”, 2021).

1.3 The VCM

The voluntary carbon market has been four years behind a functional carbon market for the last twenty years. The earliest records of this type of market were from the late eighties when the first investment from the private sector appeared in planting trees in Guatemala. In an unregulated landscape, carbon credit certifiers started appearing, with the American Carbon Registry being the first private registry for voluntary offsets in the United States. Following

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Climate Action Reserve and Verra with the Verified Carbon Program (VCS) acting in the United States of America (USA) and Gold Standard in Europe, these institutions claim to certify projects, according to their methodologies, that have as objective the removal or avoidance of GHG emissions by compensating project developers with carbon credits.

The development of the VCM has been a gradual process compared to the compliance market, only constituting a small percentage of the global cut in GHG emissions. Nevertheless, it has gained traction recently with a new emerging global awareness of climate change. A growth spurt occurred from 2019 to 2021 when the market issued more than 300 million credits, and demand was at an all-time high. The following year, the reality of complex market mechanisms came to light, resulting in a slight fall in credit issuance. Nevertheless, market speculators believe that by 2030, the VCM will grow 15 times compared with 2021 (McKinsey 2022).

1.4 Expected Contribution

The task in this field lab with Celfocus is to provide as much information as possible regarding the current state of the global carbon market. After a lengthy process of meetings, two Research Questions (RQ) were developed to address their objectives: i) How will the voluntary carbon market evolve, and how will policy and regulation affect the market adoption in Europe? ii) What are the certification costs of carbon projects, their trends and the investment opportunities that can be explored in South America and Africa? These topics will cover various issues such as market framework and functioning, technology in the VCM, policies and regulations, and investment opportunities. This research provides information to help Celfocus decide whether and how to build its carbon credit marketplace, ensuring sustainability.

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1.5 Structure

This work project begins by addressing the pressing issue of Climate Change and introducing the Voluntary Carbon Market. A thorough literature review examines the intricate structure of the market, the integration of blockchain technology, and policies and regulations governing the market, serving as a foundation for subsequent analyses. In addition, rigorous data analysis and comparative exploration of market trends, costs, and regional dynamics provide a comprehensive view of the market's evolving landscape. The Discussion section synthesises these components, fostering a nuanced understanding of the Voluntary Carbon Market. This thesis concludes by summarising key insights and implications.

2 Literature Review

2.1 VCM Structure

The compliance carbon markets work as a cap-and-trade system (Cap: Establishes a cap on the total amount of greenhouse gases that regulated industries can emit. Trade: Companies/ Countries receive or buy emission allowances (permits), representing the right to emit a specific amount of greenhouse gases. These allowances can be traded among companies/countries.) where companies are obligated to participate if they do not meet the limit to their annual GHG emissions limit, which will be "capped" and lowered every year until 2050, when countries will reach the ambitious goal of 'Net Zero'. An example of a compliance market is the European Union Emission Trading Scheme (EU ETS), regulated via the European Parliament and the Council of the European Union. Companies covered under the ETS must report their emissions annually, subject to verification processes to ensure accuracy.

Meanwhile, in voluntary markets, there is no governmental body ahead of them, nor is it necessary for companies to participate. It is a market for those who wish to help the environment while offsetting GHG emissions. As described by **(**Kollmuss, Zink, and Polycarp, 2014**)**, the voluntary markets do not require nor implement any particular policy mandates as the markets come from a voluntary ideology to help towards the climate change cause.

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2.1 Stakeholders

The dynamic and voluntary nature of the carbon market involves a diverse array of stakeholders. Although numerous entities play a role, there are four key stakeholders, as detailed in Appendix 1. First, the project owner, who can be a singular or multiple proponents, is responsible for carrying out a project and has the legal right to do so. Project developers are usually companies that want to offset the emissions of their products or services.

Secondly, the registries set the standards and methodologies for GHG reduction or avoidance projects like Verra, Gold Standard, America Carbon Registry, and Climate Action Reserve by providing a registry system where all the projects and the carbon credits are stored.

Then, there is the Third-Party Verification Body (VVB). These are the companies that review, verify, and validate the projects based on the proposed methodology, according to the registry the project is registered. To act, a VVB must register within the registry, or it will not be able to validate a project.

Lastly, there is the buyer. If project developers have a surplus of credits they want to sell, they will turn to the buyer, a singular or multiple party, who wishes to trade or offset emissions using credits. The transaction of credits is either a direct trade between developer and buyer or in an exchange like CTX (Carbon Trading Exchange).

Recently, more services, such as procurement, have emerged in the industry (Abatable, South Pole). These services gather financial resources for companies that want to offset their emissions by buying carbon credits or developing projects that generate such credits.

2.2 Certification Process

The certification of projects is a long-lasting bottleneck in project development, as seen in Appendix 2. To better visualise, the authors built a hypothetical example below:

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Company X, headquartered in Portugal, wants to offset their product emissions. They need to gather data and information on their product emissions. After assessing their emissions, it was discovered that they emit 1 million tons of carbon dioxide annually. The following steps of company X are described in the figure below:

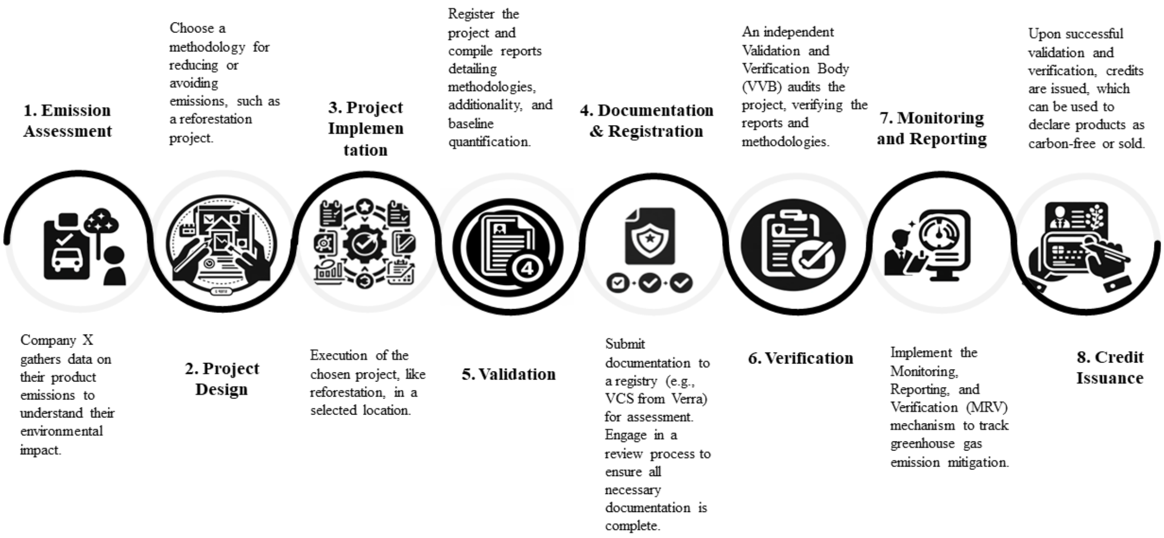

Fig. 1 – Carbon Project Certification Process.

In the end, as shown in Appendix 3, the registry issues a certification form, which serves as proof of the retirement of Verified Carbon Units (VCUs). This form is evidence of the carbon emissions that have been effectively retired. Now, company X can say that its products are carbon-free and sell the surplus of credits if necessary.

2.3 Carbon Emission Methodologies

Carbon Emission Methodologies quantify a project's actual and accurate greenhouse gas emission, often called carbon credits or VCUs. These methodologies are complex studies of a sector's activity that avoid or reduce emissions in one way or another. These are usually

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extensive documents as they convey all the development standards for a project: Additionality, Permanence, Leakage, and the necessary baseline equations to calculate the emissions offset.

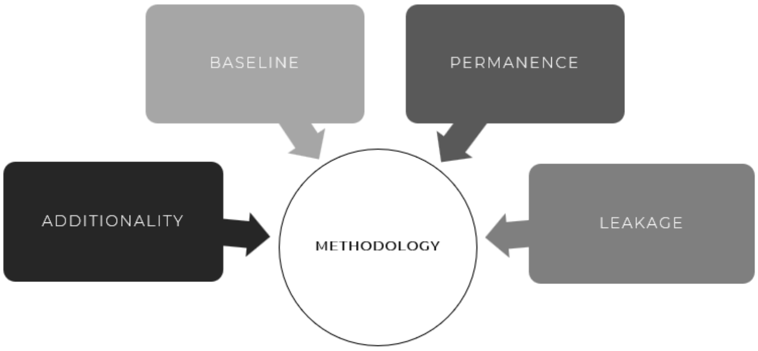

Fig. 2 – Components of Carbon Methodologies

To this end, carbon offset programs(registries) have been developing their technical methodologies following the United Nations (UN), which vary significantly according to the project scope, type, and location. These take time to develop and are usually compiled with specialists and institutional bodies with expertise in areas of interest such as Reforestation/Afforestation and Renewable Energy.

Carbon offset programs are developed per United Nations methodologies and tailored to specific project scopes, types, and locations. These methodologies involve experts in various fields like reforestation and renewable energy. Additionality is a fundamental principle in Voluntary Carbon Markets and is often misunderstood. Downey (2022) explained that a project is additional if it leads to emission reductions that would not occur naturally or through market forces alone. For example, a profitable solar project may be considered non-additional if it can operate without carbon credit sales. The United Nations Methodological Tool, Appendix 4 (UNFCCC/CCNUCC 2008), provides a framework for assessing additionality, including baseline scenarios and investment analysis. Additionality plays a key role as Michaelowa, Hermwille, Obergasse, and Butzengeiger (2018) argue, 'additionality is key to ensuring that no fictitious carbon units, that is, units that do not represent real emission reductions, compromise global carbon markets.'

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Richars and Huebner (2012) define Permanence as the longevity and durability of carbon benefits. Carbon projects are deemed permanent if they store carbon for 100 years or more. However, physical disruptions can release stored carbon, negating benefits, an issue highlighted by Downey (2022).

Leakage refers to a potential unintended increase of GHG emissions in one location due to action taken to reduce emissions elsewhere. For example, if a carbon offset project protects a forest from logging but this leads to a necessity of logging elsewhere, then carbon offsets would not necessarily decrease emissions. In 2020, the European Commission published a new list of sectors and sub-sectors considered significantly riskier for carbon leakage and has policies to support investment in these areas (European Commission,2019). By incentivising companies and projects to set up operations there, they aim to prevent leaking in those areas while helping more challenging industries transition to low-carbon practices.

Lastly, the Baseline estimation is critical to define when starting a new carbon project. The Baseline sets the ground comparison for calculating all other standards and the carbon units. For example, a baseline for tropical reforestation projects like Harris et al. (2012) developed shows an understanding of the current situation of the tropical forests, including the rate of deforestation, area and density, making it possible to calculate more accurate emissions avoided numbers. For context, his estimate is around 25 to 50% of the recently published estimates, showing that the baseline varies greatly depending on who does them, their methods, and their interests. Regardless, one undeniable truth persists: without accurate and dependable estimates, any carbon market is at risk of failing to meet its objectives and promises, ultimately fostering mistrust.

2.4 Value-Chain

The development of projects is a costly process; the highest monetary cost occurs during a project implementation. This results in long-term investment, with very high upfront costs,

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which will only generate revenue after the certification process when selling the respective credit. The whole value chain can be seen in Appendix 5.

It is vital to note that project developers can receive revenue by creating methodologies. Certifiers of verified carbon units, such as Verra, give monetary support for developing these methodologies. Project developers who decide to do so will receive financial compensation at a variable rate based on credits issued, as shown in Appendix 6.

In a deeper view of what constitutes the costs of different projects, a study by Al Juaied and Whitmore (2009) reviewed different project types and their costs. Although every project generates carbon emissions, the price of each will mainly depend on its project scope. This makes sense, as an afforestation project will always have different costs from a technical point of view compared to a renewable energy one. Furthermore, projects within the same scope but of varied types - such as energy generation via solar panels or wind turbines - will exhibit vastly different implementation costs. This discrepancy spans all scopes and types of projects, resulting in a substantial divergence in implementation cost.

3 Blockchain on The VCM

3.1 Blockchain

Blockchain is a technology regarded by many as a transformative and revolutionary innovation. According to Conte de Leon et al. (2017), a blockchain can be defined as a "digital information recording method capable of recording data using a logbook approach and with the following essential characteristics: i) Ordered; ii) Incremental; iii) Sound (cryptographically verifiable up to a given block) and IV) Digital".

There are currently three types of blockchain in use, as noted by Vokerla et al. (2019). Private blockchain, where the access is tightly controlled, and the "general" public can read but not alter any information. Consortium Blockchains, a semi-decentralized blockchain, is still tightly controlled by a larger group of entities. Moreover, finally, Public Blockchains, where

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everyone can join as a node and participate in the network if they have an internet connection and a computer device that can run the blockchain. This is where true decentralisation exists. Being a peer-to-peer network where one or more nodes share resources without needing a centralised system, blockchain will facilitate direct communication between project developers and buyers. Buyers can search for projects and automatically know the credits that align with their preferences. Regardless of the network type, every blockchain comprises a distributed ledger technology (DLT) that maintains a continuously growing list of ordered records called blocks. As shown in Appendix 7, blocks contain their unique hash (digital fingerprint), the timestamp of a recent batch of validated transactions, and the previous block's hash. For these blocks to be created and published in the network, there needs to be a consensus mechanism that can manage the network's security. This mechanism can be described as a "set of certain mathematical rules and functions that allow it to reach an agreement between all participants

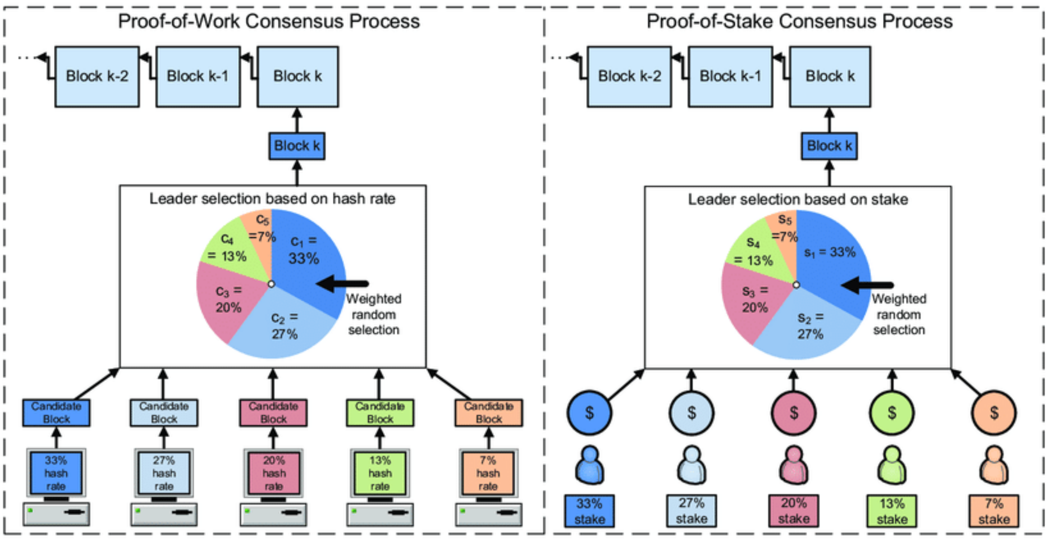

Fig. 3: PoW and PoS Consensus Mechanisms Comparison.

Source:Proof-of-Stake Consensus Mechanisms for Future Blockchain Networks: Fundamentals, Applications and Opportunities"

(nodes) and ensure the operability of the network" (Vilkov and Tian, 2023). Different Blockchains have implemented different consensus mechanisms, but two have been extremely

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popular: Proof of work (PoW) and Proof of Stake (PoS). Figure 3 sums up the differences in both processes.

However, when considering a specific blockchain application within the carbon market, utilising Proof of Work (PoW) becomes unfeasible and potentially counterproductive. PoW necessitates an exorbitant number of energy-intensive computations to solve the mathematical equations required for hash discovery, contributing to Bitcoin mining's electricity consumption surpassing that of numerous developed nations (Corbet, Lucey, and Yarovaya, 2021). Therefore, employing a PoW-based blockchain solution to assist the carbon market could exacerbate climate change issues. Instead, a Proof of Stake (PoS) solution offers enhanced energy efficiency. Ethereum, a cryptocurrency that has transitioned its mechanism from PoW to PoS, has achieved a remarkable 99.9% reduction in energy consumption, rendering it a reasonable and applicable choice for the carbon market (Paola, 2022).

Another critical property of blockchain, and why its use could be so valuable for the VCM, is the immutability of its records. As Hofmann et al. (2017) put it, "recorded data cannot be manipulated or modified after being accepted by the blockchain network". This would provide much more confidence in the quality and legitimacy of carbon credits, backed by actual data on the blockchain that cannot be altered. Wrongdoing like the ones discussed in section 4 could be more readily identified and prevented using blockchain technology.

Another key problem highlighted by Tabitha Whiting (2023) is when the trading of credits occurs between countries, with both the seller and the buyer counting them towards their own emissions reduction goals. Double counting "can result from double issuance, double claiming, and double use" (Marchant, Cooper, and Gough-Stone, 2022). Double counting is a big problem because the real impact is half what is accounted for. By using Blockchain, levels of traceability and monitoring increase such that this problem might become a "non-issue by

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automatically retiring a credit once purchased" and storing that information on its ledger. (Marchant, Cooper, and Gough-Stone, 2022).

3.2 Current Implementations

Blockchain-based solutions in the VCM landscape have started to appear in recent years, with two exciting projects worth the emphasis.

3.2.1 KlimaDAO

KlimaDAO is an example of a decentralised autonomous organisation (DAO) that fulfils the need for a global, borderless entity that coordinates agency relationships, enforces expectations, and limits liabilities through smart contracts. These digital organisations can be used for various purposes, including exchanging digital assets, speculating, facilitating cross-border money transfers, and time stamping. DAOs also have potential applications in financial transactions, secure voting, autonomous organisations, company management, freedom of speech networks, online games, crowdfunding, and speculation, among many other possibilities that cannot be anticipated (Kaal 2021)

KlimaDAO is a digital reserve currency backed by carbon credits. Much like gold once gave value to the US dollar, the $Klima token is backed by natural assets, in this case, BCT (Base Carbon Ton) and MC02 (Moss Carbon Credit), where one BCT or MC02 equates to a ton of sequestered carbon. Specifically, BCT is a token created by a crypto project named Toucan

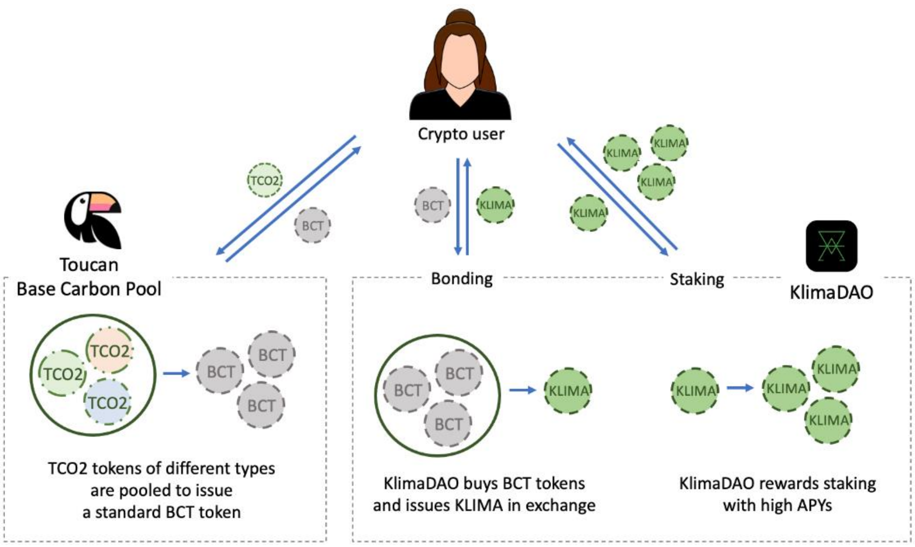

Fig. 4 – Example of an interaction between Toucan, KlimaDao and crypto user. | Source:(Gutierrez 2021)

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Protocol that takes carbon off-chain and brings it to the blockchain. Figure 4 illustrates this interaction between BCT, Klima and a crypto user. If a registry like Verra approves the emission of credits for a specific project, Toucan puts those credits on the blockchain, which can now be tracked and re-sold. MC02 has a similar use case, but it only operates with projects from the Brazilian Amazon.

For now, KlimaDAO and the Toucan Protocol have a market cap of over $10 million, a small portion of the total cryptocurrency market cap today at around 1.4 trillion.

3.2.2 Nori

Nori is a carbon removal marketplace with innovative blockchain technology based on tokenising carbon offsets as Non-Fungible Tokens (NFTs). They have partnered with many farmers to create regenerative agriculture projects that store carbon in the soil. What makes Nori unique is the Nori Carbon Removal Certificate that accompanies each purchase, providing the exact amount of carbon removal credits and their serial number, recorded on the blockchain (Appendix 8). By purchasing with Nori, one is also buying credits from a project whose compromise is to sequester carbon for at least ten years, as assured by Nori. After creating projects, an independent third party estimates carbon removals and verifies everything every three years. Moreover, every detail about the project is stored in their blockchain and is publicly accessible through their website. Credits can be bought, and customers can select how many they want. The certification is then issued and can be used to prove ownership of the credits and prevent double counting, as each certificate is unique and delivered to only one individual.

Nori's solution fills the gap of having a blockchain technology solution backing their services, but also an easy-to-use friendly marketplace perfect to match buyers and sellers around the globe. It is worth noting that no one needs to transact in cryptocurrencies; all can be done through dollars, and credits can be bought with a few clicks, like a standard online purchase.

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Nori and KlimaDao were the first to bring blockchain to registering, selling, and retiring credits. Nonetheless, the role of blockchain in this market is still completing its early steps, and one stage has yet to be disrupted.

3.3 Future Implementations

Currently, MRV practices are all but standardised; every register has its methods and programs. Different projects have different methodologies, and this lack of standardisation leads to problems in "inefficiency, credibility, utility, and cohesiveness of MRV processes and results" (Bauman 2020).

3.3.1 Digital MRV

One idea to combat these issues is the introduction of a digital MRV, where IoT devices can do all the measurements and verify emission reductions regularly without any human interference, avoiding human errors. Figure 5 represents a general digital MRV process.

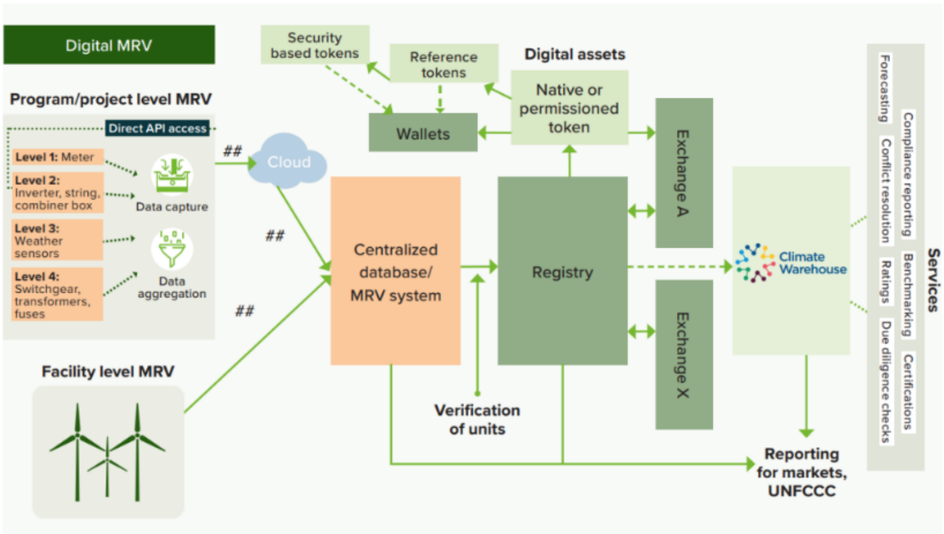

Fig. 5 - End-to-end digitalization of carbon market infrastructure using Digital MRV.

Source: World Bank. 2022. Digital Monitoring, Reporting, and Verification Systems and Their Application in

A universally adopted Digital MRV framework requires consistency and adaptability to ensure its applicability across different contexts. This standardisation will also expand access to the carbon market as regulatory frameworks become more comprehensive and transparent, ensuring a level playing field for all participants. Lastly, Digital MRV has the potential to act

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as a catalyst, driving corporate supply chains towards increased "transparency and accuracy on climate and sustainability impacts"(Climate Ledger Initiative, 2018).

Creating a blockchain solution will eventually lead to more efficiency, transparency and traceability in the carbon market, decrease existing barriers and increase data quality (Fuessler et al. 2018).

4 Policies & Regulations:

Throughout this research, one can see how VCM has the potential to help mitigate climate change. Nonetheless, according to Battocletti, Enriques, and Romano (2023), there is "evidence that the VCM has not always delivered on its promises." As a result, tighter regulation has long been asked for. This section explores policies and regulations alongside some of the main controversies that have shaken this market's confidence.

4.1 VCM Controversies

No industry or company is usually exempt from controversy or another throughout their lifespan, but the Carbon Credit market is very different. At the beginning of 2023, a Guardian report on a handful of rainforest conservation projects raised significant doubts on whether these projects are practical. According to their research, only a handful of Verra's rainforest projects showed evidence of deforestation reductions, with further analysis indicating that 94% of the credits had no benefit to the climate (Greenfield 2022). The analysis targets a specific type of credit called REED+, which is short for Reduced Emissions from Deforestations and Forest Degradation. The "+" mark refers to additional forest-related activities. One example of a REED+ credit is keeping and protecting a forest that would otherwise be cut down for business purposes. Landowners get the revenue from credits and, in return, delay cutting the forest for wood or any other profitable activity. While many claim REED+ type of credits are a failed scheme ("REDD+: A Scheme Rotten at the Core | World Rainforest Movement" 2019), Barbara Haya, director of the Berkeley Cabron Trading Project, believes "rainforest protection credits

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are the most common type on the market at the moment", adding that "These problems are not just limited to this credit type. These problems exist with nearly every kind of credit." (Greenfield 2023a). It is worth noting that Disney, Shell and Gucci have all bought rainforest credits from Verra, leading some of them to label their products as "carbon neutral". This investigation resulted in a lot of distress and uncertainty. Verra's CEO left the company following the news after more than 15 years of running the business, despite no wrongdoing ever being confessed.

In another example, an article by the New Yorker in 2023, entitled "Great Cash-for-Carbon Hustle" (Heidi Blake 2023), highlights a scandal with a Project Developer called the South Pole in a project named Kariba. This project faced allegations of financial irregularities, mismanagement of funds, and inflated claims regarding reducing carbon emissions, with some even saying the project "actually resulted in more carbon emissions". An audit took place after the project was completed ten years later and found that only fifteen million of the forty-two million carbon credits had been backed by avoided emissions. In response, South Pole always insisted that the Kariba credits sold would ultimately be backed by actual emissions in the future. However, people visiting the project site found nothing but abandoned vegetable gardens.

Projects producing credits with an inflated rate and low reliability are uncommon, diminishing trust in the system and the offsets companies buy. This helps explain why the demand for this market has collapsed for the first time in years, as Sarah Mcfarlane and Susanna Twidale (2023) noted.

4.2 Legislation in the VCM

The Paris Agreement was crucial for accelerating the VCM as we know it today, with Article 6 having several subsections outlining most of the structure. Article 6 acknowledged that countries could pursue voluntary cooperation in implementing their nationally determined

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contributions to allow for higher mitigation ambition and promote sustainable development. Subsection 6.2 describes the process that allows countries to trade emission reductions and removals with one another through bilateral or multilateral agreements. These traded credits are called Internationally Transferred Mitigation Outcomes (ITMOs). Either country can buy them to meet their NDCs or private entities to meet voluntary goals to reach net zero. An example can be seen in Appendix 9. Another important subsection is Article 6.4, the successor of the Clean Development Mechanism (CDM), the first international carbon market developed under the Kyoto Protocol in 1997. This article establishes a voluntary carbon market: "A company in one country can reduce emissions in that country and have those reductions credited to sell them to another country. That second company may use them to comply with its emission reduction obligations or to help it meet net zero." (Article 6.4 Mechanism | United Nations). Here, carbon credits are sorted into three categories, depending on whether they are UN accredited and have undergone adjustments. Credits resulting from these initiatives are called mitigation contributions or unauthorised credits. Appendix 10 lays out the structure of the subsection, explaining which type of credits may or may not be authorised to count towards NDC's contributions.

Following the controversies discussed in the former section, two big questions remain unanswered in Article 6. One is the decision to include or exclude REED+ credits inside Article 6.4, as there is no official definition of removals, reductions, or avoidance. The second consideration is whether Article 6.4 will allow independent registries such as Verra or Gold Standard to participate in this mechanism and supply credits.

4.3 Important Legislations in other Markets

4.3.1 Markets in Crypto-Assets

MiCA, short for "Markets in Crypto-Assets," is a proposed regulatory framework within the European Union (EU) designed to regulate various crypto-assets and related services. This

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initiative is part of the EU's broader Digital Finance Package. MiCA's goal is to ensure legal clarity, consumer protection, and financial stability while promoting innovation and uniformity in terms of regulation. MiCA establishes the rules for the issuance, admission of trading and operation of crypto assets.

The draft defines crypto assets as "a digital representation of value or rights that may be transferred and stored electronically, using distributed ledger technology or similar technology" (C. Maia and Vieira dos Santos 2021, 2). Among many other features, MiCA stands out for establishing a single licensing regime for crypto issuers, setting requirements, promoting legal certainty, introducing a taxonomy for crypto assets, and categorising them into different types. Appendix 11 lays the structure of that taxonomy, and (C. Maia and Vieira dos Santos 2021) go much deeper into analysing MiCA's framework throughout their research.

In short, MiCA divides crypto assets into three distinct categories. The first one is utility tokens, which refer to any unique crypto project in terms of value and include governance tokens that allow users to vote or participate in a specific crypto ecosystem. Mana and BAT are some examples of it. The second class are asset-references tokens (ART). These are tokens based on an underlying asset, like a commodity or real estate, and pegged to their value. The final class is referred to as e-money, like centralised stablecoins, but does not apply to any stablecoins issued by the IMF. The bill does not apply to blockchains or coins like Bitcoin, Ethereum, and Cardano. When it comes to NFTs, they now need to meet standards by registering with the authorities and presenting a whitepaper to avoid fraud and better schemes.

How exactly does MiCA relate to the carbon credit market? How can this influence it? Blockchain can help address some of VCM's issues, as discussed above. It can enhance trust in entities and projects by using decentralised structures that care for all procedures or improve the digital MRV, helping with data measurement and processing transparency. Blockchain can

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provide the necessary infrastructure to combat climate change at speed and scale ('Blockchain for Scaling Climate Action | World Economic Forum' 2023).

Despite MiCA's framework primarily protecting the euro against the rise of stablecoins, it also promotes the use of blockchain under a supervised look. This will allow for the development of projects under clear regulatory circumstances throughout Europe. This encourages cross-border operations, international cooperation, and support from governments and banks to support and finance blockchain initiatives, something that did not happen before. In addition, Europe has had the most significant trading volume of traded carbon for more than five years Qin and Coker (2023). All these factors combined will encourage more players into space and equip them with better funding to succeed in bringing value to the carbon markets.

4.3.2 Corporate Sustainability Reporting Directive

The Corporate Sustainability Reporting Directive (CSRD) is a significant piece of legislation implemented by the European Union. It mandates all large companies and lists Small and Medium Enterprises (SMEs) to publish regular reports on their environmental and social impact activities. This directive is designed to help investors, consumers, policymakers, and other stakeholders evaluate these companies' non-financial performance.

CSRD plays a crucial role in the Voluntary Carbon Market. The CSRD requires companies to report their greenhouse gas emissions, a key aspect of the VCM. By making this information publicly available, the CSRD enhances the transparency and accountability of the VCM. This allows stakeholders to assess a company's carbon footprint and the effectiveness of its carbon-offsetting efforts. This can influence investment decisions and drive companies to reduce emissions and participate more actively in VCM. Whittingham et al. (2023).

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5 Research Methodology

5.1 Research context

Celfocus gave a set of objectives to address the task at hand, four main areas of study were found, and the research questions were made. To face the questions, a mixed-method analysis was undertaken, enabling a broader understanding of the research Malina, Nørreklit, and Selto (2011).

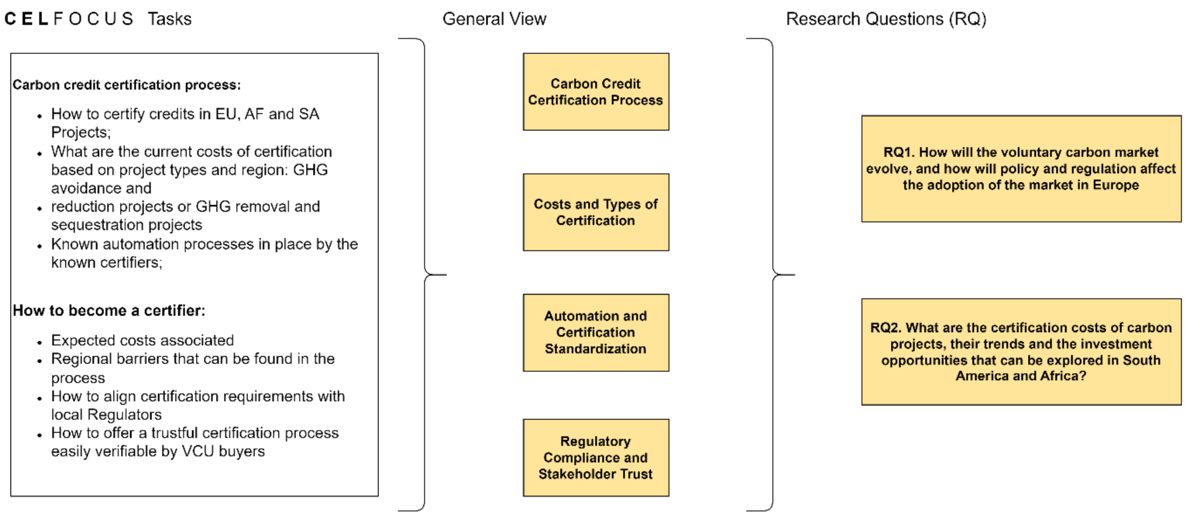

Fig. 6 – Research Question Formulation Process with Celfocus

The methodologies in this section are divided into qualitative and quantitative, and each part is structured in three steps: i) Data Collection and Processing, ii) Methods, and iii) Findings. Refining the Research Questions with Celfocus was an extensive process (Figure 6). It led to the identification of two key research questions:

5.2 Qualitative

The qualitative research of this paper reaches for the utmost insightful understanding through the use of interviews, as it is regarded appropriate when the researcher or investigator explores a novel domain of study or aims to examine and formulate theories on significant issues Jamshed (2014).

5.2.1 Data Collection and Processing

Voluntary carbon market stakeholders represent a great source of accurate raw information regarding understanding the market environment. The authors contacted representatives from

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registries about the certification process and legal experts in touch with European regulation on the carbon market to get a more comprehensive understanding of policies.

This process was carried out through snowball sampling Goodman (1961). This resulted in six semi-structured interviews, as represented in Appendix 12. All the interviews were conducted through video calls, using web applications such as Microsoft Teams, Zoom and Google Meets, allowing for recording and easier access to automatic transcripts. Participants were informed of the option of anonymity to ensure responses would be anonymised and used solely for research purposes. Consent was obtained before the recording, detailing the purpose of the research, the voluntary nature of participation, and assurance of confidentiality.

The authors prepared a script to guide these interviews to provide a foundational structure for the discussions. This script is available in Appendix 13 and served as a reference point during the interviews. These were designed to explore the diverse impacts of each participant on their interactions within the voluntary carbon market. Slight deviations occurred during this, allowing for a natural flow of conversation and an in-depth exploration of participants' perspectives.

5.2.2 Data Analysis Methods

Interview transcripts were meticulously examined using conventional (inductive) content analysis, as presented in Appendix 14, as Hsieh and Shannon (2005) outlined. Despite the structured script, interviews naturally meandered, leading to responses that did not always fit into predetermined categories. The authors used the process of noticing, collecting, and thinking to address this issue, inspired by Seidel's approach.

The inductive content analysis on transcripts described by Delve and Limpaecher (2023) enables a deep understanding of the data. While segregating information into themes helps identify patterns and categories altogether, it has some issues, as it can be challenging to balance

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immersion in the data and focus on the research question. The development of codes demonstrates a detailed focus on the content. As referred before, there was a natural flow to the interviews to assist in the inductive conduct, noticing, collecting, and thinking methods used. Noticing facilitated the identification and coding of interview segments, collecting was instrumental in organising these coded insights, and thinking involved analytical examination of the segmented and organised data. The recursive nature of noticing allowed for additional questions during the interviews, enriching the depth of discussion.

5.2.3 Qualitative Results

Quality of credits was a hot topic amongst interviewees, who expressed significant remarks. Mentioning recent articles from The Guardian, project developers expressed uncertainty about the methodologies used by registries. To address this issue, project developers mentioned that a second layer of a project evaluation can bring calm to the market. Procurement services have advertised "high-quality credits" with additional measures in the standard process, including stringent criteria for removing project types, emphasising additionality, permanence, and leakage. Quality concerns significantly impact the credibility, price and effectiveness of the voluntary carbon market, potentially eroding the trust that both investors and the public have in carbon credit initiatives. Nevertheless, registries stay firm on their standards, as it was said to be an error and learning mechanism. Overall, research has revealed a need for improved quality standards, and interviewees have suggested adopting more rigorous certification processes and transparency measures to address this issue.

Transparency, the lack of transparency in project development, was highlighted in every interview. All acknowledge the significant implications for public perception, investor confidence, and the functionality of the voluntary carbon market. Despite the availability of specific information on registries' websites, interviewees emphasised the inefficiency of platforms providing up-to-date and comprehensive details, including images and reports on

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projects under development. Establishing a public platform with real-time project updates, detailed reports, and visual documentation is critical to fostering trust among stakeholders, attracting investors, and ensuring the proper functioning of a future marketplace. This may result in a more local supply as information is closer to the supplier, cutting short investment incentives for less developed countries.

Legal barriers are a significant challenge to the development of carbon credit projects, particularly in the context of European Union regulations, according to both project developers and legal experts. These barriers relate to national laws, project size, methodology application, and compliance with varying national policies. The impending impact of EU regulations on project development has raised concerns about credit quality assurance. However, a registry representative has revealed that certification bodies are committed to helping governments transition to a greener future and are available to assist with this process. To address these legal barriers, a collaborative effort is necessary to adapt certification frameworks and ensure they are aligned with evolving regulatory landscapes, promoting a smoother project development process.

Few interviewees provided sources for datasets or information about carbon pricing. When provided, the authors encountered paywalls to get carbon credit prices. Trading of credits is conducted in a non-public sight inside registries or by procurement services. Carbon trading is mainly done on a demand basis from companies that advertise products as sustainable and carbon-free and pledge to go net zero until 2050. A higher demand searches for projects already producing credits, disregarding projects in the early stages of development where financing is most needed. Credits are bought with the vision of a company's footprint, usually for the next 10-15 years.

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A Blockchain-based marketplace spiked interest among interviewees. Most were not fully knowledgeable about how the market could work and if there was already an implemented solution. Even so, most appealed to the solution based on their conception of the nature of blockchain. A remark made by a project developer went back on the idea, stating that buyers of carbon credits and companies funding projects can and happen to decide to be anonymous. Despite that, it was said to be a smart solution regarding transparency. As it is currently one of the most pressing issues, besides traceability and double counting, ledger technology could solve it. A spokesperson for a registry has indicated that it is possible that governments may consolidate registries in the future, utilising either blockchain technology or a more advanced system, in order to establish a global standard.

Overall, interviewees highlighted that the market objectives passed through the need to achieve the net-neutrality goals brought from the Paris Agreement, picking up the individual objectives of each country. The VCM is a powerful tool to mitigate climate change and bring development to third-world countries with sustainable investment, complying with the Sustainability Development Goals (SDG). Nonetheless, there is a consensus among interviewees that the market is flawed and filled with a lack of credibility, regulation, and harmful practices.

5.3 Challenges and opportunities in the VCM (Quantitative)

Interviews served as an essential method to gather data. However, with the vast market landscape, authors found it best to perform secondary data analysis Johnston (2014) since it can enclose data from a wide range of aspects needed to face the requirements given by Celfocus.

The figure represents the contribution of each step taken to answer the research question; further down in this section, there is data collection, data pre-processing and analysis. These sub-sections have information on the data gathered, curated, and analysed and its respective methodologies.

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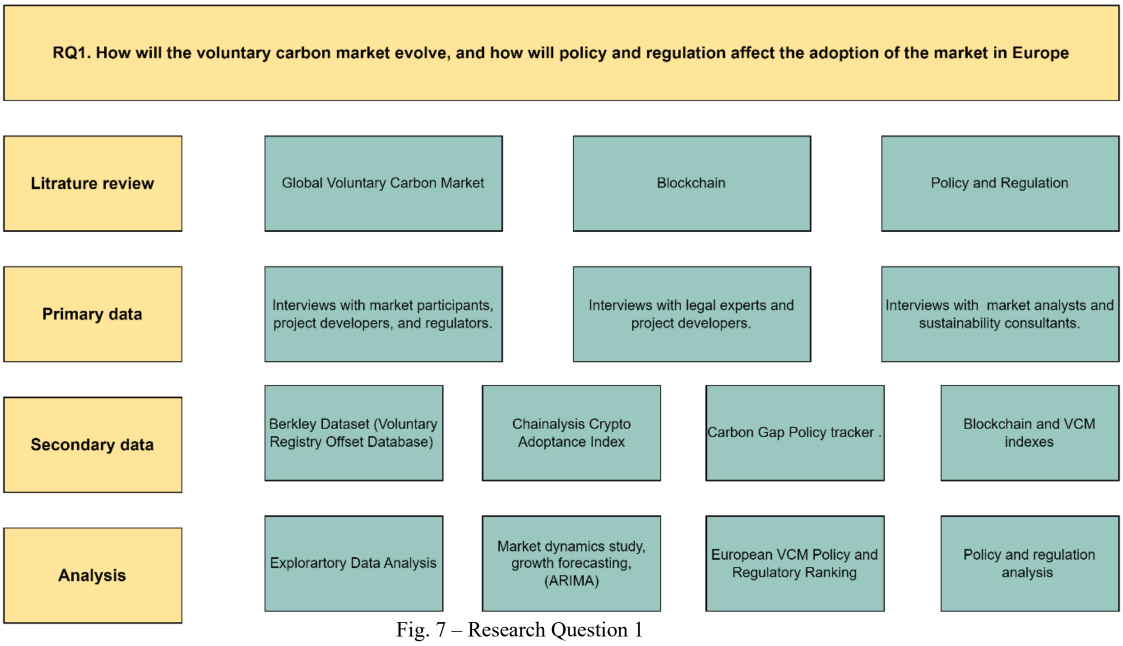

Fig. 7 – Research Question 1

5.3.1 Data Collection

The data collection and analysis process relied on the programming language Python for its agility and versatility. The Carbon Dioxide Removal (CDR) Policy Tracker provides information on regulations and policies related to carbon in European nations. Information from the website was compiled into a data frame using web scraping, which resulted in a data frame with regulations for each country listed on the policy tracker website. Saving the data in a CSV (comma-separated value) file allowed easy and quick access. Additionally, the Global Index of Cryptocurrency Adoption by Chainalysis 2022 was manually translated into an Excel file to perform a quicker and more effortless analysis later by reading the data with Python commands.

Carbon projects and credits data already existed in a dataset from the Ivy S. So, Barbara K. Haya, Micah Elias. (2023, May). Voluntary Registry Offsets Database, Berkeley Carbon Trading Project, University of California, Berkeley. The dataset has various versions, and to that effect, authors built code that allows a user to choose the dataset version using web scraping techniques and download the chosen one. The data set compiles information from the four primary registries that certify projects in the VCM, including data on credits issued and retired,

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the registry responsible, and the origin country of the project. The latest version comprises over 157 variables and 7,933 unique projects registered.

5.3.2 Data Pre-processing

Data pre-processing is needed, or it may cause problems and make data analysis unnecessarily complicated, as described by Famili et al. (1997). For the merger of the policy tracker dataset and the global index, countries had different nomenclatures and null values that had to be renamed and removed, respectively. The authors identified 21 irrelevant variables to the study on the Berkley dataset and 20,000 missing values curated via removal or filled using neutral values.

With the ambition of creating an ARIMA model later to forecast the number of carbon credits. Data must be stationary, performing the Augmented Dickey-Fuller (ADF) measure; the authors found the data non-stationary. To make data stationary, authors apply many transformation methods, such as differencing, second-order differencing, logical scale, and box-cox, to name a few (Salles et al. 2019). These are evaluated by finding the methods that negate the null hypothesis ($H0$: The time series is non-stationary (has a unit root)) and applying the AUTO ARIMA model to get performance measures such as Mean Squared Error (MSE) and Mean Absolute Error (MAE).

5.3.3 Data Analysis Methods

An extensive exploratory analysis Thomas and Mathur (2019) was needed to ensure market knowledge. All the EDA is represented in Jupiter Notebooks and can be found at https://gitlab.com/bmanarte/voluntary-crabon-market-analytics.

At first, Choropleth mapping was used to gain global insight into each country, project and credit issued. This technique is a fundamental spatial analysis tool that can effectively detect global trends and outliers. The technique highlights extreme values and facilitates the nuanced comparison of multiple regions, shedding light on variations that might otherwise go unnoticed

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Schiewe (2019). Employing this method in the dataset reveals hidden spatial patterns and unveils invaluable insights for this project.

A critical aspect of this work project was the analysis of different project types. To that effect, the second analysis method was the development of treemaps. These data visualisation techniques give users an overview of large and complex tree-like structures with a faster processing time than traditional node-link diagrams Long et al. (2017). The efficiency of treemaps in decision-making is remarkable, as they can efficiently represent specific niches of data, revealing scalability along the way. In this particular visualisation, a tree map was constructed by segregating each registry and calculating the number of credits issued per project type, revealing the most "profitable" project type registries.

Next, a Time series analysis was conducted to forecast market evolution. For that effect, data had to be stationary (Alghamdi et al. 2019). The Auto ARIMA, short for Automatic Autoregressive Integrated Moving Average (ARIMA) model, is a common approach in time-series analysis to the targets of this project; the model predicts future emission of carbon credits Mélard and Pasteels (2000). Unlike traditional ARIMA models, Auto ARIMA automatically selects the optimal values for the model parameters (p, d, q) through an iterative process, making it a convenient choice for analysts and researchers.

The policy tracker dataset has various variables that can be quantified. With the adoption of the VCM in thought, the creation of a ranking was ahead. Rankings play an important role in decision-making, although they can be misleading and ineffective due to the amount of data and the weights given to the variables, Altbach (2006). For that effect, in discussion with the company, codes were created for each value. Three types of variables were identified: binary, ordinal, and nominal. To code the binary variables, "Yes" equalled 1, and "No" or any missing value equalled 0. Ordinal values started at one and grew based on the importance of other

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categories discussed with Celfocus. Nominal variables were treated as Binary because countries had either regulation or no regulation, so countries with no regulation had zero value. Meanwhile, countries with a structured plan to adopt a VCM solution were coded with one. Additionally, to contribute to the ranking, the Global Crypto Adoption Index was added to the data frame. All the encoding and definitions can be found in Appendix 15. To connect both datasets, data was normalised so there would not be any difference in weights and scales; using the Constrained Min-Max method, described by (Mazziotta and Pareto 2022), the result outputs a desirable outcome ranking countries likelier to adopt the VCM higher on the overall sum.

5.3.4 Quantitative Findings

A spatial comparative analysis among registries, presented in Figure 8, revealed each registry's geographical area of action. All have a global approach to the certification process besides CAR, which only acts in North and Central America; carbon certifiers such as Verra and Gold Standard have activity globally with an emphasis in Asia, where more than one-third of projects are active. American Carbon Registry and Climate Action Reserve have the most active projects in North and Central America. Overall, the VCS program has more than one-third of the projects (1725), with GS right behind with a few hundred projects behind from the VCS (1367), and finally, CAR and ACR, which only get to part of the market.

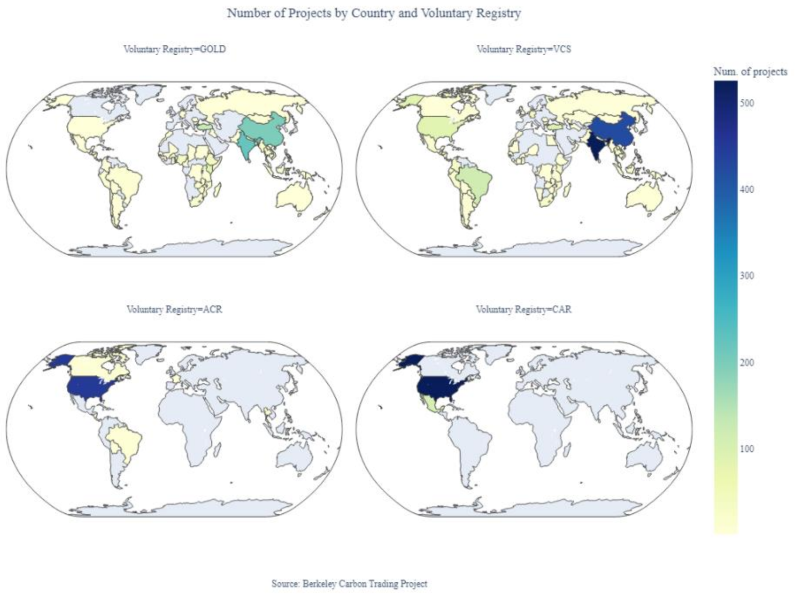

Fig. 8 – Choropleth

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Figure 9 shows the comparative Treemap for the VCS registry. Other Registries can be seen in Appendix 16, showing the difference in verified carbon credits issued by project types. This visualisation allows us to go deeper into registry preferences for project types. A common theme for afforestation and reforestation projects surges from all registries except GS, where projects are conducted with SGDs in mind. Looking deeper into Gold Standard, 30% of credit issued comes from renewable energy, most specifically wind, followed up by cookstoves. The VCS program has an astonishing amount of over 400 million credits issued on the REDD+ methodology, taking up 38% of the total credits issued, with the earliest project started in 2003.

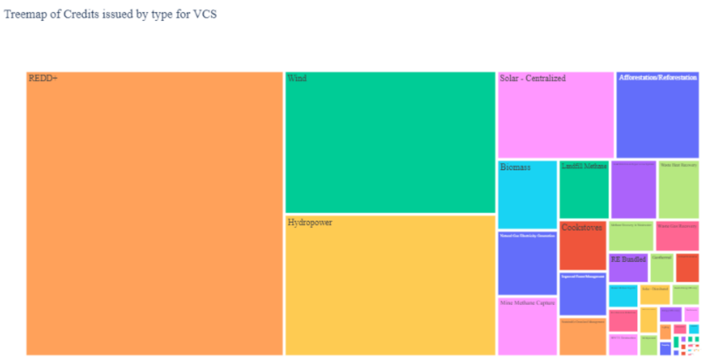

Fig. 9 – VCS Treemap

Next, the Arima model to predict credit issuance is created using data previously made stationary. Evaluating the model's accuracy, as described by Yokum and Armstrong (2005), is

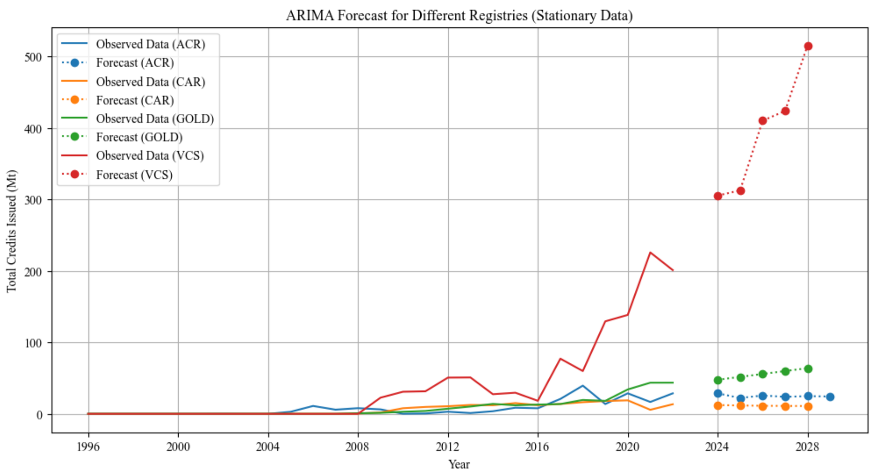

Fig. 10 – Forecasting with ARIMA Model

the most crucial criterion for assessing a model's fitness. Three performance measures, MSE, MAE, and Akaike Information Criterion (AIC), were used as the accuracy criteria.

The Total Credits Issued for ACR show a notable increase from 1996 to 2022, with intermittent periods of substantial growth. The values remained relatively low until 2005 but experienced significant spikes in subsequent years, reaching a peak in 2020. However, in 2021, there will be a decrease in Total Credits Issued, followed by a slight increase in 2022. The ARIMA model for ACR demonstrated reasonable accuracy, with an MSE of approximately 54.69 and a mean absolute error MAE of approximately 7.16.

CAR exhibits a similar trend with a steady increase in Total Credits Issued over the years. The values were minimal until 2008, after which a continuous upward trajectory existed. The ARIMA model exhibited a commendable performance, with an MSE of about 101.95 and an MAE of approximately 9.32.

The Total Credits Issued for GOLD depict a varying pattern. There are periods of significant growth, such as from 2012 to 2015, followed by relatively stable values. Notably, there is a dip in 2021 before a rebound in 2022. The ARIMA model showed a robust forecasting ability, resulting in an MSE of roughly 190.28 and an MAE of around 13.25.

VCS has the highest total credits issued, showcasing a remarkable growth trend. The values steadily increased, reaching a substantial peak in 2019 and 2020. However, there is a considerable drop in 2021, followed by a rebound in 2022. The ARIMA model provided valuable insights, but its forecasting performance was marked by the highest MSE of approximately 404.84 and a comparatively elevated MAE of about 15.88.

AIC is a measure that balances the goodness of fit and model complexity. Among the registries, CAR has the lowest AIC value (59.34), suggesting that the ARIMA model for CAR provides an excellent fit to the data while maintaining a balance between complexity and explanatory power. VCS and GOLD also have relatively low AIC values (98.03 and 68.36, respectively), indicating reasonable model fits. The ACR program, on the other hand, has the

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highest value, including AIC (125.88). The measures imply that the model for ACR might be more complex or less optimal in explaining the observed data compared to the other registries and may require further model refinement.

The VCM Adoption Ranking in Figure 11 reveals a nuanced picture of European countries' readiness to adopt the carbon market.

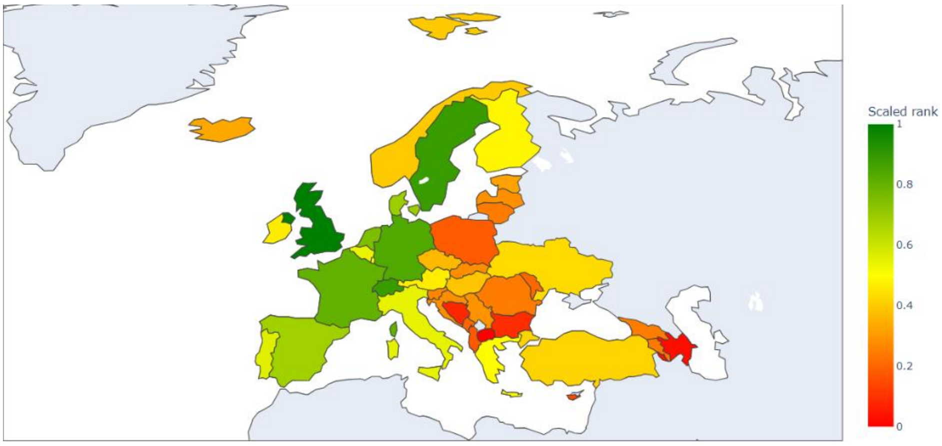

Fig. 11 – European VCM Adoption Ranking

The United Kingdom emerges as the frontrunner, showcasing a robust balance between progressive policies and a high level of crypto adoption, contributing to its top-ranking position. Sweden and Switzerland closely follow, emphasising these nations' overall commitment and preparedness. Nations that exceed in setting national regulations, for example, the United Kingdom, have a separate target for avoiding and removing emissions. Sweden has a net zero target year earlier than these two, and Switzerland has set their CDR targets before every country.

The significance of crypto adoption is evident in the rankings, with countries like the United Kingdom and Germany scoring high and securing top positions. This suggests that a favourable environment for blockchain may enhance a country's overall readiness to engage in the carbon market.

However, the results also highlight considerable diversity among European nations, with some countries needing to catch up in policy and crypto adoption scores. For instance,

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Bulgaria ranks bottom with a zero policy and regulation score. Evaluating the variables, there is a target year to reach net zero yet little to no policy implementation, including the lack of an interim target or a separate plan for buying credits from other countries.

The analysis underscores the importance of comprehensive policies and regulations in shaping a country's carbon market readiness. The top-performing nations not only exhibit firm commitments to net-zero goals through the application of internal policies but also leverage blockchain and crypto technologies, creating a synergistic effect.

5.3.5 Limitations and Considerations

On the quantitative side, data accessibility and quality pose challenges, particularly with issues such as manual translation affecting the reliability of certain information. Besides, the Country VCM Adoption Index had a generally low stakeholder input in weighing variables and quality information it compiled, so it is crucial to reconsider variables and add a time variable that pinpoints the new changes to policy and regulation. Additionally, the ARIMA modelling for forecasting assumes past trends will continue, overlooking dynamic shifts in the market influenced by social factors such as the current publicity on carbon markets. While these limitations are considered, they do not diminish the valuable insights gained from this study.

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6 Discussion

The current state of the Voluntary Carbon Market (VCM), as described by Espenan (2023), faces numerous challenges stemming from its centralised structure, lack of standardisation, and issues with transparency and credibility. The existing market dynamics contribute to inefficiencies, manipulation, and a lack of reliability in offsetting greenhouse gas emissions, which leads to a need for substantial improvements and regulatory interventions.

At its core, the VCM faces critical issues due to centralised control held by registries, allowing them to create and approve carbon sequestration methodologies without adequate regulatory oversight. This lack of standardised procedures fosters unhealthy competition, leading to potential manipulation in credit verification. Registries, acting independently, develop rules and issue carbon credits, profiting from each project they endorse. The involvement of Validation and Verification Bodies, which act by registries' rules, further blurs the lines of impartial validation, creating conflicts of interest.

The market's lack of transparency and education aggravates these problems, with carbon credit buyers often misled by the overselling of credits without compromise to reduce emissions. This misrepresentation undermines the credibility of claims of carbon neutrality, or environmental responsibility companies make. Moreover, the absence of incentives for smaller quantities of carbon credits discourages genuine efforts in emission reduction.

The complexities surrounding methodologies, particularly in estimating emission reductions accurately, contribute to the market's unreliability. The industry's lack of structured education and training programs further perpetuates the issues, leading to inexperienced personnel and a trial-and-error approach by companies.

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The divergence in market forecasts from different analysts, as noted by White, Rathi, and Pogkas (2023), exemplifies the uncertainty and lack of uniformity in the VCM. This lack of quality assurance, alongside the debate on initiatives like REDD+ and the concept of additionality, underscores the market's dubious nature.

Governments, especially in the EU, are moving to address these issues through regulatory frameworks emphasising project quality, quantifiable benefits, long-term sustainability, and contribution to climate goals. This shift aims to ensure carbon credits' credibility and stimulate the emergence of reliable certification bodies. However, despite these efforts, the VCM's reliance on developing projects in regions with softer regulations reveals a disconnect in achieving global emission reduction goals.

Blockchain technology offers a potential solution to enhance transparency, traceability, and credibility within the VCM. However, scalability, energy consumption, and interoperability challenges must be addressed to integrate into the market successfully.

The analysis explored trends regarding the number of projects within these scopes to enhance this understanding. Notably, while renewable energy and forestry and land use show signs of waning popularity and demand, Household and community credits emerge as an exceptionally reliable credit type, justifying their higher-than-average certification cost seen before.

When considering investment prospects in Europe, South America and Africa, it becomes apparent that African projects demonstrate higher readiness, preparedness, and a lower risk profile for carbon project investments. However, South America remains the most influential region for reducing GHG emissions and fostering community benefits. Specifically, countries like Kenya and Peru emerge as pivotal locations within their respective regions for the development of carbon projects. Additionally, Uruguay shines for its favourable investment

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landscape and outstanding environmental conditions. Lastly, there is Europe, hiding under the umbrella of other markets; while being well technologically developed in Carbon Dioxide Removal (CDR), it does not attract many projects. Being one of the regions starting to advance in policy and regulation, it may open a new window for new investors and buyers.

7 Limitations

Despite the comprehensive mixed-method approach undertaken in this project, certain limitations must be acknowledged. The qualitative research, relying on interviews with voluntary carbon market stakeholders, faced challenges in securing broad participation, with interview requests being rejected or yielding no response. Despite having a structured script, subjectivity in the qualitative data analysis introduces the potential for varied interpretations and biases. Acknowledging the comprehensive nature of research on VCM, it is imperative to recognise certain limitations to provide an unbalanced assessment of the study. One notable limitation arises from the data constraints encountered during the research process, particularly the absence of information on selling prices in the over-the-counter market that are the main registries. It is imperative to note that the research focus on project scopes and regions does not sufficiently consider the influence of external factors, such as regulatory changes or geopolitical events. It is essential to recognise that such external factors can influence the dynamics of the voluntary carbon market, and a comprehensive understanding of the market requires an examination of these factors.

8 Conclusion

The VCM needs renovation. The old market model struggles for transparency, credibility, and education, reflected in the downtrend movement in the number of projects and credits emitted. The VCM faces multifaceted challenges that require regulatory interventions,

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educational initiatives, technological advancements, and industry-wide collaboration to ensure credibility, transparency, and efficacy in mitigating greenhouse gas emissions.

Local projects and initiatives, when combined with advanced technologies like blockchain, may hold the key to restructuring the market in a way that fosters trust, enhances transparency, and aligns with its intended purpose. The work project helped Celfocus to acquire the necessary tools for developing their solution, which could potentially be used in other regions as well. Despite its imperfections, the VCM (Voluntary Carbon Market) remains a powerful instrument that can be leveraged to address the climate crisis.

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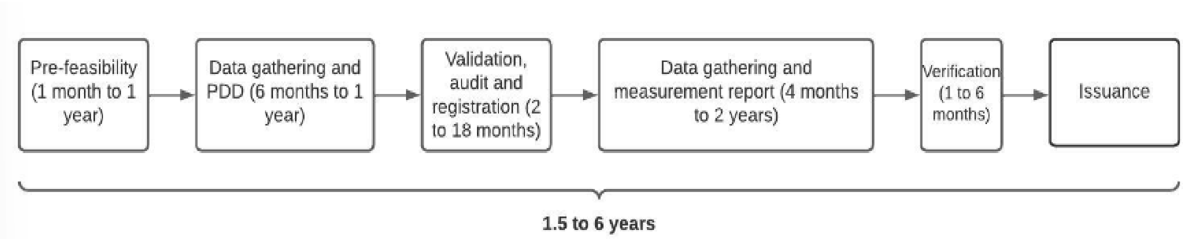
10 Appendix

Appendix 1: Carbon Management Ecosystem

Source: Carbonbase Ecosystem Diagram, 2022, compiled from Bloomberg, World Resource Institute, World Bank sources

Appendix 2: Certification Process



Source: The Voluntary Carbon Market: Market Failures and Policy Implications, 2023

Appendix 3: Certification form

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VERRA

Verified Carbon Standard

Certificate of Verified Carbon Unit (VCU) Retirement

Verra, in its capacity as administrator of the Verra Registry, does hereby certify that on 27 Jan 2022, 100 Verified Carbon Units (VCUs) were retired on behalf of:

Project Name
"Weyerhaeuser Uruguay" Forest Plantations on degraded grasslands under extensive grazing

VCU Serial Number
9857-148501148-148501247-VCS-VCU-261-VER-UY-14-960-01012009-31122009-0

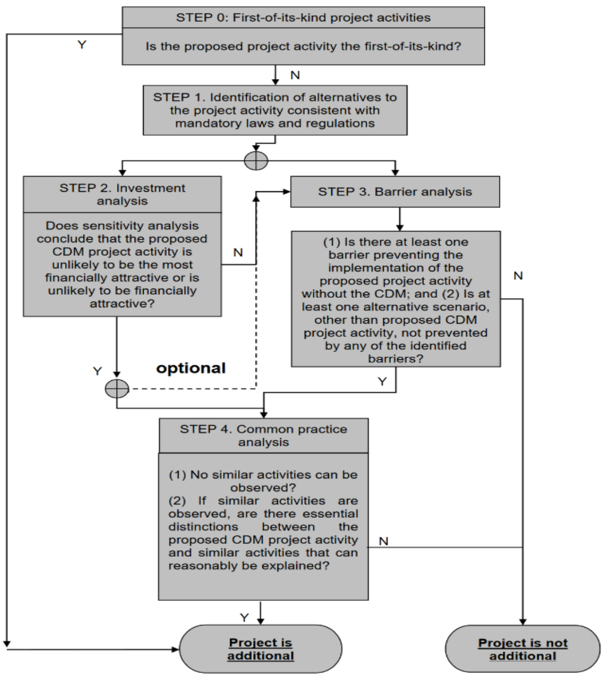
Additional Certifications

Powered by APX

Source: Verra(https://verra.org/)

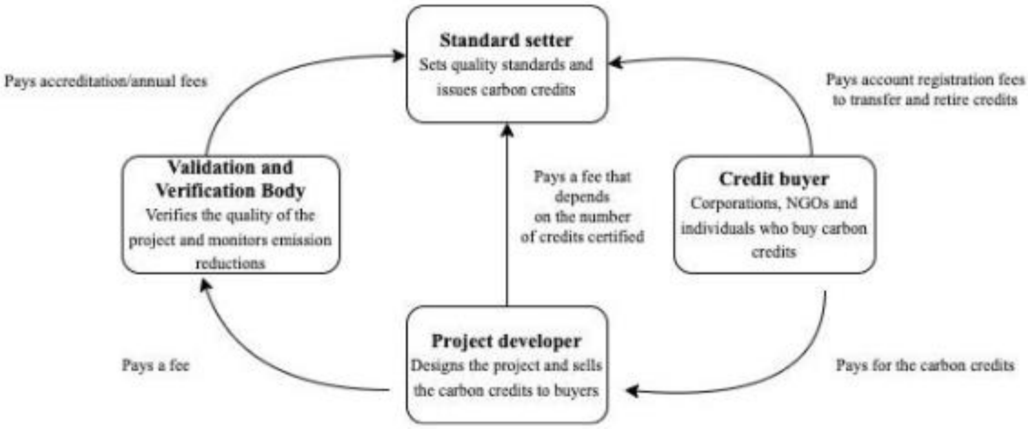
Appendix 4: Additionality flow chart

Figure 1 **Flowchart of the step-wise approach**



Source: Clean Development Mechanism (CDM) TOOL01- Tool for the demonstration and assessment of additionality

Appendix 5: Value chain



Source: [The Voluntary Carbon Market: Market Failures and Policy Implications, 2023]

Appendix 6: Methodology compensation rates

# of VCUs issued	USD / VCU
1-1,000,000	USD 0.02
1,000,001-2,000,000	USD 0.018
2,000,001-4,000,000	USD 0.016
4,000,001-6,000,000	USD 0.012
6,000,001-8,000,000	USD 0.008
8,000,001-10,000,000	USD 0.004
10,000,000-60,000,000	USD 0.002

Source: VCS Program-Fee-Schedule-v4.3-FINAL, 2023

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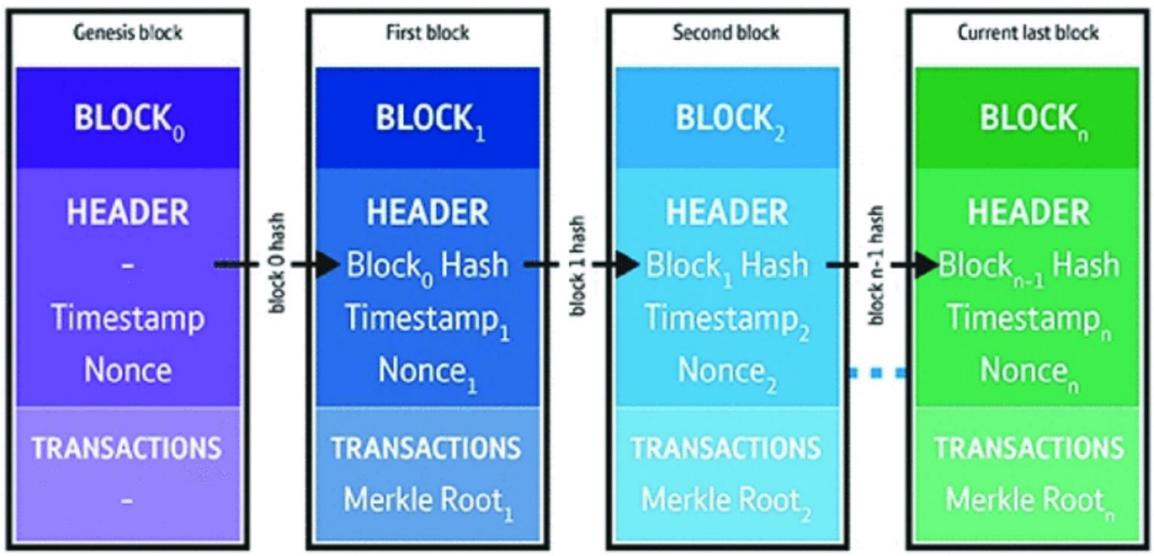
Appendix 7: The operation principle of blockchain



Source: https://ieeexplore.ieee.org/document/8899450

Appendix 8: Nori Certification Form

Nori Certificate of Carbon Removal

This certifies that the buyer, **Michael Leggett**, paid the supplier, **Harborview Farms**, for ownership of **24 Nori Carbon Removal Tonnes (NRTs)** on **December 9, 2019**.

Trey Hill — Supplied by Harborview Farms

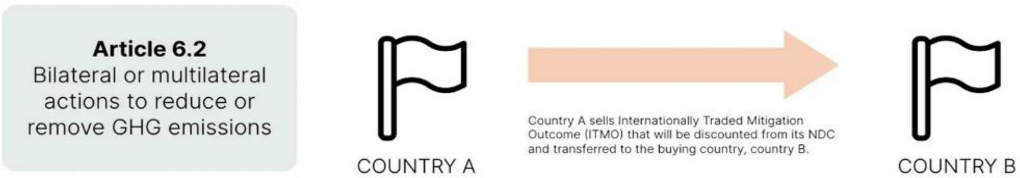
Janice McMahon — Verified by Aster Global, INC

Paul Gambill — Issued by Nori, LLC

SERIAL - 20191206_m1_USMD029_f1_y18_n159.32-n183.32

Source: Nori (**https://nori.com/**)

Appendix 9: Emissions Reduction Trading Example



Source: Abatable, 2022: https://cdn.sanity.io/images/uxhxwji3/production/0e40627826c5c8b9e44131e583e285f215f1d1d8-1671x999.png

Appendix 10: Structure of credits that count towards NDC

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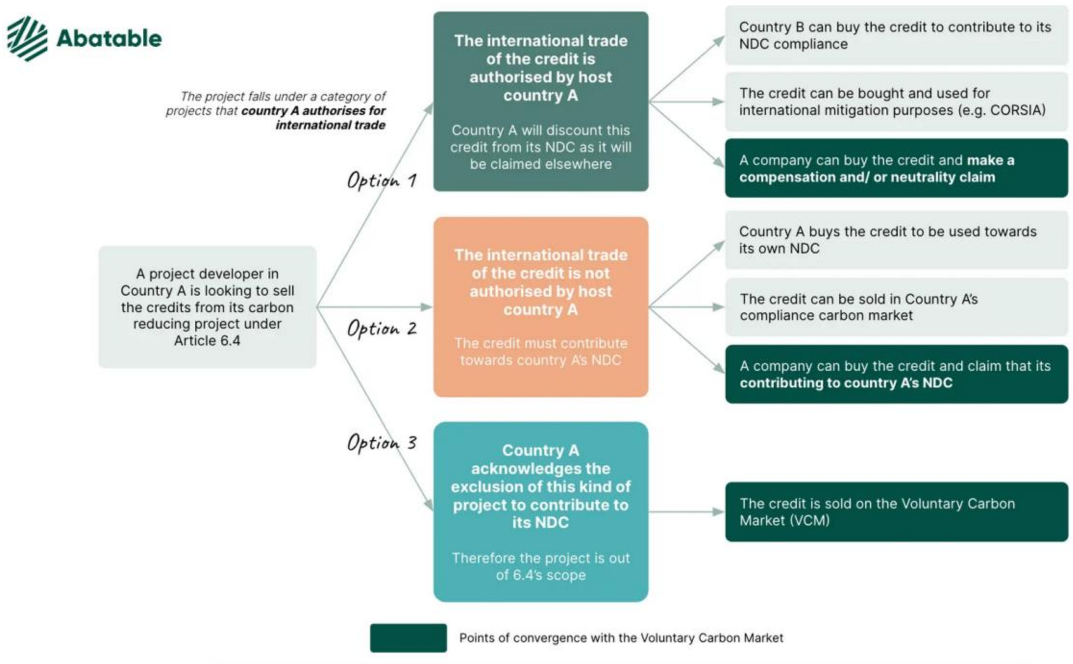

Source: Abatable, 2022: https://cdn.sanity.io/images/uxhxwji3/production/0e40627826c5c8b9e44131e583e285f215f1d1d8-1671x999.png

Appendix 11: Taxonomy of crypto assets under MiCA

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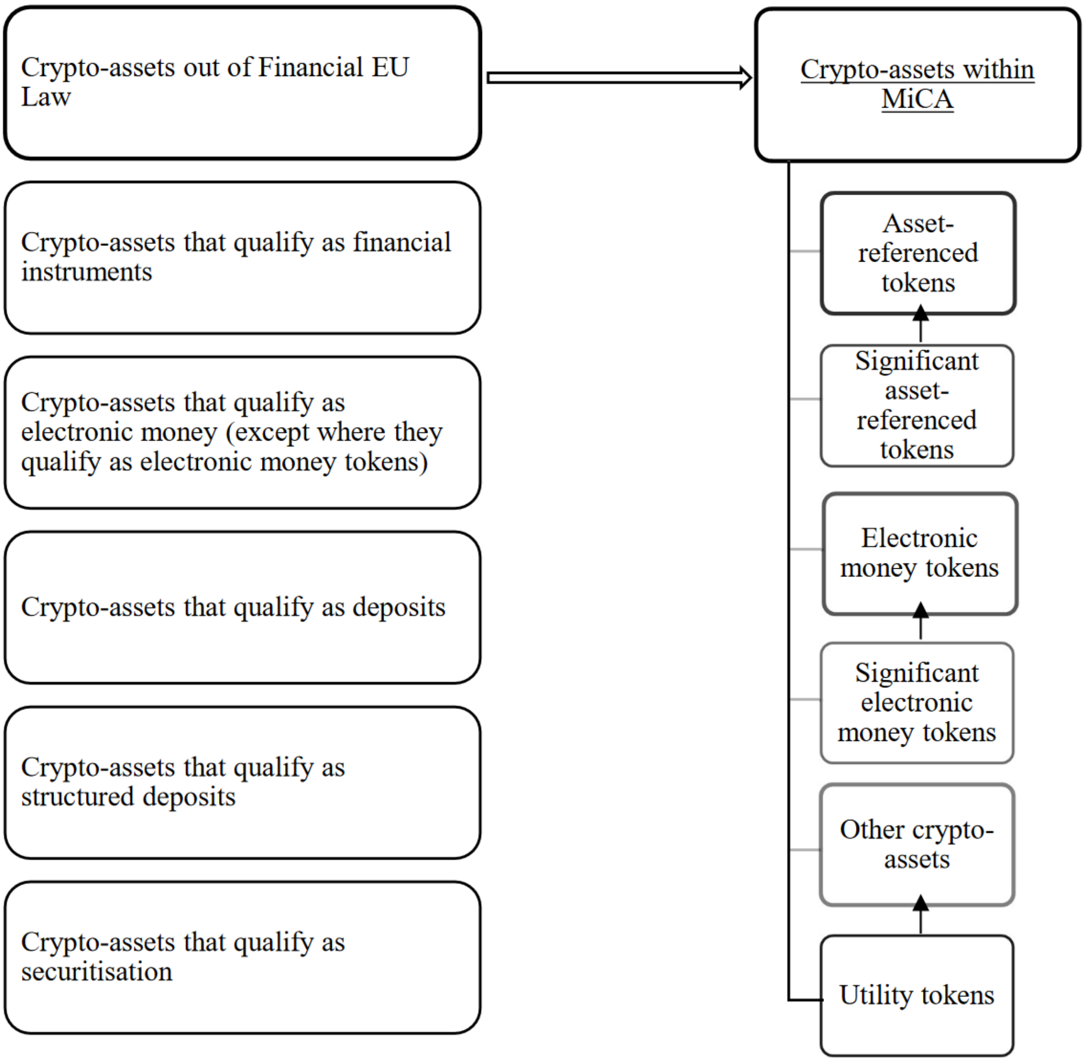

Source: Maia, Santos (2021)

Appendix 12: Semi Structured Interviews

Position	Company/ Sector	Duration
Data Analyst	Project Developer	1h
Director	Project Developer	40 min
Professor	Project Developer & Methodology Developer	45min
Director	Project Developer & Methodology Developer	30min
Lawyer	Policy and Regulation	2h
Senior Manager Program Secretariat	Verra	1h

Appendix 13: Interview Script

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Job/Company related

How are you involved in the voluntary carbon market?

How does one assess the quality of carbon credits?

What's your company's investment philosophy and criteria when deciding to fund carbon offset projects or project developers? Are there any immediate red-flags easy to spot? – Quality

How do project developers interact with marketplaces? What is the process that a project developer goes through?

Project Development and general topics

What difficulties arise from being a project developer? What is the hardest thing to deal with?

Marketplaces usually provide a platform that allows project developers to connect with capital providers, in percentage what's the cost of developing a project?

Do you have any expertise in credit prices from working in the industry? If so, do you know on average how much credit should be sold for any given scope if a project wants to make a profit?

Marketplaces (personal view)

What is the key factor in a good voluntary carbon marketplace?

What is missing from existing marketplaces?

In your thought, do you think a blockchain solution could better the VCM?

Should a marketplace have a direct impact on the quality verification of carbon credits?

In your view, what is the biggest problem with VCM at the moment and how can it be fixed?

Appendix 14: Interviews Content Analysis

Quality	"Verra has been a standard setter for a long time it's one of the oldest in the market and it's still in a error and learn method
Clear_Market_Processes	"Our work follows the project documentation and then we have close to no contact with project developers"
Legislation_blocks	"There's Local, problems as people trying to take illegally ownership of fields"
Costs_&_Price_information	"There are four phases of a project that require a monetary incentive to start, project design, implementation, certification, and verification, where undoability the more costly side is the implementation"
Breakeven_point	"Project vary a lot based on region and type there's no clear point"
Key_market_factors	"In 2021 from 10 credist issued 7 were from Verra","Vera is actively reaching out to governments that are regularizing the VCM"
Validation_&_Verification	"The company interacts more with the vvb's to transparency

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Blockchain_Solution	"In 10 to 15 years there will be a unification of registries
Key_market_problems	"3 to 10 years to get the carbon credits", "Lack of a marketplace"

Appendix 15: CDR Policy Tracker Encoded

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Variable	Encoded Values	Defenition
Target Type	1=Emissions reduction target, 2=Carbon neutral(ity), 3=Climate Neutral, 4=Net zero, 5= Net Negative	Specifies which climate action target a country has set for itself. **Net negative:** A country is considered to be net negative when it removes more greenhouse gases from the atmosphere than it emits. This can be achieved through various means, such as afforestation, reforestation, and the deployment of carbon capture and storage technologies. **Net zero:** Net zero refers to the state in which a country's greenhouse gas emissions are balanced by an equivalent amount of emissions removed from the atmosphere or offset through various mechanisms. The goal is to achieve a balance between emissions produced and emissions removed, resulting in no net increase in overall greenhouse gas concentrations **Climate neutral:** Climate neutrality, or being climate neutral, is a state in which the total greenhouse gas emissions produced by a country are offset by the same amount of emissions removed or reduced. This can involve a combination of reducing emissions, investing in renewable energy, and utilizing carbon offset projects. **Carbon neutral(ity):** Carbon neutrality means that the net amount of carbon dioxide (CO2) emissions released into the atmosphere by a country is equal to the amount of CO2 absorbed or offset. Achieving carbon neutrality often involves a combination of reducing emissions, investing in renewable energy, and purchasing carbon credits. **Emission reduction target:** An emission reduction target is a specific and quantifiable goal set by a country to decrease its greenhouse gas emissions over a specified period. These targets are often expressed as a percentage reduction from a baseline year and are a key component of a country's climate action plan to mitigate the impacts of climate change.
Separate Target for Emission Reduction and Removals	0=No & NaN (missing value), 1=Yes	Some entities differentiate their emission reductions targets from their removals targets. Separate targets for emission reductions and removals improves transparency, making it easier to track progress and compare the level of target ambition. The achievement of the Paris Agreement temperature goals requires both rapid emission reductions and the removal of residual emissions. Separating emissions reduction and removal targets recognises that the outcomes of removal activities are generally not equivalent to the outcome of emission reduction activities.
GHG Emissions	5=[111000001; +], 4=[58000001;111000000], 3=[250000001;58000000], 2=[11000001;25000000.], 1 = [0 ,11000000]	A country's total GHG emissions
Target Status	1=Proposed / in discussion, 2=Declaration / pledge, 3=In policy document, 4=In law, 5= Achieved(self-declared), 6= Achieved (externaly validated)	**Achieved (externally validated):** Net zero has been externally verified by an independent third party. e.g. the Science Based Targets initiative; **Achieved (self-declared):** Net zero has been declared unilaterally by the entity but not verified externally; **In law:** The target has legal force, for example is enshrined in legislation or in an administrative order; **In policy document:** The target is included in a policy or planning document. For countries, for example, this could include policy strategy documents published by ministries, as well as Nationally Determined Contributions (NDCs) and/or Long-term Strategies (LTSs) that have been submitted to the UNFCCC; **Declaration / pledge:** The entity has announced a target but not yet institutionalised that pledge in any way (e.g. merely referenced in a press release, verbal announcement by Head of Government, etc.); **Proposed / in discussion:** The entity's leadership is considering a target or has joined an international initiative (e.g. the Climate Neutrality Coalition or Climate Ambition Alliance) pledging to set a net zero target, but it has not yet taken steps to operationalise this pledge.
Target Year	5=[2030;2034], 4=[2035;2039], 3=[2040;2044], 2=[2045;2049], 1=[2050, +]	Year does the country plan to reach net zero GHG emissions
Type of Interim Target	0=NaN (missing value) ,1=No target, 2=Reduction v. BAU', 3=Emissions intensity targets , 4=Absolute emissions targets, 5=Emissions reduction target	Interim targets can come in many different varieties using many different baselines, some of which are more transparent and robust than others. In general, '**emissions reduction targets**' and '**absolute emissions targets**' are more robust than other types of targets. **Emissions reduction targets** aim to decrease annual greenhouse gas (GHG) emissions by a target year compared with a historical baseline year, for example 'X will reduce its GHG emissions by 50% below 1990 levels by 2030. ' **Absolute emissions targets** specify an amount of emissions to aim for by a certain year or time period, regardless of what it currently is. e.g. 'X will reduce emissions to no more than 10m tonnes of CO2e in 2025.' Some entities may set an absolute emissions target over a period of e.g. 5 to 10 years. **Emissions intensity targets** set an emissions target relative to a non-emissions unit such as per unit of output or per unit of GDP, for example 'X will reduce the amount of CO2 emissions produced per unit of GDP by 18% over the period 2021 to 2025. ' **Reduction against Business as Usual (BAU)** specifies a reduction compared with a baseline of what emissions were projected to have been at a certain date, for example 'X will reduce emissions 29% below business-as-usual by 2030.'
GHGs Covered	0=Not Specified, 1=Carbon dioxide (CO2) only, 2=Carbon dioxide and other GHGs	Greenhouse gas coverage specifies the scope of gases affected by the target. **Carbon dioxide (CO2) and other GHGs:** Net zero has been externally verified by an independent third party. e.g. the Science Based Targets initiative **Carbon dioxide (CO2) only:** The target only covers the entity's carbon dioxide (CO2) emissions.
Comprehensive CDR Target	0=na & No, 1=Yes	Comprehensive Carbon Dioxide Removal (CDR) Target indicates whether a country has set a goal that encompasses a wide range of carbon removal strategies and technologies. CDR involves the removal of carbon dioxide from the atmosphere, and a comprehensive target may include both conventional and novel removal methods.
CDR Target for Conventional Removals	0=na & No, 1=Yes	Carbon Dioxide Removal (CDR) Target for Conventional Removals specifies whether a country has established a goal specifically focused on traditional or well-established methods of carbon removal. Conventional removal methods often include approaches such as afforestation, reforestation, and carbon capture and storage (CCS).
CDR Target for Novel Removals	0=na & No, 1=Yes	Carbon Dioxide Removal (CDR) Target for Novel Removals indicates whether a country has set a goal that includes innovative or emerging methods of carbon removal. Novel removals may involve cutting-edge technologies or approaches that go beyond traditional methods, and they could include advancements in direct air capture, ocean-based solutions, or other innovative carbon removal technologies.
Historical Emissions	0=na & No, 1=Yes	Does the target include historical emissions emitted by the entity?
Annual Reporting Mechanism	3=Annual reporting, 2=Less than annual reporting, 1=No reporting mechanism	Does the country have an annual reporting mechanism for its climate change mitigation efforts? **Annual reporting:** annual reporting" means that the country provides regular and systematic updates on its progress in implementing and achieving its climate change mitigation targets and actions. This reporting typically occurs on a yearly basis. **Less than annual reporting: T**he country provides updates on its progress in implementing and achieving climate change mitigation targets at intervals that are longer than one year but are still systematic and regular. **No reporting mechanism:** There is no established and systematic process for the country to regularly communicate or report on the progress of its actions and initiatives aimed at mitigating climate change.
Plans for CDR	4=Yes (nature-based and CCS-based removals), 3=Yes (nature-based removals e.g. Forestation, soil carbon enhancement), 2=Yes (unspecified), 1=Not Specified, 0=No	Has a country specified whether it wants to deploy CDR? **Yes (nature-based and CCS-based removals):** This indicates that the country has explicitly stated its intention to deploy a combination of nature-based solutions (such as afforestation and soil carbon enhancement) and technology-based solutions like Carbon Capture and Storage (CCS) for carbon removal. The country has a well-defined and comprehensive strategy that includes both natural and technological approaches to CDR. **Yes (nature-based removals e.g. Forestation, soil carbon enhancement):** In this case, the country has specified its commitment to nature-based CDR methods, emphasizing activities like afforestation and soil carbon enhancement. While it may not explicitly mention CCS, the country is clear about its reliance on natural processes for carbon removal. **Yes (unspecified):** A score of 2 suggests that the country has expressed a willingness to deploy CDR measures, but the details are not explicitly outlined. The plans might be in the early stages, and the specific approaches, whether nature-based or technology-driven, are yet to be determined or disclosed. **Not Specified:** A country receiving a score of 1 implies that there is no clear information available regarding its stance on CDR deployment. The country may not have communicated its plans or intentions related to carbon removal strategies. **No:** This indicates that the country has explicitly stated it does not have plans to deploy any form of CDR. The focus is on other climate change mitigation strategies, and carbon removal is not part of the current agenda.
Planning to Use External Carbon Credits	1= Yes, 0=Not Specified & No	Does the target allow for traded credits from outside the actor's territory / value chain to meet the target?
Support for R&D and Innovation	1 = Yes, 0=Nan	Does the country have policies or financial incentives in play for R&D and innovation in this carbon credit sector
Public Consultations and Upcoming policies	1 = Yes, 0 = Nan	Is the country introducing and debating policies regarding this theme

Chainalysis Variables Definition

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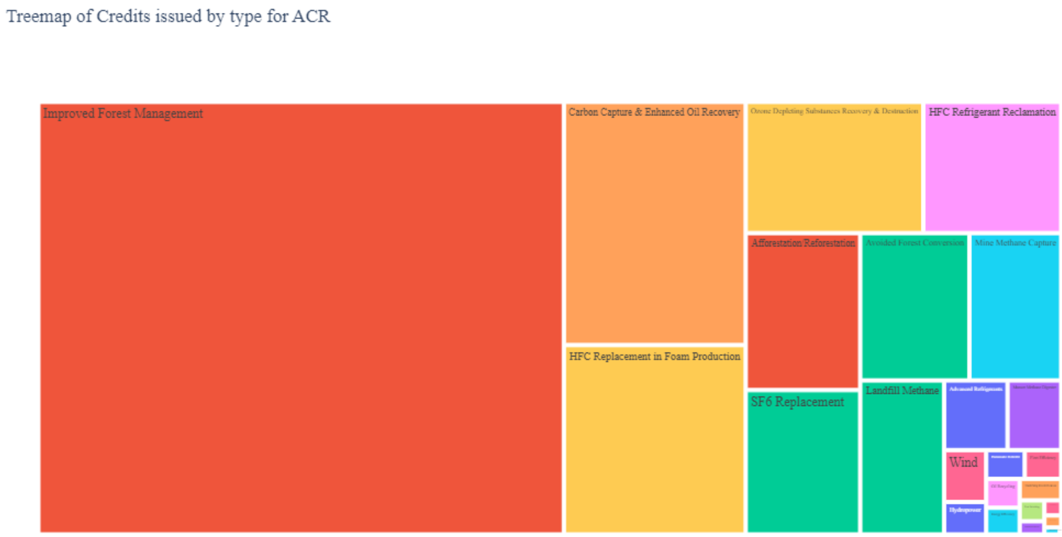
Variable	Values	Defenition
Centralized Service Value Received Ranking	[1 ; 40]	This index ranks each country by total cryptocurrency activity occurring on centralized services. The rankings are then weighted to favor countries where that amount is more significant based on the wealth of the average person and the value of money generally within the country.
Retail Centralized Service Value Received Rank	[1 ; 40]	This metric focuses on measuring the involvement of individual cryptocurrency users at centralized services, particularly non-professionals, by assessing their transactions in retail-sized amounts (under $10,000 worth of cryptocurrency). The rankings are influenced by the country's PPP per capita, favoring those with lower PPP per capita figures.
P2P Exchange Trade Volume Ranking	[1 ; 40]	Peer-to-peer (P2P) exchange activity plays a significant role in emerging cryptocurrency markets. This sub-index ranks countries based on their P2P trade volume and gives preference to countries with lower PPP per capita and fewer internet users.
DeFi Value Received Ranking	[1 ; 40]	This index ranks each country by total DeFi (Decentralized Finance) activity, but weights the rankings to favor countries where that amount is more significant based on the wealth of the average person and value of money generally within the country. The higher the ratio of on-chain value received to PPP per capita, the higher the ranking.
Retail DeFi Value Received Ranking	[1 ; 40]	This index measures the DeFi activity of non-professional, individual cryptocurrency users, based on how much cryptocurrency they've sent to DeFi protocols in retail-sized transactions, meaning under $10,000 USD, compared to the wealth of the average person.

Appendix 16: Comparative Tree Map



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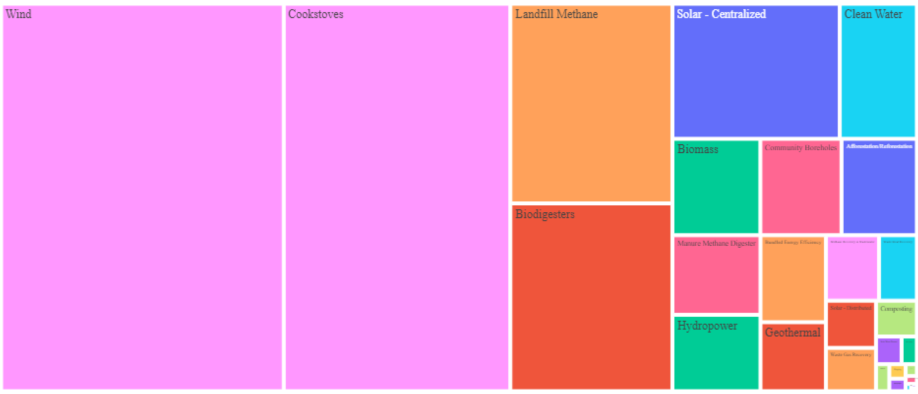
Treemap of Credits issued by type for CAR

Treemap of Credits issued by type for GOLD



Source: Berkeley Dataset