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The dynamics of voluntary carbon markets:
An empirical analysis of the carbon credits lifecycle

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February 2025

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Executive summary

Global Voluntary Carbon Markets can become an important tool in the pursuit of climate related goals. Not only do they help firms to meet their carbon targets, but they also create a channel for funding that will encourage entrepreneurs to invent or scale up carbon removal and carbon limitation solutions. However, they currently face various challenges including a lack of transparency and significant market inefficiencies. Moreover, issues around the integrity of the market have stimulated the view that offsetting is an illegitimate approach that delays transition. A step to address some of these issues was taken at the COP29 meeting, where governments agreed UN standards for international carbon markets.

Understanding the speed at which carbon credits are generated, issued and consumed is important because it provides information about the effectiveness of the market in transferring funds from the buyer of credits to the project developer, about the balance between demand and supply, and about the behaviour of end-users (those who buy the credits for offsetting their carbon emissions). The aim of this study is to analyse these dynamics. We use a dataset of carbon offset projects with vintage years from 1996 until 31 December 2024 across the four major voluntary registries, covering around 94% of the total market. Only projects that have issued credits are considered, resulting in a sample of 5,138 projects.

Key findings include:

As of the end of 2024, around 2.40 billion carbon credits have been issued, of which around 56% have been retired. Although carbon projects have been developed in 143 countries, a majority (73.73%) of the projects that have issued credits are developed in emerging and developing countries, collectively generating 75.13% of the total carbon credits. *Forestry and Land Use* and *Renewable Energy* are the categories with the largest amounts of credits issued and retired. Issuance and retirement also vary by registry, with Verra showing the largest share of issuance (57%) and of retirements (58%), while Climate Action Reserve (CAR) has the highest ratio of credits retired vs credits issued (76%). Finally, projects aimed at the reduction of emissions generate most of the credits (82%), followed by those using a mixed (reduction/removal) approach (14%).

Since 2021 the supply of credits has decreased, and demand remains sluggish. From 2017 to 2021 credit issuance grew rapidly, reaching a peak of around 300 million tCO_2 in 2021. After that, issuance has declined, even if the number of projects has grown (driven largely by the grow in *Household and Community* projects). This decline is driven by a decrease in the supply of large-scale *Renewable Energy* projects and a decline in *Forestry and Land Use* projects, which coincides with media reports about the credibility of credits related to forestry. On the other hand, retirement has only increased slowly, contributing to the imbalance between supply and demand, with not enough end-users coming to the market. The withdrawal of end-users could be driven by different factors, including concerns about the quality of the credits or the lack of transparent pricing in spot markets.

It tends to take a long time to issue credits. On average, it takes 2.45 years to issue credits after the carbon removal took place; and for 50% of the projects it took at least 1.93 years, with a maximum observed of 20.81 years. This suggests lengthy monitoring-verification cycles, which means higher costs for issuers and impedes the timely flow of funds. The efficiency of credit issuance is also influenced by the project's category, with *Chemical Processes* offering the fastest issuance on average (1.15 years) and *Transportation* the slowest (4.81 years); and by its registry, with Climate Action Reserve providing the fastest time to issue (1.25 years) and Verra the longest (3.23 years).

The time to issuance has increased through the years, which suggests processes struggling to scaling up. From 2010 to 2024 the issuance lag has increased from 1.91 to 2.28 years, with a peak of 4.36 in 2021. Moreover, we found a positive and significant correlation between issuance lag and the number of new projects, which supports the notion that validation and issuance processes may already be struggling with scaling up.

The average age of the credits at retirement is of 4.43 years, but it varies across project categories and registries. The time between the retirement of credits and the time when the carbon removal took place is an indicator of end-user preferences between newer or older credits. The retirement age varies across project categories, from 3.07 years (*Household and Community* projects) up to 8.99 years (*Transport*). Projects registered trough Verra exhibit the highest retirement age on average (5.60 years) while those with Gold Standard offer the lowest (3.23 years).

The trend in investor purchasing behaviour between older and newer credits changed after 2021. Overall, the retirement age has increased, from 2.26 years in 2010 to 5.17 years in 2024. This is partially a consequence of the fact that end-users have more choice of vintage years as credits accumulate over time. It is also a consequence of the increase in the issuance lag. Moreover, the retirement age is also driven by investors' preferences. While the increase in retirement age observed from 2015 to 2021 shows end-users increasingly buying older credits on average during the period, the results also show a preference for credits closer to their issuance date, a trend that changed after 2021.

Retirements from smaller end-users has been increasing. Almost 54% of retirements are of sizes smaller than 10 tCO_2e, with a mean of 2,730 tCO_2e, suggesting a substantial participation from medium and small firms (or even individuals). We also observe a shift in the type of end-users: while in 2010 the top ten credit purchasers collectively retired over 89% of credits, this proportion has been declining over time, reaching 60.49% in 2024 (with a minimum value of 46.69% in 2022), which indicates smaller end-users are increasingly participating more in the market.

Bringing VCMs to the high standards of automatization, efficiency and transparency that characterise the regulated markets is key for VCMs development. Traditional exchanges can, and already do, play a central role in the carbon ecosystem, offering standardization solutions; supporting fair and transparent trading and providing infrastructures that enable price formation; and offer efficiency, robustness, and scaling-up capacity.

Spot Voluntary Carbon Markets, unlike futures, are largely unregulated. As they grow, this will probably change. However, it is important to note that, while high standards consistent with IOSCO principles should apply to the operation of markets, the exact form of VCM should not be subject to prescriptive rules. Rather, it is better that markets develop in line with user requirements, which may legitimately vary over time and across or within jurisdictions, depending on factors such as legal regime, mix of participants and types of carbon projects.

1. Introduction

Global voluntary carbon markets (VCMs) have the potential to help mitigate climate change by facilitating efforts to reduce greenhouse gases. In these markets, companies can voluntarily choose to purchase **carbon credits** to offset their carbon emissions. These credits (or 'carbon offsets') are generated by projects that either reduce the emission of **carbon-dioxide (CO2)** into the atmosphere (such as transitioning to renewable energy) or remove CO2 out of the atmosphere (for example, by reforestation or investing in technology that filters CO2 out of the atmosphere).[1] VCMs not only help firms to meet their carbon targets, but they create a channel for funding that will encourage entrepreneurs to invent or scale up carbon removal and carbon limitation solutions.

Since they were initially introduced in the 1990s, VCMs have grown significantly, reaching a peak value of USD 2.1 billion in 2021 (Forest Trends' Ecosystem Marketplace, 2024). Although in the last years they have declined, with MSCI estimates showing a value of only 1.4 billion in 2024, they are still expected to reach between USD 7 and USD 35 billion by 2030 and, up to USD 250 billion by 2050.[2]

But to achieve this change in scale and meet their objectives, VCMs need to overcome significant challenges. First, there is the question of credit quality and integrity. One element that has eroded confidence in VCMs is that they have often failed to deliver the carbon removals they promise.[3] Moreover, there is a risk that they are used as a substitute for the direct reduction of emissions, which has led to concerns that offsetting is an illegitimate approach that delays transition. In July 2024, more than 80 environmental NGOs published a joint statement saying carbon offsets undermine climate action and should be excluded from voluntary and regulatory frameworks on climate transition planning.[4] And in a draft policy document, the UN task force on global carbon markets stated that firms should not use carbon credits to offset emissions outside of state-regulated schemes.[5]

An important step to address some of these issues was taken in November 2024 at the COP29 meeting, where nearly 200 nations agreed strong basic standards for a UN-backed international carbon market. There was also agreement on the final building blocks that set out how carbon markets will operate under the Paris Agreement, making country-to-country trading and a carbon crediting mechanism fully operational, providing clarity on how countries will authorize the trade of carbon credits and how registries tracking this will operate. Environmental integrity is expected to be ensured up front through technical reviews in a transparent process.[6] However, technical work implementing these decisions remains and there was also a view that the agreements were not strong enough.[7]

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[1] But companies should prioritize reducing their own emissions and not rely on buying carbon credits to save the climate, according to the US Treasury Secretary, "Janet Yellen warns companies not to rely on carbon credits to save the climate," Financial Times, May 28, 2024.

[2] See *Frozen Carbon Credit Market May Thaw as 2030 Gets Closer*, MSCI Blog post,6 January 2025.

[3] For a recent case see: Carbon credits from cookstove emissions largely worthless, study finds, Financial Times, January 23, 2024. See also: https://www.cam.ac.uk/stories/carbon-credits-hot-air

[4] Market for carbon credits faces fresh blow as offsets slammed, Alastair Marsh, Bloomberg, 2 July 2024. The full statement can be found at: https://newclimate.org/sites/default/files/2024-07/Joint-CSO-Statement-Offsetting.pdf

[5] UN attacks companies' reliance on carbon credits to hit climate targets, Kenza Brian, Financial Times, July 23, 2024

[6] See https://unfccc.int/news/cop29-un-climate-conference-agrees-to-triple-finance-to-developing-countries-protecting-lives-and

[7] See, for example, CarbonMarketWatch perspective: Countries face no real repercussions if they fail to abide by the rules

From a market design perspective, participants also encounter different hurdles. According to an industry-wide survey by Nasdaq which included project developers, brokers, custodians, financial investors, market operators and corporate end-users, the challenges in issuance, verification, trading, reporting and retirement processes are preventing 18% of all survey respondents from entering the market, while 56% of corporates would like to double their activity if only the market were to become more efficient (Nasdaq, 2023).

One part of the problem is that carbon credits are mostly traded on over the counter (OTC) markets, where participants engage on a bilateral basis. According to IOSCO, the predominance of OTC trading can be explained by different factors, including the relatively small size of the market and the lack of standardization in the credits (IOSCO, 2023). The lack of transparency and the fragmentation of the OTC market leads to information asymmetries, which in turn translate into high search costs, poor liquidity, and market inefficiencies.

The lack of automation and standardisation of processes is another problem. According to Nasdaq's survey, 94% of the processes in the credit trade cycle are managed manually and participants face serious issues in their carbon activities because of problems in project verification (40%), in settlement (38%), in project listing (37%), and in retirement/management (13%). In the case of listing, one key issue is the time taken to issue credits, with 57% of project owners seeing their businesses severely limited by the fact that new credit listings can take months to be onboarded (Nasdaq, 2023). In another survey of 80 corporations worldwide conducted by SIX Group, 46% of respondents identified the lack of standardization as a major concern in the voluntary carbon market, while 55% emphasized the need for greater transparency in the market (SIX, 2023).

VCMs can constitute a useful element for the green transition, but for that to happen it is essential to improve the functioning of these markets, increasing their transparency and integrity. While OTC markets are suitable for some buyers, centralized trading platforms, characteristic of regulated exchanges, are key to making carbon credits accessible to a broader pool of market participants, deepening the liquidity in the market, adding transparency and price efficiency, and improving market quality.[8] This is one of the reasons why regulated exchanges can play a significant role in the development of VCMs, increasing standardization and fungibility and providing an infrastructure that stimulates efficient price formation and offers high levels of transparency. They can help especially with price signalling, by bringing together different types of participants, including hedgers and market makers. The 'price dialogue' that results from this interaction is the tried and trusted way to create good quality data that is of value to participants and can inform the pricing of newly issued credits.

Against this background, the aim of this study is to provide an empirical analysis of the dynamics of issuance and retirement of carbon credits and to measure the efficacy of these processes. For this purpose, we consider three metrics: the ***issuance lag,*** which measures how quickly funds are being transferred from the buyer of credits to the project developer; the ***retirement age,*** which is a measure of the age of credits at retirement and is an indicator of the preference of end-users (that is, those who buy the credits for offsetting their carbon emissions) between recent or older credits; and the ***trading life,*** which is an indicator of the time between issuance and retirement.

[8] For the importance of limit order books for enhancing liquidity and transparency, one can refer to the case of bond markets. See, for example, (Benos & Gurrola-Perez, 2022).

For this analysis, we will use data from the **Voluntary Registry Offsets Database** (VROD) developed by Berkeley Carbon Trading Project.[9] The database contains data of all carbon offset projects listed by the four major independent voluntary offset project registries—American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verra (VCS).

The rest of the paper is organized as follows: Section 2 presents an overview of carbon markets (compliance and voluntary). In Section 3 we describe the dataset and examine the statistics of issuance and retirement across regions and categories, and through time. In Section 4 we analyse the issuance lag and retirement rate across projects. In Section 5 we conclude.

2. Carbon markets

Carbon markets have their origin in the 1997 *Kyoto Protocol to the United Nations Framework Convention on Climate Change,* which came into force in 2005.[10] The primary goal of the Kyoto Protocol was to limit and reduce **greenhouse gases (GHG)** emissions[11] in accordance to agreed individual country targets. These targets were binding.

In this context, carbon markets are a fundamental tool for governments and firms to achieve their climate change mitigation objectives. Their aim to reduce GHG emissions is based on setting a price on them, so that there is a cost for emitting GHG into the atmosphere, and by allowing to offset emissions against carbon dioxide reducing projects. The basic unit is **one (metric) ton of carbon dioxide (tCO2)**, or the equivalent amount of other greenhouse gases (**a ton of carbon dioxide equivalent, tCO2e**).[12]

An essential aspect of the Kyoto Protocol was the introduction of the **Clean Development Mechanism (CDM),** defined in Art. 12**,** which allows industrialized countries with emission reduction commitments to invest in emission reduction projects in developing countries. The projects generate saleable **certified emission reduction credits (CERs)**, each equivalent to a ton of CO2, which can be used to offset the emissions of CO2.[13]

The development of carbon markets was further promoted by the 2015 **Paris Agreement**, a legally binding international treaty on climate change which came into force in 2016. The agreement aims to limit the increase in the global average temperature to well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels.[14] Under the Paris Agreement, each participating country reports its national climate action plans to reduce their greenhouse gas emissions and to meet the goals of the Paris Agreement, together with their actions to adapt to the impact of climate change. These action plans are known as the national determined contributions (NDCs). Article 6 of the Paris Agreement allows countries to voluntarily cooperate with

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[9] Voluntary Registry Offset Database v10, https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/offsets-database
[10] https://digitallibrary.un.org/record/250111?ln=en&v=pdf
[11] Greenhouse gases comprise (in addition to carbon dioxide) methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons.
[12] One tCO2 can be visualized as the amount of gas fitting in a 9 meter per-side cube. On average, a car emits one tCO2 for about every 2,500 miles (see https://climate.mit.edu/ask-mit/how-much-ton-carbon-dioxide).
[13] See https://unfccc.int
[14] See https://unfccc.int/process-and-meetings/the-paris-agreement

each other, using market-based or non-market based cooperative approaches, to achieve emission reduction targets set out in their NDCs.

There are three tools which countries can draw upon under Article 6, one of which is the Paris Agreement Crediting Mechanism (PACM); under this mechanism, a company in one country can reduce emissions in that country and have those reductions credited, so that it can sell them to another company in another country. That second company may use them for complying with its own emission reduction obligations or to help it meet net-zero targets. In November 2024, at COP29, countries agreed standards for the centralised carbon market under the PACM.

In the next sections we describe the two main types of carbon markets: compliance and voluntary.

2.1 Compliance carbon markets (CCMs)

Compliance Carbon Markets (CCMs), also known as **Emission Trading Systems (ETS)**, were established in 2005, following the Kyoto Protocol, and are the main emissions trading mechanism under UN's framework. They were established to help participants fulfil mandatory targets set by government and are regulated by mandatory national, regional, or international carbon reduction regimes.[15] The trading instrument is a **carbon allowance,** which is a government-issued permit that gives the holder the right to emit one ton of carbon dioxide or equivalent (tCO2e). To ensure that allowances are properly accounted for, many jurisdictions have set out ETS registries that track ownership, transfer and retirement of allowances.

In 2023, the world CCMs reached a value of USD 949 billion, of which the EU ETS markets had the largest share, with around USD 829 billion, that is, 87%.[16] As of April 1, 2024, the 36 ETSs in operation across the world covered almost 9.9 billion tCO2e, representing over 18% of global GHG emissions (ICAP, 2024).

Participants can use secondary markets to sell or buy spot allowances and may also use derivatives to manage risks linked to allowances.

The trading of carbon allowances can be done on-exchange or OTC. In the EU, trading takes place on three venues: the **European Energy Exchange (EEX),** which is part of **Deutsche Börse Group**, **ICE Endex**, and **Nasdaq Oslo**. In the US, several exchanges, including **ICE Futures**, **CME**, and **Nodal Exchange** (which is part of EEX Group), offer futures and options contracts on carbon allowances. In addition, securities exchanges like **Nasdaq**, list and trade exchange-traded funds (ETFs) with exposure to carbon allowances or offsets.[17] In the UK, **ICE Futures Europe** offers trading in UK emission allowances (UKA) futures. In other markets, like the Chinese, the ETS market is mostly OTC (IOSCO, 2022).

2.2 Global voluntary carbon markets (VCMs)

In contrast with compliance carbon markets, global voluntary carbon markets (VCMs) function on a voluntary basis and are largely unregulated. Companies and individuals can voluntarily choose to purchase carbon credits to offset their carbon emissions and support a claim about their carbon reduction efforts, rather than to meet an obligation (although some compliance markets accept

[15] Mandatory & Voluntary Offset Markets - Carbon Offset Guide
[16] Global Carbon markets value hit record USD 949 billion last year -LSEG, Susanna Twidale, *Reuters*, February 12, 2024.
[17] See, for example, https://www.nasdaq.com/articles/3-etfs-for-accessing-carbon-markets

voluntary credits to meet obligatory requirements). Carbon credits are generated by projects that either avoid or remove greenhouse gas emissions. Each **carbon credit** (or **carbon offset**) is a tradable financial instrument representing a ton of CO2 emissions, or its equivalent, being reduced or removed from the atmosphere.

Voluntary carbon markets originated in the 1990s and were developed by non-governmental participants seeking a way to certify GHG emission reductions and removals outside of the UN compliance scheme (IOSCO, 2023). In 2024, the VCMs reached an annual value of USD 1.4 billion (after reaching a peak of USD 2.1 billion in 2021),[18] and they are expected to reach between USD 7 and 35 billion by 2030.[19] The expected growth could be driven by various demand factors, including the implementation of mandatory reporting under the CORSIA program (in 2027), the expected convergence of compliance and voluntary markets under Article 6 of the Paris Agreement, and the growing need for carbon removal in financial institutions' portfolios and lending books (Nasdaq, 2023).

In addition to the independent voluntary offset programs, some offset programs are incorporated into governmental emission trading systems as a compliance tool. Because demand for compliance offset credits is driven by regulatory obligations, compliance offset prices tend to be higher than in the voluntary market.[20] Governmental carbon offset programs include the California Compliance Offset Program, Regional Greenhouse Gas Initiative (RGGI), the Alberta Emission Offset Program (AEOP), the J-Credit scheme in Japan, or the Thai Voluntary Emission Reduction (T-VER) in Thailand.[21]

Primary markets

Carbon credits are generated by carbon projects that contribute to control the GHG in the atmosphere. Depending on their approach, projects can be categorized into three types: **Reduction** (or **avoidance**) refers to projects that aim to prevent or reduce the release of greenhouse gas emissions into the atmosphere, (e.g., transitioning to renewable energy, building improved cookstoves to replace or minimize the use of firewood for cooking). **Removal** refers to projects that apply natural resources or technologies to sequester carbon or to remove it from the atmosphere. They include reforestation projects, biochar production, and technologies that filter CO2 out of the atmosphere. **Mixed projects** are those that involve both emissions reductions and carbon removals. The approach used also affects the price of the credits; credits tied to projects that remove and store carbon, for example, attract a price premium, for their permanence and lower risks (Nasdaq, 2023). The GHG reduction/removal is estimated by calculating the difference between emissions from a baseline scenario with emissions under the project scenario.

Projects can fall within different **categories** or **scopes**. For example, the Voluntary Registry Offsets Database classifies projects under nine major categories: *Agriculture*, *Carbon Capture & Storage*, *Chemical Processes*, *Forestry & Land Use*, *Household & Community*, *Industrial & Commercial*, *Renewable Energy*, *Transportation*, and *Waste Management*.[22] Each of these major categories is in turn subdivided in subcategories. For example, *Carbon Capture and Storage* includes three

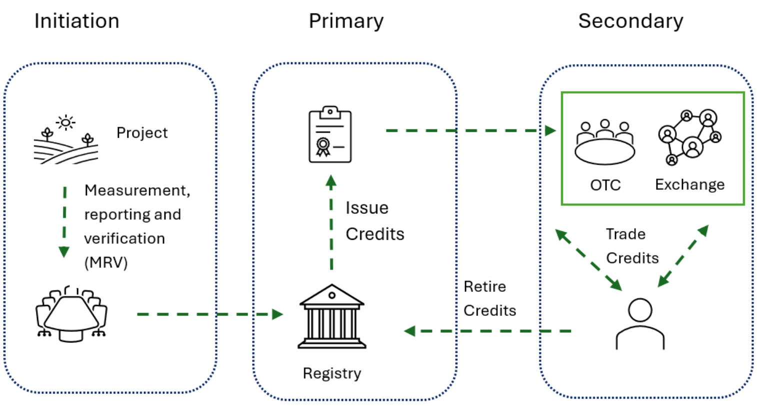
[18] Forest Trends' Ecosystems Marketplace Report 2024. State of the Voluntary Carbon Markets 2024. Washington DC. It is worth noting that 2022 also saw higher value (USD 1.98 bn) and volume (254 mtCO2).
[19] See *Frozen Carbon Credit Market May Thaw as 2030 Gets Closer*, MSCI Blog post,6 January 2025.
[20] Mandatory & Voluntary Offset Markets - Carbon Offset Guide
[21] Comparisons of Offset Programs - Carbon Offset Guide. The World Bank lists at least 43 of these governmental mechanisms; see Carbon Pricing Dashboard
[22] VROD-ScopesTypes-v8.pdf (berkeley.edu)

subcategories: *Carbon Capture & Enhanced Oil Recovery*, *Carbon Capture in Concrete*, and *Carbon Capture in Plastic*.[23]

Figure 1 illustrates in general terms the lifecycle of carbon credits from issuance to retirement. The initial step involves the launch of a climate mitigation project by the **developer**, which is the entity that plans, designs, and creates the project and lists it in an independent **registry**.[24] Registries establish their specific standards and assess projects for compliance with these standards.[25] A **validation and verification body (VVB)** is required to assess the project. Once the registry is satisfied with the validation of the project's design it will certify the project and approve a **crediting period** (the period where credits can be issued). The next step consists of the **measurement, reporting, and verification (MRV)** of the project's GHG reduction. This is the process of quantifying the greenhouse gas emissions that the project has reduced over a specified period against a baseline scenario and presenting these results to the VVB for verification. The registry will then review the monitoring report and, if satisfied, will issue credits accordingly.

Once credits have been issued, participants can choose to either buy and sell the credits for a profit, (in a secondary market, see next section), or to buy and retire the credits. **Retiring** a carbon credit means the holder of the credit claims the offset of carbon credits against its own carbon emissions. Once the credit is retired, the registry removes it from circulation so that it can no longer be traded in the market. Retirements are recorded in the registry to ensure transparency and to prevent double counting. In addition to tracking all credits that have been issued and retired, registries are also responsible for transferring tradable credits, and tracing transactions between buyers and sellers.

Figure 1 Illustration of Voluntary Carbon Markets



Source: The WFE

[23] There is no universal categorisation. In (Forest Trends' Ecosystem Marketplace, 2024), for example, there are only eight categories.
[24] Although there may be cases where the owner of the project is not the entity registering it. For example, in the case of a cooperative, the developer can register a project which is the aggregation of individual projects.
[25] A standard usually incorporates a variety of methodologies, which are specific rules for a particular type of credit or project.

The first registry, the **American Carbon Registry (ACR)**, was founded in 1996.[26] **Gold Standard,** based in Switzerland, was founded in 2003. [27] **Verra,** with headquarters in Washington, D.C., was established in 2007, and it manages the Verified Carbon Standard (VCS) program.[28] Established also in 2007, the **Climate Action Reserve (CAR)** is based in the United States, with projects primarily implemented within North America.[29]

Table 1 Voluntary carbon markets by registry

	Projects	Issued		Retired
		(millions)	*(share)*	*(millions)*
Verra - Verified Carbon Standard (VCS)	4,484	1,371	57%	787
Gold Standard	3,591	384	16%	193
Climate Action Reserve (CAR)	1,015	204	9%	156
American Carbon Registry (ACR)	831	287	12%	166
Others*	1,381	152	6%	49
Total	11,302	2,398		1,351

**Others include Global Carbon Council, Plan Vivo, Puro Earth, Cercarbono, and Social Carbon.*
Sources: Verra, Gold Standard, Climate Action Reserve and American Carbon Registry data were obtained from the Voluntary Registry Offsets Database. Data of Others are from AlliedOffsets. Sums may not coincide due to rounding. Data as of December 2024.

As of December 2024, Verra and Gold Standard were the two major global registries, issuing around 57% and 16% of carbon credits respectively, while the market share of carbon credit issuance for CAR and ACR is around 9% and 12% respectively (Table 1).[30]

While market participants must satisfy themselves as to the credentials of verification agencies, taking into account their track record and methodology, it is worth noting the existence of two similarly named bodies that set global standards relating to carbon markets: the **Integrity Council for Voluntary Carbon Markets (ICVCM)** and the **Voluntary Carbon Markets Integrity Initiative (VCMI)**.

Additional terminology related to carbon credits includes the **vintage year**, which is the year when the CO2 emission reduction or removal took place (or is estimated to take place in the future). Each project may have several vintage years, reflecting the long duration of emission reduction efforts. The **issuance date**, which is usually different from the vintage year, refers to the date on which the carbon credit is officially issued and becomes available for trading (see Figure 2). The issuance date is typically later than the vintage year. In fact, it could be years later, largely because of the administrative processes involved in validating and certifying the carbon projects (Si, Marbough, Moore, & Stern, 2021).[31]

Co-benefit refers to the additional benefits the carbon projects bring to society beyond the primary function of carbon emission reduction. These benefits may include job creation, biodiversity protection, or public-health improvement.

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[26] See https://acrcarbon.org/
[27] Vision + Impacts | The Gold Standard
[28] 2022 Verra Annual Report, 2022-Verra-Annual-Report.pdf
[29] Climate Action Reserve Annual Report 2023.
[30] Other registries include Plan Vivo (0.5% of market share of credit issuance) and Global Carbon Council (0.1% of market share).
[31] Credit standards may also allow projects to gradually issue credits to satisfy buffer requirements that account for the risk of reversal of the carbon removal (Forest Trends' Ecosystem Marketplace, 2024).

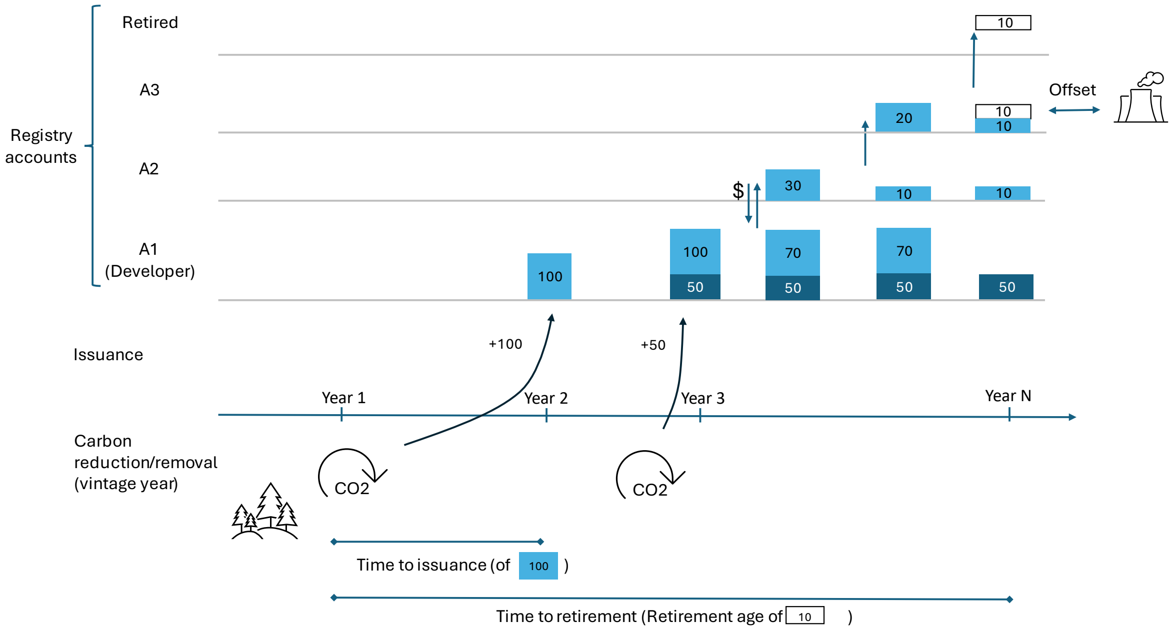
Secondary markets

Once credits are issued, they can be purchased, sold or traded on secondary markets. The demand of carbon credits is mainly driven by the net-zero targets as they offer purchasers the possibility of offsetting them against their current residual emissions. (Climate Change Committee, 2022). Typical purchasers of carbon credits are financial services firms, oil, gas & petrochemical companies, and consumer goods organizations.

The secondary market for carbon credits operates either over the counter (OTC), where the trades are conducted bilaterally through brokers or dealers, or through organized platforms offering different trading protocols, including request for quotes (RFQ), auctions, and limit order books (LOB) (see Table 1). According to (IOSCO, 2023), most carbon credits trades are currently executed bilaterally or through an intermediary, with very little public pricing information available.

Secondary trading is crucial to ensure that market prices remain up to date, which in turn can underpin new-issuance prices. However, there doesn't seem to be a true secondary market for voluntary carbon credits and data is scarce, which has negative implications for the price-discovery process and the quality of the market.

Figure 2 The issuance- retirement cycle



The figure offers a stylized representation of the issuance-retirement cycle. The vintage year is the year when the removal/reduction takes place. In the example, there is a correspondent issuance of 100 credits (year 1) and 50 credits (year 2), which are credited to the developer's account at the registry.
Source: WFE

One of the main challenges to the pricing of credits has been the heterogeneity of projects and the differences in the methodologies used to measure the carbon impact and certify the credits. As a consequence, the pricing of carbon credits varies according to the scope, the size of the project, its location, vintage year, or certification programme. This negatively affects liquidity and depth.

One solution has been to create standardised spot contracts. That is, contracts that represent credits of the same high quality. Having a standardised product facilitates trading through a limit order book (LOB), enhancing transparency and price discovery. It also serves as a benchmark and allows the creation of derivative contracts (see Box 1). The derivative contracts designed by **CME** and **ICE**, for example, are a good example of how regulated exchanges can play an important role in the development of VCMs, increasing the standardisation of the markets, providing an infrastructure that stimulates efficient price formation and offers high levels of transparency, and creating derivative products that contribute to the efficiency of the spot market.

Box 1 Standardised contracts

Given the heterogeneity of projects and of the quality of credits, some benchmark contracts have been created to enable market participants to buy high-quality carbon offsets—ensuring that the credits are generated by projects of similar quality and type.

- **CBL Global Emission Offsets (GEOs)** are based on carbon offsets that adhere to CORSIA, the international aviation industry standard for emissions offsetting. These offsets are sourced from the three major registries – Verra, the American Carbon Registry, and the Climate Action Reserve.
- **CBL Global Nature-based Emission Offsets (N-GEOs)** are nature-based offsets projects from the Verra registry – projects that fall under the Agriculture, Forestry, or Other Land Use (AFOLU) categories.
- **CBL Core Global Emissions Offsets (C-GEOs)**, are comprised of tech-based, non-AFOLU offset projects from the Verra registry that align with the Core Carbon Principles set by the Taskforce on Scaling Voluntary Carbon Markets.

The creation of standardised spot contracts also enables the creation of derivative products. CME futures contracts, for example, have CBL spot contracts as underlying.
Similarly, **ICE Futures** contracts on Nature-Based Solution Carbon Credits, require the underlying credits to comply with Verra's Climate, Community and Biodiversity (CCB) standards.
In 2022, **Net Zero Markets** launched the **Global Emission Reduction** or **GER**, a carbon pricing benchmark made up of a basket of four sub-contracts that encompass Base Carbon, Prime Carbon, Forestry Carbon and Carbon Capture. This benchmark can be traded as a spot contract on **AirCarbon Exchange (ACX)** and as a futures contract on EEX Group's US-based **Nodal Exchange**.

Various platforms and networks for trading carbon markets at the spot and derivatives levels are being developed or are already in place, often led by the regulated exchange. The trading mechanisms (or market microstructure) chosen may legitimately vary. Not all marketplaces will necessarily use limit order books, perhaps using mechanisms such as requests for quotes (RFQ). Table 2 presents some of the major trading platforms for spot and futures. Of the exchange-traded markets, the main spot market is CBL, which accounts for more than 95% of global spot volume traded on exchanges.[32] In 2022, the value of credits traded on CBL was USD 795 million, while total volume traded was 116 million tons. CBL contracts also serve as underlying of CME futures contracts.

[32] According to https://xpansiv.com/xsignals/

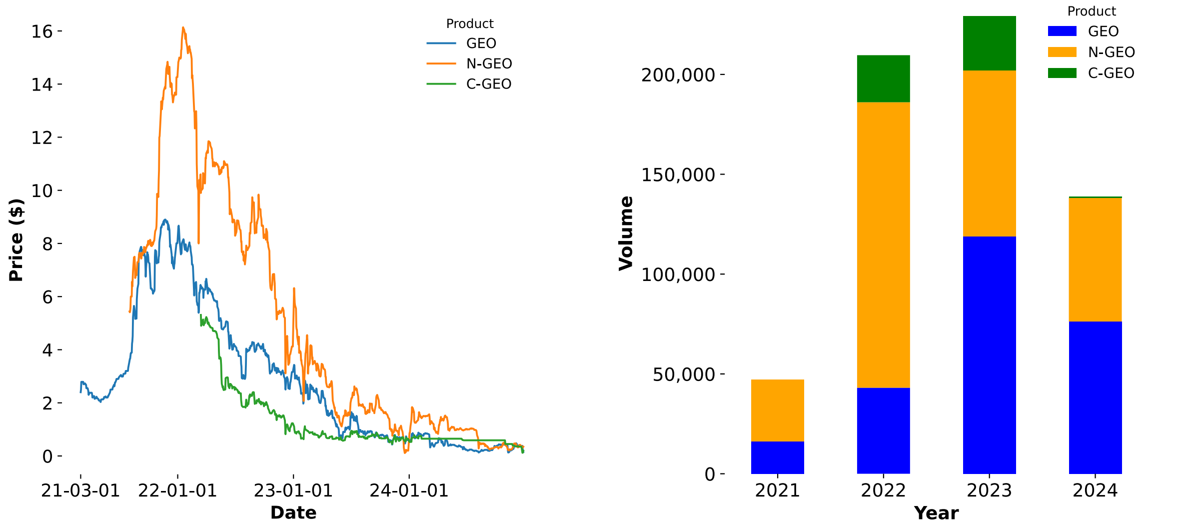
As in many other markets, futures and options play a major role in allowing participants to plan ahead, offering price discovery for future points in time and, in some cases, providing enough information to help set the spot price.

Table 2 Voluntary carbon secondary markets: main platforms

Platform	Base country	VCM products	Trading protocols	Year of launch
Carbon Trade Exchange (CTX)	Australia, EU, US	Spot	Bilateral	2009
MÉXICO2 Mexican Carbon Platform (BMV)	Mexico	Spot	Bilateral	2013
AirCarbon Exchange (ACX)	Singapore, Abu Dhabi	Spot contracts (including GER contracts)	LOB, RFQ, bilateral, auction	2019
Xpansiv- CBL	US and Australia	Spot contracts (GEO, N-GEO, C-GEO, D-Geo, ACCUs, and Aviation contracts)	LOB, RFQ, auction, bilateral	2019
CME Group	US	Futures (CBL C-GEO futures, CBL N-GEO futures, CBL GEO futures contracts)	LOB	2020
Climate Impact X (CIX)†	Singapore	Spot contracts (CIX Nature X, CIX Cookstoves X, CAX contracts)	LOB, bilateral	2021
Trayport (TMX)**	Canada	Spot contracts	LOB, bilateral	2021
HKEX Core Climate	China (Hong Kong)	Spot	Bilateral	2022
ICE	US	Futures on Nature-Based Solution Carbon Credits (NBSCC)	LOB, auction	2022
Nodal Exchange (EEX Group)***	US	Carbon Removal futures, GER and VER futures	LOB	2022
Xpansiv-JSE Ventures Carbon Market	South Africa	Spot	LOB, RFQ, auction, bilateral	2023
Abaxx Exchange	Canada	CORSIA futures, REDD+ Futures	LOB	2023
Bursa Carbon Exchange (Bursa Malaysia)	Malaysia	Spot contracts (MNC+, GTC, GNC+)	LOB, auction, bilateral	2023
AFRICARBONX (The Egyptian Exchange)****	Egypt	CER, NBSCC, GEO, and their forward contracts	Auction, bilateral, LOB	2024

**CBL and Xpansiv were founded in 2009 and 2016, respectively. In 2019 they merged to form the Xpansiv CBL Holding Group.*
***The digital trading platform – Joule – is available to trade voluntary carbon offsets with The Voluntary Climate Marketplace (TVCM) operated by IncubEx*
**** EEX Group is part of Deutsche Börse Group.*
†Shareholders include Singapore Exchange (SGX Group). The platform is built on Nasdaq technology.
***** AFRICARBONX is Egypt's first voluntary carbon market, developed internally by the Egyptian Exchange (EGX) using its own capacities. The platform, which supports the trading of carbon credits to offset carbon emissions, was announced as ready for market participation in November 2023. The official launch of the market took place on August 2023.*
Platforms are ordered by year of launch.
Sources: (IOSCO, 2023), WFE survey and platforms' websites.

Figure 3 Price and trading volumes of carbon offset futures



The left panel shows the daily prices of December-expiry carbon offset futures; the right panel shows the annual trading volumes of carbon offset futures. The orange line (bar) represents the CBL Nature-Based Global Emission Offset (N-GEO) futures, the blue line (bar) represents the CBL Global Emission Offset (GEO) futures, and the green line (bar) represents the CBL Core Global Emission Offset (C-GEO) futures. For the carbon offset futures price plot, we use the closest-to-maturity December future contract. For the volume plot, the data for 2021 covers the period from March to December. One futures contract delivers 1,000 carbon offsets.
Source: CME, Refinitiv.

The left panel of Figure 3 shows the daily price of three types of carbon futures contracts from March 2021 to December 2024. The CBL futures contracts expire monthly, with December contracts being the most frequently traded, similar to the ICE EUA futures (carbon allowance futures).[33] Following (Fuchs, Stroebel, & Terstegge, 2024), we choose the closest December futures contract as the primary measure of carbon price. The Nature-Based Global Emission Offset (N-GEO) contracts are the most popular among all three types of contracts and attract the highest prices. Since 2022, the prices of all futures products have steadily declined and the price gap among the three contracts has narrowed. By the end of 2024, the price of all three futures products have dropped to below one USD.

The right panel of Figure 3 displays the total trading volume of three futures contracts for each year. Despite rising prices in 2021, total trading volumes in 2021 remained relatively low due to the futures contracts only being introduced in March 2021. In 2022, the total trading volume surged from 50,000 to 200,000, with N-GEO contracts being the primary driver of this increase. In 2023, although N-GEO volumes decreased, the overall trading volume expanded slightly, driven by a large grow in GEO.

[33] Most of the trading volumes of concentrated in the next (front-year) December expiry futures contract, according to (ESMA, 2022).

However, in 2024, trading volumes contracted significantly, with both N-GEO and GEO experiencing reduced activity, and C-GEO being delisted from the exchange.[34]

One reason for the price reduction may be the oversupply of carbon credits, with issued credits consistently exceeding retired credits (see Figure 9). Secondly, investors might be adjusting their expectations based on evolving market conditions, particularly on natural-based carbon offsets. As we show later, the reduction of credit issuance in 2022 is mainly driven by *Forestry & Land Use* projects, which are also a major component of N-GEO futures. This decline in issuance could also explain the slowdown in N-GEO trading and the decrease in prices.

3. Overview of issuance and retirement

In this section we provide summary statistics of issuance and retirement of carbon credits, including by location, scope, registry, and method. In the last part we examine the trends in credit issuance and retirement over time.

3.1 Data and summary statistics

We obtained the carbon project data from the **Voluntary Registry Offsets Database (VROD)** developed by Berkeley Carbon Trading Project.[35] The database contains all carbon offset projects listed by the four major voluntary offset project registries—American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verra (VCS), covering around 94% of issuance in VCMs. While each registry records issuances, retirements, and cancellations differently, the VROD offers a homogenized set of data (Haya, Abayo, So, & Elias, 2023).[36]

The period we consider includes all projects until December 31, 2024, summing a total of 9,921 carbon offset projects. However, we exclude those projects with no credits issued, resulting in a final number of 5,138 projects, with a total of 2.25 billion of credits issued.[37] The earliest vintage year is 1996 and the latest is 2024. The issuance years range from 2002 to 2024, and retirements range from 2004 to 2024. For each project, we obtain the fundamental information of the project, including its ID, name, location, name of registry, category, methodology, the number of credits issued and retired each vintage year, etc. Additionally, we also utilise issuance and retirement data to analyse the issuance

[34] In December 2024, the New York Mercantile Exchange (NYMEX). officially delisted the C-GEO Futures from the CME Globex platform. There was zero open interest. See Product modification Summary: Delist CBL Core Global Emissions Offset (C-GEO) Futures - Effective December 09, 2024 - CME Group

[35] Voluntary Registry Offset Database v10, https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/offsets-database

[36] The dataset also includes buffer pool contributions. All registries maintain a buffer pool to cover the risk that credited carbon storage, such as in forests and grasslands, is released back into the atmosphere (Haya, Abayo, So, & Elias, 2023). It also includes reversals, which represent credits that must be cancelled if the CO2 removal is reversed.

[37] Projects appear in the database (on the registries) once they have first applied to be registered or when they are first registered (eligible to issue credits) in the registries. Registered projects are then able to monitor their GHG benefits over time and submit paperwork to issue credits at a time they wish or annually (timing depends on the registry and project type). There are two reasons why some projects may have zero credits. First, newly registered projects may not have yet submitted their first issuance request yet. Second, older projects that did not move forward and thus never issued credits.

and retirement times, as well as to investigate the beneficiaries of retirement. Table 3 presents the summary statistics of all carbon projects in our dataset.

The total carbon credits issued by project varies widely, from two tCO2e to nearly 40 million tCO2e. This reflects the diversity of projects involved, from projects about rural communities in Mali adopting sustainable practices (three tCO2e), to projects to distribute fuel-efficient improved cookstoves in Bangladesh (10 million tCO2e), or a project to avoid deforestation and forest degradation in Cordillera Azul National Park in Peru (36 million tCO2e).[38]

Table 3 Summary statistics of carbon projects

	Mean	Median	St. Dev.	Min	Max	Number of projects
Credits issued (tCO2e)	437,139	90,073	1,717,890	2	39,998,290	5,138
Credits retired (tCO2e)	253,227	37,524	1,064,386	0	29,796,121	5,138
Number of vintage years	4.50	4	3.30	1	27	5,138
Number of issuance years	2.61	2	2.22	1	16	5,138
Number of retirement years	3.35	2	3.22	0	17	5,138

The table presents summary statistics of the total amount of credits that have been issued or retired for each project, of the number of vintage years during which carbon credits were accrued for each project, and of the number of years in which carbon credits issuance/retirement occurred. Based on data up to December 31, 2024.

We also note that the dataset contains carbon projects that are still in the process of issuing carbon credits and have not yet terminated. Thus, the minimum amount of carbon credits issued does not necessarily reflect the entire credits accrued by the projects throughout their lifespan. Of the credits issued, 58% have been retired **(retirement ratio).**

Every project generates carbon credits across different vintage years, with an average number of vintage years larger than 4 and a maximum of 27.[39] The issuance of carbon credits can also involve several years: the average number of issuance years is 2.61 and the maximum is 16 years. On the other hand, the average number of years in which credits have been retired (3.35 years) surpasses those in which there are issuances, while the maximum number of retirement years is as high as 17 years (note that there may be multiple credit issuances or retirements within one year).

It is also interesting to examine whether the above statistics differ when considering the scope of the project. As mentioned earlier, there are nine project categories or scopes in the VRO database.[40] Table 4 reports the summary statistics of projects grouped by their scope. For the sake of clarity, only the mean values of each variable are reported. Clearly, projects in different scopes exhibit distinct characteristics.

[38] This is an example of a Reduction of Emissions from Deforestation and Degradation (REDD) project. REDD projects are seen as an international mechanism to help tropical countries, where most carbon is accumulated, to fight deforestation.

[39] The project with the largest number of vintage years is an afforestation/reforestation project in the *Forestry & Land Use* category, its vintage years ranging from 1996 to 2022.

[40] See VROD-ScopesTypes-v10.docx (berkeley.edu) for a table of project scope and project type mapping

In terms of average of credits issued and credits retired per project, *Carbon Capture & Storage* projects rank the first, with 2.74 million tCO2e (and only eight projects). However, if we look at the retirement ratio, *Transportation* projects have the highest ratio (73%) while *Household and Community* has the lowest (46%).

The origination of *Waste Management* projects is the most disperse in time, with the largest number of vintage years on average (5.46 years). On the other hand, *Chemical Processes* projects exhibit the most concentrated lifecycle, with the smallest number of vintage, issuance and retirement years on average (1.36, 1.26 and 1.76 years respectively). As for the number of projects, the top category is *Renewable Energy,* followed by *Household & Community*.

Table 4 Average issuance and retirement by project scope

Scope	Average credits issued (tCO2e)	Average credits retired (tCO2e)	Average number of vintage years	Average number of issuance years	Average number of retirement years	Number
Agriculture	109,770	67,317	3.87	2.60	2.56	303
Carbon Capture & Storage	2,736,142	1,876,269	4.88	2.13	3.25	8
Chemical Processes	322,348	157,425	1.36	1.26	1.76	450
Forestry & Land Use	1,119,740	705,946	4.63	2.37	3.36	741
Household & Community	164,047	75,153	4.62	3.21	2.73	1,413
Industrial & Commercial	525,323	295,243	3.38	1.88	3.21	255
Renewable Energy	468,413	265,545	5.32	2.48	4.20	1,528
Transportation	29,073	21,130	4.49	1.81	4.92	53
Waste Management	343,818	215,436	5.46	3.56	4.54	387

This table presents the average of credits issued, credits retired, number of vintage years, number of issuance years and number of retirement years across projects, grouped by project scope. The last column reports the number of projects in each group.

3.2 Cross-sectional analysis

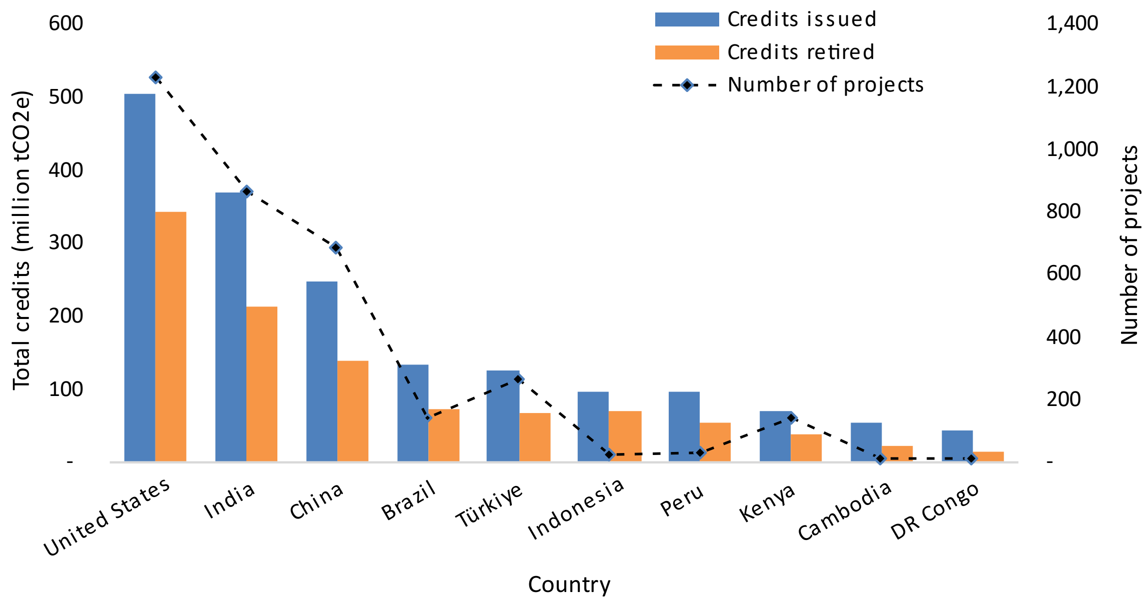
In this section we analyse carbon projects across various dimensions, including developer country, developer region, registry, project method, and project scope.

As of the end of 2024, carbon projects with credits issued have been developed in 108 countries. Among these countries, the United States leads the ranking, having issued credits over 500 million tCO2e, followed by India (370 million tCO2e) and China (248 million tCO2e). Figure 4 illustrates the top 10 countries by the number of carbon credits issued.

The majority of retirements also originate from the three countries with largest issuance. The United States emerges as the country with highest demand for credit offsets, having retired 68% of its total amount of carbon credits issued. In terms of number of projects, the United States, India and China also hold the top positions. Of all the projects, 73.73% originate in emerging and developing countries, collectively generating 75.13% of the total carbon credits.[41]

[41] The classification of emerging and developing countries is based on the IMF classification (https://www.imf.org/en/Publications/WEO/weo-database/2023/April/groups-and-aggregates).

Figure 4 Carbon projects by developer country (Top 10 countries by number of credits issued)



This figure plots the total credits issued and retired by projects that are developed in each country (left), and the number of projects of each country (right).

In Table 5 we further examine the distribution of project scopes across the top 10 countries considered in Figure 4. The United States leads with a total of 1,233 projects, with the largest share (33%) falling under *Chemical Processes*. India follows with 867 projects, 69% of which are in *Renewable Energy*, while China has 683 projects, with 48% of them in *Renewable Energy* too. Notably, *Carbon Capture & Storage* projects are only present in the United States.

Next, we aggregate the projects by the region of the developer. Figure 5 plots the number of carbon credits that have been issued and retired, as well as the number of projects in each region. Given that the United States is the major carbon project supplier (Figure 4), North America stands out as the region with the largest issuance and retirement of carbon credits, and with the largest number of projects. It is followed by Southern Asia and Latin America and the Caribbean. Even though the total credits issued from Latin America and the Caribbean exceed those from Eastern Asia and Sub-Saharan Africa, the number of projects from Latin America and the Caribbean is smaller than the other two regions, meaning that the average scale of projects from Eastern Asia and Sub-Saharan Africa is smaller. Notably, despite Europe's relatively minor contribution to the development of carbon projects, its retirement ratio (87%) surpasses that of other regions.[42]

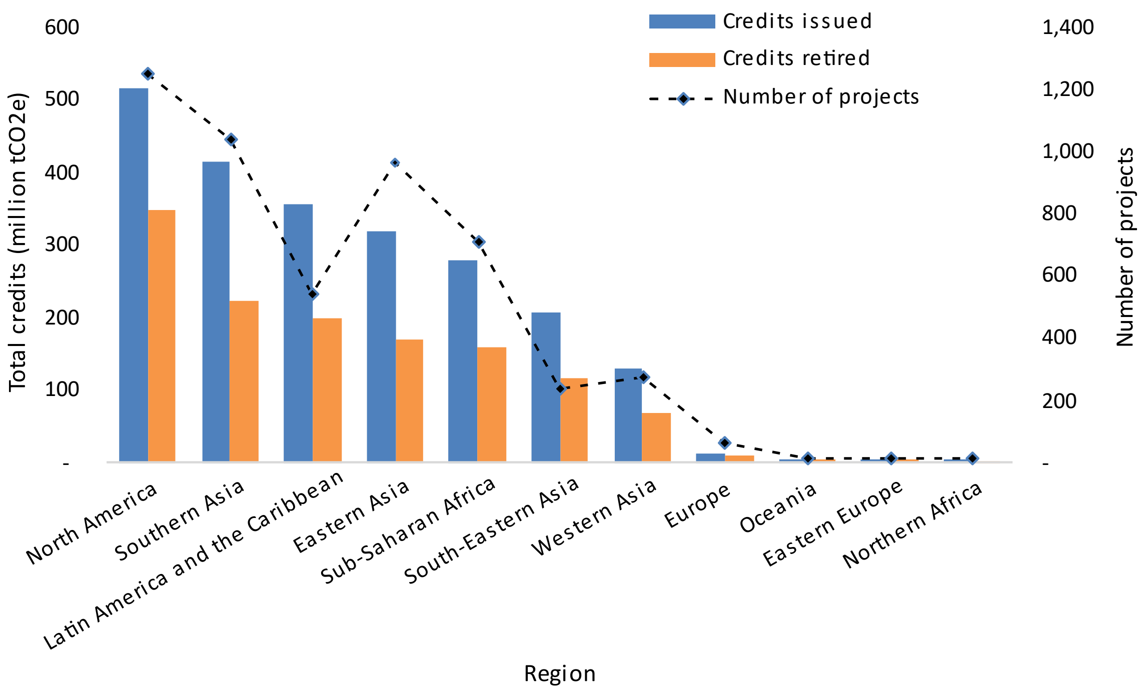
[42] Here, Europe region is comprised of France, Germany, Netherlands, Switzerland, and the United Kingdom.

Table 5 Number of projects under each scope by country (Top 10 countries by number of credits issued)

	United States	India	China	Brazil	Turkey	Indonesia	Peru	Kenya	Cambodia	DR Congo
Agriculture	182	10	60	18	9	-	-	4	-	-
Carbon Capture & Storage	7	-	-	-	-	-	-	-	-	-
Chemical Processes	413	1	2	-	-	-	-	-	-	-
Forestry & Land Use	302	11	48	35	-	4	17	12	4	3
Household & Community	2	206	124	4	-	3	6	119	7	7
Industrial & Commercial	100	34	41	1	4	3	1	-	-	-
Renewable Energy	14	594	330	68	235	13	3	7	2	1
Transportation	38	5	1	2	1	-	1	-	-	-
Waste Management	175	6	77	16	17	3	-	1	-	-
Total	**1,233**	**867**	**683**	**144**	**266**	**26**	**28**	**143**	**13**	**11**

This table reports the number of projects under each scope by the top 10 countries that have issued the most credits. DRC stands for Democratic Republic of Congo. This represents 3,130 projects in total.

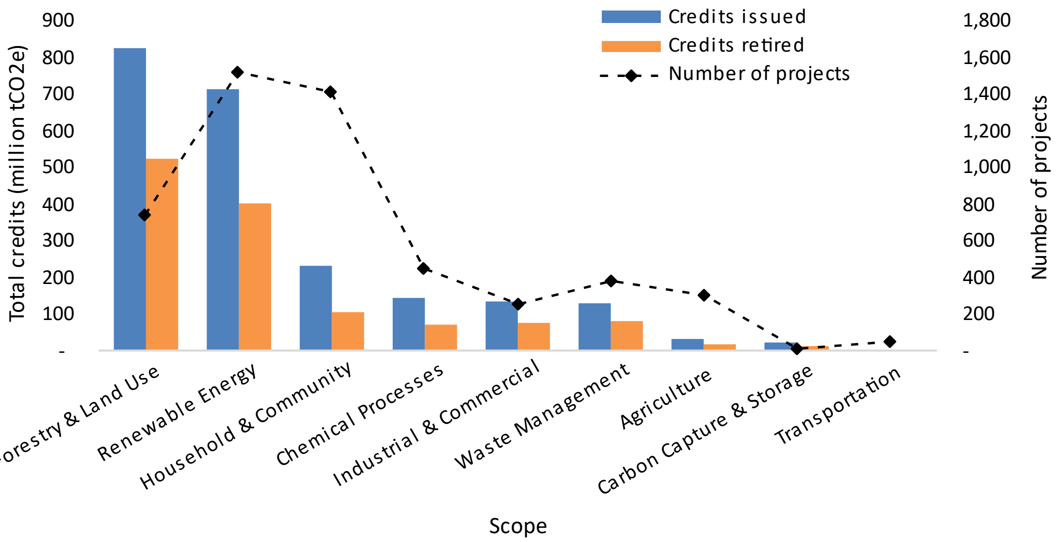
Figure 5 Carbon projects by developers' region



This figure plots the total credits issued and retired by projects that are developed in each region (left), and the number of projects of each region (right).

When we examine the projects by category, we find that the projects generating the highest volume of carbon credits are primarily those in the *Forestry & Land Use* and *Renewable Energy* categories (Figure 6). However, the number of carbon projects for *Forestry & Land Use* is substantially lower than that of *Renewable Energy* projects, even falling below *Household & Community* projects. This disparity is due to the larger scale typically associated with *Forestry & Land Use* projects compared to the other two scopes (see Table 4).

Figure 6 Carbon projects by scope



This figure plots the total credits issued and retired by projects' scope (left), and the number of projects for each scope (right). In the Transportation category there are 53 projects, 1.54 million tCO2e issued, and 1.12 million tCO2 retired.

Figure 7 illustrates the total amount of issued and retired credits, and the number of projects for each registry. Verra plays a dominant role in registering carbon projects with a total of 1,971 projects. Among the four registries, Climate Action Reserve shows the highest credit retirement ratio, with projects registered through this registry having 76% of their credits retired.

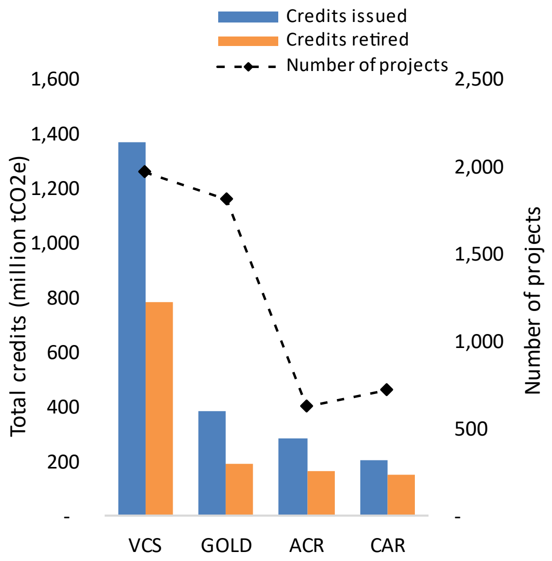
A closer examination of the project scopes for each registry reveals that 67% of projects registered with Gold Standard are *Household & Community* projects (Table 6). This type of project is typically small scale. In contrast, 54% of the projects registered with Verra are *Renewable Energy* projects (1,060 projects) which tend to be larger in scale (Table 4).

Table 6 Number of projects under each scope by registry

	VCS	GOLD	ACR	CAR
Agriculture	102	26	25	150
Carbon Capture & Storage	3	0	5	0
Chemical Processes	15	0	301	134
Forestry & Land Use	251	19	164	307
Household & Community	191	1222	0	0
Industrial & Commercial	158	18	72	7
Renewable Energy	1060	463	5	0
Transportation	13	4	36	0
Waste Management	178	63	18	128
Total	1971	1815	626	726

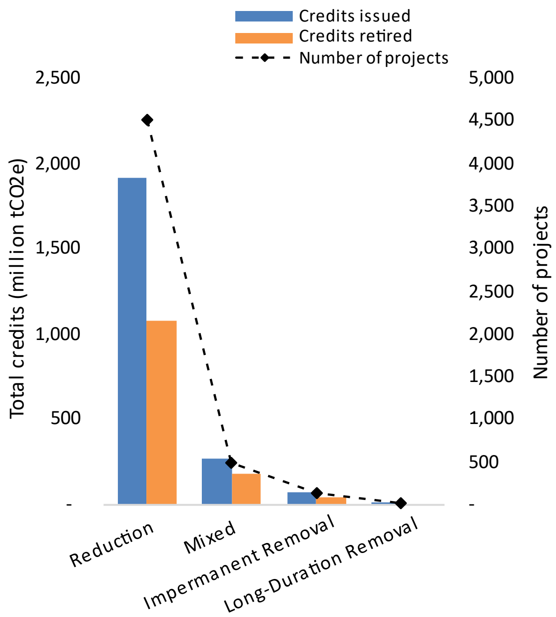
This table displays the number of projects grouped by project scope for each of the four major registries: Verra (VCS), Gold Standard (GOLD), American Carbon Registry (ACR) and Climate Action Reserve (CAR).

Figure 7 Carbon projects by registry



The figure plots the total credits issued, total credits retired, and the number of projects registered for each of the four major registries: Verra (VCS), Gold Standard (GOLD), American Carbon Registry (ACR) and Climate Action Reserve (CAR). The dataset only includes the 4,627 projects with a positive number of credits issued.

Figure 8 Carbon projects by method



The figure plots the total credits issued and retired by projects of each method (left axis), and the number of projects of each method (right axis).

Figure 8 illustrates the total amount of credits issued and retired by projects according to different methods, and the number of projects for each method. Reduction projects constitute the majority of carbon credits. Mixed projects rank second, but the numbers are far smaller than the reduction projects. Due to the difficulty of removing the carbon out of the atmosphere, the number of projects and the total amount of issued credits and retired credits of removal projects are smaller.

According to the dataset, the eight long-duration removal projects that have issued credits consist of carbon-absorbing concrete projects (*Carbon Capture & Storage*), while the 131 impermanent removal projects are afforestation/reforestation projects (*Forestry & Land Use*), which involve activities such as planting trees and reducing barriers to natural regeneration in non-urban areas.

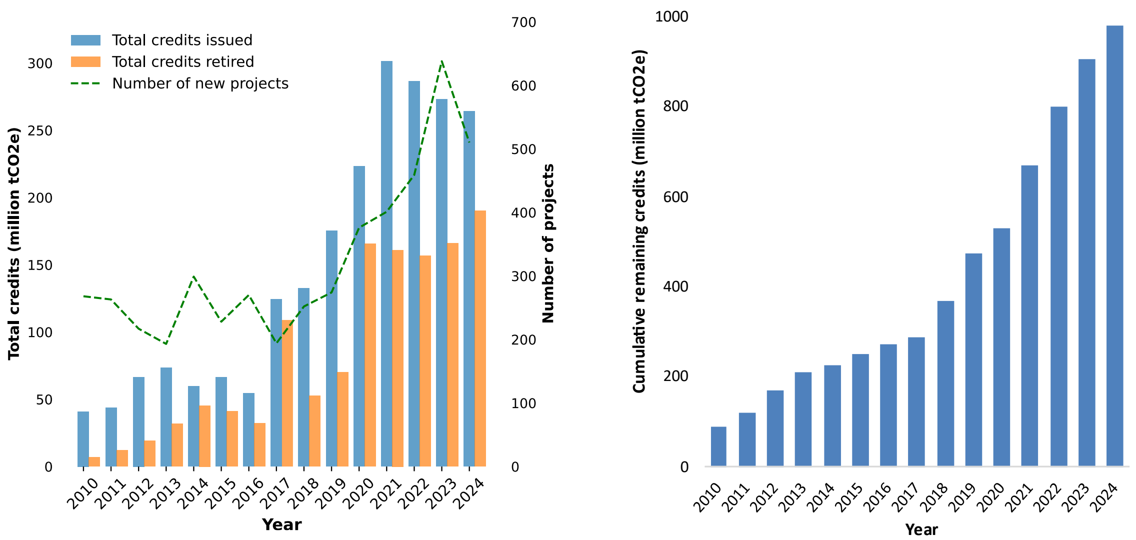
3.3 Imbalance between issuance and retirement over time

Since the 2002, when the first credits were issued, and until 2021, the voluntary carbon market has exhibited an expansion trend. However, before 2017, the annual issuance of carbon credits remained relatively stable, below 50 million tCO2e. From 2017, two years after the Paris Agreement, and until 2021, the market experienced a notable surge of 142% in carbon credit issuance, reaching 300 million tCO2e (see left panel of Figure 9).[43] Subsequently, from 2022 to 2024, the issuance of carbon credits has declined 12%, and the total issuance in 2024 was of 264.06 million tCO2e.

[43] For ease of visualisation, the time series graphs only show the period from 2010 to 2024.

The retirement of carbon credits shows a different pattern, with an increase of 48% from 2017 to 2021 and then a further increase of 18%, with the peak of credit retirement occurring in 2024 at around 190.02 million tCO2e. This means a retirement ratio of 72%, below the peak retirement ratio of 84% achieved in 2017. Meanwhile, since 2017, the number of new carbon projects increased consistently from 2017 until 2023 and then decreased in 2024. For each year, we count as *new* projects those that have issue credits for the first time in that year.

Figure 9 Evolution of carbon credits issuance and retirement



The graph shows the total carbon credits issued/retired during each year (left axis), and the number of new projects issued of each year (right axis).

The figure plots the cumulative remaining credits. The quantity of remaining credits is calculated as the difference between issued credits and retired credits.

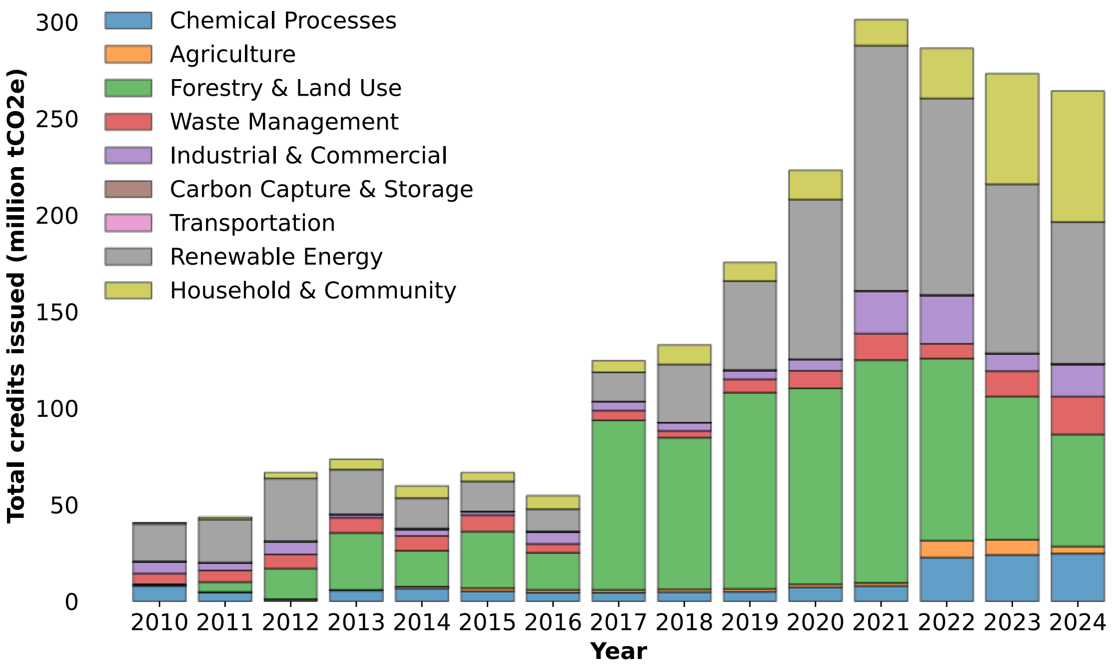
Since the first issuance, in 2002, the total number of issued credits has consistently exceeded the number of retired credits each year. This ongoing surplus has resulted in an expanding stockpile of available credits, including from older vintages. This imbalance between issuance and retirement may have important implications for the market's dynamics and the price of carbon credits.

According to the World Bank (World Bank, 2023), two potential reasons may explain the observed drop in carbon credit issuance in 2022. First, a growing focus on nature-based projects and a reduction in the cost of renewables have decreased the supply of large-scale renewable energy projects, which are typically the main source of carbon credits. This is consistent with what we observe when we split the projects by scope (Figure 10**Error! Reference source not found.**). Overall, we can see that two major contributors to carbon credit issuance are *Forestry & Land* use projects and *Renewable Energy* projects. Notably, the surge in carbon credit issuance in 2017 is primarily driven by the expansion of *Forestry & Land Use* projects. And from 2017 to 2021, *Renewable Energy* increased 731%. But from 2021 to 2024, *Forestry & Land Use* projects and *Renewable Energy* projects experienced a reduction in credit issuance of 50% and 42%, respectively. During the same period, there was a 4-fold increase in *Household & Community* issuance, resulting in a 26% share of the total credits issued in 2024.

The second potential reason could be that an increase in new projects has caused delays in project monitoring and verification. This would be consistent with the results presented in Section 4, where we find a positive correlation between the time to issue and the expansion of the voluntary carbon market.

Finally, the decline after 2021 in issuance in *Forestry & Land Use* coincides with negative reports about the quality of some forestry carbon offsets.[44]

Figure 10 Carbon credits issuance by project category



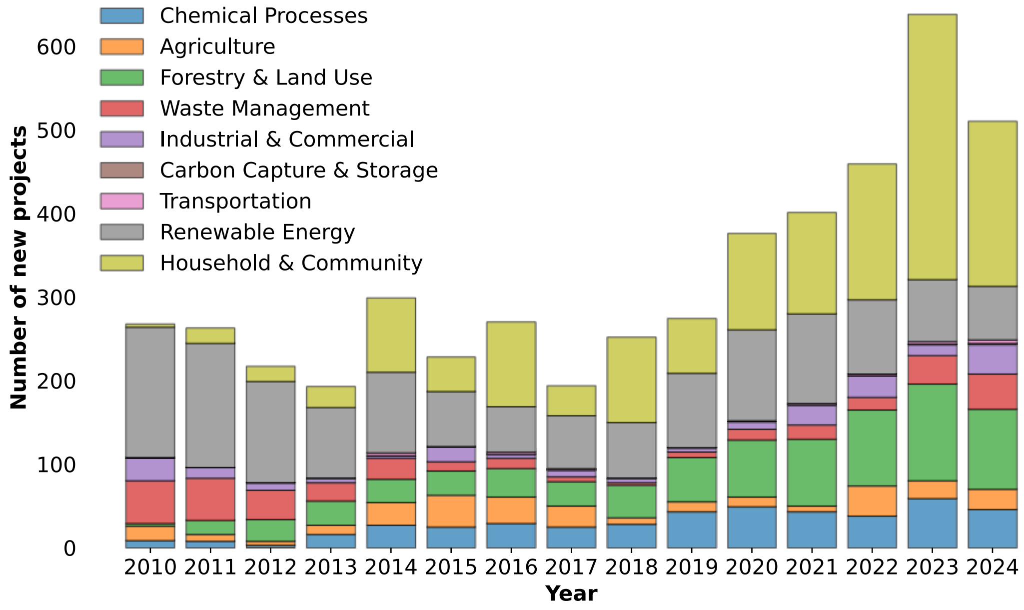
This figure plots the amount of carbon credits issued from the year 2010 to 2023, the projects are grouped by their scope.

In Figure 11, we depict the number of new projects categorized by scope. *Renewable Energy* and *Forestry & Land Use* projects have consistently been major suppliers of new projects. *Household & Community* projects has emerged in the last years as the largest scope in terms of new projects.

Next, we examine the quantity of carbon credits retired from each type of project (Figure 12). Similar to credit issuance, *Forestry & Land Use* projects and *Renewable Energy* projects are the two most popular types of projects. Notably, the surge of credit retirement in 2017, and its decline in the following two years, can be attributed largely to *Forestry & Land Use* projects. The same can be said about the spike observed in 2020 and the decline in retirements in 2021 and 2022 (which coincides

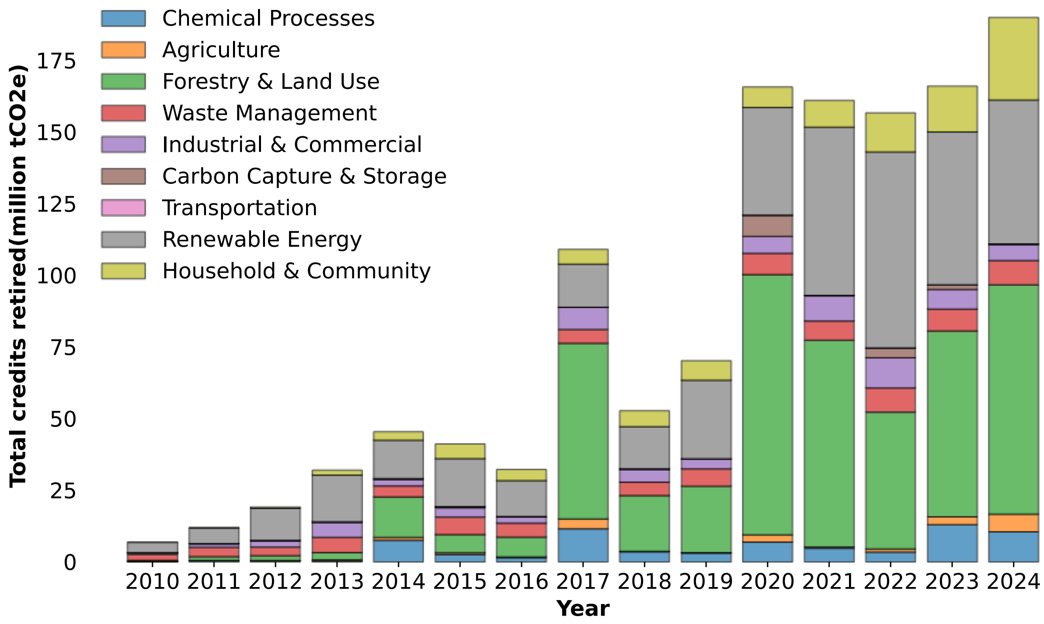
[44] See, for example, a 2023 report revealing that over 90% of rainforest carbon offsets are essentially worthless "Revealed: more than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows", The Guardian (18 January, 2023)

Figure 11 Number of new projects by project scope



The figure plots the number of new projects over the years 2010 to 2023, grouped by their scope. The year refers to the first issuance year of the project.

Figure 12 Credits retired by project scope



The figure plots the amount of carbon credits retired over the years 2010 to 2023, grouped by project scope.

with reports questioning the quality of some carbon credits; see footnote 44).[45] In addition, in 2021, crypto companies were banned from Verra, due to concerns that tokenisation would increase the opacity of the market.[46]

4. Issuance lag, trading life, and retirement age

The speed at which carbon credits are issued and consumed after the carbon removal took place is important because it provides information about the efficacy of the market in transferring funds from the buyer of credits to the project developer, about the balance between demand and supply, and about the behaviour of end-users (those who buy the credits for offsetting their carbon emissions). To capture these elements, we will associate to each project three metrics:

- ***Issuance lag*** is a value-weighted average of the time that it takes to issue carbon credits after the carbon removal happened (the issuance usually occurs after the vintage year).[47] It is a measure of how quickly funds are being transferred from the buyer of credits to the project developer. It is important because delays in the issuance process increase costs and impede timely access to funds. It also negatively impacts the rest of the credit lifecycle, delaying the retirement process.
- ***Retirement age*** is the value-weighted average time between the carbon removal or reduction actions and the offsetting of the corresponding credits by the end-user. The retirement age is an important factor, as credits from more recent vintages seem to achieve higher premium relative to the baseline (Xpansiv, 2022).[48]
- ***Trading life*** is the value weighted average of the time between issuance and retirement, when the credit may be available in the secondary markets.

Considered together, these metrics provide information about the balance between supply and end-user demand and about the preferences of the end-users regarding the age of the credits.

4.1 Issuance lag

We will first consider, for each project, the value-weighted average of the times between issuance and vintage years. More precisely, let P denote a project and let $v_j(P)$ denote a vintage year. For each vintage year, let $y_i(v_j, P)$ be the associated issuance years. For each vintage year and year of issuance, let $c_{i,j} = c(y_i(v_j, P))$ denote the number of credits issued.

Consider the difference in years between issuance and vintage year:

[45] Another example is Delta, one of the major users of credits, and who announced that, since 31 March 2022, it had transitioned its focus away from carbon offsets toward decarbonisation of their operations. "Delta Air Lines faces lawsuit over $1bn carbon neutrality claim", *The Guardian*, 30 May, 2023.

[46] See "Five Need-to-Knows About the Future of Voluntary Carbon Offset Markets," BloombergNEF blog (Jan. 2023).

[47] Gold Standard provides the ability to generate ex-ante credits, called PERs (Planned Emissions Reductions), for forestation projects. PERs represent future carbon sequestration in trees. Once the sequestration is verified through ex-post monitoring, PERs can be transitioned to VERs (Verified Emissions Reductions) to be used like any ex-post credit. We exclude the PERs in our analysis.

[48] The comparison was done between eligible credits and the standardised contract N-GEO used as benchmark. See Xpansiv 2022 VCM Review

$$d_{i,j}(P) = y_i(v_j, P) - v_j(P)$$

Note that if the credit issuance coincides with the vintage year, the difference is calculated as zero.

Since, for each carbon project P, there are usually multiple credit issuances, we calculate the value-weighted average of the times to issue, using the number of issued credits in each issuance as weighting factor, giving greater importance to issuance with larger credit allocation. We call this the **issuance lag**:

$$Issuance\_lag(P) = \frac{1}{\sum_{i,j} c_{i,j}(P)} \sum_{i,j} c_{i,j}(P) \cdot d_{i,j}(P)\,) \quad (1)$$

Table 7 presents the summary statistics of carbon credit issuance. The average lag across projects to issue credit is 2.45 years, with a maximum of 20.81 years. Around 50% of projects have an issuance lag of 1.93 years or more. It is worth contrasting these figures with the shorter times usually needed to issue shares or bonds on an exchange. For example, issuing a green bond on an exchange usually takes between eight and 12 weeks (excluding scoping work),[49] while a typical IPO process takes about 6 months.[50]

Long issuance lags suggest lengthy monitoring-verification cycles, which means higher costs for issuers, impedes timely access to capital and is a disincentive to participate in the markets.

Table 7 Summary statistics of carbon credit issuance

Issuance metric	Mean	StDev	Min	Median	Max	Number
Issuance lag (years)	2.45	1.98	0	1.93	20.81	5,136
Number of issuances per project	6.97	9.61	1	4	200	5,136
Number of issuances per vintage	1.42	1.05	1	1	22.86	5,136

The table shows summary statistics for each metric, estimated across all projects. The number of issuances per vintage is, for each project, the number of issuances divided by the number of vintage years.

The average number of issuances per project ranges from one to 200. Given that projects with a greater number of vintage years are expected to also have a larger number of issuances, we estimate the total number of issuances of a project divided by its number of vintage years, which results in 1.42 issuances per vintage year, meaning that credit issuance happens on average more than once per vintage year. The maximum number of issuances per vintage year could reach 22.86.

The quantity of credits issued (the issuance size) varies within each issuance, as well as across projects. In Figure 13 we depict the frequency distribution of issuance sizes. It is characterized by a strong right skew, with 43.64% of the issuances smaller than 10,000 tCO_2.[51] The mean issuance size is 62,188

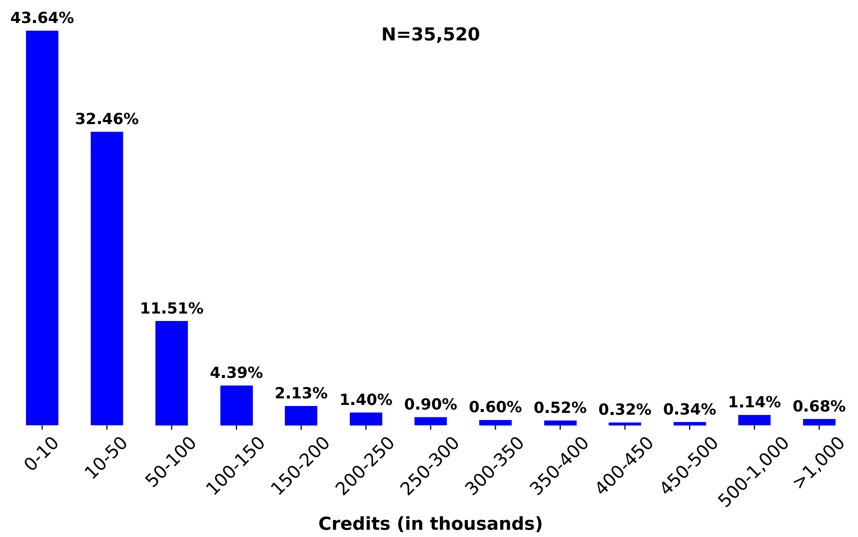
[49] See IFC Green Bond Handbook. The eight to 12 weeks is a reasonable benchmark for the structuring and issuance of a green bond, but the actual timeline can vary depending on several factors, especially for an exchange-traded green bond, including the complexity of the issuer's green framework, the external review process, and regulatory approvals. Market conditions and investor engagement can also impact timing.

[50] SIX-IPO Guide, for example.

[51] To give an approximate idea of the size, it is roughly estimated that 37 hectares of protected woodland will capture 10,000 tCO_2 in a 30-year period (see UK Forestry Commission, Responding to the climate emergency with new trees and woodlands)

tCO2e, with a minimum issuance size of one tCO2e and a maximum issuance size of 14.86 million tCO2e.

Figure 13 The frequency distribution of issuances by issuance size



The figure displays the distribution by the size of the issuance. The frequency is calculated as the number of issuances with credits quantities falling within each range, divided by the total number of issuances in the sample (N=35,520).

Issuance variation by project category and registry

Next, to assess whether the issuance time is affected by the project category, we group the projects by category and compute the mean of each metric within each category. Table 8 shows that, *Chemical Processes* projects incur the fastest issuance process, at 1.15 years on average. *Transportation* projects encounter the longest issuance process, with an average time to issue of 4.81 years. In terms of number of issuances per project, *Waste Management* projects rank the first and issue 7.97 times per project, while *Chemical Processes* projects rank the last with 1.84 average issuance. Since *Chemical Processes* projects also has the largest number of issuances per vintage, with 1.19 issuance per vintage year, this category seems to have the smaller number of vintage years, consistent with the results in Table 4.

The frequency distribution of the quantities of issued credits also varies by project category, as it is shown in Figure 14. Most of the distributions show a pronounced right-skew, the exception being the *Carbon Capture & Storage* project, where 36.96% of issuances exceed 500,000 tCO2e. On the other hand, categories like *Transportation* show many issuances of low value, with a scarcity of issuances of more than 100,000 tCO2e.

Table 8 Credit issuance by project scope

Scope	Average issuance lag (years)	Average number of issuances	Average issuances per vintage	Number of projects
Agriculture	1.88	4.54	1.13	303
Carbon Capture & Storage	2.02	5.75	1.16	8
Chemical Processes	1.15	1.84	1.19	450
Forestry & Land Use	2.76	9.93	1.88	740
Household & Community	1.91	6.72	1.38	1413
Industrial & Commercial	2.85	4.93	1.31	254
Renewable Energy	3.22	7.91	1.39	1528
Transportation	4.81	5.19	1.15	53
Waste Management	2.14	7.97	1.34	387

The table reports the average of each issuance measure across projects grouped by scope.

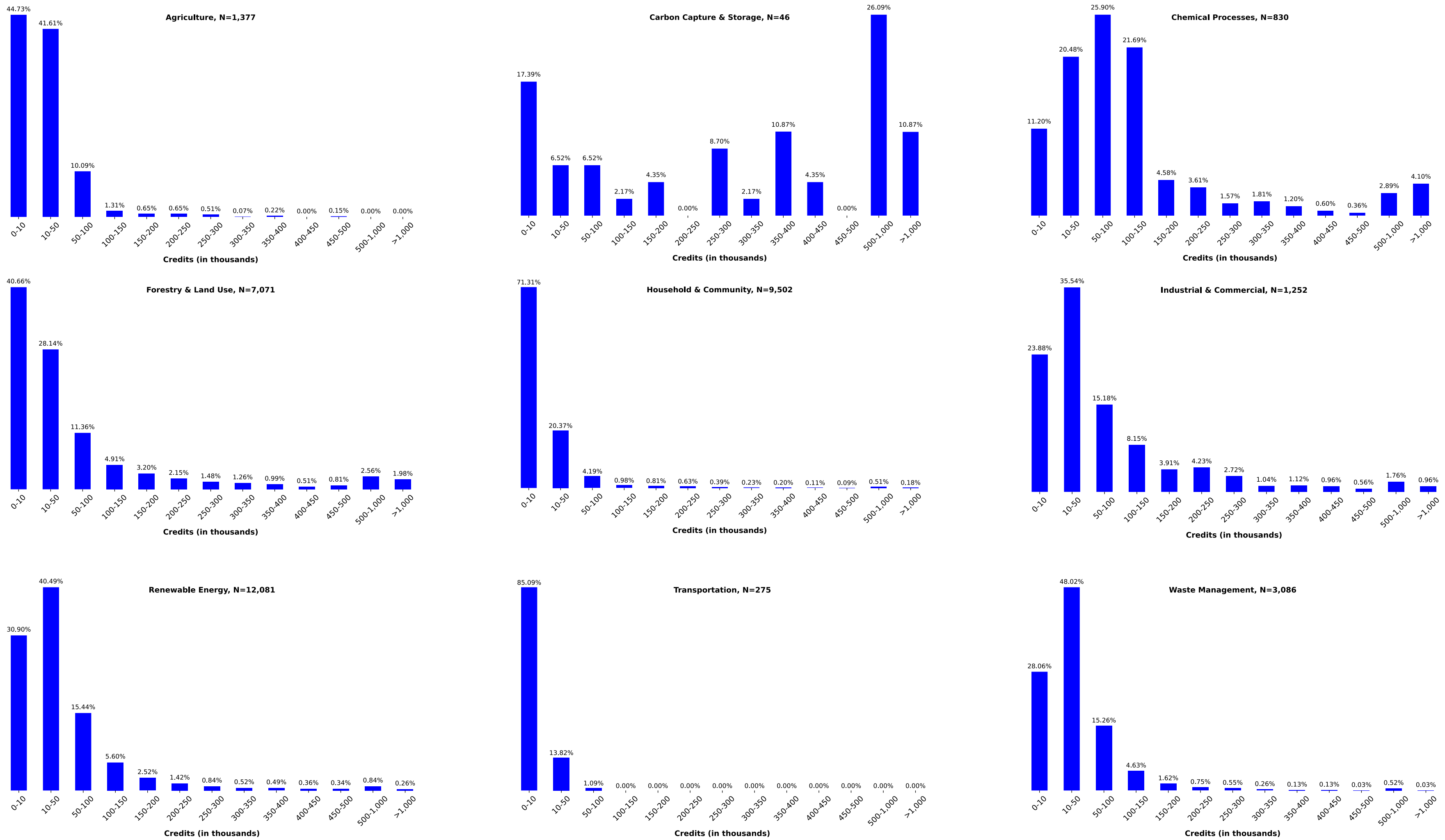
The efficiency of carbon credit issuance is also influenced by the voluntary registry where projects are registered. Table 9 reports the mean of each issuance measure with the projects grouped by registry. Verra (VCS) is the registry with the highest number of registered projects, the longest average time to issue (3.68 years) and the highest average number of issuances per vintage year. In contrast, projects registered with Climate Action Reserve (CAR) encounter the shortest time to issue, at 1.25 years on average, and the number of issuances per vintage year is the lowest compared to projects registered with other registries.

Table 9 Credit issuance by registry

Registry	Average issuance lag (years)	Average number of issuances	Average number of issuances per vintage	Number of projects
ACR	1.52	3.36	1.25	626
CAR	1.25	5.52	1.23	726
GOLD	1.92	7.36	1.38	1,815
VCS	3.68	8.29	1.57	1,969

The table shows the average of each issuance measure across projects grouped by registry.

Figure 14 The frequency distribution of issuances by issuance size, estimated by project category



The figures illustrate the frequency of issuance size by project scope. For each project category (scope) , the frequency is calculated as the number of issuances with size falling within each range, divided by the total number of issuances in the sample.

4.2 Retirement age and trading life

Similarly to how we defined the issuance lag, for each project we calculate (1) the **retirement age**, which is the value-weighted average of the time (in years) between vintage years and retirement years, using the quantity of credit retired as weighting factor; and (2) the **trading life**, which is the value-weighted average of the time from credit issuances to their retirement, using the credits retired as weighting factor.

Table 10 reports the summary statistics of carbon credit retirement across all projects in our sample.[52] The retirement age exhibits a wide distribution with a minimum of zero years and maximum of 22.26 years. The mean is 4.43 years. Given that the credit retirement must happen after credit issuance, it is natural that the age at retirement is typically longer than the time to issue (Table 7).

In Table 10 we also report the statistics for the trading life across projects. [53] The average trading life of credits from a project is 1.71 years, with 50% of credits having more than 1.16 years of trading life.

Table 10 Summary statistics of carbon credit retirement

	Mean	SD	Min	Median	Max	Number of retirements
Retirement age (years)	4.43	2.81	0	3.63	22.26	3,772
Trading life (years)	1.71	1.85	0	1.16	15.44	3,749
Number of retirements per project	105.66	667.41	1	14	29,105	3,772
Number of retirements per vintage	21.29	147.44	1	4	7,276	3,772

This table reports the mean, standard deviation, minimum, median, maximum value of retirement age and trading life, estimated across projects. The number of retirements is the number of retirements of each project. Number of retirements per vintage is calculated as the number of retirements of a project divided by the number of vintage years.

In contrast with credit issuance, credit retirement strongly relies on end-user demand and preferences, leading to significant variations in the number of retirements per project. The average number of retirements per project is 105.66, with a median retirement of only 14. The maximum number of retirements for a single project reaches 29,105. To provide further insights, we divide the number of retirements of a project by its number of vintage years, resulting in an average of 21.29 retirements per vintage year., with a median value of only four. This disparity reveals the substantial variability in the retirement frequency across projects.

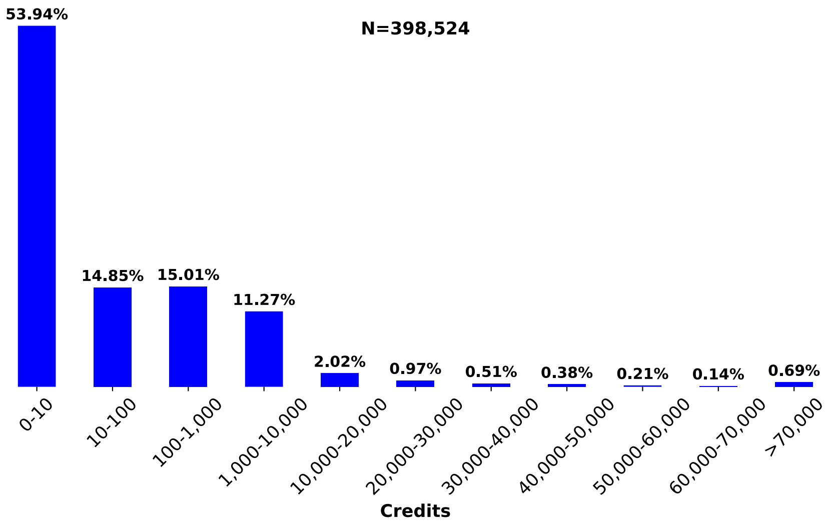
We now compute the frequency distribution of the retirements according to their size (Figure 15). There are in total 398,524 retirement records in the sample. The mean quantity of retired credits is 2,730 tCO2e, while the median is only seven tCO2e. The minimum quantity of retired credits is one tCO2e, and the maximum is 5.25 million tCO2e. The distribution of retired credits exhibits a significant

[52] We exclude observations where retirement date is missing, or the retirement year precedes the vintage year. These are mainly Planned Emission Reductions (PERs) issued by Gold Standard (see footnote 47). PERs represent future carbon sequestration in trees. We also exclude the observations where either vintage year or retirement year is missing.

[53] ACR, Gold Standard and Verra include the issuance date of credits in their retirement records, while CAR does not. For credits issued by CAR, we manually merge the issuance date of credits from the issuance records. However, for some projects where credits from a single vintage year were issued across multiple periods, it is not possible to determine the exact issuance date. Consequently, these credits have been excluded from the calculation of the trading life.

right-skewness, with 53.94% of the retired credits no larger than ten tCO2e and only around 16.20% of the retirements exceeding 1,000 tCO2e. The prevalence of small size retirements, compared to the average quantity of credits per project shown in Table *3*, suggests that most end-users in the voluntary carbon markets are small entities, or even individuals. While is positive that small and medium buyers are finding carbon credits a useful tool to meet their sustainability goals, support environmental projects, meet shareholder expectations or enhance their brand value, demand from larger end-users, especially from carbon-intensive industries, can stimulate larger issuances, generate volumes in the market and accelerate decarbonisation efforts.

Figure 15 Frequency distribution of retirements by retirement size



This figure displays the frequency distribution by retirement size. The frequency is calculated as the number of retirements whose size falls within a given range, divided by the total number of retirements. There are N=398,524 retirements in the sample.

Retirement by project category and registry

To investigate whether the retirement age of projects exhibit variation across scopes, Table 11 reports the mean value of each measure with projects grouped by their scope or category. The retirement age and the trading life exhibit a similar pattern across different scopes. *Household & Community* projects have the shortest retirement age, while *Carbon Capture & Storage* projects show the longest.

In terms of total number of retirements of each project, *Forestry & Land Use* projects significantly surpass other types of projects, followed by *Renewable Energy* projects. These two types of projects also rank as the top two in terms of number of retirements per vintage year, which reflects their popularity within the voluntary carbon market.

Figure 16 shows the frequency distribution of retired credits quantities by each project scope. As with issuance, eight out of the nine categories exhibit significant right-skewness, similar to the distribution of the whole sample. The exception again is the *Carbon Capture & Storage* projects, where 14.14% of retired credits exceed 70,000 tCO2e. *Forest & Land Use* projects, *Household & Community* projects, *Industrial & Commercial* projects, as well as *Renewable Energy* projects all exhibit strong right-skewed distribution of retired credits, with the most frequent quantity of retired credits being less than 10 tCO2e.

Table 11 Summary statistics of carbon credit retirement by project scope

Scope	Retirement age (years)	Trading life (years)	Number of retirements	Retirements per vintage	Number of projects
Agriculture	4.49	2.13	16.07	4.27	152
Carbon Capture & Storage	8.36	6.61	39.60	7.67	5
Chemical Processes	3.95	1.63	28.69	20.20	153
Forestry & Land Use	4.57	1.17	325.36	58.37	483
Household & Community	3.07	1.16	57.99	11.19	1097
Industrial & Commercial	6.75	2.86	60.91	15.81	161
Renewable Energy	5.12	1.98	106.95	22.75	1356
Transportation	8.99	3.89	15.35	3.56	46
Waste Management	4.29	2.12	47.66	7.82	319

This table shows the mean value of each retirement measure calculated within each project category. We first calculate each measure for each project, and then we calculate the mean of each measure within each project scope.

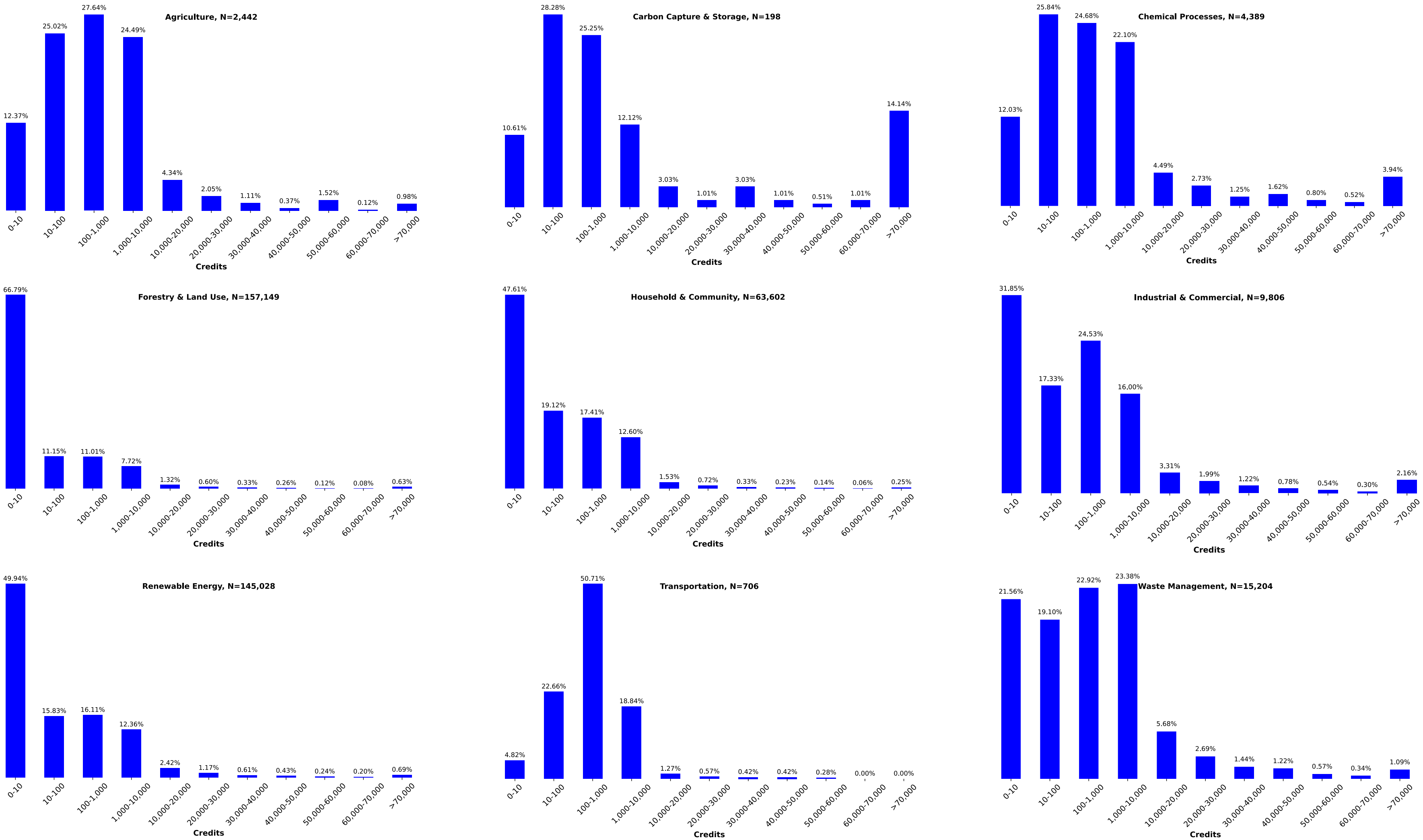
Next, we examine the retirement age across project registries. Table 12 provides the mean values of each retirement measure for projects grouped by their voluntary registries. By definition, longer issuance lags should tend to increase the retirement age. Consistent with this, projects registered through Verra (VCS) exhibit the longest retirement age. However, the data suggests that other factors affect retirement: projects registered in ACR have a low issuance lag (see Table 9) but have the longest trading life and a large retirement age. Projects registered through Gold Standard experience the shortest retirement age and shortest trading life.

Table 12 Credit retirement by project registry

Registry	Average retirement age (years)	Average trading life (years)	Average number of retirements	Average retirements per vintage	Number of projects
ACR	4.67	2.12	24.50	10.92	258
CAR	3.44	2.01	23.42	4.59	357
GOLD	3.23	1.34	93.91	17.24	1,436
VCS	5.60	1.90	144.68	29.69	1,721

This table reports the average of each measure across the projects grouped by registries.

Figure 16 The frequency distribution of retirements by retirement size, estimated for each project scope



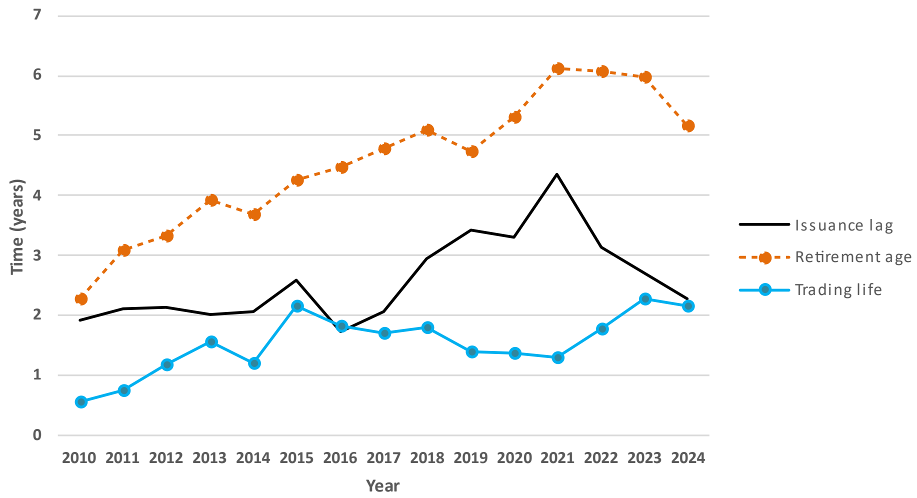
The figures illustrate, for each project scope, the frequency distribution of retirements by retirement size.

4.3 Issuance and retirement over time

In this section we examine how the time to issue and the time to retirement vary over time. For this purpose, instead of calculating the value-weighted averages over a given project, as in equation (1), we estimate them over a given year. Figure 17 plots the evolution of these averages from 2010 to 2024. We note that the issuance lag has an increasing trend from 2010 to 2024, from 1.91 years in 2010 to 4.36 years in 2021, and decreases sharply to 2.28 years in 2024. The increase in issuance lag seems to coincide with the expansion of the VCMs, but it could also be driven by other factors, like an increase in the rigour of the MRV processes. To test whether the growth of the VCM could be a factor, we estimate the correlation between the issuance lag and the number of new projects at different lead/lags. The results show that, in the period starting 2010, the correlation peaks to 56% and is statistically significant when we consider the number of new projects with a 2-year lead. Since the time before first issuance corresponds to the verification and certification processes, and this process takes around two years on average, this result suggests that the increase in the number of new projects to process could be driving the increase in issuance lag. In other words, it points to difficulties in scaling-up processes in the monitoring, verification and certification cycle.[54]

The retirement age exhibits a trend similar to that of the issuance lag, which is partially a consequence of longer issuance lags leading on average to longer retirement times. But the increase in retirement age is also a result of the accumulation of credits through time (which offers investors the choice of buying increasingly older credits) and of investors' preferences for older credits. To account for the effect of the issuance lag, we consider the trading life, which captures the difference between retirement age and issuance lag. We observe it increases from 0.54 years in 2010 to 2.15 years in 2024, capturing the credit accumulation effect. However, it does not have a constant positive trend, which suggests changes in investors' preferences. In particular, the decreasing trend observed in trading life between 2015 and 2021 suggests a preference for retiring credits closer to their issuance date.

Figure 17 Evolution of issuance lag and retirement age of carbon credits



This figure shows the issuance lag, the retirement age and the trading life from 2010 to 2024. Each of the variables is estimated as value-weighted averages over a given year.

[54] Of course, correlation does not imply causation. However, this result is consistent with the fact that the lack of automation and standardisation observed in these markets can only hinder scaling-up.

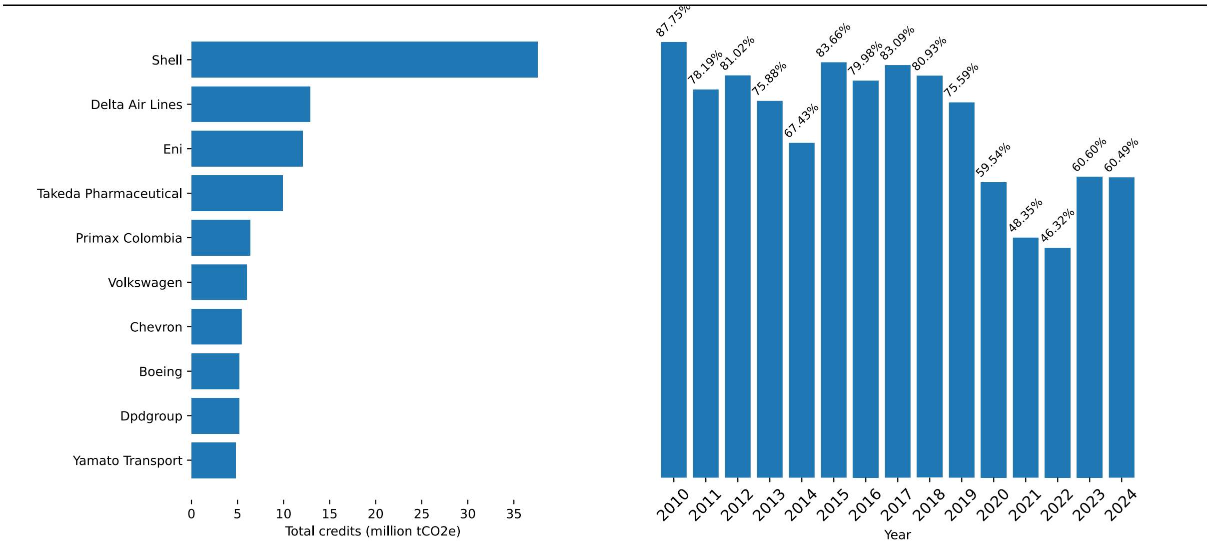
4.4 Retirement beneficiaries

The Voluntary Registry Offset database also includes information regarding the carbon credit retirement beneficiary,[55] which enables the identification of the major players in these markets.

The left panel in Figure 18 plots the top ten companies that have retired the most carbon credits. Most of these companies are from industries particularly sensitive to carbon policies, such as oil and gas, vehicle manufacturing, and airline companies. Shell significantly outperforms other companies, ranking first in carbon retirement with more than 35 million tCO2e in credits retired.

Next, we aggregate the total credits retired by the top ten beneficiaries of each year and calculate the percentage that their total credit retirement represents relative to the total credit retirement of that year. The right panel in Figure 18 plots the percentage of credits retired by the top ten beneficiaries each year, from 2010 to 2024. The carbon credits retirements have been concentrated among the large market players. Despite a declining trend in the proportion of carbon credits retired by the top ten beneficiaries, with the minimum proportion reaching 46.32%, close to half of the retirements are still attributed to these entities. The declining proportion of large end-users indicates an increase in the participation of smaller end-users in the carbon market.

Figure 18 Top ten companies for carbon credit retirement



The figure shows the top ten companies by carbon credit retirements. The quantity of retired carbon credits reflects the retirement by each beneficiary through projects registered in Verra, Gold Standard, American Carbon Registry, and Climate Action Reserve till the end of 2024.

The figure shows the total carbon credits retired by the top 10 beneficiaries as a percentage of the total credits retired each year. The top 10 retirement beneficiaries are ranked by their aggregate credit retirement each year.

[55] Verra provides information about the retirement beneficiaries, so we rely mainly on the retirement beneficiaries to extract the name of company/individual. For other projects, we use the retirement details to extract company/individual names.

5. Conclusions

The analysis of carbon offset projects in this report reveals several interesting trends in the credit issuance and retirement cycle in voluntary carbon markets.

Firstly, involvement in the voluntary carbon markets has been growing, with more than ten thousand projects initiated across 143 countries and around 2.26 billion carbon credits issued. From 2010 to 2021 the market experienced consistent expansion, with a peak in carbon credit issuance in 2021. However, from 2022 onwards, we observe a decline in carbon credit issuance, contrasting with a marginal increase in credit retirement. A further investigation into project scope dynamics reveals *Forestry & Land Use* and *Renewable Energy* projects as the primary contributors to carbon credit issuance. While both project types experienced a reduction in issuance from 2022 to 2024, *Household & Community* projects and *Chemical Process* projects demonstrated an expansion during the same period.

The geographical distribution of these projects reflects the asymmetries in the efforts in climate mitigation: Except for the United States (which is the major source of projects and credit issuances), developing countries from South Asia and Latin America contribute the majority of carbon projects and carbon credits.

If categorized by the method employed, reduction projects significantly dominate projects based on removal or mixed methods. Among the four voluntary registries, Verra leads in numbers of project registration and certification.

With regards to the efficiency in carbon credit issuance, on average, it takes 2.45 years form vintage to issuance date. However, this lag varies across project scope and registries. *Chemical Processes* projects demonstrate the fastest issuance, while *Transportation* projects encounter the longest delay. Projects registered with the Climate Action Reserve (CAR) exhibit the shortest time to issue, while those registered with Verra show the longest. Moreover, there is a trend of increasing issuance time, particularly noticeable after 2018, when the market was strongly expanding. This could point to either an increase in the complexity of the certification and verification processes or to the difficulties of scaling up these processes, or to both.

On average, the time from credit vintage year to retirement is 4.43 years, with *Household & Community* projects exhibiting the shortest retirement age and *Transportation* projects take the longest. As with issuances, the retirement age also varies by registry: projects registered with Gold Standard exhibit the fastest retirement process while projects with Verra incur the longest retirement times.

The retirement age is characterized by an upward trend, partially driven by the accumulation of credits but also by the increase in issuance lag. In terms of retirement quantities, more than 50% of retirements are of sizes smaller than 10 tCO_2e, suggesting a substantial participation from medium and small buyers of credits. We also observe a general declining trend in the proportional contribution from large end-users, particularly the top ten retirement beneficiaries. This suggests an increased diversification in market participation in voluntary carbon markets.

Moving forward, an analysis of the secondary market, particularly investor activities and price discovery, will be essential for a comprehensive understanding of the market.

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