# Decoding the Carbon Footprint Registry: Offsetting Practices within Spain's Voluntary Climate Disclosure Framework

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**Abstract**

This study examines the structure, functioning, and evolution of Spain's Carbon Footprint Registry, a government-led mechanism designed to promote voluntary climate disclosure, emissions reduction tracking, and carbon offsetting through domestic forest-based carbon removal projects. The Registry connects forest project developers supplying carbon offsets with organisations seeking to disclose, reduce, and compensate their greenhouse gas emissions. Drawing on a mixed-methods approach, the analysis combines quantitative data from the Registry covering the period 2014–2024 with qualitative evidence from in-depth interviews. It explores participation trends, determinants of organisational offsetting behaviour, patterns of carbon unit retirement, and stakeholder perceptions of the system's effectiveness and credibility. The results indicate steadily increasing participation, particularly among small and medium-sized enterprises. Length of participation in the Registry emerges as the strongest predictor of offsetting behaviour. While the propensity to offset is highest during the initial years of engagement, it continues to increase at a diminishing rate over time. At the project level, mixed conifer and broadleaf forest initiatives exhibit higher probabilities of carbon unit retirement compared with pure conifer or pure broadleaf stands, suggesting that project composition influences offset uptake, potentially through perceived co-benefits and environmental credibility. Despite these positive trends, overall offsetting activity remains limited, constraining the Registry's aggregate mitigation impact. Interviewed stakeholders highlight administrative bottlenecks, methodological constraints, and concerns regarding market credibility. The findings underscore the need for methodological refinement, strengthened governance, and closer alignment with emerging regulatory frameworks and integrity standards for carbon markets.

**Keywords**: Carbon footprint registry; Voluntary carbon markets; Forest-based offsets; Mixed-methods analysis; Offsetting behaviour.

**JEL**: Q50, Q56.

# 1 Introduction

Since the early 1990s, international negotiations have sought to develop effective responses to the threat of climate change, leading to major agreements such as the Kyoto Protocol and the Paris Agreement (Kuyper et al., 2018). The article 4 of the Agreement explicitly states the need to achieve a balance between anthropogenic emissions and greenhouse gas (GHG) removals by sinks in the second half of the $21^{st}$ century, laying the foundation for the global net-zero emissions commitment. As of mid-2024, 101 parties, representing 107 countries and about 82% of global GHG emissions, had formally adopted net-zero targets (UNEP, 2024). At the organisational level, this has translated into a rapid expansion of voluntary net-zero pledges by companies and institutions (SBTi, 2025).

The proliferation of climate neutrality commitments has been accompanied by the expansion of economic instruments aimed at incentivising GHG emissions mitigation and offsetting (Hickey et al., 2023; Kochar et al., 2025). These instruments encompass fiscal incentives and market-based mechanisms, such as carbon taxes, emissions trading systems, and carbon credit markets (World Bank, 2025). Globally, over 80 carbon pricing initiatives are currently in operation, covering approximately 28% of global GHG emissions and mobilising around USD 100 billion annually (World Bank, 2024, 2025). Among regulated mechanisms, the European Union Emissions Trading System (EU ETS) remains the most established. In parallel, Voluntary Carbon Markets (VCMs) have evolved as platforms through which organisations and individuals acquire credits outside regulatory frameworks, primarily to offset residual emissions and demonstrate progress towards climate targets (Probst et al., 2024).

Carbon markets are increasingly characterised by overlapping regulatory and voluntary systems and heterogeneous accreditation frameworks (World Bank, 2025). Credit supply originates from national schemes, independent standards (e.g. Verra, Gold Standard) (Haya et al., 2025), and mechanisms under the Paris Agreement, while demand is driven by compliance entities, airlines under CORSIA[1], sovereign buyers acquiring internationally transferred mitigation outcomes, and organisations pursuing voluntary net-zero goals (Broekhoff et al., 2019). Alongside international standards, several countries have established national-level mechanisms reflecting domestic approaches to voluntary carbon accounting and offsetting (Cevallos et al., 2019).

In Spain, two complementary instruments illustrate this national approach. The Spanish Carbon Fund for a Sustainable Economy (FES-CO2), created in 2011, supports emission reductions in non-ETS sectors by purchasing verified credits from domestic projects. In addition, the Ministry for the Ecological Transition and the Demographic Challenge (MITECO) established in 2014 the Carbon Footprint Registry (hereafter, The Registry), which is a government-led national mechanism for voluntary climate disclosure, emissions reduction tracking, and offsetting efforts (MITECO, 2024). The Registry enables organizations to offset emissions through validated domestic forested-based carbon removal projects, currently operationalised in two typologies: forest creation (through afforestation/reforestation (AR)), and post-wildfire forest restoration.

[1]Carbon Offsetting and Reduction Scheme for International Aviation, which is a global mechanism established by the International Civil Aviation Organization to mitigate carbon dioxide ($CO_2$) emissions from international flights (Larsson et al., 2019).

Unlike international VCM standards, the carbon units generated under the Registry do not constitute tradable credits, as they are non-transferable, lack financial asset status, and cannot be used for compliance in regulated markets. Their operation is confined to a domestic framework of validation and verification, resulting in a national mechanism for voluntary offsetting that is not aligned with emerging international integrity benchmarks (e.g. ICVCM, 2024), and with the requirements established under the EU Carbon Removal Certification Framework (CRCF) (European Parliament, 2024). Comparative assessments of carbon crediting initiatives (Delacote et al., 2024) highlight that unlike many international standards, the Registry does not ensure public access to detailed project documentation, provides no information on transactions or price signals, and lacks reporting on value distribution among actors. These transparency gaps limit traceability and external scrutiny, reducing the Registry's ability to demonstrate environmental integrity or align with recognised best practices.

Not surprisingly, participation in the Registry remains limited in practice. Between 2008 and 2024, only 6,055 organisations and individuals registered their carbon footprint at least once,representing less than 0.2% of all active firms in Spain, according to the Central Business Directory as of January 2024 (INE, 2024). Of these, merely 8% have proceeded to offset emissions through domestic projects. Such modest engagement may reflect the institutional and methodological constraints of the current framework, particularly the non-tradable nature of units and the absence of international recognition,which together diminish its perceived value and weaken incentives for participation.

Against this background, in which Spanish forests face persistent challenges of land abandonment, low economic profitability and limited access to finance (Lasanta et al., 2021; MITECO, 2022), the study offers a critical, evidence-based assessment of the Registry, its functioning, evolution and future prospects. The forestry sector is under pressure to sustain active management and improve financial viability, and is increasingly exploring new revenue streams beyond traditional timber markets, including participation in environmental markets, certification and carbon schemes (Chiti et al., 2024). In this context, the analysis also considers the Registry's performance and its potential future role within evolving regulatory frameworks (e.g., European Parliament, 2024).

To address this objective, the study adopts a mixed methods approach that captures both the quantitative evolution of the Registry and the qualitative perspectives of the actors shaping its operation. This approach is increasingly used in studies of voluntary carbon markets, as it allows quantitative market data to be combined with qualitative insights into stakeholder behaviour, governance, and institutional dynamics (e.g., Birchall et al., 2016; Koronka et al., 2022; Lou et al., 2023).

The analysis therefore integrates publicly available Registry data with in-depth interviews involving stakeholders engaged in, or influencing, both the demand and supply of carbon units, as well as the Registry's management. In addition to descriptive and institutional assessment, the study formally examines the determinants of organisational offsetting behaviour. Complementarily, at the carbon removal project level, it analyses the likelihood of carbon unit retirement as a function of project characteristics. Together, these quantitative models and qualitative insights provide a comprehensive evaluation of the Registry's structure, performance, and future prospects. They allow us to identify not only participation patterns and stakeholder perceptions, but also the institutional and technical factors shaping offset uptake and carbon unit use, thereby clarifying the conditions under which the Registry may effectively contribute to climate action and the revitalisation of the forestry sector.

The results show that participation in the Registry has increased steadily since its creation, particularly among small and medium- sized enterprises (SMEs), reflecting growing engagement with voluntary climate disclosure. However, offsetting remains limited, creating an imbalance between the expanding supply of forest-based carbon removal projects and the relatively low demand for carbon units, even though many organisations view offsetting as part of broader net-zero strategies (Morales and Ovando, 2025). The analysis indicates that offsetting is strongly associated with organisational experience within the Registry and broader engagement in emissions management, while the retirement of carbon units depends on project characteristics such as forest composition and project maturity. Strengthening methodological tools, transparency, and the integration of carbon projects with sustainable forest management could enhance the Registry's credibility and its capacity to mobilise both supply and demand for forest-based mitigation.

# 2 Institutional background: Key aspects of the Carbon Footprint Registry

## 2.1 Regulatory framework and operational features

The Carbon Footprint Registry, created by Royal Decree (RD) 163/2014 and amended by RD 214/2025, operates as a voluntary framework for greenhouse gas disclosure, emissions monitoring, and carbon offsetting in Spain (Spanish Government, 2025). Participating entities are required to report direct (Scope 1) and energy-related indirect emissions (Scope 2), while the reporting of other indirect emissions (Scope 3)—covering upstream and downstream value-chain activities—remains voluntary.[2] Together, Scope 1 and Scope 2 emissions are referred to as operational emissions.

Carbon footprint estimates must generally undergo independent verification, although exemptions apply to SMEs, public administrations, and non-profit organisations that use official emission factors. Registered organisations receive the *Calculate* label. The *Calculate+Reduce* label is awarded to entities that demonstrate a verified downward trend in emission intensity over at least four consecutive years, based on comparisons of three-year moving averages (MITECO, 2025a).

The *Calculate+Offset* label recognises organisations that offset part or all of their operational emissions through carbon units generated by domestic removal projects listed in the Registry. No minimum offsetting requirement is imposed, and organisations may combine carbon units from multiple projects (MITECO, 2024). Historically, eligible projects have focused on afforestation and post-wildfire restoration. RD 214/2025 expands the scope of eligible activities to include additional carbon removal categories such as blue carbon and product-based carbon storage, although

[2]Under Spanish legislation transposing Directive 2014/95/EU and subsequently Directive (EU) 2022/2464 on corporate sustainability reporting (CSRD), large companies and certain public-interest entities must disclose material Scope 3 emissions as part of their non-financial or sustainability reporting obligations.

detailed technical guidelines for these activities remain under development (Spanish Government, 2025).

Eligible carbon removal projects must be located in Spain and cover at least one hectare, although smaller plots may be aggregated. Projects must reach a minimum canopy cover of 20% and a potential tree height of at least 3 m, and must have been established after the 2012/2013 planting season. In addition, each project requires a management plan, the use of the official *ex-ante* carbon calculator, and a permanence commitment of at least 30 years (MITECO, 2024).

Following project establishment, developers must demonstrate the legal rights to the carbon removals generated. Under current rules, only 20% of the total expected removals can initially be issued as carbon units, of which 10% are allocated to a buffer pool to mitigate reversal risks. Monitoring reports must be submitted every five years (MITECO, 2024). Additional units beyond the initial 20% are intended to be issued through verified *ex-post* calculations. However, as of mid-March 2026 this mechanism remains inactive due to the absence of an approved methodology for *ex-post* accounting.

## 2.2 Stakeholder structure and interactions

The ecosystem surrounding the Registry and the forest-based carbon removal projects linked to it involves several categories of actors interacting throughout the lifecycle of carbon compensation activities (Figure 1). These actors collectively shape both the demand for carbon units and the supply of carbon removal projects, yielding these carbon units.

First, the Registry managers—represented by the Spanish Climate Change Office (OECC) within the Ministry for the Ecological Transition and the Demographic Challenge (MITECO)—are responsible for the operational management of the Registry and the development of its regulatory and methodological framework. In this role, the OECC acts as both regulator and system coordinator. Second, organisations that calculate and register their carbon footprint represent the primary demand-side actors. These include companies of various sizes, public administrations, non-profit organisations, and occasionally individuals. Registered entities may voluntarily acquire carbon units generated by domestic removal projects to offset part or all of their operational emissions.

On the supply side, landowners play a key role, including communal forest associations, public landowners such as municipalities, regional governments, and other public institutions, as well as, to a lesser extent, private landowners. In many cases, landowners transfer the carbon removal rights generated on their land to project promoters, although some act directly as project developers. Project promoters constitute another important actor group. They are responsible for structuring and coordinating carbon removal initiatives, organising project financing, ensuring compliance with Registry requirements, and establishing agreements with landowners to secure the rights to register carbon removals. In some cases, promoters also participate directly in project design and implementation. Finally, forest project developers or forestry service companies often act as specialised intermediaries within the system. These actors provide technical expertise, including forest planning, land management, preparation of documentation, and support during the registration process. They frequently facilitate collaboration between landowners and project

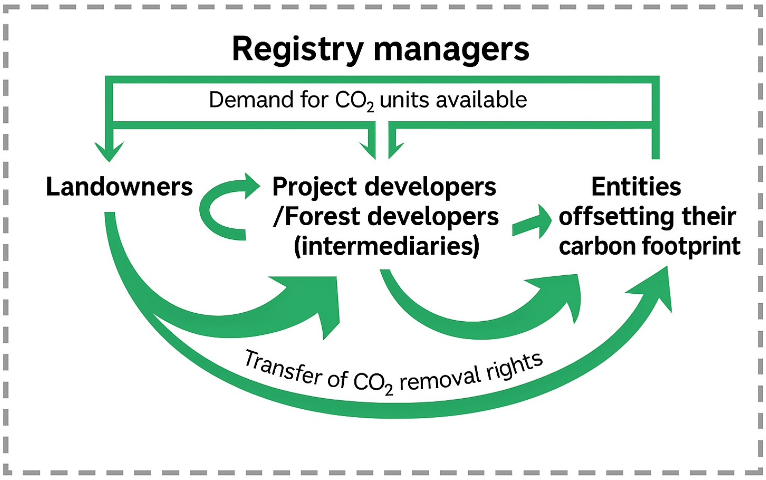


Figure 1: Internal Registry stakeholders and their interactions concerning the supply and demand of carbon units

promoters, thereby contributing to the technical and administrative feasibility of carbon removal projects.

Together, these actors form the institutional architecture of the Registry and shape the functioning of the associated carbon removal market. While the Registry defines the regulatory framework and eligibility criteria, the transactions linking carbon unit supply and demand are largely organised through private bilateral agreements. These contracts determine key elements such as the allocation of carbon removal rights, project responsibilities, and financial conditions. However, contract terms—particularly carbon unit prices—are not publicly disclosed, limiting transparency regarding the economic functioning of the system.

# 3 Materials and methods

## 3.1 Registry data compilation and processing

The quantitative component of this study draws on public information from the Registry, updated to July 2025. The dataset comprises three components: (i) registered carbon footprints, (ii) carbon offset transactions, and (iii) carbon removal projects. The first dataset includes information on registered entities, such as official name, tax ID, sector, type (independent worker, public entity, firm or non-profit), organisational size (micro, small, medium and large enterprises), year of registration, and the official label obtained each reporting period. It also includes data on total reported emissions, disaggregated, where available, into Scope 1+2 and Scope 3 emissions, as well as the percentage reduction achieved and the proportion of emissions offset (MITECO, 2025b).

The second dataset contains information on carbon offset transactions. For each participating entity, it specifies the year carbon footprint is offset, the carbon removal project used, and the volume of retired carbon removals (in (metric) tonnes of $CO_2$) (MITECO, 2025c). Each transaction is linked to a unique identifier for the retired units and records the percentage of the registered footprint that was offset. The dataset also includes the date of compensation, and an internal project reference code. The third dataset details information on registered carbon removal projects. Each project is identified by a unique project code, together with its name, location (municipality, province, and region), and surface area (in hectares) (MITECO, 2025d). It specifies the expected carbon removals over the permanence period, the available (issued) units, the retired units allocated to compensation, and the units assigned to the carbon buffer pool. Additional fields include the developer and contact details, the registration date, and a short project description. In most cases, descriptions provide basic information such as the species used (though without indication of their proportional relevance in the plantation mix), the type of project (AR or post-fire restoration), and, in some cases, the techniques employed for woodland expansion (for instance, natural regeneration or plantation). However, there is no standardised format for these descriptions, and in several cases the project type or species mix is not specified.

All datasets were systematically cleaned and harmonised. This process involved identifying and removing duplicate records, standardising organisational names across the databases, and connecting offset transactions with project records through unique retired carbon unit identifiers and carbon removal project codes. Furthermore, project descriptions were examined individually to classify, in broad terms, the forest typologies (native forest, monoculture plantations, or mixed forests) and the type of intervention. Descriptions were also used to estimate the total area with presence of different forest species.

## 3.2 Modelling offsetting and carbon units retirement

This analysis draws on two complementary datasets derived from publicly available Registry records. The first contains organisation-level information on carbon footprint registration and compensation activities, and is used to assess the determinants of organisational offsetting behaviour. The second comprises project-level data on registered carbon removal initiatives and associated carbon units, enabling the examination of factors linked to the retirement of issued units.

Descriptive statistics are employed to characterise participation patterns at both organisational and project levels, including temporal trends in registrations, the distribution of entities and projects across sectors, regions, and size categories, and the main attributes of reported footprints and carbon removal activities.

Special attention was given to identifying the determinants of organisational offsetting behaviour. Differences across entity size categories were analysed using statistical procedures aligned with the measurement scale and distributional properties of the variables under consideration. For pairwise comparisons between organisations that engage in offsetting and those that do not, we employed the Wilcoxon rank-sum test (Mann and Whitney, 1947). This non-parametric approach is appropriate for skewed continuous variables, as it relies on rank information rather than distributional assumptions and is robust to right-skewness and extreme values, which characterise the emissions data. One-sample Wald tests for binomial proportions were applied to compare subgroup-specific proportions with the overall Registry proportion. The tests were conducted for binary indicators, including whether an entity undertakes emission reductions and whether it engages in offsetting. This approach relies on standard large-sample normal approximation methods for inference on a single proportion relative to a reference value (Agresti, 2013).

To analyse organisational offsetting behaviour, a series of logistic regression models were estimated, a standard empirical approach for examining engagement and disclosure decisions (Brammer and Pavelin, 2006; Frost et al., 2023). A stepwise selection procedure was employed to derive a parsimonious specification of the probability of offsetting (Derksen and Keselman, 1992). The modelling strategy began with a broader set of theoretically motivated predictors and retained only those variables that contributed incremental explanatory power when evaluated jointly. The dependent variable is binary and indicates whether an entity undertook compensation activities. Alternative specifications were estimated to assess robustness and progressively account for organisational characteristics and emissions profiles. Years of participation in the Registry were included to capture potential exposure and learning effects[3], thereby distinguishing structural differences across organisational types from experience-related dynamics.

A separate logistic model was estimated to examine the determinants of carbon units retirement from registered carbon removal projects, where the binary dependent variable indicates whether carbon units had been retired by a buyer. In this case, project-level variables such as forest type, apparent forest stand age (in years)[4], project size (in hectares), expected unit carbon removal (in $tCO_2$ per year and hectare), and project duration (in years) were included as covariates. Non-linearities were tested through quadratic and logarithmic transformations of key variables (e.g. apparent stand age). All models were estimated with robust standard errors to account for potential heteroscedasticity.

After model estimation, several diagnostic tests were conducted to assess model fit and predictive performance. The confusion matrix and the percentage of correctly classified observations were used to evaluate the models' ability to discriminate between outcome categories. Model calibration was examined using the Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow, 1980), while discriminative capacity was assessed through the Receiver Operating Characteristic (ROC) curve and the corresponding Area Under the Curve (AUC) statistic.[5] (Mandrekar, 2010). In addition, the link test (Pregibon, 1980) was employed to detect potential functional form misspecification. All logistic models and diagnostic tests were implemented in Stata 17.

## 3.3 Analytical integration of quantitative and qualitative evidence

The qualitative analysis examined stakeholder perceptions of the functioning of the Registry across five main dimensions. It explored the motivations for participation and preferences regarding forest-based carbon removal projects, assessed the administrative and operational performance of the system, and analysed the effectiveness of the technical tools and methodologies used to estimate and certify carbon removals.

[3] A piecewise linear spline for years in the Registry, with a knot at three years, was implemented to allow the effect of participation duration on the probability of compensation to differ before and after this threshold.

[4] Tree age is estimated assuming that the project starts in the year of registration. While this assumption may hold for some projects, it does not necessarily apply to all, as projects established after the 2012/2013 planting season may also be registered.

[5] Following conventional criteria, AUC values above 0.7 were considered indicative of acceptable discrimination, values above 0.8 of good discrimination, and values above 0.9 of excellent discrimination (Hosmer and Lemeshow, 2000)

It also examined financing arrangements, ownership and transaction practices related to carbon units, and gathered stakeholder perspectives on future challenges and priorities for improving the system.

This qualitative evidence complements the quantitative analysis of Registry data by providing insights into the behavioural and institutional mechanisms underlying the observed patterns. While the econometric models identify statistical relationships between organisational and project characteristics and the likelihood of offsetting or carbon unit retirement, the interviews help explain how organisational motivations, administrative constraints, and perceptions of market credibility shape these outcomes.

The qualitative component is based on 25 semi-structured interviews conducted with stakeholders representing the main actor groups involved in the operation of the Registry (Table A1 in the Appendix). Stakeholders were identified through a mapping exercise grounded in established approaches to stakeholder analysis (Bonke and Winch, 2002; Selman, 2004). Following Selman (2004), actors were first distinguished according to their motivations, separating demand- and supply-side participants with economic interests (Figure 1) from actors motivated primarily by environmental integrity or governance concerns. They were subsequently classified as internal or external depending on their relationship with the Registry. Internal stakeholders were those directly involved in generating, validating, or retiring carbon units, identified through the Registry's regulatory framework and public data. External stakeholders included organisations providing guidance, technical support, or broader influence on forest-carbon initiatives (Bonke and Winch, 2002). Additional external actors were identified through a snowball procedure whereby initial interviewees suggested further relevant participants (Luyet et al., 2012).

Sampling strategies were adapted to the characteristics of each stakeholder group (Reed, 2008). On the supply side, organisations acting as project promoters or developers were identified through purposive sampling (Palinkas et al., 2015). Among 35 organisations contacted, 14 interviews were conducted with landowners and project developers (DF#), with particularly strong participation from forestry service companies involved in project development and management. On the demand side, organisations registered in the Registry were stratified by type and size, prioritising those with higher offsetting activity following stratified sampling approaches. Approximately 30 invitations resulted in six interviews with companies that offset their emissions (EM#). To broaden the range of perspectives, additional interviews were conducted with organisations capable of influencing the sector (GI#), including forestry associations, certification bodies, and environmental NGOs. Of the ten organisations contacted in this group, six agreed to participate.

Interview transcripts were analysed using an inductive thematic approach (Thomas, 2006). Transcripts were first generated using speech-recognition software and subsequently verified manually against the recordings. Statements were then coded and grouped into thematic categories corresponding to the analytical dimensions described above. This procedure allowed the identification of recurring patterns in stakeholder perceptions and facilitated comparisons across actor groups. In the results section, selected quotations are presented to illustrate stakeholder perspectives and to provide contextual explanations for the patterns identified in the quantitative analysis. The conduct and processing of in-depth interviews received prior approval from the institutional ethics committee (CE: 057/2023).

# 4 Results and discussion

## 4.1 Participation and climate disclosure patterns

By the end of July 2025, 6,055 entities (including appoximately 70 individuals) had registered at least one annual GHG emissions report between 2014 and 2024, generating a total of 15,322 records. The analysis includes, 5,792 entities (approximately 92%), which report absolute Scopes 1 and 2 emissions, measured in equivalent tonnes of carbon dioxide (t $CO_2$e)[6]. Only a 12% of those entities report Scope 3 emissions (Table 1). Most participating entities in the Registry fall within the SME category, which includes micro-firms with fewer than 10 employees, small firms with 10 to 49 employees, and medium-sized firms with 50 to 249 employees. Among these, small firms constitute the largest group of registered entities, followed by medium-sized and micro-firms. Large firms, defined as those employing 250 or more workers, represent a smaller share of participants, while public administrations and non-profit organisations form distinct but numerically limited categories.

Table 1 documents marked heterogeneity across entity types in terms of registration patterns, emissions profiles, and mitigation engagement. Average annual operational emissions (i.e. Scope 1+2) increase monotonically with firm size, with large firms reporting emissions that are many orders of magnitude higher than those of micro-, small-, and medium-sized firms. Larger entities also exhibit longer participation histories in the Registry, consistent with earlier and more sustained engagement in voluntary climate disclosure. Clear size-related gradients are also observed in mitigation behaviour. The prevalence of verified emission reduction efforts rises steadily with firm size, from roughly one quarter among micro and small firms to over 41% among large firms. A similar pattern holds for offsetting, which remains uncommon among smaller entities but is substantially more frequent among large firms and non-profit organisations. Public administrations display intermediate levels of participation in reduction efforts but comparatively low engagement in offsetting.

These size-related differences translate into a strong concentration of both emissions and mitigation activity among a limited number of large entities. Cumulated reported emissions amount to approximately 3,490 million (M) t$CO_2$e, of which about 26% correspond to operational emissions (913 Mt$CO_2$e). Although companies represent the vast majority of participants (92%), with SMEs accounting for 77% of registered entities considered, their contribution to aggregate Scope 1+2 emissions remains marginal. Large companies, representing about 14% of entities account for 95.5% of Scope1+2 emissions, whereas SMEs contribute just 3.1% (Figure A1 in the Appendix). Together, the table-level and aggregate evidence underscore the disproportionate role of large firms within the Registry, as they dominate reported emissions and show higher engagement in mitigation efforts, thereby shaping both the scale and direction of observed climate action outcomes.

Consistent with the strong concentration of emissions and mitigation activity among a relatively small number of large entities, participation in the Registry remains low: only around 2.2% of public entities (MHFP, 2025) and less than 0.2% of active firms (INE, 2024) have ever registered . This limited uptake is particularly pronounced among smaller organisations, which dominate participation numerically but account

[6] A total of 306 entities were excluded from the analysis, as they reported only relative carbon footprints (e.g., emissions expressed per unit of revenue) or did not report any emissions (43 cases), thereby limiting comparability across observations.

Table 1: Number of entities, time registered, annual emissions, and mitigation efforts by type

| Group | N. registered[‡] | Average years | Annual emissions SCs 1+2[∓] | Annual emissions Total[∓] | Share of entities (%) reducing | Share of entities (%) offsetting | Share of entities (%) SC3 |
|---|---|---|---|---|---|---|---|
| Micro-firm[⊤] | 506 | 1.9 (1.8) | 133 (1,597) | 268 (3,364) | 23.3* | 7.7 | 2.2* |
| Small-firm[⊤] | 1,977 | 2.2 (1.9) | 385 (3,912) | 650 (5,854) | 24.2* | 4.0* | 9.0 |
| Medium-firm[⊤] | 1,655 | 2.6 (2.1) | 3,256 (58,133) | 3,995 (58,901) | 32.3 | 8.0 | 8.7* |
| Other-firms[⊤] | 322 | 2.0 (1.9) | 5,253 (51,591) | 12,087 (116,669) | 28.4* | 6.6* | 6.2* |
| SME | 4,460 | 2.3 (2.0) | 1,773 (38,146) | 2,673 (47,883) | 29.0* | 7.1* | 6.9* |
| Large-firm | 810 | 3.6 (2.7) | 115,423 (1,390,716) | 463,682 (6,076,207) | 41.5* | 17.0* | 46.0* |
| Public admin. | 400 | 2.5 (2.3) | 4,096 (15,859) | 4,590 (17,694) | 32.8 | 3.0* | 4.8* |
| Non-profit | 79 | 3.2 (2.7) | 384 (1,459) | 516 (2,106) | 39.2 | 15.2 | 15.2 |
| All entities | 5,749 | 2.5 (2.2) | 17,928 (524,327) | 67,730 (2,285,574) | 31.1 | 8.3 | 12.4 |

Notes: [⊤]Micro to medium-sized firms, and other firms are classified as SME. [‡]Number of entities that report absolute greenhouse gas emissions. [∓]GHG emissions are measured in $tCO_2e$, for Scopes (SC) 1+2 and Total emissions including in addition Scope 3 emissions. Standard deviations are reported in parentheses. *Indicates statistical significance ($p < 0.01$) of differences in group mean share values relative to the average share of all entities registered (using one-sample tests for proportions).

for only a minor share of reported emissions.

Even with this restricted coverage the volume of Scope 1+2 emissions reported through the Registry is substantial. This share represented around 30% of national emissions during 2014–2018 and declined to roughly 20% in 2019–2022 (Figure A2 in the Appendix). The drop to 13% in 2023 is likely explained by reporting delays, especially among smaller entities with shorter registration histories, since Registry submissions for that year were still incomplete at the time of analysis.

Participation patterns also helped interpret the temporal evolution of reported emissions. While the number of registered carbon footprints rose steadily between 2014 and 2022, the average emissions per registered organisation declined markedly, from 331.9 thousand (k) $tCO_2e$ in 2014 to 19.3 $ktCO_2e$ in 2022. Over the same period, national GHG emissions fell by 13%, compared to a 96% reduction in the mean footprint of registered entities. This suggests that organisations participating in the Registry have, on average, reduced their emissions more rapidly than the national trend. The pattern also reflects the progressive entry of organisations with smaller emission profiles, as participation expanded beyond the larger emitters that had dominated the early years of the Registry.

The interviews explored the motivations that lead organisations to participate in the Registry. A frequently cited reason was a commitment to sustainability and climate responsibility, with several organisations (EM2, EM3 and EM6) noting that participation forms part of broader corporate strategies to reduce emissions and align with environmental and conservation policies. Several organisations (EM1, EM3, EM5 and EM6) also highlighted that participation increases the visibility of their climate efforts and helps communicate these actions to stakeholders at national and international levels. Registry labels were mentioned as one mechanism supporting this visibility, although some respondents noted that participation mainly serves communication purposes and offers limited practical advantages (EM1).

From a more instrumental perspective, several organisations also highlighted the potential competitive advantages associated with the Registry. EM4 and EM5 pointed to benefits such as preferential access to public procurement and the use of the compensation label as a commercial differentiator. At the same time, interviewees emphasised the value of internal recognition. For instance, EM6 noted that participation in the Registry has helped raise employee awareness and strengthen internal engagement with sustainability initiatives.

## 4.2 Determinants of carbon offsetting

Overall participation in offsetting remains limited: only 8.2% of Registry participants partially offset their direct carbon footprints between 2013 and 2023. Substantial and statistically significant differences emerge across entity types (Table 1). Large firms and third-sector organisations exhibit markedly higher participation in offsetting, with shares of approximately 17% and 15%, respectively, both significantly above the Registry average. By contrast, offsetting is significantly less prevalent among SMEs (around 7%) and public administrations (about 3%).

Beyond participation rates, among the 477 entities that undertook any offsetting effort, the average the scale of offsetting also differs substantially by firm size. For the SMEs that undertook offsetting (315 cases), the estimated average volume of retired carbon offsets was 55 $tCO_2$ (±16), equivalent to about one third (35.4%) of their operational emissions over 2013–2023. By contrast, large firms that undertook offsetting (138) retired, on average, 421.0 $tCO_2$ (±397.8), which represents about 6.6% of their operational emissions.

An analysis of differences in operational emissions between organisations that offset and those that do not reveals heterogeneous patterns across entity types (Table 2). Across all categories, entities engaging in offsetting (Group 1) show substantially longer participation in the Registry than non-offsetters (Group 0), with differences ranging from around two additional years among SMEs to more than three years among large firms and public administrations. Offsetters also exhibit systematically higher recognised reduction effort levels, particularly among SMEs and large firms, where average reduction shares are roughly twice those observed among non-offsetting entities.

However, this pattern should not be interpreted as evidence of intrinsically stronger mitigation behaviour among offsetters. Instead, higher recognised reduction efforts largely reflect longer participation in the Registry, as the certification of reductions requires verified declines in emission intensity sustained over at least three consecutive years (see Section 2.1). Consequently, organisations with longer registration histories are more likely both to qualify for recognised reductions and to engage in offsetting. This suggests that offsetting is associated with greater continuity and maturity of engagement within the Registry. In this context, the positive relationship between Registry tenure and the likelihood of offsetting is consistent with organisational learning and institutional embedding effects, whereby firms gradually expand their climate strategies as they accumulate experience with carbon accounting and disclosure systems (Lou et al., 2023).

Table 2: Differences in operational emissions and mitigation efforts by entity type and offsetting status

| Entity type | Offset status† | N. observations | Years‡ | Emissions and mitigation efforts† | | | |
|---|---|---|---|---|---|---|---|
| | | | | SC 1+2 | Total | Effort levels (%) | |
| | | | | | | reduc. | offset |
| SMEs | 0 | 4,145 | 2.13** (1.77) | 1,842** (39,541) | 2,784** (49,642) | 3.0** (9.8) | |
| | 1 | 315 | 4.21** (2.92) | 866** (5,347) | 1,223** (5,816) | 6.6* (18.9) | 35.4 (39.1) |
| Large firms | 0 | 672 | 3.19** (2.37) | 132,831 (1,525,867) | 543,618** (6,667,625) | 5.8** (17.4) | |
| | 1 | 138 | 5.90** (3.01) | 30,649 (94,235) | 74,428** (302,273) | 10.9** (25.1) | 6.6 (17.8) |
| Public admin. | 0 | 388 | 2.32** (2.13) | 3,976** (15,988) | 4,443** (17,784) | 3.1* (9.4) | |
| | 1 | 12 | 7.50** (2.43) | 7,956** (10,638) | 9,345** (14,305) | 3.4* (3.7) | 12.3 (29.8) |
| Non-profits | 0 | 67 | 2.73** (2.49) | 227 (413) | 277 (492) | 3.5* (8.3) | |
| | 1 | 12 | 5.67** (2.81) | 1,261 (3,617) | 1,854 (5,263) | 5.9* (11.1) | 27.3 (37.4) |
| All entities | 0 | 5,272 | 2.28** (1.93) | 18,675 ( 547,304) | 71,812** (2,386,191) | 3.3** (11.1) | |
| | 1 | 477 | 4.82** (3.05) | 9,671 (52,520) | 22,622** (165,594) | 7.8** (20.6) | 26.3 (36.4) |

Notes: †Offsetting status, with Group 0 indicating non-offsetting entities and Group 1 indicating offsetting entities. 2025.‡ Number of years disclosing emissions in the Registry. †Average registered Scope (SC) 1+2 and Total SC 1+2+3 emissions by entity type and offsetting status in $tCO_2$ and year. Effort levels are estimated based on the proportion of SC 1+2 emissions that are reduced and offset. $^{*}p < 0.1$ and $^{**}p < 0.01$ indicate statistical significance for intergroup differences, which are measured based on a two-sample Wilcoxon rank-sum (Mann–Whitney) test. Standard deviations are reported in parentheses.

These descriptive patterns were further corroborated by a multivariable logistic regression analysis (Table 3). The dependent variable is a binary indicator of whether the organisation undertook compensation. Model 1 includes entity type, years of participation in the Registry (entered linearly), total registered emissions (in logarithmic form as $\ln tCO_2e$)[7], recognised reduction intensity, defined as the share of operational emissions reduced, and a dummy variable indicating whether Scope 3 emissions were reported. Model 2 extends this framework by modelling years of participation using a piecewise linear specification with a knot at three years.

Table 3 reports average marginal effects from the logistic regression models, interpreted as changes in the log-odds of undertaking compensation. Across both speci-

[7]The log transformation of emissions was motivated by their strongly right-skewed distribution.

fications, entity type, years in the Registry, emission scale, reduction intensity, and Scope 3 reporting emerge as significant predictors of offsetting behaviour. Large firms exhibit a significantly higher probability of offsetting than SMEs. In both models, being a large firm increases the probability of offsetting by approximately 6%. In contrast, public administrations are around 4% less likely to offset relative to SMEs. No statistically significant difference is observed for non-profit organisations. The consistency of these effects across models indicates that the results are not sensitive to the alternative specification of years in the registry.

In this sense, years in the Registry (tenure) represent the strongest predictor of offsetting. In the linear specification (Model 1), each additional year of participation increases the probability of offsetting by approximately 2.6%. These results suggest that organisations with longer Registry tenure may be more familiar with reporting procedures, more embedded in climate governance networks, or subject to greater reputational incentives, all of which could increase the likelihood of engaging in offsetting activities.

When years in the registry are modelled as a piecewise linear specification with a knot at three years. The results indicate a substantially stronger effect during the first three years of participation (approximately 5.2% per year), followed by a more moderate but still significant increase thereafter (around 2.1% per additional year). This pattern suggests that offsetting propensity rises sharply during early engagement with the Registry and continues to grow at a slower pace with longer tenure.

Emission scale, measured as the logarithm of total registered emissions, is negatively associated with offsetting. A one-unit increase in log emissions reduces the probability of compensation by roughly 1 percentage point, holding other factors constant. Although statistically significant, the magnitude of this effect is comparatively modest. Reduction intensity, by constraint, is positively associated with offsetting, though the marginal effect is also small in absolute terms: a one-percentage-point increase in recognised reduction effort raises the probability of compensation by approximately 0.08%. This suggests that offsetting complements internal mitigation efforts rather than substitutes for them. Finally, organisations that report Scope 3 emissions are about 4–5% more likely to offset, indicating that compensation is more prevalent among entities exhibiting broader disclosure practices and more comprehensive engagement with emissions accounting.

Overall model performance is satisfactory. Both specifications yield pseudo-$R^2$ values between 0.16 and 0.17 and AUC values close to 0.80, indicating good discriminatory capacity. Diagnostic tests, including the Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow, 1980) and the link test (Pregibon, 1980), provide further insight into model adequacy. The linear specification exhibits evidence of functional form misspecification, whereas the piecewise formulation of registry tenure resolves this issue. Allowing the effect of participation duration to vary before and after three years therefore provides a more appropriate representation of the underlying data-generating process.

Nevertheless, the results should be interpreted with some caution. Offsetting remains a relatively infrequent outcome, meaning that conventional measures of predictive accuracy may overstate model performance, as correct classifications are disproportionately driven by non-compensating entities. Although discrimination is good (AUC $\approx$ 0.80), predictive performance should therefore not be interpreted

Table 3: Determinants of emission offsetting: Logit model, AME

| Variable | Model 1 | | Model 2 | |
|---|---|---|---|---|
| | AME | 95% CI | AME | 95% CI |
| Offsetting dummy | | | | |
| Large firm (ref: SME) | 0.0599*** | [0.033 ; 0.087] | 0.0591*** | [0.033 ; 0.085] |
| Public admin. (ref: SME) | -0.0399*** | [-0.059 ; -0.021] | -0.0376** | [-0.058 ; -0.017] |
| Non-profits (ref: SME) | 0.0269 | [-0.032 ; -0.087] | 0.0263 | [-0.030 ; -0.083] |
| Ln total $tCO_2e$/year | -0.0096*** | [-0.013 ; -0.006] | -0.0107*** | [-0.014 ; -0.007] |
| Reduction intensity (%) | 0.0008*** | [-0.0004 ; -0.0012] | 0.0008*** | [-0.0004 ; -0.0012] |
| Scope 3 dummy | 0.0469** | [0.020 ; 0.074] | 0.0460*** | [0.020 ; 0.072] |
| Registered years (total) | 0.0267*** | [0.024 ; 0.030] | | |
| Spline 1 ($\leq$ 3 years) | | | 0.0525*** | [0.043 ; 0.062] |
| Spline 2 (> 3 years) | | | 0.0207*** | [0.020 ; 0.072] |
| Observations | 5,749 | | 5,749 | |
| Pseudo $R^2$ | 0.1622 | | 0.1711 | |
| AUC | 0.7937 | | 0.7965 | |

Notes: AME denotes Average Marginal Effects obtained from logistic regression models. In Model 1, years in the Registry enter linearly. In Model 2, years in the Registry are specified as a piecewise linear function with a knot at three years. CI: reports confidence intervals at 95%. * $p < 0.05$; ** $p < 0.01$; ***$p < 0.001$.

as evidence of a fully specified behavioural model. Moreover, while the spline corrects the primary functional-form limitation identified in the linear specification, the possibility of additional non-linearities or interaction effects—particularly with respect to emissions scale or organisational characteristics—cannot be entirely ruled out. Accordingly, the estimated coefficients should be interpreted as associational evidence rather than as a complete structural account of offsetting behaviour.

Qualitative evidence from stakeholder interviews helps contextualise these patterns by shedding light on how organisations approach offsetting decisions in practice. Interviewees differed in how they balance emission reductions and offsetting, emphasising that offsetting should complement internal mitigation efforts. EM2 stressed that emission reductions should remain the priority, with offsetting used only where alternatives are limited. Other respondents also pointed to practical constraints affecting offsetting strategies, particularly the limited availability of projects in some regions. As EM6 explained: “In the Basque Country there are only two registered projects and one of them no longer has available absorptions [...] the number of units we offset is usually small because of the price.” These constraints also point to the relevance of the supply side of the system, particularly the availability and characteristics of carbon removal projects capable of generating units for compensation.

## 4.3 Project portfolio and characteristics

By the end of 2024, a total of 1,092 active projects[8] encompassed 22,923 ha, of which about 71% corresponded to newly planted forest and 29% to post-fire restoration. Over a 30–50 year horizon, these projects are expected to generate more than 9.7 $MtCO_2$ in lifetime carbon removals, equivalent to roughly 16% of the aggregate 2022 Scope 1+2 emissions reported by Registry participants. This estimate remains subject to future *ex post* adjustments, for which no public data are currently available. The volume of carbon units issued available for compensation across registered

[8]Thirteen projects, covering 335.1 ha, were deregistered by the end of 2024 due to fires, high mortality, or voluntary withdrawal.

projects amounted to 1.7 $MtCO_2$, representing about 17% of the total *ex ante* estimated carbon removal potential.

The descriptive statistics in Table 4 provide further insight into the main characteristics of these projects. On average, projects are relatively small in scale, covering about 21 ha, with considerable variability across initiatives. Project duration is typically long-term, averaging around 41 years. At the time of registration, projects are generally at an early stage of development, with an average (apparent) tree age of only 2.6 years. In terms of carbon outcomes, projects are expected to generate on average 8,912 $tCO_2$ of lifetime removals, of which roughly 1,546 $tCO_2$ have been issued as available carbon units for compensation. However, only a relatively small share of these units has been retired to date, averaging about 129 $tCO_2$ per project, and only 22% of projects have recorded any carbon unit retirement. The average annual carbon removal rate reaches about 11.2 $tCO_2$ $ha^{-1}$ $year^{-1}$. Around one quarter of projects are promoted by firms, suggesting that corporate actors play a relevant, though not dominant, role in the development of forest-based carbon removal initiatives within the Registry.

Table 4: Descriptive statistics of forest-based carbon project characteristics‡

| Variable (unit) | Mean | SD | 95% Conf. interval | |
|---|---|---|---|---|
| Project area (ha) | 21.0 | 26.4 | 19.4 | 22.6 |
| Project duration (years) | 41.00 | 7.8 | 40.5 | 41.5 |
| Apparent tree age (years) | 2.6 | 1.6 | 2.5 | 2.7 |
| Total $CO_2$ (t) | 8,912 | 19,764 | 7,740 | 10,085 |
| Issued $CO_2$ (t) | 1,546 | 3,571 | 1,334 | 1,758 |
| Retired $CO_2$ (t) | 128.9 | 659.1 | 89.8 | 168.0 |
| C removal rate (t $CO_2$ $ha^{-1}$ $y^{-1}$) | 11.2 | 14.7 | 10.4 | 12.1 |
| Total number of species planted (N) | 2.0 | 2.0 | 1.9 | 2.1 |
| Number of native species (N) | 1.7 | 1.9 | 1.6 | 1.8 |
| Binary variables | Share of projects (%) | | Share of area (%) | |
| Retired $CO_2$ (Yes=1) | 22 | | 20 | |
| Monoculture (Yes=1) | 7 | | 4 | |
| Only native species (Yes=1) | 78 | | 77 | |
| Galicia (Yes=1) | 53 | | 50 | |
| Project promoted by a firm (Yes=1) | 24 | | 19 | |

‡Includes carbon removal projects registered up to 31 December 2024 (N = 1,092). SD: Standard deviation.

The project portfolio also exhibits clear structural patterns. Plantations typically involve a limited number of species—around two on average—while a large majority of projects rely exclusively on native species (78%). Species distribution, measured as the total area in which each species is present regardless of its share within mixed stands, is highly concentrated (Figure A3 in the Appendix). *Pinus pinaster* dominates the portfolio, accounting for about 40% of the planted or restored area, followed by *P. sylvestris* (around 20%) and *Eucalyptus* spp. (about 12%). Other taxa—such as *Quercus ilex*, *Q. faginea*, *Betula* spp., *P. pinea*, *P. nigra*, and *Juniperus* spp.—represent smaller shares, generally below 10%. Differences across species also emerge in project scale and spatial distribution. Some species appear across many small initiatives, while others are concentrated in fewer but larger projects. For instance, *Castanea sativa* is present in 424 projects with an average area of only

3.3 hectares per project, indicating a dispersed pattern. By contrast, *P. pinaster* appears in just 53 projects but with a much larger average area of about 177 hectares per project.

These patterns are broadly consistent with insights from interviews with forest developers. Respondents emphasised that species selection is mainly driven by local ecological conditions and the objective of promoting multifunctional forest systems. A recurrent theme was the preference for native and locally adapted species. As DF12 noted: "Always native species that fit the site [...] the idea of a resilient, biodiverse native forest." Ecological factors such as altitude, slope orientation and soil characteristics were frequently mentioned as key determinants guiding species selection (DF4, DF10, DF11).

Projects are also geographically concentrated, with more than half of projects and planted or restored area located in Galicia, indicating a strong territorial clustering of Registry-based carbon removal activities (Figures A4 and A5 in the Appendix). The largest areas are found in Ourense and Pontevedra (each exceeding 4,400 ha), followed by Huelva and Lugo, while most other provinces host substantially smaller areas, often below 1,500 ha. Conifer-dominated stands account for the largest share of project area, exceeding 40% in Galicia, Extremadura and Murcia. Mixed broadleaf–conifer stands are especially prominent in Castilla y León, Aragón and Navarra, whereas pure broadleaf stands dominate in Andalusia and the Canary Islands.

Interviews also revealed an ongoing debate between monoculture plantations and more diverse forest systems. Several respondents advocated mixed-species plantations and management approaches that enhance biodiversity and ecosystem services. DF2 described its experience by stating: "Our forest is multifunctional [...] we also carried out social planting initiatives." Similarly, GI2 argued that carbon payments could encourage more diverse projects compatible with ecosystem conservation, including improved forest management and the protection of existing forests.

## 4.4 Determinants of carbon unit retirement

Despite the progressive expansion of forest-based carbon removal projects within the Registry, the effective mobilisation of issued carbon units remains limited. By end-2024, cumulative retirement of carbon units reached 140.7 kt$CO_2$, corresponding to only 8.3% of the issued units. Retirements allocate units to specific beneficiaries for $CO_2$ equivalent compensation, with traceability regarding the owner, date, and compensation period, thereby converting potential carbon removals into auditable offset. Although the overall retirement rate remains relatively limited in aggregate terms, understanding the factors associated with the likelihood of retirement is essential to assess how project characteristics may influence the actual mobilisation of issued units.

To this end, a project-level logistic model (based on 993 valid observations)[9] was estimated to assess the likelihood of carbon unit retirement as a function of forest type (monocultures, mixed conifers, mixed broadleaves, and mixed conifers and broadleaves), apparent age and its quadratic term ($age^2$), log-transformed area, annual carbon removal per hectare, project duration and its quadratic term ($duration^2$),

[9] Projects for which species type and composition were undefined were excluded from the analysis.

number of native species, and whether the project developer (promotor) is a firm that directly retires the issued carbon units for its own compensation purposes. Stepwise selection retained mixed forest types, age terms, log-transformed area, and project duration, yielding a parsimonious specification.

The results of this specification highlight several project characteristics associated with the likelihood of carbon unit retirement. Based on the average marginal effects reported in Table 5, forest composition plays an important role. Projects with mixed forest structures exhibit significantly higher probabilities of carbon unit retirement than monoculture plantations. In particular, mixed conifer and mixed conifer and broadleaf stands increase the probability of retirement by about 19%, while mixed broadleaf increase it by roughly 11%.

Table 5: Average marginal effects for the likelihood of carbon unit retirement

| Variable | AME (SE)‡ | 95% Conf. interval |
|---|---|---|
| Retirement dummy | | |
| Broadleaf (BL) mix (ref: MONC.†) | 0.114* (0.054) | [0.009 ; 0.219] |
| Conifers (CF) mix (ref: MONC.) | 0.191*** (0.057) | [0.080 ; 0.302] |
| Mixed BL & CF (ref: MONC.) | 0.195*** (0.026) | [[0.143 ; 0.247] |
| ln(Area) (in hectares) | -0.026* (0.010) | [-0.046 ; -0.005] |
| Age (years) | 0.196*** (0.019) | [0.159; 0.233] |
| $\text{Age}^2$ ($\text{years}^2$) | -0.013*** (0.002) | [-0.016 ; -0.009] |
| Duration (years) | -0.004*(0.002) | [-0.007 ; -0.001] |
| Observations | 993 | |
| Pseudo $R^2$ | 0.2837 | |
| AUC | 0.8511 | |

Notes: ‡AME denotes Average Marginal Effects obtained from logistic regression model. Delta-methods standard error (SE) are reported in parenthesis.
†MONC. represents conifer or broadleaf mono-specific plantations as the reference category for the forest type categorical variable.
*p < 0.05; **p < 0.01; ***p < 0.001.

Project age also emerges as a significant determinant. The positive coefficient for apparent age and the negative coefficient for its quadratic term indicate a hump-shaped relationship, suggesting that retirement probabilities peak at intermediate stages of project development. In contrast, project size and duration are negatively associated with retirement probability, as larger projects and those with longer planned durations show slightly lower likelihoods of carbon unit retirement.

The logistic specification exhibits good predictive performance, with an AUC of 0.851. The model also achieves strong classification results, with a specificity of 93.1% and an overall accuracy of 82.1% (see Table A3 in the Appendix).

Taken together, these results indicate that although the Registry has generated a sizeable portfolio of forest-based carbon removal projects, the effective demand for carbon units remains limited. Similar imbalances between credit supply and actual demand have been observed in voluntary carbon markets globally, where the rapid expansion of carbon removal projects has often outpaced organisations' willingness to purchase offsets (Kochar et al., 2025; Hickey et al., 2023).

At the same time, projects characterised by mixed forest structures and intermediate stand ages appear more likely to mobilise issued carbon units. Insights from stakeholder interviews help contextualise these patterns by highlighting how organisations select projects for compensation. Several respondents indicated that project design and management practices influence buyer preferences, particularly when organisations seek initiatives that combine carbon sequestration with broader environmental benefits. In this regard, some project developers noted that buyers tend to favour projects based on native species and responsible forest management practices (DF7, DF8, DF10).

Interviews also highlighted the importance of project location in shaping offsetting strategies. Several organisations (EM5 and EM6) emphasised the advantages of investing in projects located within Spain, particularly reforestation initiatives on degraded land or land under their ownership. EM5 stressed the ecological and social benefits of such projects: "The logical thing is to reforest your own land, especially since there are many possibilities to do so [...] it also creates local employment, which we considered essential."

This preference for locally based projects was also mentioned by EM1 and GI5. The latter collaborates with forest developers in priority areas identified by MITECO, supporting reforestation initiatives using native species and involving local communities. As GI5 explained: "These organisations establish agreements with volunteers and local residents so that reforestation uses species that naturally occur in that area." However, some organisations adopt a more flexible strategy, combining domestic and international offsetting options (EM4).

## 4.5 Institutional and operational constraints of the Registry

Although most respondents recognised the Registry as a valuable voluntary instrument supporting climate mitigation and forest restoration, many pointed to operational barriers that constrain its effectiveness. Common concerns included bureaucratic delays during project validation, extensive documentation requirements, and difficulties communicating with the responsible authorities within MITECO. As one project developer noted, the process is "simple but extremely time-consuming" (DF6). Several respondents also highlighted limitations in institutional capacity. In practice, some actors reported learning to navigate the system through trial and error. As one forest developer explained, "you move forward step by step, making mistakes and learning along the way" (DF1). Uncertainties in procedural requirements were also mentioned, particularly regarding land classification criteria used to demonstrate that plots had not been forested prior to the reference year established in the methodology (DF9). Long validation times were frequently cited as a major obstacle, with some projects reportedly taking more than a year to complete the process (GI6). Some interviewees also questioned restrictions embedded in the current framework, such as the exclusion of urban or peri-urban areas from eligibility for carbon removal projects (DF7).

Interviewees also discussed the performance of several technical instruments underpinning the Registry, including the *ex ante* carbon calculator, the system of verification and validation, and the carbon guarantee fund. The *ex ante* calculator was generally considered a useful tool for estimating potential carbon removals and facilitating project planning, particularly by providing early estimates that can support project financing. However, several respondents criticised its technical assumptions, highlighting the lack of geographic differentiation and the limited consideration of site-specific conditions. As one interviewee noted, the tool should distinguish more clearly between ecological zones, for example between northern and Mediterranean areas (DF3). Others questioned the inclusion of certain non-native species, arguing that species selection should prioritise ecological suitability and long-term sustainability (GI1, GI4).

The verification and validation system was also perceived as an area requiring improvement. Some respondents raised concerns regarding the clarity of current procedures and the capacity to ensure effective long-term monitoring of projects over the 30–50 year commitment period. Several interviewees therefore suggested strengthening monitoring mechanisms and introducing independent technical oversight to verify that project commitments are fulfilled (DF10).

Finally, the carbon guarantee fund, designed to cover risks associated with project failure, was viewed with some uncertainty. Several respondents reported confusion regarding its scope and the types of risks it actually covers, while others noted that regulatory provisions had changed repeatedly, creating uncertainty for project developers (DF5). Many stakeholders therefore emphasised the need for clearer rules and more robust risk-management mechanisms to ensure long-term project security.

Ensuring the environmental integrity of the system was nevertheless considered essential. Several stakeholders emphasised that carbon credits must demonstrate robust additionality in order to maintain credibility. As one business representative stated, "additionality is fundamental—we must be demanding" (EM2). At the same time, others argued that certification procedures should be sufficiently flexible to accommodate a wider diversity of project types and territorial conditions (EM4).

## 4.6 Future perspectives and recommendations

Interviewees described a variety of financing arrangements supporting forest carbon projects, including public subsidies, corporate social responsibility initiatives, voluntary carbon credit purchases, and hybrid funding models. In many cases, offsetting activities are embedded within broader corporate sustainability strategies, while local authorities sometimes use carbon projects to finance environmental restoration initiatives. Two main financing structures emerged from the interviews. The first involves direct corporate investment in projects in exchange for carbon units, while the second consists of mixed public–private financing schemes. Although these arrangements may help mobilise resources for forest restoration, some stakeholders raised concerns about their implications for additionality and market integrity (GI1). Ownership of carbon units was also widely discussed. Several respondents argued that forest landowners should retain rights to the carbon credits generated on their land in order to incentivise participation and support sustainable forest management (GI2, GI3). As one participant noted, society should recognise and remunerate the environmental services provided by forest ecosystems (GI3).

Companies' preferences also influence compensation strategies. Some firms prioritise projects located near their operations, while others select projects primarily based on the cost per tonne of $CO_2$. As one interviewee explained, "a firm might choose a project close to its headquarters or simply go for the cheapest tonne" (DF8). Despite the growing interest in these arrangements, respondents highlighted persistent constraints, including limited financial resources, regulatory uncertainty, and coordination challenges among stakeholders.

Beyond financing considerations, interviewees identified several priorities for improving the effectiveness of the Registry. A first area concerns *methodological innovation*. Several participants suggested expanding the range of eligible project types to include other nature-based solutions such as wetland or grassland restoration, as well as incorporating indicators that capture biodiversity and ecosystem services (EM3, EM4). Some also advocated greater flexibility at the regional level to better reflect ecological and administrative differences across Spain (GI6).

A second priority relates to *long-term forest management*. Respondents stressed that reforestation projects require continuous management to ensure their ecological integrity and carbon sequestration performance. As one developer noted, "a reforestation without management makes no sense" (DF1). Legal and administrative barriers, particularly regarding long-term commitments by public entities, were also identified as potential obstacles (DF4).

Interviewees also emphasised the need to strengthen *professional capacity and technical expertise*. Several respondents pointed to shortages of specialised knowledge and limited communication between forestry professionals and policymakers. Improving technical supervision and ensuring that innovative practices are implemented under appropriate professional oversight were considered important steps.

Finally, *market credibility and governance* emerged as central concerns. Several stakeholders warned that speculation, administrative bottlenecks, and insufficient transparency could undermine trust in the voluntary carbon market. Strengthening traceability and certification systems was therefore considered essential. As one interviewee emphasised, "the final user must perceive that the process is impeccable" (GI3). Business representatives also stressed that offsetting should be used only for residual emissions after substantial internal decarbonisation efforts (EM1, EM2). At the institutional level, respondents highlighted the need for clearer procedures, stronger coordination among actors, and harmonised national standards to avoid regulatory fragmentation across regions.

## 4.7 Implications for voluntary carbon markets and forest carbon initiatives

Taken together, the evidence presented in this study suggests that the Spanish Carbon Footprint Registry reflects broader dynamics observed in voluntary carbon markets. Participation in offset markets depends not only on the availability of carbon removal projects but also on the credibility of certification systems, the transparency of governance arrangements, and the strategic motivations of participating organisations (Kochar et al., 2025; Delacote et al., 2024). In this context, the limited demand for carbon units observed in the Registry is consistent with wider findings indicating that organisations tend to engage cautiously in offset markets, particularly where institutional incentives are limited or where transparency regarding project performance and transactions remains constrained.

At the organisational level, the results also align with studies showing that participation in voluntary carbon initiatives often develops gradually as firms accumulate experience with emissions accounting and climate governance mechanisms (Lou et al., 2023). The positive association between Registry tenure and offsetting behaviour suggests the presence of learning effects and institutional embedding processes. Organisations that progressively develop internal capacities for carbon accounting and disclosure may therefore be more likely to integrate offsetting into broader decarbonisation strategies.

From the supply-side perspective, the higher probability of carbon unit retirement observed for mixed forest projects is consistent with evidence that buyers increasingly value projects delivering benefits beyond carbon sequestration (e.g., Lee et al., 2018; Triana and Ota, 2024; Morales and Ovando, 2025). Research on forest carbon initiatives indicates that biodiversity, ecosystem resilience, and broader landscape restoration outcomes can influence the perceived credibility and attractiveness of carbon projects (Koronka et al., 2022). These preferences reflect the growing importance of environmental co-benefits in voluntary carbon markets, where organisations often seek initiatives aligned with wider sustainability objectives.

More broadly, the findings highlight the potential role of carbon offset mechanisms as complementary instruments for supporting sustainable forest management. In Europe, forest sectors frequently face structural challenges related to low profitability and limited investment in long-term management. Carbon markets and carbon farming schemes are increasingly viewed as potential financial mechanisms capable of mobilising additional resources for forest restoration and ecosystem management (Chiti et al., 2024). However, realising this potential requires institutional frameworks that effectively link climate mitigation objectives with credible governance arrangements and robust monitoring systems.

Overall, the Spanish Registry represents an important institutional experiment in integrating voluntary climate disclosure with domestic forest-based carbon removal initiatives. Strengthening its methodological tools, transparency, and governance could enhance its credibility and stimulate greater participation from both project developers and organisations seeking to offset emissions. As voluntary carbon markets continue to evolve globally, domestic mechanisms such as the Registry may play an increasingly relevant role in connecting organisational climate commitments with nature-based mitigation opportunities.

# 5 Conclusions

This study analysed the functioning of Spain's Carbon Footprint Registry by combining quantitative evidence on disclosure, offsetting behaviour and project characteristics with qualitative insights from stakeholder interviews. The results show that the Registry has expanded steadily since its creation, particularly among SMEs, reflecting growing engagement with voluntary climate disclosure. However, the effective use of carbon units remains limited, revealing a clear imbalance between the growing supply of forest-based carbon removal projects and the relatively weak demand for offsets among participating organisations.

The quantitative analysis helps clarify the factors shaping this imbalance between supply and demand. On the demand side, offsetting remains relatively uncommon among participating organisations and tends to occur mainly among entities with longer participation in the Registry, stronger mitigation engagement, and broader emissions disclosure practices. This suggests that compensation activities are concentrated among organisations with greater experience in carbon accounting and more developed climate strategies. On the supply side, the likelihood that carbon units are effectively retired depends on several project characteristics. Projects with mixed forest structures and intermediate stand ages exhibit higher probabilities of unit retirement. These patterns indicate that both organisational demand for offsets and the design and maturity of carbon removal projects influence the effective mobilisation of carbon units within the Registry.

The qualitative analysis helps explain these patterns. Interviews indicate that organisations generally view offsetting as a complement to internal mitigation efforts rather than a substitute for emissions reductions. Stakeholders also emphasised the importance of local and ecologically adapted projects, often favouring initiatives that combine carbon sequestration with broader environmental and social benefits. At the same time, respondents pointed to institutional and operational constraints that limit the effectiveness of the Registry, including administrative complexity, methodological limitations in technical tools, and uncertainties regarding long-term project management and risk coverage.

Several priorities for strengthening the system emerged from the interviews. Stakeholders emphasised the need to better integrate carbon projects with sustainable forest management to ensure long-term ecological performance. They also highlighted the importance of improving key technical tools, particularly the carbon calculator, monitoring procedures, and risk management mechanisms, to enhance transparency and usability. In addition, reinforcing the credibility of the Registry through clearer procedures, stronger verification systems, and better coordination among public and private actors was considered essential to build trust and stimulate demand for carbon units.

Overall, these findings suggest that the Registry could play a more significant role in Spain's climate mitigation strategy by linking voluntary carbon disclosure with nature-based solutions and sustainable forest management. Strengthening its technical foundations and institutional credibility will be key to increasing participation and enabling the system to contribute more effectively to national decarbonisation objectives.

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# Appendix: Supplementary Results

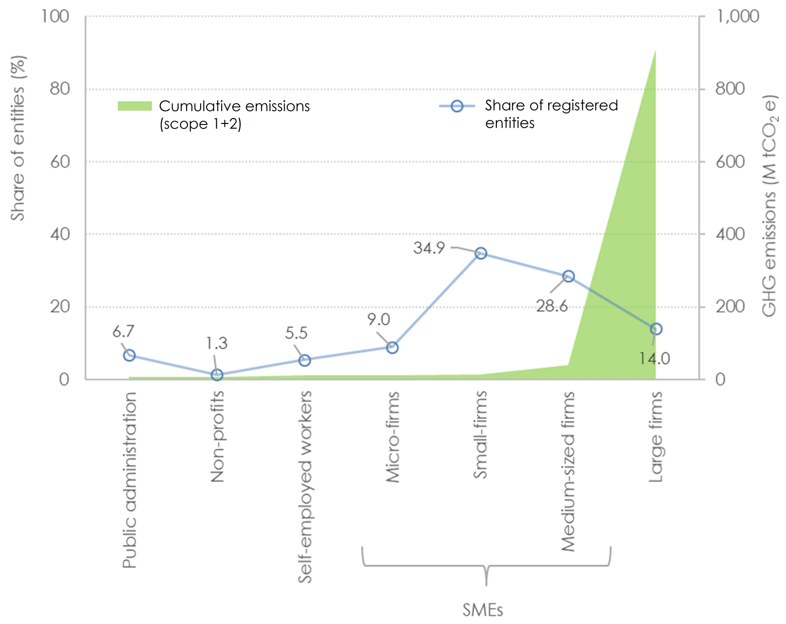



Figure A1: Distribution of entities by category and responsibility for cumulative registered operational emissions (Scopes 1+2) (2008–2023)

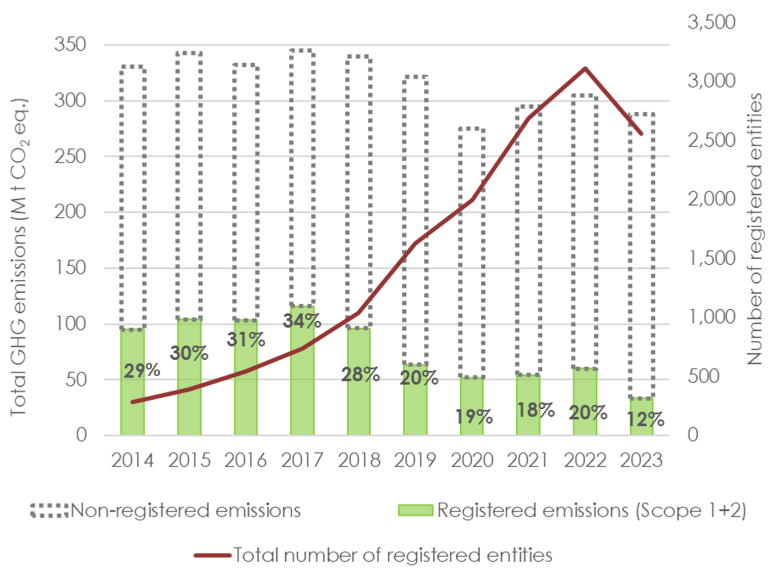
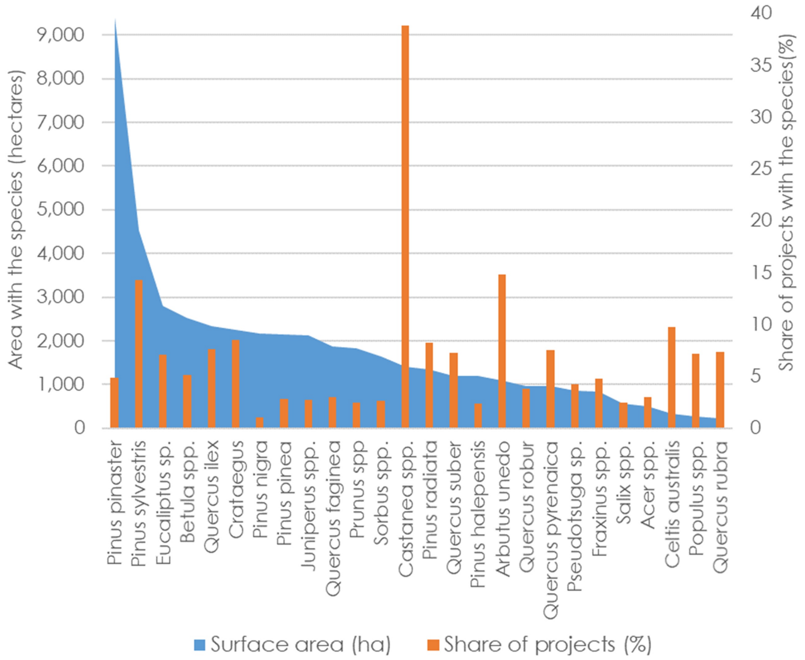
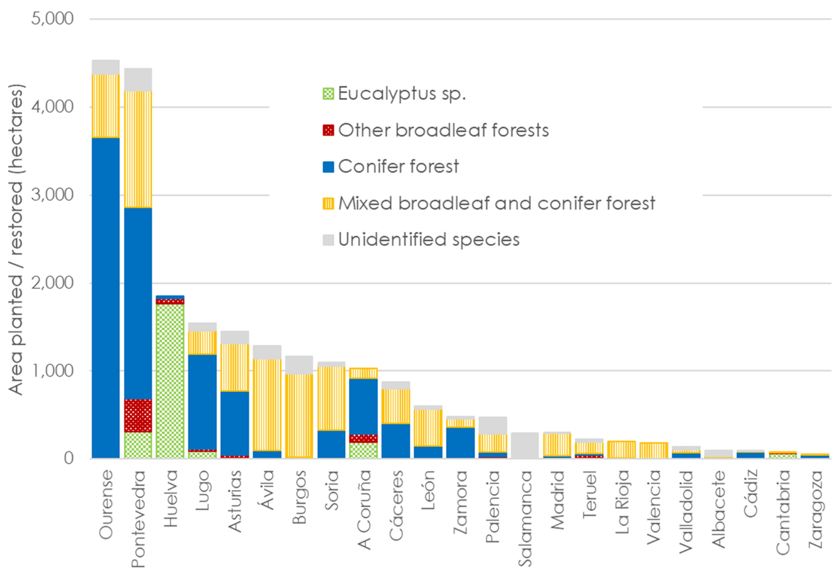



Figure A2: Trends in registered and unregistered operational emissions (Scopes 1+2), national GHG-emission shares, and registered entities in Spain




*Note:* *The presence of a species refers to the number of hectares in which that species was planted, but not necessarily in mono-specific stands; therefore, multiple species may have been planted within the same hectare.

Figure A3: Distribution of forest species presence* across planted or restored areas in forest carbon removal projects




*Note:* Only provinces with 50 or more hectares of carbon removal projects are included.

Figure A4: Distribution of planted or restored areas by Spanish province and type of forest

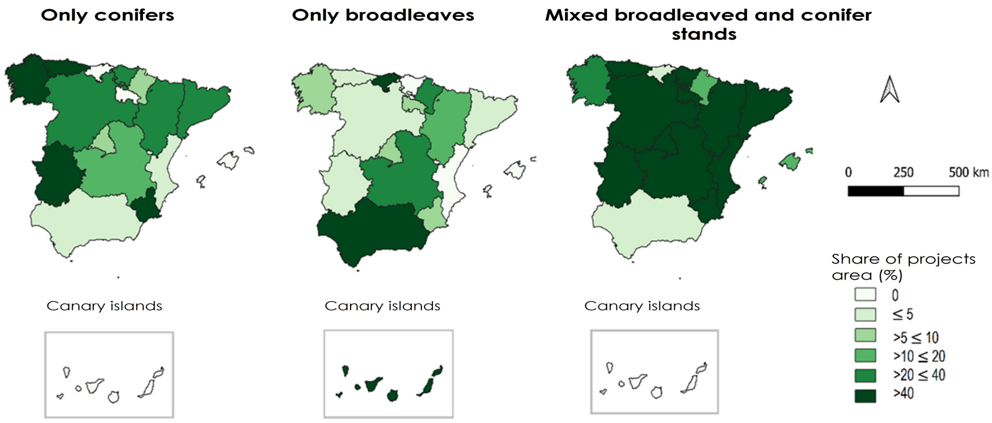



Figure A5: Share of carbon removal projects area by forest type and Autonomous Community (aggregated data for the period 2014–2024)

Table A1: Interviewees participating in the qualitative analysis

| Code | Stakeholder category | Type of organisation |
|---|---|---|
| DF1 | Landowner / developer | Forestry management company |
| DF2 | Landowner / developer | Communal forest association |
| DF3 | Landowner / developer | Forestry service company |
| DF4 | Landowner / developer | Forestry foundation |
| DF5 | Landowner / developer | Forestry association |
| DF6 | Landowner / developer | Private forest owner |
| DF7 | Landowner / developer | Municipality |
| DF8 | Landowner / developer | Forestry service company |
| DF9 | Landowner / developer | Forestry service company |
| DF10 | Landowner / developer | Forestry service company |
| DF11 | Landowner / developer | Regional public administration |
| DF12 | Landowner / developer | Forestry service company |
| EM1 | Entity | Organisation offsetting emissions |
| EM2 | Entity | Organisation offsetting emissions |
| EM3 | Entity | Organisation offsetting emissions |
| EM4 | Entity | Organisation offsetting emissions |
| EM5 | Entity | Organisation offsetting emissions |
| EM6 | Entity | Organisation offsetting emissions |
| GI1 | Influence group | Forestry association |
| GI2 | Influence group | Forestry association |
| GI3 | Influence group | Certification body |
| GI4 | Influence group | Environmental NGO |
| GI5 | Influence group | Forestry association |
| GI6 | Influence group | Forestry cooperative |

Table A2: Logistic Regression Results (Odds Ratios) for offsetting behaviour within the Registry

| Variable | Model 1[(3)] | | Model 2[(3)] | |
|---|---|---|---|---|
| | OR | Robust SE | OR | Robust SE |
| Offsetting dummy | | | | |
| Constant | 0.0410*** | 0.0048 | 0.0208*** | 0.0036 |
| Large firm[(1)] | 2.0943*** | 0.3065 | 2.0861*** | 0.2983 |
| Public admin. [(1)] | 0.4058** | 0.1221 | 0.4400** | 0.1309 |
| Non-profit [(1)] | 1.4880*** | 0.5619 | 2.2270*** | 0.1647 |
| Ln tot. GHG emiss. | 0.8682*** | 0.0212 | 0.8548*** | 0.0211 |
| Reduction intensity (%) | 1.0123*** | 0.0033 | 1.0129*** | 0.0033 |
| Scope 3 = 1 | 1.8142*** | 0.2873 | 1.7948*** | 0.0036 |
| Registered years | 1.5064*** | 0.0340 | | |
| Years spline 1 ($\leq 3$) | | | 2.2270*** | 0.1647 |
| Years Spline 2 ($> 3$) | | | 1.3687*** | 0.0373 |
| Observations | 5,792 | | 5,792 | |
| Log-likelihood | -1,380.91 | | -1,366.00 | |
| Pseudo $R^2$ | 0.1619 | | 0.1710 | |
| AUC | 0.7932 | | 0.7963 | |
| Specificity[(2)] | 0.734 | | 0.814 | |
| Overall accuracy[(2)] | 0.734 | | 0.800 | |
| Youden´s J (J-cutoff)[(2)] | 0.466 | | 0.459 | |

Notes: Odds ratios (OR) are reported from logistic regression models. *p < 0.05; ** p < 0.01; ***p < 0.001.
[(1)]The reference category for firm type is SME (Small and Medium-sized Enterprise).
[(2)]Classification statistics (specificity and overall accuracy) are computed using the Youden J–maximising cut-off, defined as the threshold that maximises the joint performance of sensitivity and specificity (Youden, 1950).
[(3)]In Model 1, years in the Registry enter linearly. In Model 2, years in the Registry are specified as a piecewise linear function with a knot at three years.

Table A3: Logistic Regression Results (Odds Ratios) for forest-based carbon unit retirement within the Registry

| Variable | Odds ratio[‡] | Robust SE |
|---|---|---|
| Retirement dummy | | |
| Broadleaf (BL) mix (ref: MONC.[†]) | 2.578* | 1.010 |
| Conifers (CF) mix (ref: MONC.) | 4.268*** | 1.598 |
| Mixed BL & CF (ref: MONC.) | 4.372*** | 0.873 |
| ln(Area) (in hectares) | 0.806** | 0.071] |
| Age (years) | 5.127*** | 0.894 |
| Age$^2$ (years$^2$) | 0.899*** | 0.0148 |
| Duration (years) | 0.970* | 0.012 |
| Constant | 0.018*** | 0.010 |
| Observations | 993 | |
| Log-likelihood | -377.07 | |
| Pseudo $R^2$ | 0.2837 | |
| AUC | 0.8511 | |
| Specificity[(‡)] | 0.931 | |
| Overall accuracy[(‡)] | 0.821 | |

Notes: *p < 0.05; ** p < 0.01; ***p < 0.001.
[†]MONC. represents conifer or broadleaf mono-specific plantations as the reference category for the forest type. [(‡)]Classification statistics (specificity and overall accuracy) are estimated using a cut-off of 0.5, , whereby observations with predicted probabilities equal to or greater than 0.5 are classified as positive outcomes.