Seeing the forest from the trees

A global analysis of the Afforestation, Reforestation and Revegetation project landscape in the voluntary carbon markets.

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Executive Summary.

A major global effort to restore degraded land is needed to achieve ambitious forest and landscape restoration goals. Not only does restoring forested areas offer a strategy for drawing down atmospheric carbon dioxide, mitigating climate change, but will safeguard essential ecosystem services, from regulating water resources to filtering the air we breathe.

Afforestation/Reforestation/Revegetation (ARR) projects, both passive and active, offer tangible solutions to facilitate landscape restoration, and the voluntary carbon market provides an essential tool to bring financial capital to these initiatives at scale.

We analysed data from 200+ projects registered with international voluntary carbon programmes to assess the current market landscape. As part of this analysis, we classified ARR approaches into three core groups: Native ARR, Mixed-Species ARR and Exotic ARR.

In addition to the insights summarised below, the analysis identified the need to review the type of ARR project eligible for carbon certification; a significant portion of projects are planting non-native species, employing timber harvesting, and not monitoring co-benefits. These projects deliver limited biodiversity benefits and have weak additionality claims.

Looking forward, there is a need to promote community-centred native restoration projects that plant richer species diversity than at present.

Trends	Reduction in ARR projects since 2019	**48%** Of ARR projects are employing timber harvesting	Since 2016, the greatest ARR activity has occurred in China
Positives	**160%** Increase in ARR projects since 2010	Increased % projects planting Native Species	Increase of larger scale Native ARR projects (>10,000 ha)
Room for Improvement	**88%** Projects planting less than 10 native species	**18%** Native ARR projects planting 10 or more species	**32%** Projects exclusively planting exotic species

Contents.

The need to restore our forests.

In an era defined by the twin crises of climate change and biodiversity loss, native reforestation stands as a powerful and essential solution. This ecological approach of restoring forests is gaining momentum worldwide, as it addresses not only the urgent need to sequester carbon but also the imperative to protect and restore biodiversity.

While projections suggest a deceleration in global forest loss by 2030[1], it is important to note that the rate of biodiversity decline may not follow a corresponding trend. This discrepancy arises from the partial mitigation of natural forest loss through the expansion of planted forests. Moreover, the true impacts on biodiversity remain inadequately quantified, primarily due to the inability to directly offset forest habitat losses in tropical regions with forest gains in other ecological zones[2]. It's worth noting that even if the productivity of planted forests increases, this improvement may come at the cost of a reduced richness in biodiversity.

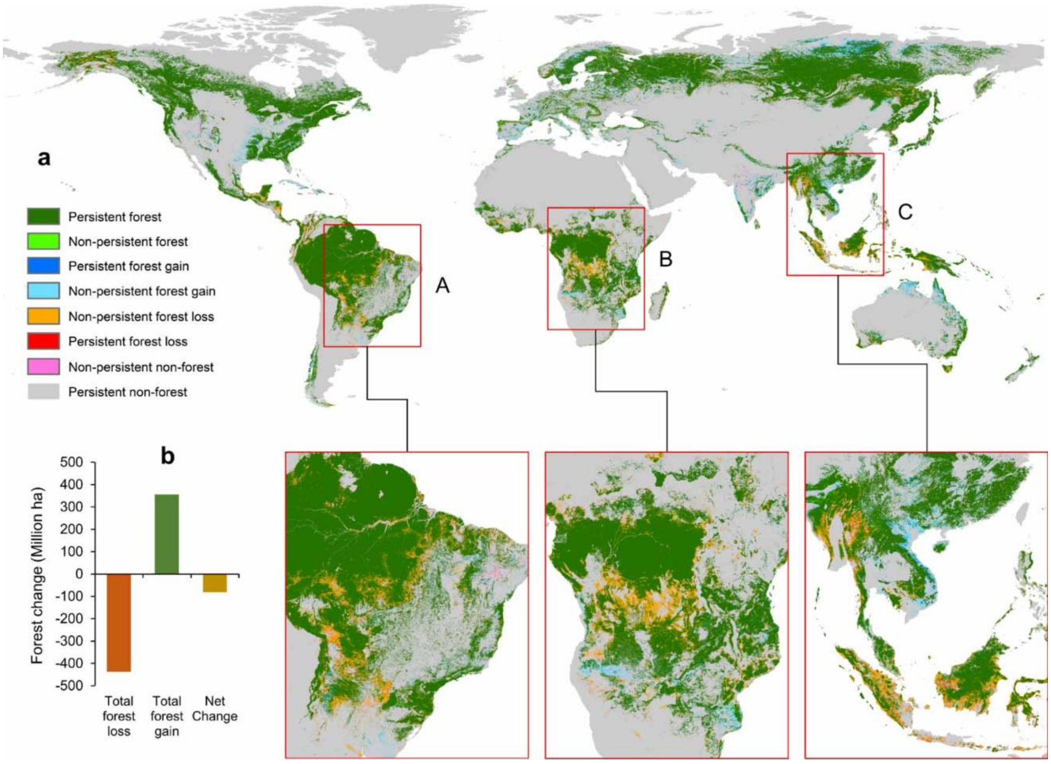

Figure 1: Global forest loss and gain across decades from 1960 to 2019. (a) Map showing the spatial distribution of forest loss and gain, with insets A, B and C showing parts of South America, Africa and Southeast Asia, respectively (b) Extent of total forest loss, gain and net change between 1960 and 2019. Total forest loss includes both persistent forest loss and non-persistent forest loss; total forest gain includes both persistent forest gain and non-persistent forest gain[3].

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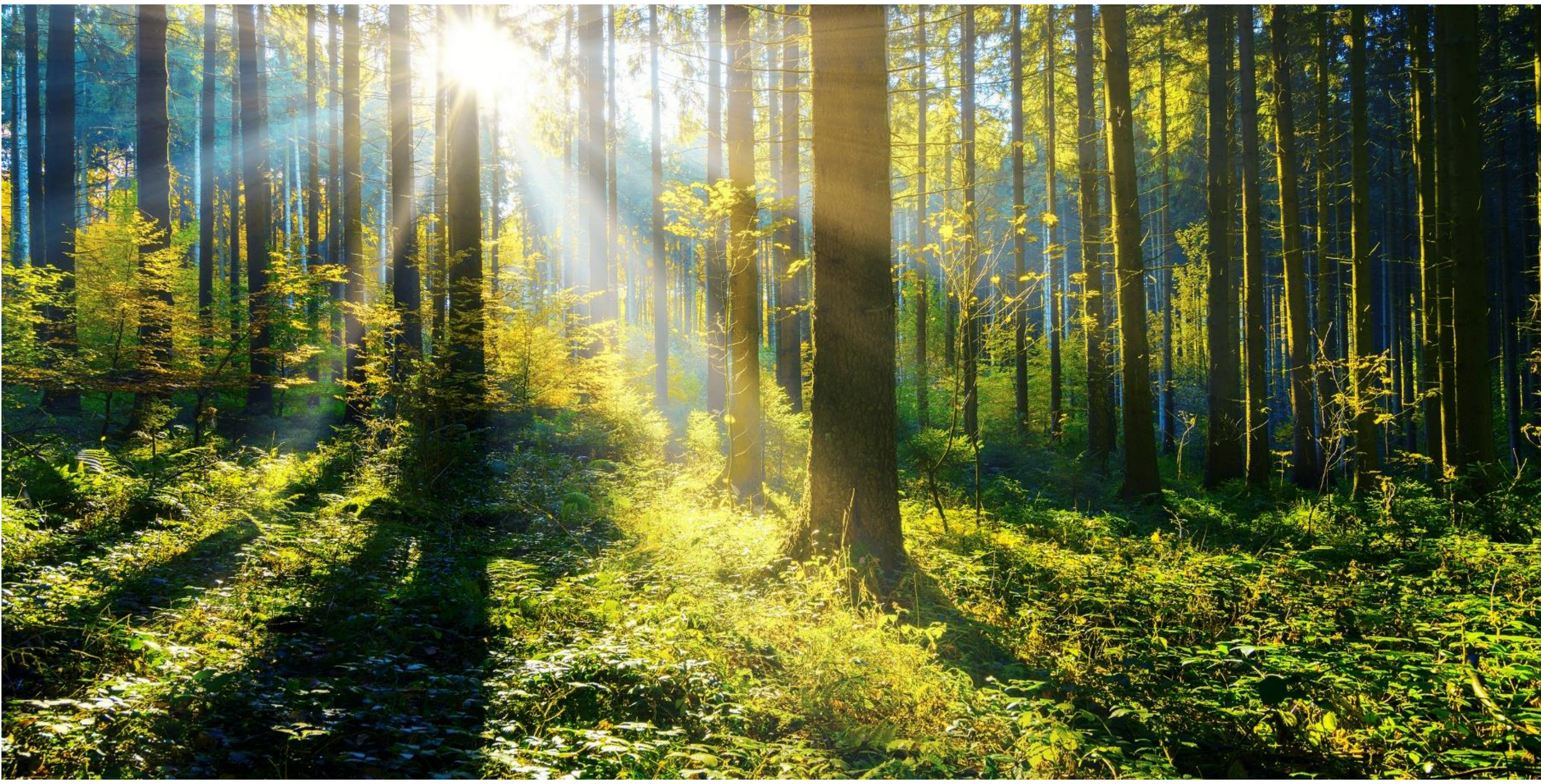
[1] Delavaux, C. S., Crowther, T. W., Zohner, C. M., Robmann, N. M., Lauber, T., van den Hoogen, J., ... & Parthasarathy, N. (2023). Native diversity buffers against the severity of non-native tree invasions. *Nature*, 1-9.

[2] Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P., Fernandez-Manjarrés, J. F., ... & Walpole, M. (2010). Scenarios for global biodiversity in the 21st century. Science, 330(6010), 1496-1501.

[3] Estoque, R. C., Dasgupta, R., Winkler, K., Avitabile, V., Johnson, B. A., Myint, S. W., ... & Lasco, R. D. (2022). Spatiotemporal pattern of global forest change over the past 60 years and the forest transition theory. Environmental Research Letters, 17(8), 084022.

Whilst tackling deforestation must be an imperative global strategy, there is also the need to restore what has been lost. Approaches must be taken to restore lost habitats passively and actively, considering the native species to the area to best mimic the conditions prior to degradation. In doing so, multiple benefits are delivered:

1. **Ecosystem Resilience**: Native trees have evolved over millennia to thrive in their specific ecosystems. They are adapted to local conditions, including climate, soil types, and pests. This resilience ensures that native forests are more likely to survive and adapt to changing environmental conditions, making them more effective carbon stores over the long term.
2. **Biodiversity Conservation**: Native reforestation is not just about planting trees but about restoring entire ecosystems. These ecosystems provide habitat for a diverse range of plants and animals, many of which are endemic and found nowhere else. As native forests regenerate, they create safe havens for endangered and vulnerable species, aiding in biodiversity conservation.
3. **Enhanced Ecosystem Services**: Native forests offer a multitude of ecosystem services, including water purification, soil fertility improvement, and regulation of local climate conditions. They also support pollinators crucial for agriculture and provide livelihoods to local communities through sustainable forestry and non-timber forest products.
4. **Reduced Invasive Species**: When non-native species are introduced to an ecosystem, they can outcompete native species and disrupt ecological balance. Native reforestation focuses on restoring the natural composition of species, which helps reduce the spread of invasive plants and animals[4].



[4] Delavaux, C. S., Crowther, T. W., Zohner, C. M., Robmann, N. M., Lauber, T., van den Hoogen, J., ... & Parthasarathy, N. (2023). Native diversity buffers against severity of non-native tree invasions. *Nature*, 1-9.

What is Afforestation, Reforestation and Revegetation?

Afforestation, reforestation, and revegetation (ARR) are three distinct practices related to restoring or establishing vegetation cover, particularly in areas where it has been lost or degraded. Each of these practices serves specific ecological, environmental, and conservation purposes:

Afforestation	The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.
Reforestation	The direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources on land that was once forested but has been converted to non-forested land in the past 50 years.
Revegetation	A direct human-induced activity to increase carbon stocks of woody biomass on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation.

In summary, ARR is the implementation of activities that increase carbon stocks in woody biomass (and in some cases soils) by establishing, increasing and/or restoring vegetative cover through planting, sowing and/or the human-assisted natural regeneration of woody vegetation.

Approaches to ARR

Native

A native ARR approach involves planting a mix of tree species that are naturally found in the project's specific region or ecosystem. This approach prioritizes the use of native tree species in reforestation and afforestation projects.

The overarching objective is to maximize the restoration efforts, striving to recreate the characteristics of the original forest. This approach not only aids in reclaiming the distinctive features of the original habitat but also serves to attract and support the local fauna that may have migrated due to the loss of their natural environment.[5]

Figure 2: Example of native forest (Credits: forestindustries.info - link here)

Mixed

A mixed species ARR approach involves the managed planting of multiple tree species within a defined area. Unlike a monoculture plantation, which consists of a single tree species, a mixed species plantation involves the deliberate interplanting of several different tree species or even a combination of trees with other crops or agricultural plants. This analysis classifies the Mixed ARR approach where the project involves both the planting of both native and non-native species.

Figure 3: Example of mixed forestry plantation (Credits: Peter Spathelf (2014). Link here)

[5] Rodríguez, J. C., & Sabogal, C. (2019). Restoring degraded forest land with native tree species: The experience of "Bosques Amazónicos" in Ucayali, Peru. *Forests*, *10*(10), 851.

Exotic

An Exotic ARR approach consists of non-native species being planted for commercial purposes. This may include monocultures where a single tree species is intentionally and densely planted over a large area.

Studies[6] have highlighted that whilst exotic tree plantations cannot replicate the irreplaceable value of primary forests in supporting biodiversity, they can offer complementary conservation services to natural stands. Commercial forest plantations, involving sustainable management of exotic species, alleviate pressure on natural forests, safeguard soil integrity, sequester carbon, and generate economic income for rural communities[7].

Figure 4: Example of an exotic plantation - Eucalytpus in Thailand. (Credits: Tony Rodd (2009). Link here)

[6] Reisman-Berman, O., Keasar, T., & Tel-Zur, N. (2019). Native and non-native species for dryland afforestation: bridging ecosystem integrity and livelihood support. *Annals of Forest Science*, *76*(4), 1-13.
[7] Genberger, G., & Liu, J. (2013). Performance of smallholder teak plantations (Tectona grandis) in Xishuangbanna, south-west China. *Journal of Tropical Forest Science*, 289-298.

Analysis of ARR carbon projects worldwide.

We analysed data on the implementation of ARR carbon projects that have registered under one of the following global certification programmes since 1999: American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, Plan Vivo, SOCIALCARBON and Verified Carbon Standard (VCS).

Further details on the data collection and analysis approach taken can be found in Appendix 2.

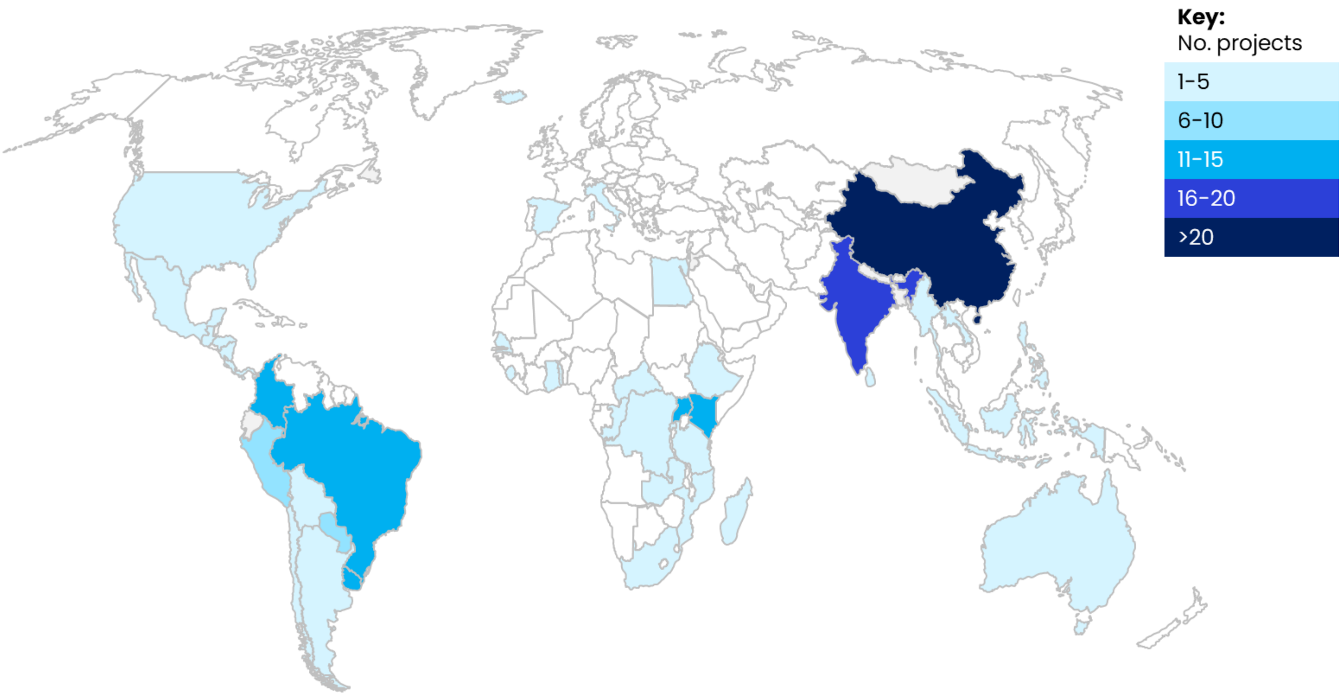
General ARR Analysis

What is the global distribution of ARR projects?

212 ARR projects in the voluntary carbon market have either issued carbon credits or been listed since 2015. Our analysis found several projects listed between 1999 and 2015 that have not issued any credits and therefore were excluded from the analysis. See Appendix 2 for further details on the data collection and processing approach used.

Asia and Latin American represent the greater proportion of ARR projects globally. Since 2013, 57 ARR projects have been listed within China, with the vast majority (56 out of 57) being listed from 2015 onwards.

Figure 5: Global distribution of ARR projects since 1999



What is the distribution of ARR approaches?

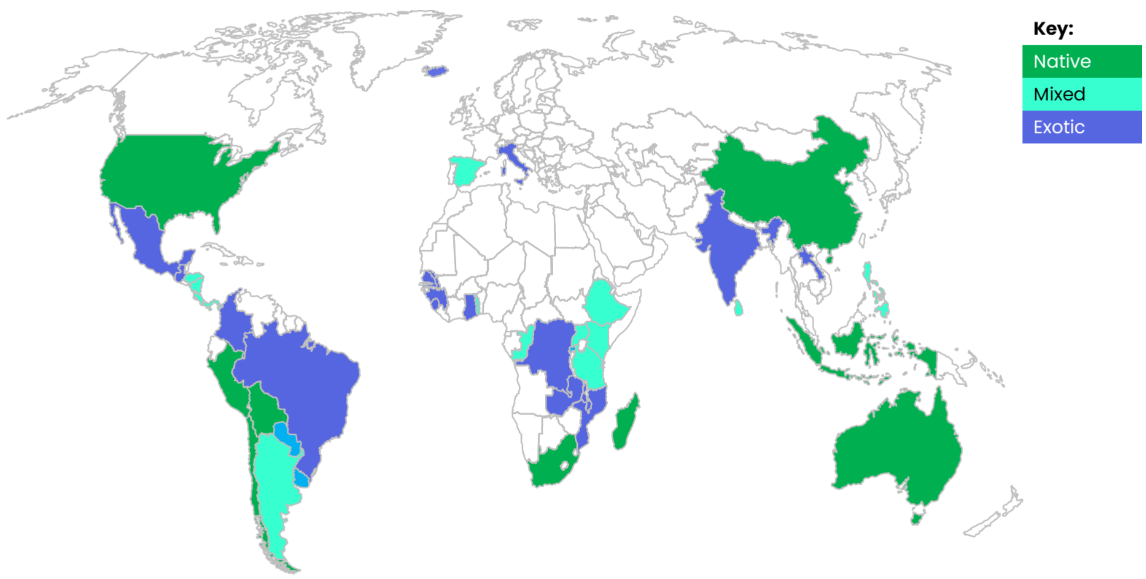
Globally, on average 44% of projects are implementing a Native ARR approach, this is closely followed by 32% of project implementing an Exotic ARR approach. It should be noted that these insights are heavily influenced by China. China stands out not only for having the most ARR projects among all the countries in the world, but also for its strong emphasis on native species restoration (93% of projects are applying a Native ARR approach). This is anomalous – other countries with more than 5 ARR projects have a greater variety in the ARR approaches being implemented.

When re-assessing the global averages without China, the results are drastically different: only 25% of projects are implementing a Native ARR approach, meanwhile Exotic plantations and Mixed-Species plantations account for 42% and 33% of global ARR projects. Further research is required to assess why such a disproportional number of Chinese projects are applying a Native ARR approach when compared to the global average.

Table 1: ARR approach by region

Region	Total Projects	Native	Mixed-Species	Exotic
Global	**212**	**44%**	**24%**	**32%**
North America	6	33.33%	16.67%	50.00%
Central America	12	25.00%	41.67%	33.33%
South America	52	23.08%	23.08%	53.85%
Europe	3	33.33%	33.33%	33.33%
Southeast Asia	9	44.44%	11.11%	44.44%
South Asia	20	25.00%	30.00%	45.00%
East Asia	57	92.98%	5.26%	1.75%
North Africa	1	0.00%	0.00%	100.00%
Sub Saharan Africa	50	22.00%	46.00%	32.00%
Oceania	2	100.00%	0.00%	0.00%

Figure 6: Primary ARR Approach per country



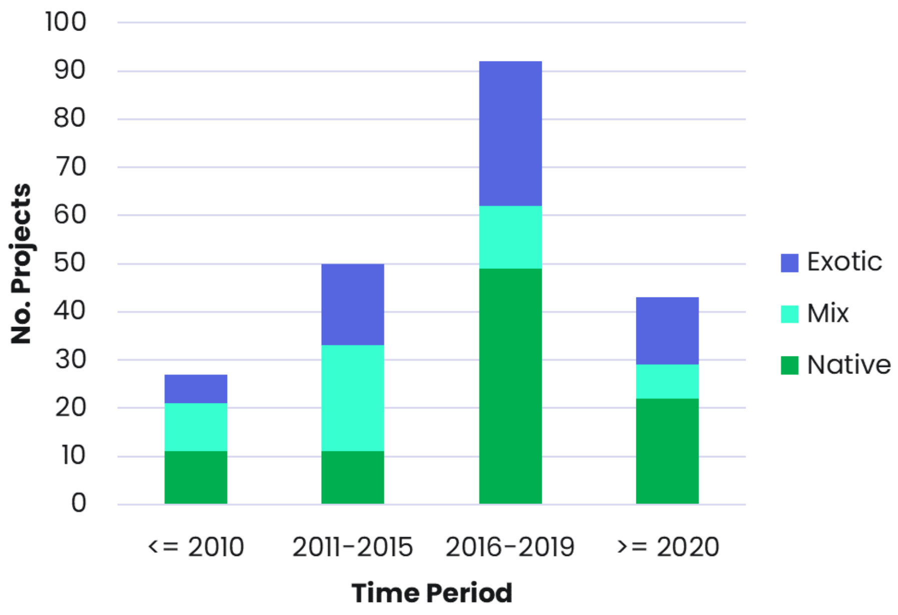
A common trend across all the analysis was the prevalence of ARR projects planting fast-growing species such as Eucalpytus or Teak. These two species were the most common across the projects implementing either a Mixed Species and Exotic ARR approach. Where these species are native, such as Oceania, projects may appear to be applying a Native ARR approach when in fact they are often commercial plantations for timber products.

What are the key trends over time?

As shown in Figure 7: ARR Approach over time, since 2016 a notable shift has been observed within ARR Projects, with native projects assuming a more prominent position. This marked transition represents a significant departure from previous practices, indicating a growing emphasis on biodiversity within ARR projects. However, these insights are heavily influenced by Chinese ARR projects.

The analysis also highlights a reduction in projects being registered from 2020 and after when compared to the previous timeframe (2016-2019). However, given the 2020 timeframe is still under way this insight should be treated with caution.

Figure 7: ARR Approach over time



Is timber harvesting common across ARR projects?

Timber harvesting stands out as a prevalent practice across ARR carbon projects, constituting roughly half of all registered projects across various methodologies, standards, and geographical regions. The logging practice is particularly prominent in projects that utilize exotic species to generate carbon stocks (90% of Exotic ARR projects involve timber harvesting). Typically, these projects are associated with traditional wood industry companies for whom carbon income serves as an additional source of revenue. Conversely, projects that heavily emphasize native species appear to be less reliant on timber harvesting (15% of Native ARR projects involve timber harvesting). Instead, they prioritize biodiversity enhancement and may incorporate activities like fruit harvesting and other non-timber forest uses.

Timber harvesting is present in 52% of registered Mixed-Species ARR projects. This is likely because commercially valuable native and exotic species are planted to supplement project income.

Figure 8: ARR Projects with Timber Harvest

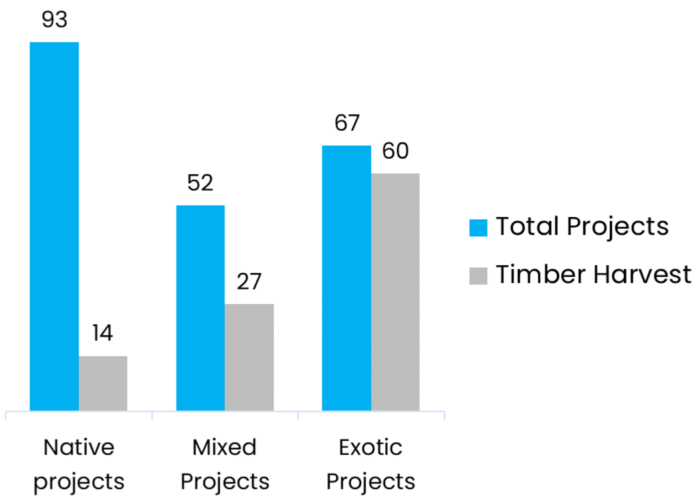
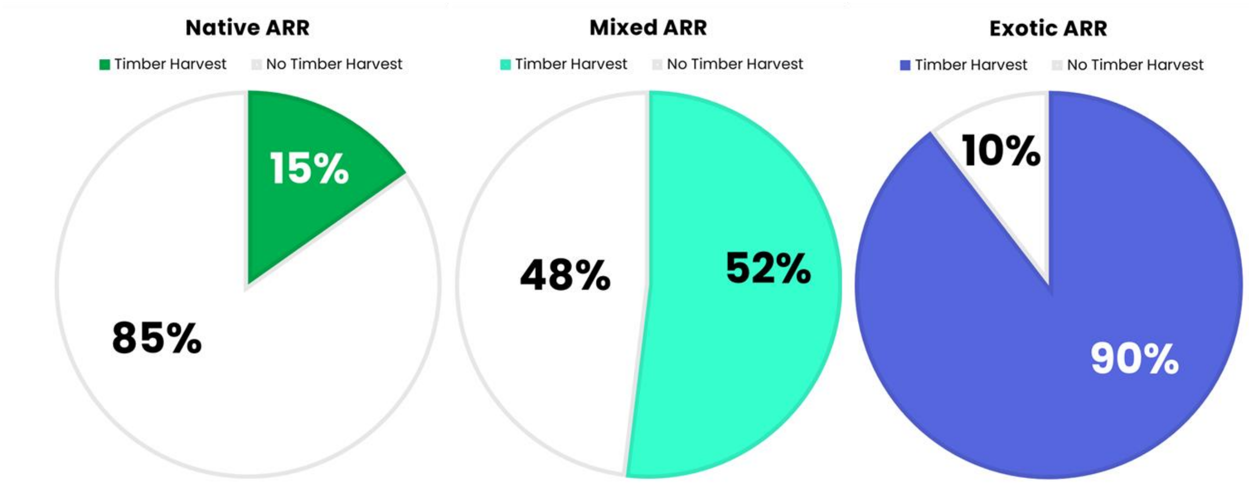
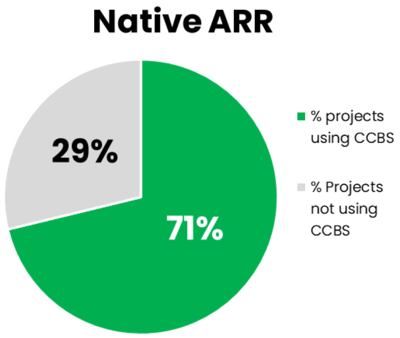
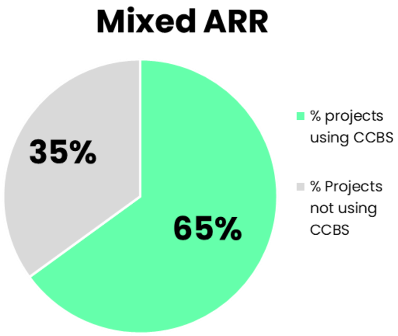


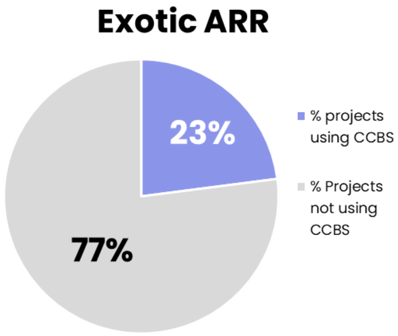
Figure 9: Timber Harvesting by ARR approach



To delve deeper, we analysed all VCS ARR projects to assess whether the ARR approach influenced whether the projects also applied for additional certification under the Climate, Community and Biodiversity Standard (CCBS). The analysis aligned with our hypothesis that native ARR projects are more focused on broader impacts beyond just carbon, such as biodiversity. 71% of all VCS Native ARR projects use CCBS, in contrast to 23% of Exotic ARR projects.







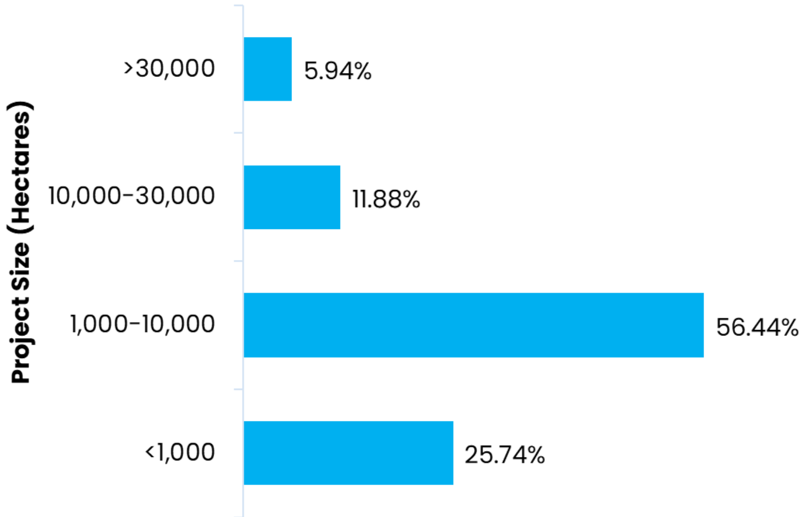
When analysing the link between the monitoring of broader impacts of a project, such as biodiversity, there was a clear negative correlation between the use of CCBS and timber harvesting for projects registered under VCS. Of the 92 projects analysed using CCBS, only 23% employ timber harvesting. In contrast, 73% of VCS ARR projects not using CCBS employ timber harvesting.

When analysing global trends, timber harvesting is most prevalent in two global regions, Central America and South America, where 92% and 83% of all ARR projects, respectively, utilise this activity. On the other hand, East Asia has the lowest rate of timber harvesting, with only 3.51% of ARR projects utilising the practice.

Does project scale influence timber harvesting?

Most projects employing timber harvesting are concentrated in smaller areas, typically encompassing less than 10,000 hectares. Specifically, 25% of projects encompassing under 1,000 hectares incorporate timber harvesting, whilst 56% of all projects spanning between 1,000 and 10,000 hectares engage in this activity. Timber harvesting becomes less prevalent in larger projects, with only 12% of projects of scale between 10,000 and 30,000 hectares promoting this practice. This trend may be related to the economic viability of plantations and investment returns; smaller commercial plantations will have lower upfront costs and faster payback periods.

Figure 10: Size of projects and timber harvesting

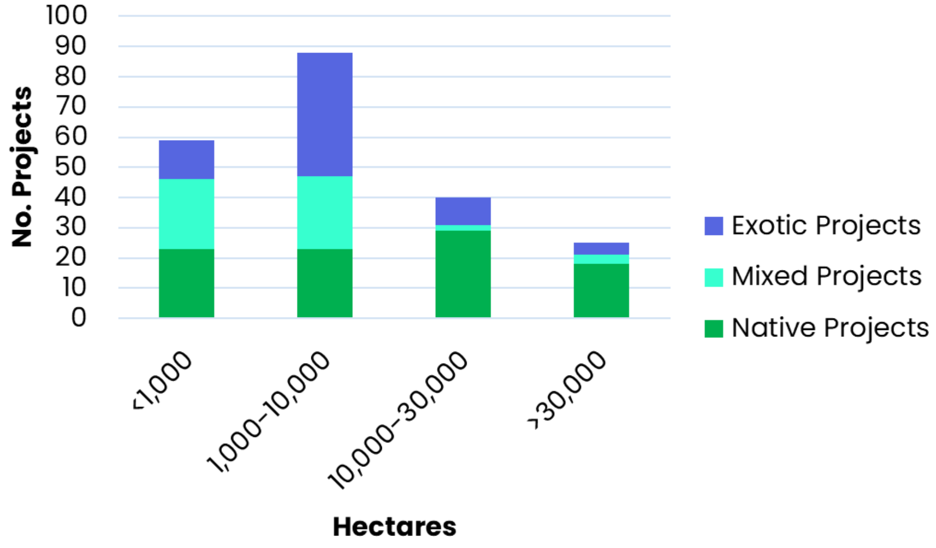


Does project scale influence the ARR approach?

When hypothesizing this analysis, it was assumed that Native ARR projects would be smaller in size. The challenge with active native restoration is often related to access to a large supply of native seedlings/samplings[8]. In addition, due to the significant upfront funding required for ARR projects and the lagged carbon generation, the lack of alternative income models (e.g. from timber harvesting), means that Native ARR projects would be more suited to small project scales. The results of the analysis show a different story. Native ARR projects are being implemented at both small and large scales. Conversely, Mixed and Exotic ARR projects are disproportionally being implemented at scales smaller than 10,000 hectares, with the number of projects significantly decreasing passed this threshold.

[8] According to Davis (2021), when it comes to native plant populations, protocols for sourcing are less advanced on a species-specific level.

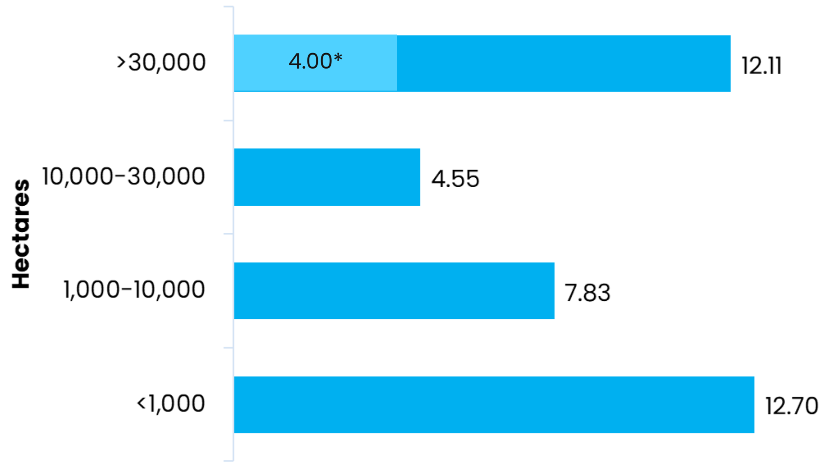
Figure 11: Project Size by Approach



Does project scale influence the number of species planted and the ARR approach?

The analysis indicates that true Native ARR projects, i.e. projects planting more than 10 native species, primarily occur on a small scale (<1,000 hectares). The average number of species planted by Native ARR projects of a scale greater than 30,000 hectares was 12.11, however this value is heavily distorted by a single project in Brazil which is planning to plant over 150 different native species[9]. When this project is excluded, the average species per hectare drops to 4.00.

Figure 12: No. Native Species Planted in Native ARR projects / scale



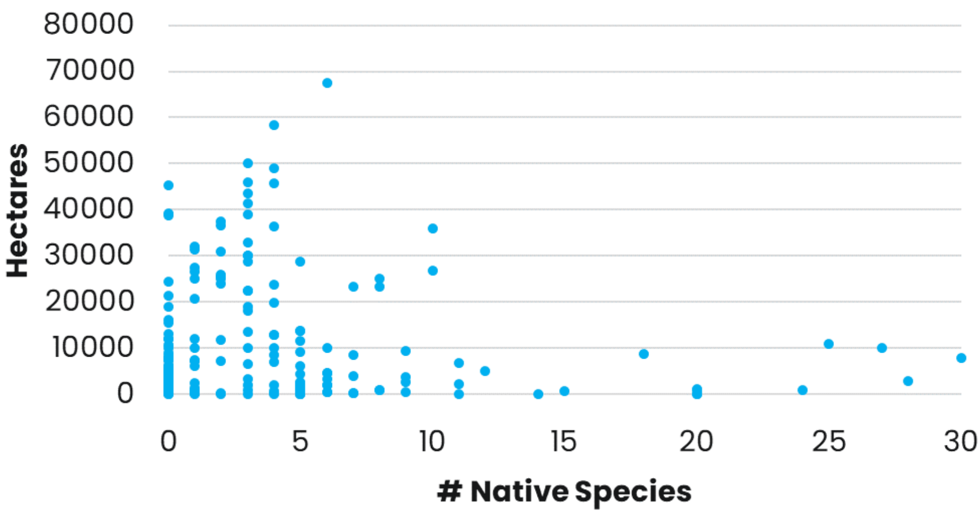
* When Brazilian anomoly is excluded.

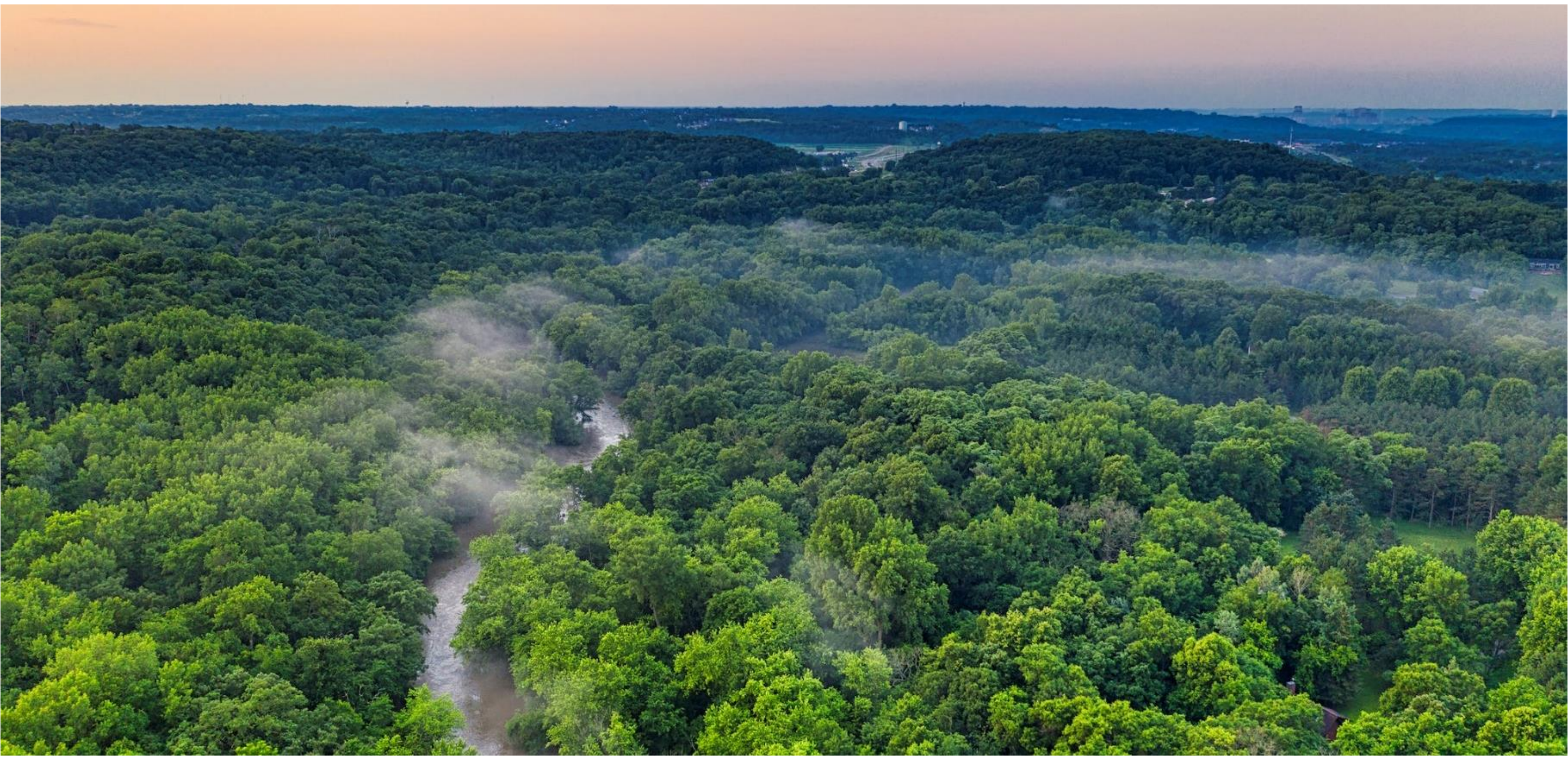
[9] Corridors for Life ARR Grouped Project, VCS ID: 3727

The majority of ARR projects being implemented are planting less than 10 native species (88% of ARR projects). Of the classified Native ARR projects being implemented, only 18% are planting 10 or more species and 57% are planting 4 or less species. Whilst further research is needed to understand why so few species are being planted, these insights highlight a current flaw in the market – projects may be selecting native species based on their carbon potential and not designing ARR projects from an ecosystem-health perspective. If this is the case, it undermines many of the benefits of a native ARR approach.

One reason for the limited native species diversity being planted may be availability of native seedlings/samplings, however many of the countries where ARR is more active (more than 5 projects being implemented) have infrastructure to support the planting more a diverse number of native species at scale (e.g. Brazil).

Figure 13: Project Size compared with number of Native Species Planted



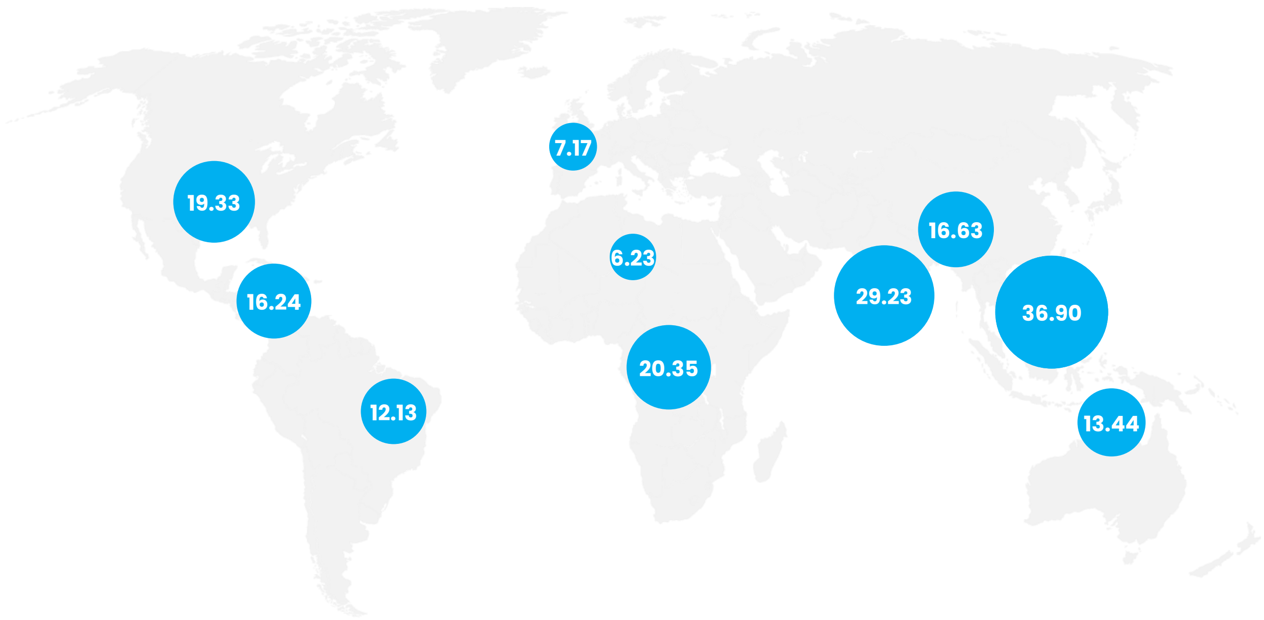


Emission removal analysis

Is there a variance in emission removals from ARR across regions and countries?

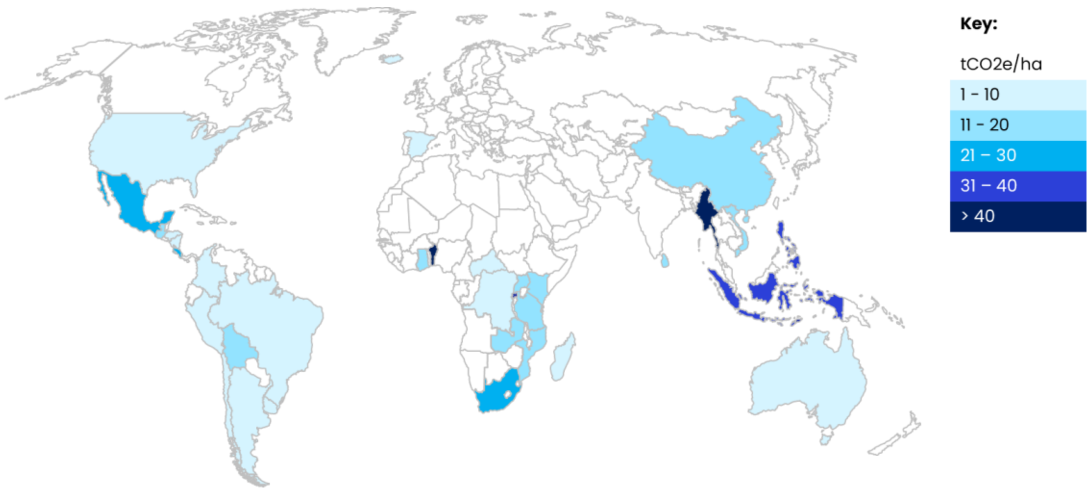
The average global annual estimated emission removals (ERs) per hectare is 13.61 tCO_2e . South East Asia has the highest average estimated annual ERs per hectare with 36.90 tCO_2e , with South Asia in 2nd place with 29.23 tCO_2e . North Africa and Europe both had the lowest average annual estimated ER per hectare with 6.23 and 6.62 tCO_2e respectively. It is important to note that these are estimated ERs and not real results. Our analysis found that projects often over-estimated the annual ERs per hectare when compared to the credits actually issued.

Figure 14: Annual ER/hectare per region



When assessing the average estimated annual ERs per hectare on a country-level, Myanmar had the highest estimated value of 70.07 tCO_2e . However, it should be noted that many of the countries which had average annual ERs per hectare values which exceeded 30 tCO_2e had less than 5 projects. When assessing projects with 5 or more projects the average value was 13.77 tCO_2e. China, which hosts the greatest number of ARR projects had an average value of 15.16 tCO_2e.

Figure 15: Average ER per hectare per country



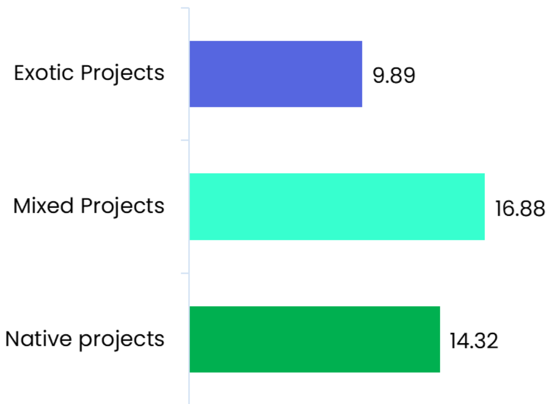
Is there a variance in emission removals across ARR approaches?

The analysis found that on average the estimated annual ER per hectare for Exotic ARR projects was 31% lower than Native ARR projects. This may be due to several reasons.

As highlighted earlier in the report, 90% of Exotic ARR projects implement timber harvesting. Through harvesting timber, carbon stored in the woody biomass is typically considered to have been released back into the atmosphere. This is called a "Loss Event" in the carbon markets and is accounted for by projects through the calculation of the long-term average carbon benefit of a project. This calculation limits the number of credits an ARR project is eligible to issue to the long-term carbon average benefit delivered by the project. The average will be calculated through the estimation of all carbon removals achieved through the growth of the trees, as well as the expected emissions resulting from the harvesting of trees.

In contrast, only 15% of Native ARR projects utilise timber harvesting. This means that the carbon stored in woody biomass is maintained and enhanced over time, resulting in a higher estimated annual ER per hectare.

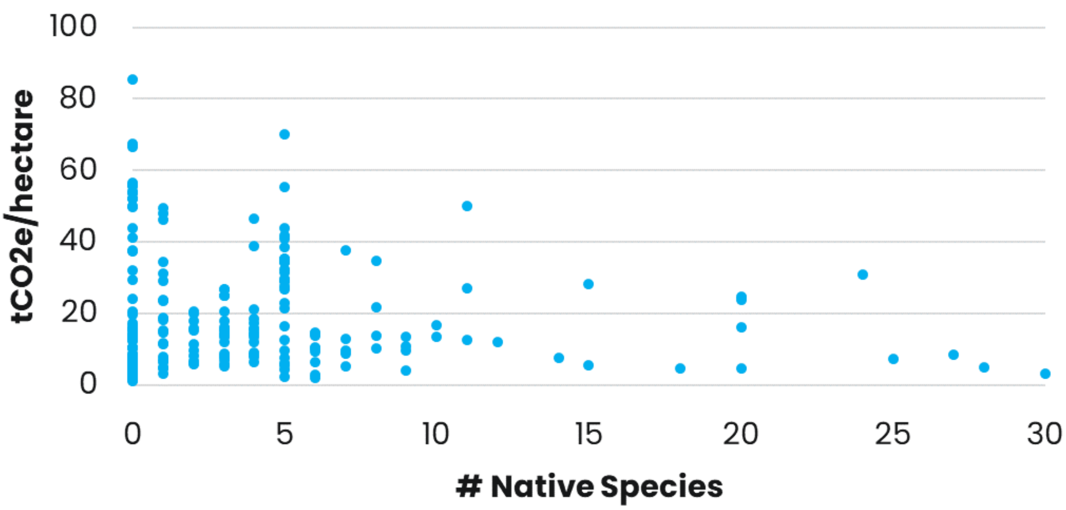
Figure 16: Estimated Annual ERs/hectare by ARR approach



Does species diversity impact emission removals?

As expected, the greater number of species planted appears to be negatively correlated with annual ER per hectare. This is likely due to the fact that projects planting fewer species deliberately select species that are fast growing and have greater carbon potential. Conversely, projects focusing on greater species diversity prioritise biodiversity and replicating native ecosystems over carbon.

Figure 17: Annual ER per hectare compared with the number of species planted



Does the GHG Methodology influence the emission removals of ARR projects?

In the context of ARR projects, the considerations for methodology selection aligns with the unique characteristics and goals of these types of projects. In this study, it can be observed that the prevailing trend in selecting methodologies indicates a strong preference for AR-ACM0003 followed by the Gold Standard ARR Methodology. AR-ACM0003 is widely adopted, with 126 projects, whilst the Gold Standard ARR Methodology has 21 projects utilising. Looking forward, the dominance of AR-ACM0003 will likely reduce following the adoption of Verra's VM0047 – their new ARR methodology that will replace AR-ACM0003 at the end of 2023.

When examining the estimated annual ERs per hectare, AR-ACM0003 has a higher value of 14.17 compared to the Gold Standard ARR Methodology, which has a value of 8.37.

It is important to note a crucial caveat in our analysis – the carbon benefits delivered by a project depend on the specific species planted and the biome in which the ARR project is situated.

Table 8: Methodologies adopted by projects

Methodology	# Projects	Estimated Annual ER (tCO2e)	Issued Credits (tCO2e)	Hectares	Estimated Annual Credit / hectare
AR-ACM0003	127	28,543,238	21,326,310	2,019,580	14.13
Gold Standard ARR Methodology	26	732,064	5,512,324	88,148	8.30
AR-AMS0007	14	1,364,394	336,937	74,742	18.25
AR-ACM0001	13	633,700	17,166,600	87,543	7.24
AR-AMS0001	13	547,736	4,296,021	24,147	22.68
Plan Vivo ARR	9	262,394	4,175,473	21,751	12.06
AR-AM0003	3	140,712	935,410	14,426	9.75
AR-AM0014	2	73,075	0	1,225	59.65
ACR ARR Methodology	1	0	6,268,282	36,017	0.00
SCM0004	1	56,637	0	7,311	7.75
AR-AM0005	1	25,000	753,975	5,625	4.44
VM0005; AR-ACM0003	1	15,512	394,400	1,000	15.51
AR-AM0005; AR-ACM0003	1	5,007	58,122	282	17.76

Looking forward.

The need to scale up ARR using a diverse mix of native species.

It is essential that Native ARR projects are implemented at scale globally to address environmental degradation, climate change, and biodiversity loss. Central to this endeavour is the deliberate choice to employ a diverse mix of native species. Native species, intricately connected to the local ecosystems, offer a range of benefits for the success of afforestation, reforestation, and revegetation efforts. Their adaptability to regional climates, soil conditions, and intricate ecological relationships contribute significantly to the establishment of resilient and thriving ecosystems. These projects should use at least 10 native species, ideally significantly more, in order to best replicate natural habitats and deliver true biodiversity benefits.

The use of diverse native species further enhances biodiversity, promoting the coexistence of varied plant and animal life. This, in turn, fosters ecological balance and resilience against environmental challenges. Moreover, native species are often better equipped to resist pests and diseases, reducing the dependence on external inputs like pesticides, sequester more carbon[10] long term and delivering better permanence of the carbon stored[11].

To achieve the scale of restoration required, natural regeneration should be promoted globally, particularly in tropical regions[12]. Studies show that natural regeneration offers an effective tool for implement large-scale forest and landscape restoration at a minimal cost when compared to active restoration[13]. However, natural regeneration is dependent of a number of abiotic and biotic conditions[14] and is not possible when the native vegetation has been cleared from the area.

Our analysis has highlighted that active Native ARR projects are uncommon. With only 12% of projects planting 10 or more native species, we must re-assess how native restoration is incentivised in the voluntary carbon market and whether alternative approaches to ARR, such as Exotic ARR, should be eligibile at all.

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[10] Chazdon, R. L., & Guariguata, M. R. (2016). Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. *Biotropica*, *48*(6), 716-730.

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Re-evaluate the eligibility of monoculture or commercial forestry.

Monoculture plantations and the planting of exotic species are common across the voluntary market, with 32% of all projects planting no native species. In addition, 90% of all exotic ARR projects utilise timber harvesting, raising questions not only about the biodiversity impacts of these projects, but also their long-term climate benefit. In many cases, the project appeared to be a commercial plantation which would have likely been implemented with or without carbon finance, raising additionality concerns.

These projects do little to address climate change and biodiversity loss, and may even result in greater ecosystem degradation. The use of inappropriate restoration methods, such as a limited species mix or species ill-suited to the modified environment, often leads to reduced diversity and delayed succession; monoculture plantations may impede rather than facilitate recovery[15]. Studies[16] also highlight that monoculture can result in a loss of soil productivity and fertility, disruption of hydrological cycles, risks associated with plantation forestry practices (e.g., introduction of exotic species), risks of promoting pests and diseases, higher risks of adverse effects of storms and fire, and negative impacts on biodiversity.

Given the environmental implications of these projects and their reliance on timber harvesting, one must question whether they should be eligible for carbon credits. Various studies have consistently shown that mixed-species plantations outperform monocultures in terms of productivity, exemplifying the manifold advantages of incorporating diverse species[17]. Looking forward, there is a need to mandate a minimum proportion of native species to be planted by ARR projects. Our belief is that this should be at least 50%.

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Embedding communities to deliver permanence.

Embedding communities into environmental initiatives is a strategic and ethical approach that recognizes the vital role residents play in ensuring the permanence and success of conservation efforts. By actively involving communities, a sense of ownership and connection to the projects is fostered, promoting a shared responsibility for environmental stewardship. This engagement goes beyond the immediate goals of the initiatives; it empowers communities to become long-term guardians of their ecosystems, contributing to the sustained well-being of both the environment and the people who call it home.

The process of embedding communities in conservation initiatives also taps into the wealth of local knowledge and expertise. Indigenous and local communities possess deep insights into the intricacies of their ecosystems, understanding the delicate balance between human activities and the environment. By integrating this traditional wisdom with modern conservation practices, we create a synergistic approach that enhances the resilience of ecological systems and ensures the permanence of positive outcomes. In essence, embedding communities in environmental projects transforms these initiatives into collaborative endeavours, weaving together the fabric of sustainable practices and enduring benefits for all involved.

Studies[18] highlight the importance of embedding communities in restoration efforts. However, many of the projects present in the market, particularly Exotic ARR projects, are run by commercial forestry organisations, presenting limited community benefits beyond employment. The market must promote greater community involvement in ARR projects. This can either be mandated in the rules or requirements of Voluntary Carbon Standards, or through carbon credit price premiums for projects that demonstrate community benefits.

[18] Chazdon, R. L., & Guariguata, M. R. (2016). Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. *Biotropica*, *48*(6), 716-730.

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Appendix 1

Key Definitions & Abbreviations

Definitions

Afforestation, Reforestation and Revegetation (ARR)	Activities that increase carbon stocks in woody biomass (and in some cases soils) by establishing, increasing and/or restoring vegetative cover through planting, sowing and/or the human-assisted natural regeneration of woody vegetation.
Agriculture, Forestry and Other Land Use (AFOLU)	The sectoral scope that covers GHG emissions and emission reductions and/or removals from project activities in the agriculture, forestry, and other land use/land use change sectors.
Grouped Project	A project to which additional instances of the project activity, which meet preestablished eligibility criteria, may be added subsequent to project validation.
Leakage	Net changes of anthropogenic emissions by GHG sources that occur outside the project boundary but are attributable to the project.
Methodology	A specific set of criteria and procedures, which apply to specific project activities, for identifying the project boundary, determining the baseline scenario, demonstrating additionality, quantifying net GHG emission reductions and/or removals, and specifying the monitoring procedures.
Monitoring Report	The document that records data to allow the assessment of the GHG emission reductions or removals generated by the project during a given time period in accordance with the monitoring plan set out in the project description
Non-Permanence Risk	The risk of a potential loss in carbon stock in the project over a period of 100 years.
Project Description Document	The document that describes the project's GHG emission reduction or removal activities
Project Ownership	The legal right to control and operate the project activities.
Standard Body	The organisations responsible for setting the rules and requirements to which projects must adhere to certify their project results.

Uncertainty	Uncertainty is a parameter associated with the result of measurement that characterizes the dispersion of the values that could be reasonably attributed to the measured amount.
Validation/Verification Body (VVB)	An organization approved by the chosen Standard to act as a validation/verification body in respect of providing validation and/or verification services in accordance with the chosen Standard's rules
Vintage	The set of GHG emission reductions or removals generated by a project during a single vintage period

Abbreviations

CCPs	Core Carbon Principles
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
ICVCM	Integrity Council for the Voluntary Carbon Market
tCO_2e	Metric tons of carbon dioxide equivalent
NDC	Nationally Determined Contribution
OTC	Over The Counter
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDG	Sustainable Development Goal
VCMI	Voluntary Carbon Markets Integrity Initiative
VVB	Validation & Verification Body

Appendix 2

Data collection and analysis approach

Our approach to data collection and analysis involved a thorough and comprehensive process.

1. **Data Retrieval:** Data was downloaded from the respective registries and the Berkeley Carbon Trading Project database v8 on the 10th May 2023.
2. **Supplementation with Documentation:** To enrich the dataset, we supplemented the collected data through a detailed review of Project Design Documents (PDDs) and accompanying documentation. This step added contextual depth to the information gathered, particularly related to timber harvesting and the number of species planted.
3. **Data Cleaning:** Subsequently, we engaged in a data cleaning process. This involved a detailed examination of PDDs to identify and address any discrepancies or anomalies in the dataset. Our aim was to ensure the accuracy and reliability of the information. Projects with no PDDs, or with a status of "Withdrawn", "Rejected", "Under Development", "On Hold" or an equivalent were excluded from the analysis.
4. **Issue Resolution and Outlier Management:** As part of the cleaning process, we focused on resolving any data issues encountered during the review of PDDs. Additionally, significant outliers were identified and addressed to maintain the integrity of the dataset.

Addressing the issues encountered throughout the process is a pivotal aspect of our data analysis, and we acknowledge and tackle various challenges to ensure the integrity of our findings:

1. **Poor Data Quality:** One of the primary challenges we encountered was poor data quality. Several PDDs lacked the level of detail we would expect of these document.
2. **Discrepancies Across Registry Page and Documentation:** Discrepancies between information on registry pages and accompanying documentation posed a notable challenge. For example, multiple projects had significant discrepancies between the project sizes (ha) and estimate annual emission reductions/removals on their registry overview page compared to their technical documentation.
3. **Long-Term Carbon Averages from Harvesting Not Accounted For:** An additional challenge lied in the oversight of long-term carbon averages resulting from harvesting activities. We noticed that several projects implementing timber harvesting did not calculate the long-term carbon average because they planned to harvest after the crediting period. This creates a scenario where projects are able to maximise carbon credits for a 30 year period without needing to accounting for harvests or non-permanence over a longer time horizon (post crediting period).
4. **Overestimation of Forecasted Emission Reductions (ERs):** Overestimation of forecasted ERs was a common issue. Several projects issued significantly less carbon credits than forecasted.

Appendix 3

ARR Data

Table 2: Total number of countries with ARR Projects

Country	No. Projects
China	57
India	18
Uganda	12
Colombia	12
Kenya	12
Brazil	12
Uruguay	11
Peru	6
Paraguay	6
South Africa	5
Ghana	5
Nicaragua	4
United States	3
Tanzania	3
Panama	3
Mexico	3
Guatemala	3
Laos	3
Ethiopia	2
Sri Lanka	2
Costa Rica	2
Australia	2
Republic of Congo	2
Philippines	2
Spain	2
Timor Leste	2
Sumatra	1
Madagascar	1
Bolivia	1
Egypt	1
Honduras	1
DRC	1
Iceland	1
Chile	1
Senegal	1
Mozambique	1
Sierra Leone	1

Argentina	1
Zambia	1
Myanmar	1
Rwanda	1
Togo	1
Central African Republic	1

Table 3: Average Annual ER/hectare per country

Country	Projects	Annual ER/hectare
China	57	15.16
India	18	28.41
Uganda	12	12.48
Colombia	12	2.02
Kenya	12	12.48
Brazil	12	7.08
Uruguay	11	4.58
Paraguay	6	17.86
Peru	5	8.42
South Africa	5	24.38
Ghana	5	18.58
Nicaragua	4	9.85
United States	3	0.38
Tanzania	3	15.56
Panama	3	10.81
Mexico	3	23.12
Guatemala	3	17.47
Laos	3	16.02
Ethiopia	2	10.11
Sri Lanka	2	18.39
Costa Rica	2	28.07
Australia	2	3.64
Republic of Congo	2	5.51
Philippines	2	37.15
Spain	2	6.89
Timor Leste	2	37.95
Sumatra	1	37.72
Madagascar	1	8.85
Bolivia	1	12.00
Egypt	1	6.23
Honduras	1	9.72
DRC	1	1.42
Iceland	1	8.26
Chile	1	5.61

Senegal	1	12.35
Mozambique	1	15.40
Sierra Leone	1	10.52
Argentina	1	3.11
Zambia	1	17.16
Myanmar	1	70.07
Rwanda	1	51.96
Togo	1	48.00
Central African Republic	1	2.91

Table 4: ARR Approaches and commercial timber harvesting

	Total projects	Native ARR	Mixed ARR	Exotic ARR
Number of projects	212	93	52	67
Number of projects with commercial timber harvest	100	14	27	60
Percentage of projects with commercial timber harvest	47.64%	15.05%	51.92%	89.55%

Table 5: Timber Harvesting on ARR Carbon Projects Globally

Region	Total Projects	# Timber Harvest	% Timber Harvest
North America	6	4	66.67%
Central America	12	11	91.67%
South America	52	43	82.69%
Europe	3	1	33.33%
South East Asia	9	5	55.56%
South Asia	20	11	55.00%
East Asia	57	2	3.51%
North Africa	1	1	100.00%

Sub Saharan Africa	50	23	46.00%
Oceania	2	0	0.00%

Table 6: Native Species Diversity per Project

Country	Average Native Species per Project
China	3.58
India	3.06
Uganda	4.67
Colombia	6.67
Kenya	4.27
Brazil	24.18
Uruguay	0.00
Peru	7.40
Paraguay	1.00
South Africa	0.80
Ghana	0.00
Nicaragua	1.25
United States	14.33
Tanzania	0.67
Panama	17.00
Mexico	0.00
Guatemala	2.33
Laos	0.00
Ethiopia	7.50
Sri Lanka	45.00
Costa Rica	14.00
Australia	25.00
Republic of Congo	0.00
Philippines	4.00
Spain	8.00
Sumatra	7.00
Timor Leste	8.00
Madagascar	3.00
Bolivia	12.00
Egypt	0.00
Honduras	7.00
DRC	0.00
Chile	0.00
Senegal	0.00
Mozambique	0.00

Sierra Leone	0.00
Argentina	1.00
Zambia	0.00
Myanmar	5.00
Rwanda	0.00
Togo	1.00
Central African Republic	0.00

Table 7: Annual ER per hectare across region

Region	Projects	Annual ER/hectare
North America	6	19.33
Central America	12	16.24
South America	49	12.43
Europe	2	6.62
South East Asia	9	36.90
South Asia	20	29.23
East Asia	57	16.63
North Africa	1	6.23
Sub Saharan Africa	49	20.66
Oceania	2	13.44