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Forestry-Backed Assets Design

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1. Introduction

Forestry projects aimed at carbon sequestration[1] share common features related to the lifecycle of trees and their carbon capture potential. However, each project also differs by a variety of attributes including location, tree type and forest age, to name a few. Such attributes modulate a project's exposure to various sources of risk, such as weather hazards and wildfire risk, as well as its ability to sequester carbon over time and meet biodiversity targets. The inherent heterogeneity and riskiness of forestry projects pose severe challenges to investors targeting narrowly defined risk-return profiles and lacking the expertise and resources to engage in effective project selection, thus hampering the ability of originators to deliver investable forestry assets to market.

Solving the predictability challenge

A common solution to these hurdles is the bundling of different assets to obtain more predictable risk profiles; we believe this principle could be applied to forestry assets as well. The statistical mechanism at play here is the Central Limit Theorem[2], whereby the pooling[3] of heterogeneous risky assets results in a portfolio of assets which, on average, have less noisy returns and smaller exposure to low frequency–high impact events. The bundling of assets is common in a variety of Asset Backed Securities (ABS), including mortgages and credit cards[4], but seems to be less explored in the context of forestry projects, whereby the standard setup seems to be the participation in forestry funds as opposed to the design of stand-alone securities appealing to different market participants.

As investors target risk-return tradeoffs consistent with their individual risk appetites, forestry bundles can be tranched to tailor investors' demand. By "tranching" we mean the slicing of the pool of forestry assets into different portions which will be incrementally exposed to risk[5]. The first few losses will be borne by the first tranche of assets (equity tranche). As losses accumulate and the equity tranche is exhausted, losses will affect a more "senior" tranche. The degree of seniority of a tranche indicates how far up the stack of tranches it sits before being affected by any losses. Standard terms used in this space include "mezzanine," "senior" and "super senior" tranches to indicate asset-backed securities increasingly shielded from the occurrence of losses, and hence delivering a lower yield on account of the safer availability of proceeds at maturity.

Solving the asymmetric information challenge

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[1] In this paper we consider reforestation projects (no plantations/monocultures) with a focus on carbon accumulation. In particular, we do not address the carbon revenue and timber market dimensions, which will be covered in a forthcoming companion paper.

[2] See Schervish (2012).

[3] A situation in which the benefits of aggregation may not materialize is when the risk exposures being bundled have extremely heavy tails, meaning that they are materially exposed to low frequency–high impact events (see Ibragimov, 2009). This is not the case for the projects under consideration in this paper.

[4] See, for example, Fabozzi and Mann (2012).

[5] See JP Morgan (2006), for example.

Another challenge that has historically plagued forestry-linked securities as an asset class is the perception by prospective investors that they have less information about the quality of the assets they may invest in than do the issuers. Fearing the buyer's curse, investors may offer lower prices for securitized forestry projects to offset their perceived informational disadvantage[6]. To solve this, issuers can retain a fraction of the asset to signal their confidence to the potential buyer.

In this report, we consider in detail these security design mechanisms in relation to forestry projects bundled into forestry-backed securities. We focus on foundational concepts of forest aggregation, which should be of interest to any originator of forestry-linked securities[7]. Once the mechanics of risk aggregation are well understood, it becomes relatively straightforward to tranche the forestry pool to deliver forestry-backed instruments with different yields depending on investors' risk appetite. We therefore devote our attention to understanding the aggregation of forestry assets along different dimensions, separately and jointly. The main risk drivers we consider in our analysis are geography, forestry vintage, wildfire risk exposure and carbon sequestration potential[8]. We also provide examples of multidimensional project screening while also taking into account the biodiversity dimension.

A summary of our main findings is as follows:

- We find that certain geographies in the tropics host the forestry projects that should be most appealing to investors and hence originators. Viability of these projects largely depends on cost structure and political stability.
- There is a large overlap between areas of the world with high carbon sequestration potential and those with high biodiversity scores, thus providing evidence of a natural, strong link between carbon sequestration forestry projects and biodiversity preservation.
- There is a common pattern of increasing carbon sequestration with older forests. The average level and dispersion of carbon sequestration vary considerably by forest age depending on the location of interest.
- Both carbon sequestration volatility and wildfire risk exposure can be greatly reduced by bundling together a relatively small number of forests within and across geographies. The diversification effects can be improved by bundling forests of different vintages.
- A multidimensional analysis of wildfire risk, carbon sequestration potential and biodiversity suggests that forestry bundles can be structured in a quantitatively reliable way to satisfy multivariate constraints. Again, we find pronounced geographical clustering of those projects featuring the most attractive risk-return tradeoffs, where return is expressed in terms of carbon sequestration and biodiversity.

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[6] See, for example, DeMarzo and Duffie (1999) and DeMarzo (2005) for a formalization of some of these tradeoffs. Similar issues arise in the context of more exotic exposures, such as pension and insurance liabilities: see Biffis and Blake (2010, 2013), for example.

[7] In this report we use the terms *issuer*, *seller* and *originator* interchangeably when referring to the securitization of forestry assets. In practice, forestry projects could be sold to the originator, who would then aggregate them before transferring them on to capital market investors. For clarity of exposition, we prefer to streamline the origination process and simply focus on the final transfer of forestry-based assets to capital market investors.

[8] Consideration of tree type/density is subsumed in the carbon sequestration potential and is not explicitly analyzed here.

- A counterpart to the geographical clustering findings is that our framework can be used to identify areas where policy intervention would be most needed and effective. Here, the availability of credit guarantees and concessional lending rates would provide an effective way to support high-return forestry projects in jurisdictions where political instability prevents the successful deployment of public–private partnerships and similar arrangements.

2. Risk Aggregation Case Studies

In this section we explore the mechanics of bundling heterogenous forestry assets across geography, forestry vintage and carbon sequestration potential.

Risk aggregation by forest vintage within a continent

As case studies, we consider forests in South America[9], Africa[10] and Asia[11]. Using data from Cook-Patton et al. (2020) capturing carbon accumulation across different locations and biomes[12], we report the carbon sequestration potential of forests of different vintages across South America and Asia in figures 1 and 2, respectively. African data is rather noisy; we will discuss that continent when considering wildfire risk in the next section. We note that our focus here is on carbon accumulation, not carbon revenue. Our results can be used in conjunction with carbon price assumptions/projections to address the carbon revenue dimension.

As can be observed from the charts, there is a common pattern of increasing carbon sequestration with older forests. This is better illustrated by the sigmoid function we use to interpolate average carbon sequestration, which has a stretched S-shaped pattern reaching a plateau beyond 30 years; see figure 3 for an alternative representation. It is also apparent from the boxplots that the dispersion of carbon sequestration increases with forest age, although sampling error gives a fair number of outliers even for young forests.

The charts reveal different average levels and dispersion in carbon sequestration by forest age in South America and Asia. South America is associated with higher average carbon sequestration and narrower confidence bands for old forests. Asia is characterized by lower dispersion in carbon sequestration potential for younger forests, but larger for older forests. The results may clearly be affected by the sampling error affecting the data source used, in particular for older forests.

[9] Countries considered include, among others: Bolivia, Brazil, Colombia, French Guiana, Guyana, Panama, Paraguay, Peru, Suriname and Venezuela. We report here the top 10 countries ranked by considering the product of the carbon sequestration potential and biodiversity metric introduced in section 3. We do the same for Africa and Asia below.

[10] Countries considered include, among others: Burundi, Cameroon, Central African Republic, Republic of Congo, Democratic Republic of Congo, Côte d'Ivoire, Liberia, Rwanda, Sierra Leone and Uganda.

[11] Countries considered include, among others: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand and Vietnam.

[12] Data are from natural reforestation projects (no monocultures) and span a variety of registered projects as well as results appearing in the extant literature.

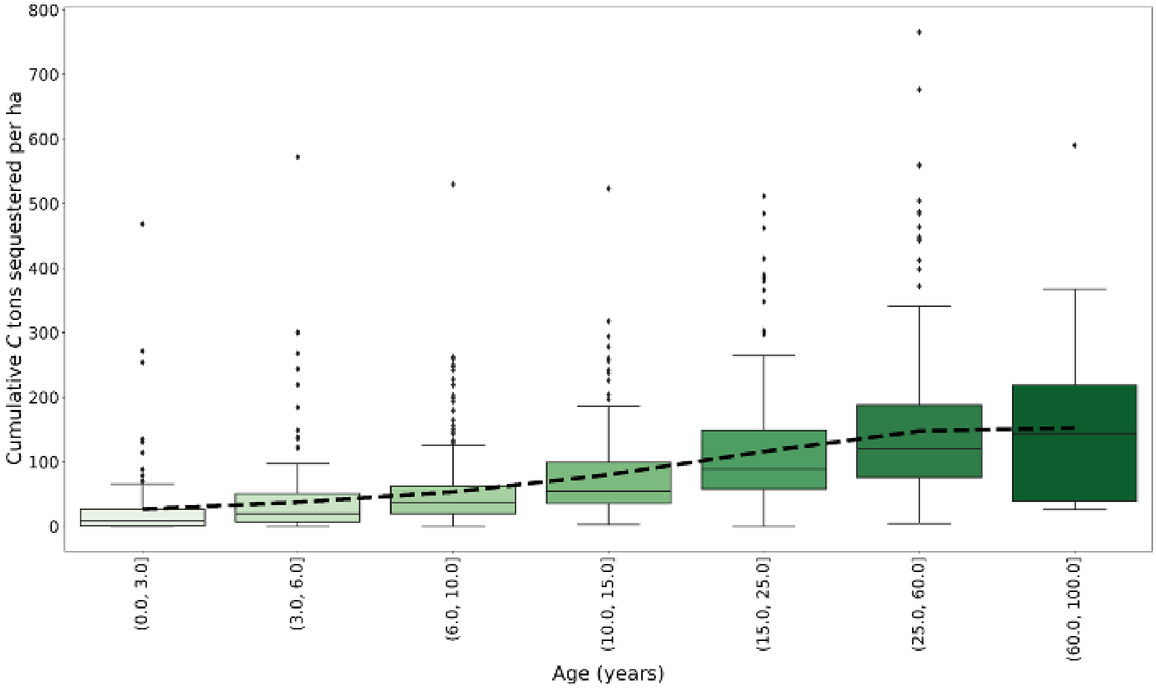

Figure 1. Carbon sequestration potential (tons of carbon per ha) for different forest vintages (stand age) using above-ground biomass and carbon across different locations in South America. Data source: Cook-Patton et al. (2020).

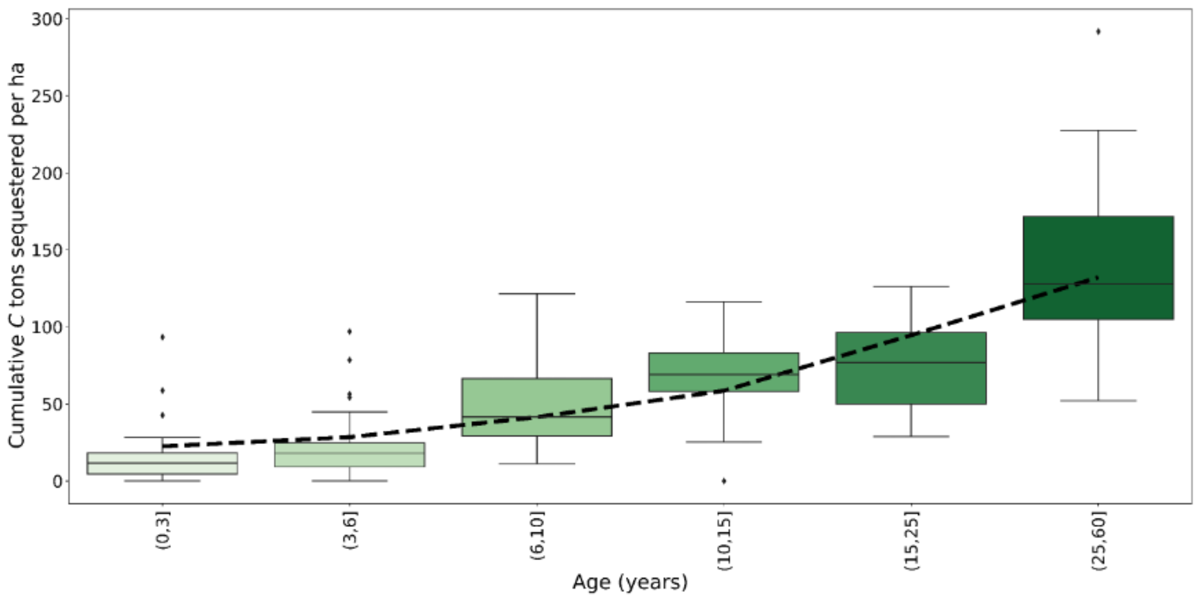

Figure 2. Carbon sequestration potential (tons of carbon per ha) for different forest vintages (stand age) using above-ground biomass and carbon across different locations in Asia. Data source: Cook-Patton et al. (2020).

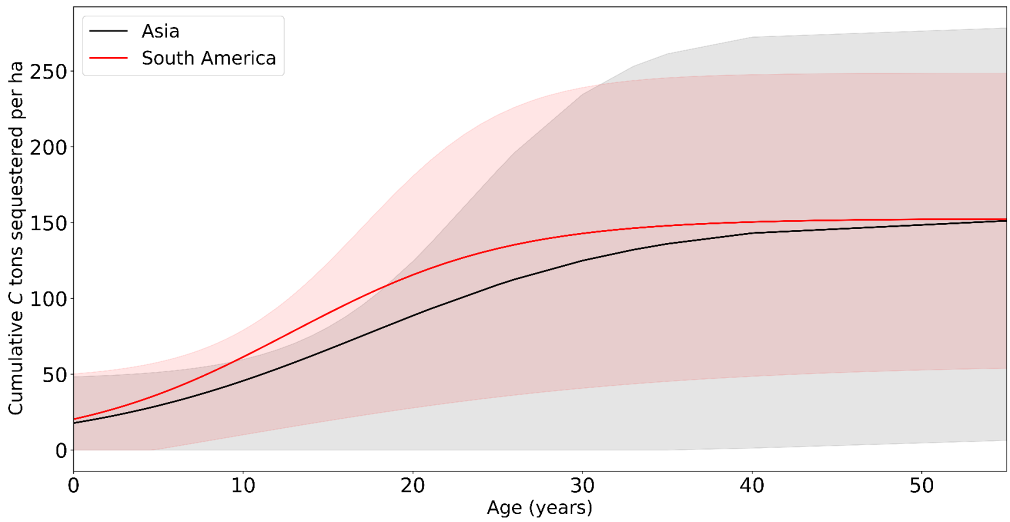

Figure 3. Carbon sequestration potential (tons of carbon per ha) for different forest vintages (stand age) using above-ground biomass and carbon across different locations in South America and Asia. The red lines are obtained by fitting sigmoid functions to the data via nonlinear least squares. The shaded grey areas represent 95% confidence bands. Data source: Cook-Patton et al. (2020).

We now explore the benefits of aggregating different forestry projects within and across the two geographical regions of interest. It is well known from modern portfolio theory that aggregating assets exposed to both idiosyncratic and systematic sources of risk can leave investors only exposed to the latter, thus dramatically simplifying pricing considerations (e.g., Goetzman et al., 2014).

Diversification by forest age

We first explore the diversification potential delivered by holding forests of different vintages. Using the same binning scheme as in figures 1 and 2, we create six stand-age categories and consider pools of at least 12 forests in each category. We then compute the average variance and average covariance of the carbon sequestration potential associated with each bucket and analyze the diversification benefits delivered by considering portfolios of different buckets via the following formula (see Goetzman et al., 2014):

$$\sigma_P^2 = \frac{1}{N}\overline{\sigma}_j^2 + \frac{N-1}{N}\overline{\sigma}_{jk}$$

where N is the number of forests in the portfolio, σ_P^2 denotes the portfolio variance, $\underline{\sigma}_j^2$ represents the average variance of carbon sequestration potential of each forest in the portfolio and $\underline{\sigma}_{jk}$ denotes their average covariance. The volatility of the portfolio is defined as the square root of the variance, i.e., by $\sigma_P = \sqrt{\sigma_P^2}$. As N grows larger, idiosyncratic risk vanishes and portfolio variance is driven by the average correlation between forestry projects, a proxy for systematic risk.

In figures 4 and 5 below, we report the forestry portfolio volatilities for the cases of Asia and South America, respectively, as the number of forestry projects of different vintages increases. We notice that in both cases portfolio volatility is halved by simply considering six projects of different vintages[13]. However, portfolio volatility is considerably higher for South America, dropping to an average slightly below 40% as opposed to a figure of 15% for Asia. Diversification across regions (as opposed to within regions) is therefore bound to generate greater volatility than a purely Asia-focused portfolio. This is illustrated in figure 6, which shows how combining a total of 12 South American vintages with Asian vintages would reduce volatility to 20%. In other words, South American risk can be diversified away with Asian forestry projects, whereas the opposite is not in general true, due to the lower portfolio volatility achievable within Asia.

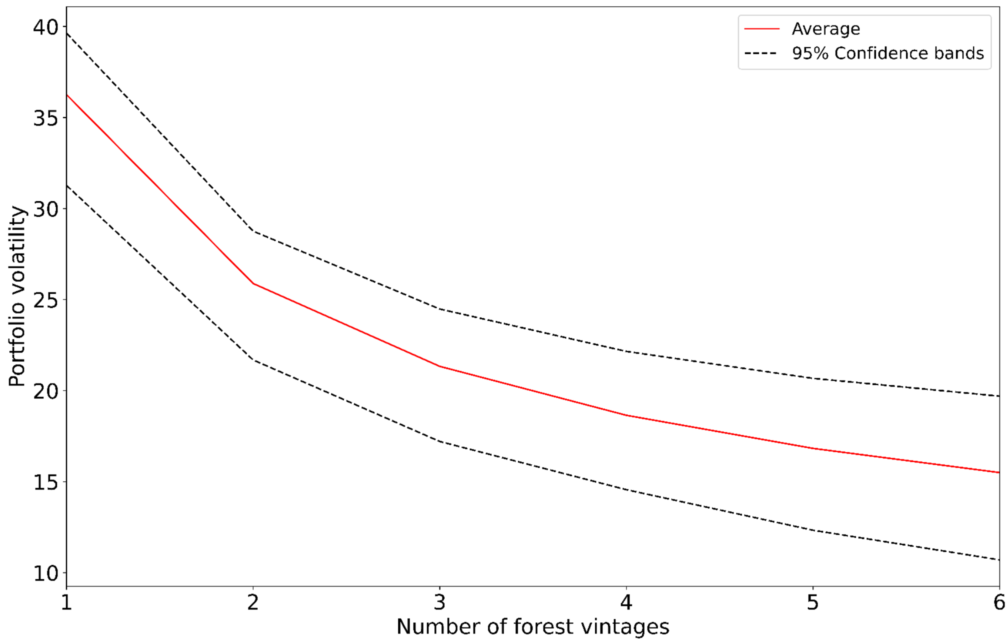

Figure 4. Forest portfolio volatility as a function of the number of randomly selected forestry vintages within Asia.

[13] We draw vintages at random and repeat the procedure multiple times to estimate the expected volatility reduction resulting from choosing vintages at random within the sample.

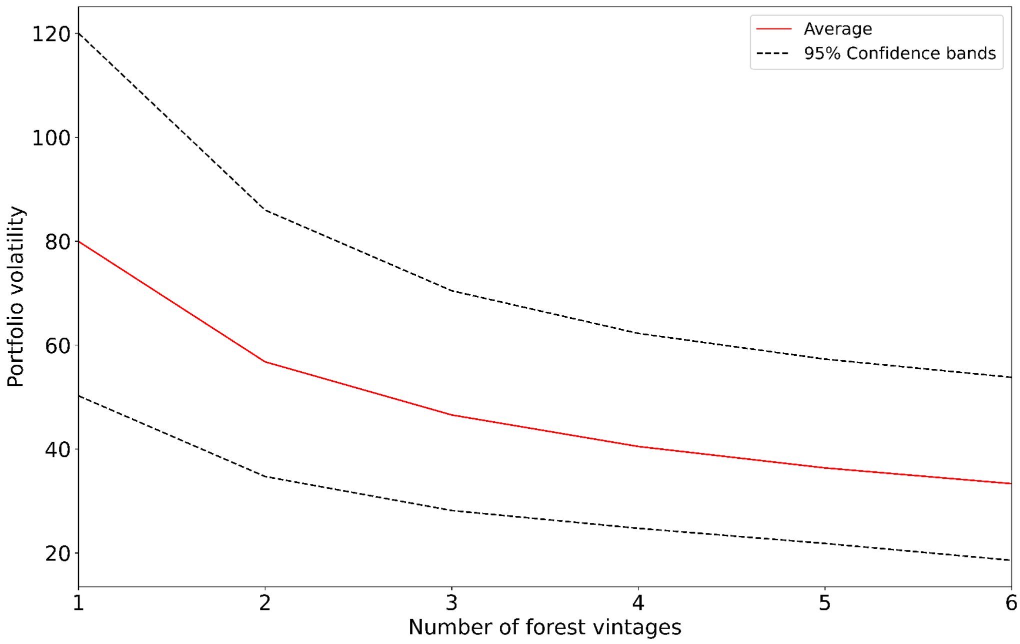

Figure 5. Forest portfolio volatility as a function of the number of randomly selected forestry vintages within South America.

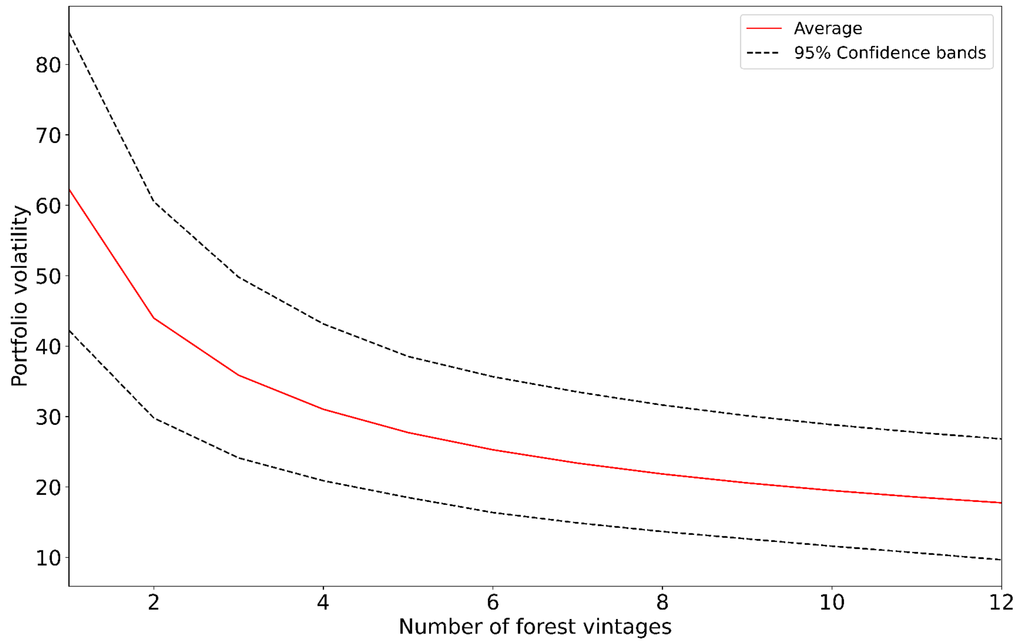

Figure 6. Forest portfolio volatility as a function of the number of randomly selected forestry vintages across South America and Asia.

Diversification by geography

The case studies considered so far assume the availability of various forestry projects of different vintages. This is clearly unrealistic for originators focusing on reforestation projects and aggregating newly planted forests. We therefore assess the benefits of diversification within and across South America and Asia for young forests, which are defined as having a vintage of between 0 and 3 years. Figures 7, 8 and 9 report the results for portfolio volatility in this case. They show that the average reduction in volatility for pools of six forests within the two regions is around 38%, meaning that diversification benefits are reduced relative to the case of diversification across vintages, where the average volatility reduction potential is 60%. On the other hand, diversification across regions seems to be more effective for young forests, as a pool of 12 forests now halves portfolio volatility (53% volatility reduction)[14]; see figure 9.

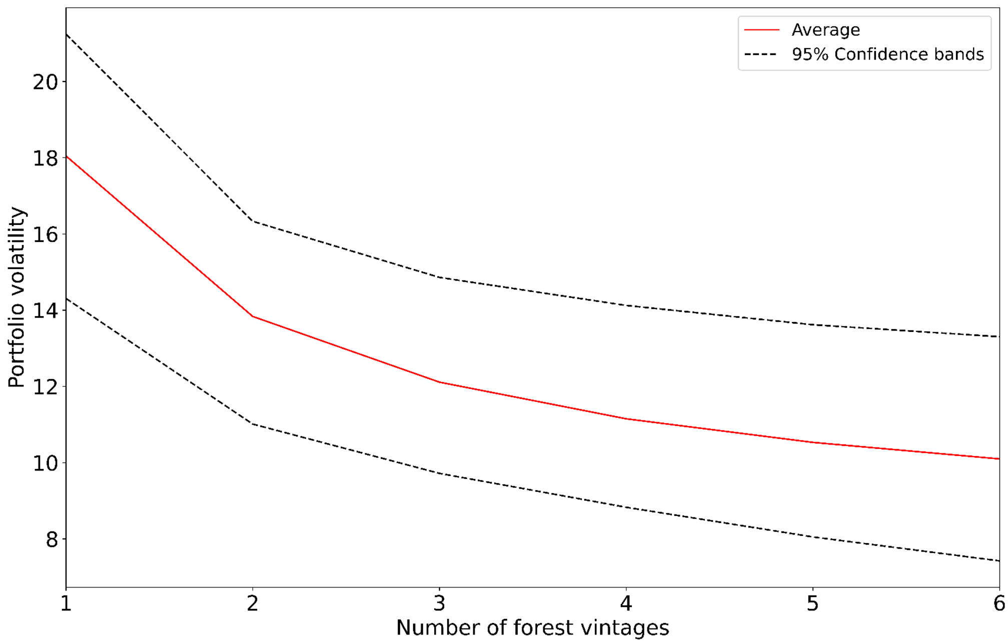

Figure 7. Forest portfolio volatility as a function of the number of randomly selected forest projects within the 0–3 years vintage bucket in Asia.

[14] For comparison, the volatility reduction for 12 forests across all vintages is 71%, which is relatively higher than the pooling benefits obtained for young forests only.

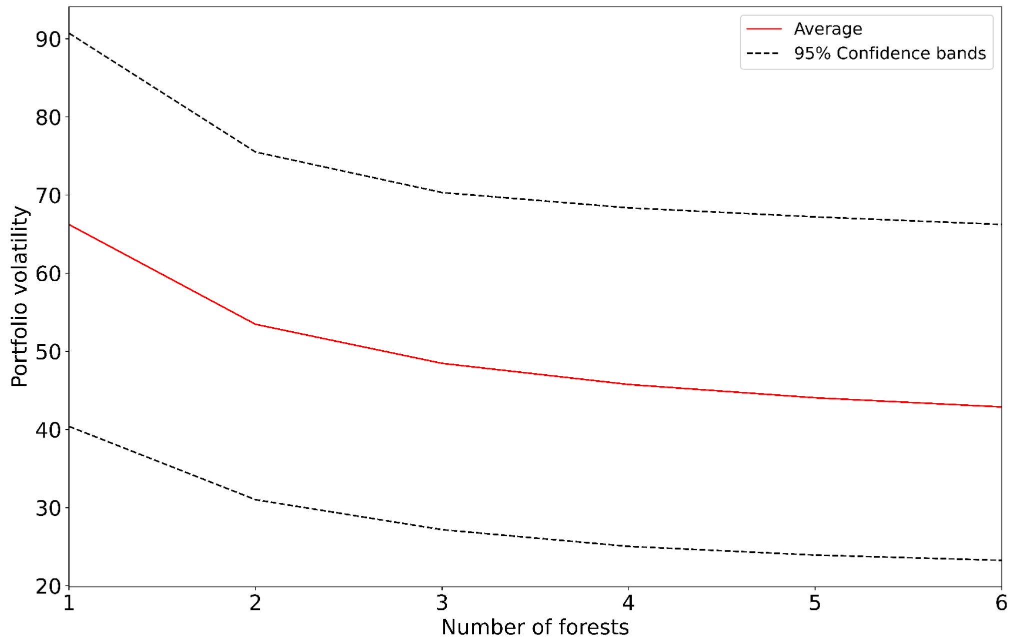

Figure 8. Forest portfolio volatility as a function of the number of randomly selected forest projects within the 0–3 years vintage bucket in South America.

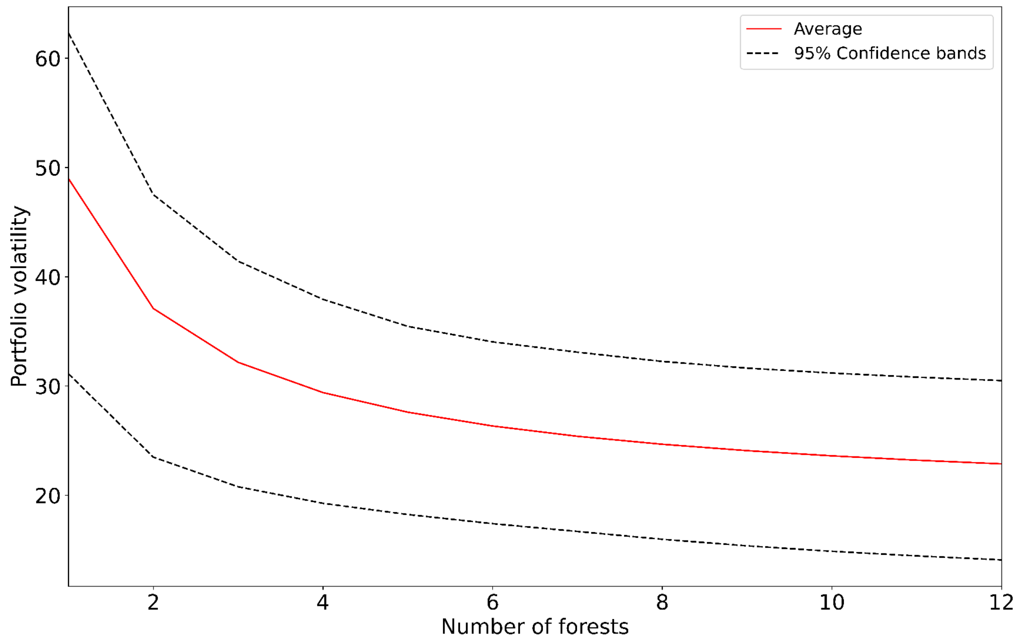

Figure 9. Forest portfolio volatility as a function of the number of randomly selected forest projects within the 0–3 years vintage buckets across Asia and South America.

3. Multidimensional Project Selection

In this section we extend the previous analysis to include wildfire risk and biodiversity targets to explore multidimensional forestry project selection across geographies. This angle provides a more sophisticated approach to bundling forestry assets, in the sense of allowing the targeting of particular tradeoffs and constraints in addition to reaping the "statistical" benefits of risk pooling.

3.1 Wildfire Risk

In the previous section, we have analyzed the benefits of diversification from the perspective of carbon sequestration potential. Although such potential is risky, in the sense of being characterized by a spread of different outcomes across projects, it is still a positive attribute of forestry assets. We now turn our attention to wildfire risk, which is probably the most compelling example of forestry downside risk resulting from a natural hazard. We use data from the Global Fire Emissions Database (GFED) project[15], which offers global coverage[16] at a monthly sampling frequency[17] and allows us to compute wildfire occurrence probabilities and severities by location. We note that these are based on historical data and do not incorporate climate change projections[18]. We use (time) averaged burned area fraction[19] as a proxy for the expected loss due to wildfire at different locations and report it on an annualized basis. Figure 10 provides a global wildfire risk vulnerability heatmap.

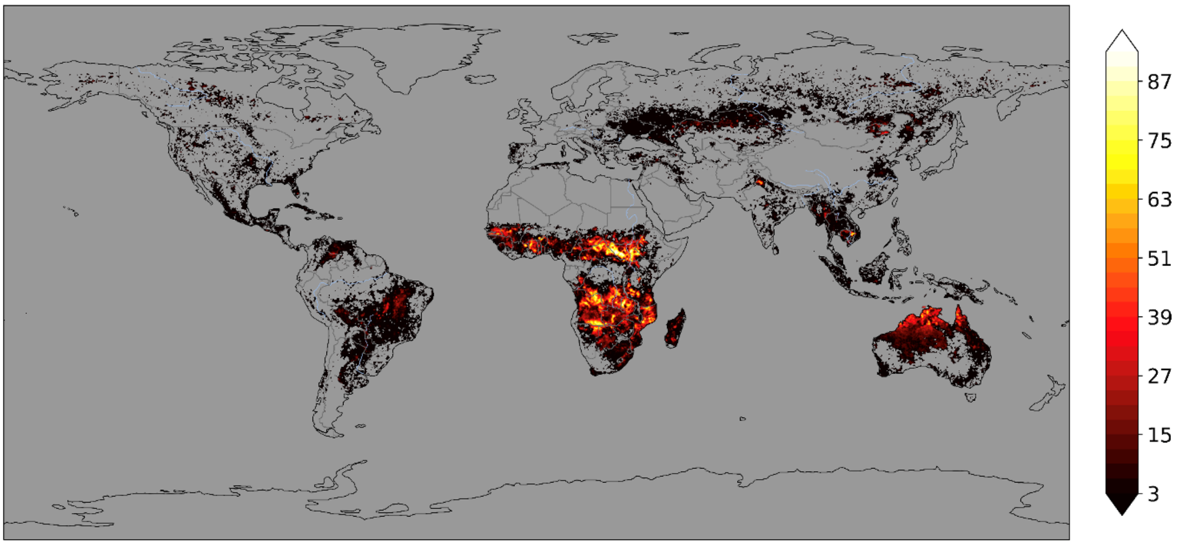

Figure 10. Wildfire risk vulnerability expressed as the percentage of burned area per location per year.

[15] See https://www.globalfiredata.org/data.html and resources here, as well as Giglio et al. (2006), Akagi et al. (2011), Giglio and van der Werf (2013) and Randerson et al. (2018).

[16] The spatial resolution of the dataset is 0.25-degree latitude by 0.25-degree longitude.

[17] The time period covered is 1995–2016 for the data of interest to us.

[18] How wildfire risk exposures will evolve along different climate pathways will be addressed in future research.

[19] This is the portion of a forest burned by a wildfire.

In figure 12, we jointly consider wildfire risk and carbon sequestration potential. For the latter, we consider Net Primary Productivity (NPP) data[20], which is directly linked to carbon sink potential (see Jin et al., 2022, and Sha et al., 2022). For our analysis, we merge synchronous monthly data across the NPP and GFED databases during 2000–2015. The NPP metric is expressed as grams of carbon captured per square meter per month at each point of the spatial grid.

We standardize the excess of the average carbon captured above the global average level[21] by its volatility, so we introduce the Carbon Sequestration potential Sharpe Ratio (CSSR) as a relevant metric. This ratio[22] is used in finance to capture an asset's risk-return tradeoff. See figure 11 for a heatmap of CSSR results at the global level. A positive CSSR ensures that the expected carbon sequestration from a project is superior to that obtained on average across the globe. The higher the CSSR, the higher the expected carbon sequestration relative to its volatility[23].

As illustrated in figure 12, there are interesting patterns in the geographical distribution of the CSSR and wildfire risk vulnerability[24]. For example, historical data suggest that equatorial Asia and Southeast Asia offered relatively low vulnerability to wildfire risk and high CSSR, whereas Central Asia was characterized by considerably lower CSSR and higher vulnerability to wildfire risk. Africa presents very dispersed and sizable wildfire risk and a wide range of CSSR, thus making forestry project selection challenging and aggregation necessary. We will refine and deepen our understanding of these findings by adding the biodiversity dimension and country-specific information in section 3.3 further below.

[20] See Field et al. (1995) for remote sensing-based estimation of NPP and Van der Werf et al. (2017) for its use in the context of global fire emissions.

[21] The global average carbon sequestration level across the territories covered by the dataset is 40.39 grams per square meter per month.

[22] The Sharpe ratio is defined as the excess return of an investment above the risk-free rate divided by the investment's volatility. As such, it represents a measure of risk-adjusted return. We consider the analog for carbon capture potential by introducing the average global carbon sequestration as a benchmark level for the normalization.

[23] In the presentation of the results, we consider only CSSR values above minus four.

[24] See the appendix for the coding of different geographical areas.

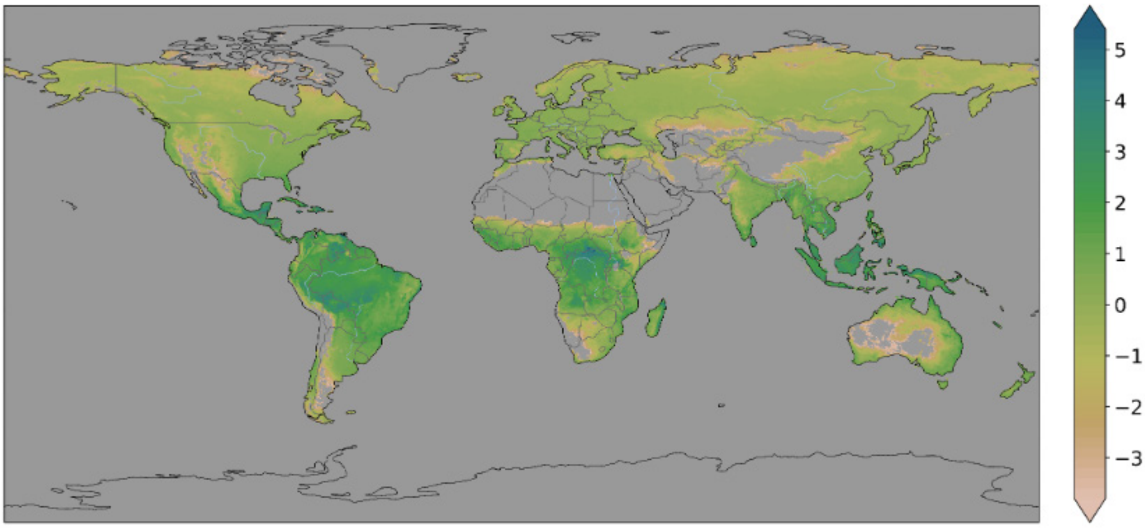

Figure 11. Carbon Sequestration potential Sharpe Ratio (CSSR) heatmap.

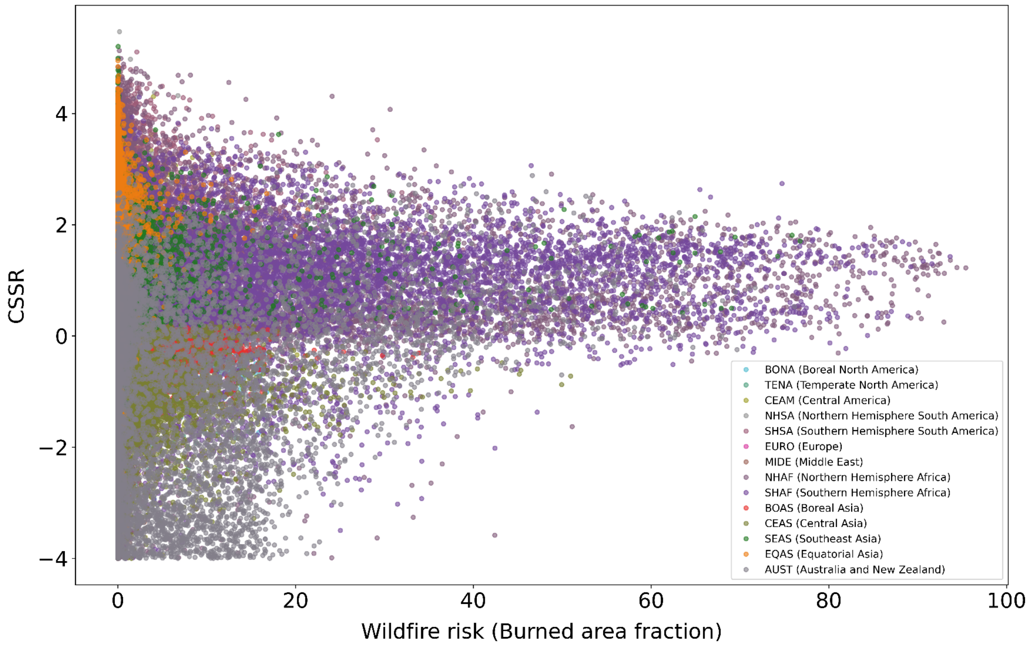

Figure 12. Wildfire risk vulnerability expressed as the percentage of burned area per location per year.

3.2. Biodiversity

Forests are not only effective carbon sinks, but also biodiversity shields, as they harbor most of the Earth's terrestrial biodiversity. Indeed, the United Nations Environment Programme reports that forests contain 60,000 different tree species, 80% of amphibian species, 75% of bird species and 68% of the world's mammal species[25]. For our examples, we use biodiversity data

[25] See FAO and UNEP's 2020 report, The State of the World's Forests, as well as OECD (2004).

provided by the International Union for Conservation of Nature (IUCN) red list website[26]. We use the species richness metric, which is defined as the number of species occurrences in each spatial grid for amphibians, birds and mammals. We normalize the metric to make it take values between zero (minimum diversity score) and one (maximum diversity score).

Figure 13 provides a heatmap for the biodiversity score. When comparing it with figure 11, we see a large overlap between areas of the world with high carbon sequestration potential and those with high biodiversity scores, thus providing evidence of a natural, strong link between carbon sequestration forestry projects and biodiversity preservation. Figure 14 further demonstrates the existence of a strong, positive relationship between our biodiversity metric and the CSSR. This suggests a natural alignment between ambitious biodiversity and carbon sequestration objectives. Geographical clustering of appealing biodiversity-CSSR scores is apparent, making South America and Asia particularly attractive. Parts of Africa also emerge as potentially important candidates in forestry bundles, but the joint impact of the wildfire risk dimension requires further analysis, which is carried out in the next section.

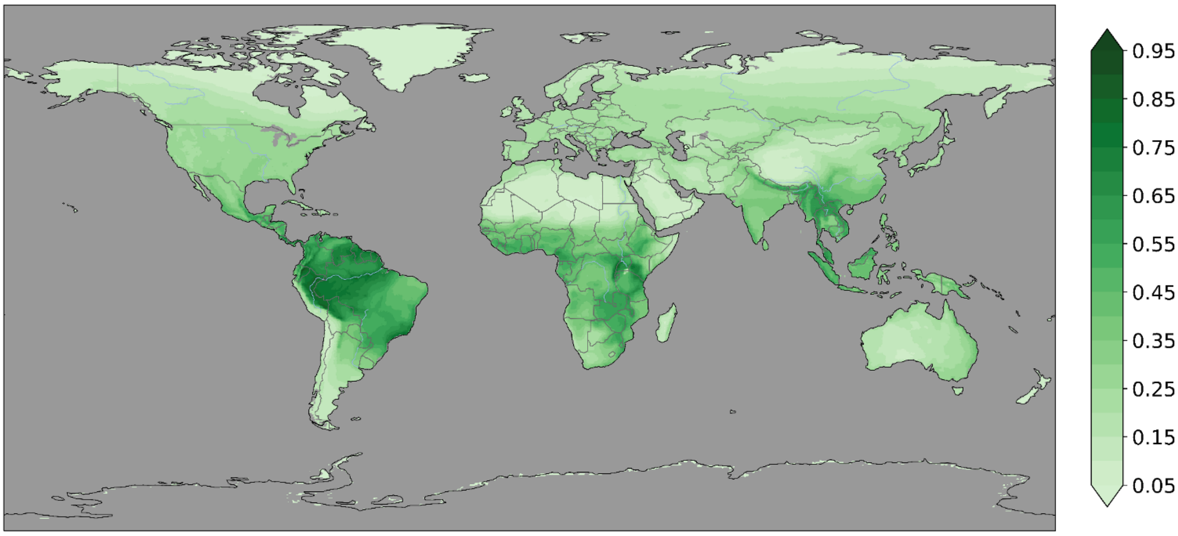

Figure 13. Biodiversity richness score (increasing from zero to one) across the globe.

[26] See https://www.iucnredlist.org/resources/other-spatial-downloads.

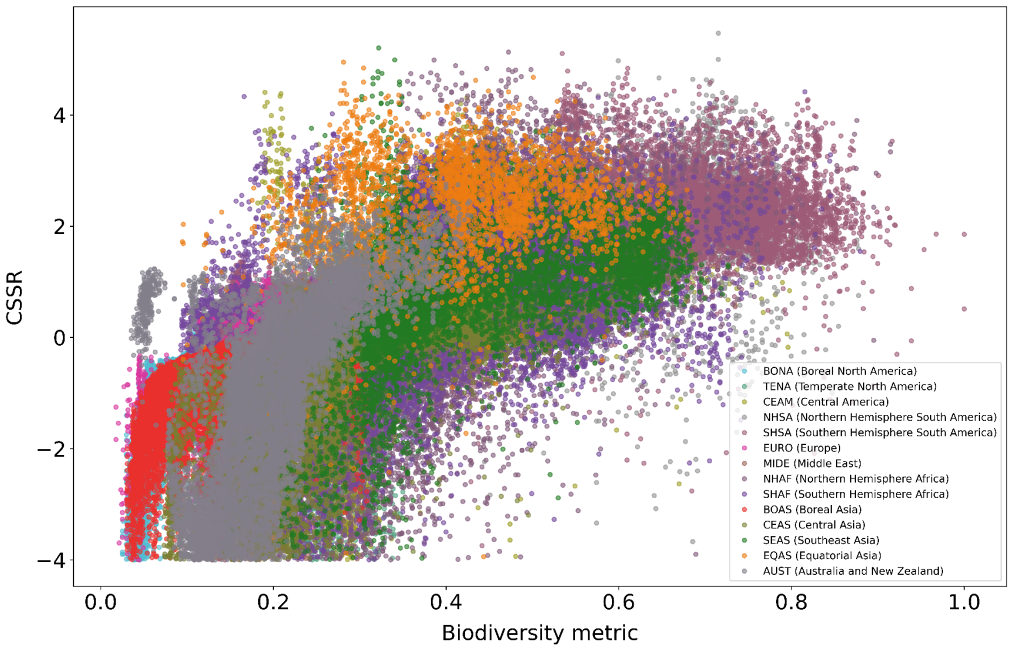

Figure 14. Carbon Sequestration Sharpe Ratio (CSSR) as a function of our biodiversity metric.

3.3. Multidimensional Analysis

The analysis of section 3.1 revealed important geographical patterns in wildfire risk exposure, whereas that in section 3.2 demonstrated a strong positive relationship between biodiversity scores and CSSR across many locations. We now provide an example of multidimensional project selection by merging these two perspectives: this will allow us to consider downside (wildfire) risk explicitly when dissecting the biodiversity-CSSR linkage.

Figure 15 provides a three-dimensional representation of the tradeoffs at hand, revealing important geographical clusters. To better understand the latter, we focus on South America, Asia and Africa separately. The results are presented in figures 16 (South America), 17 (Asia) and 18 (Africa). Analysis of the biodiversity-CSSR tradeoff now offers the ability to be more granularly selective in terms of locations. One can further envisage the introduction of broader economic and geopolitical considerations, including sovereign ratings, currency volatility and labor costs. These could now effectively be overlaid onto metrics focusing on carbon sequestration, biodiversity and wildfire risk assessment.

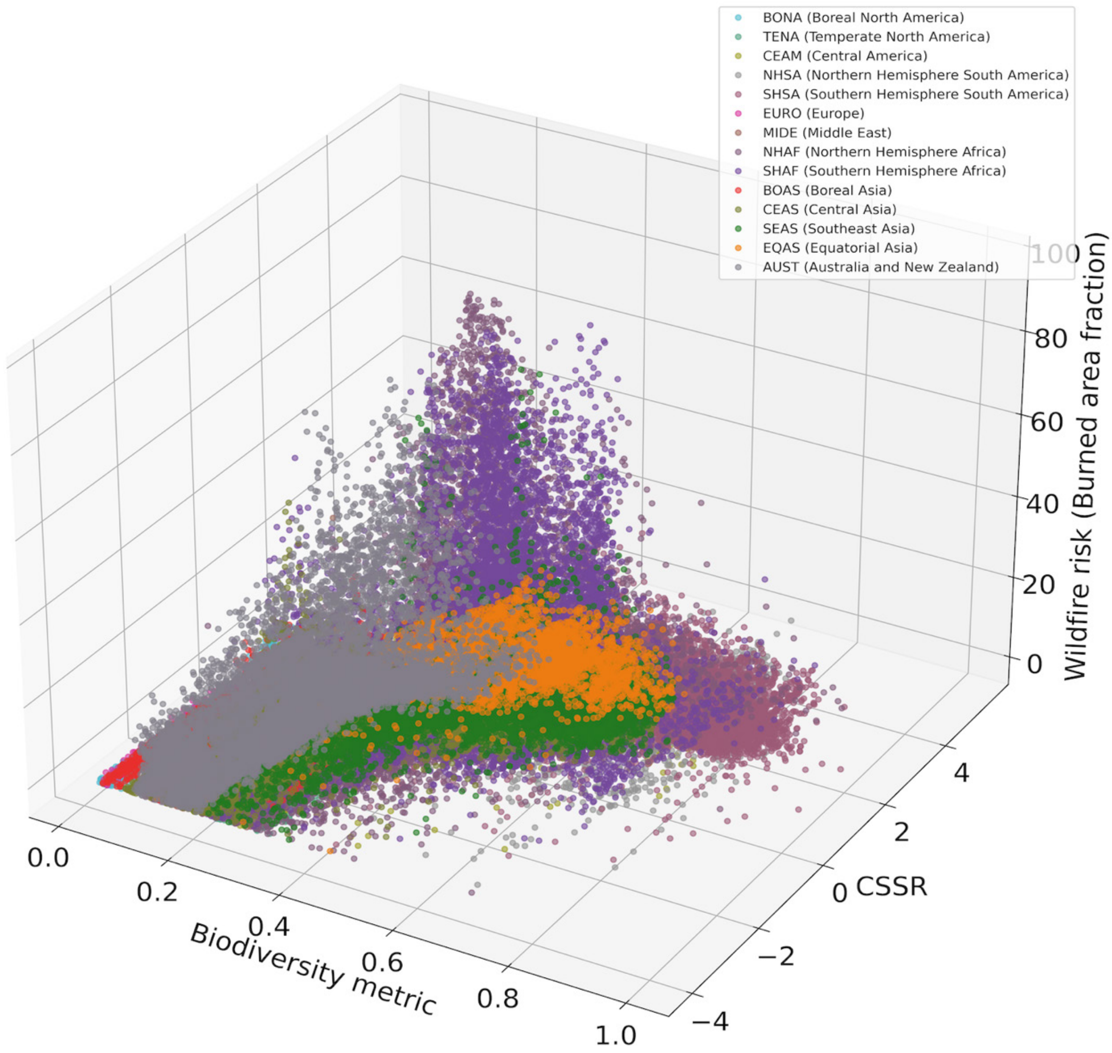

Figure 15. Carbon Sequestration Sharpe Ratio (CSSR), biodiversity score and wildfire risk exposure across global locations.

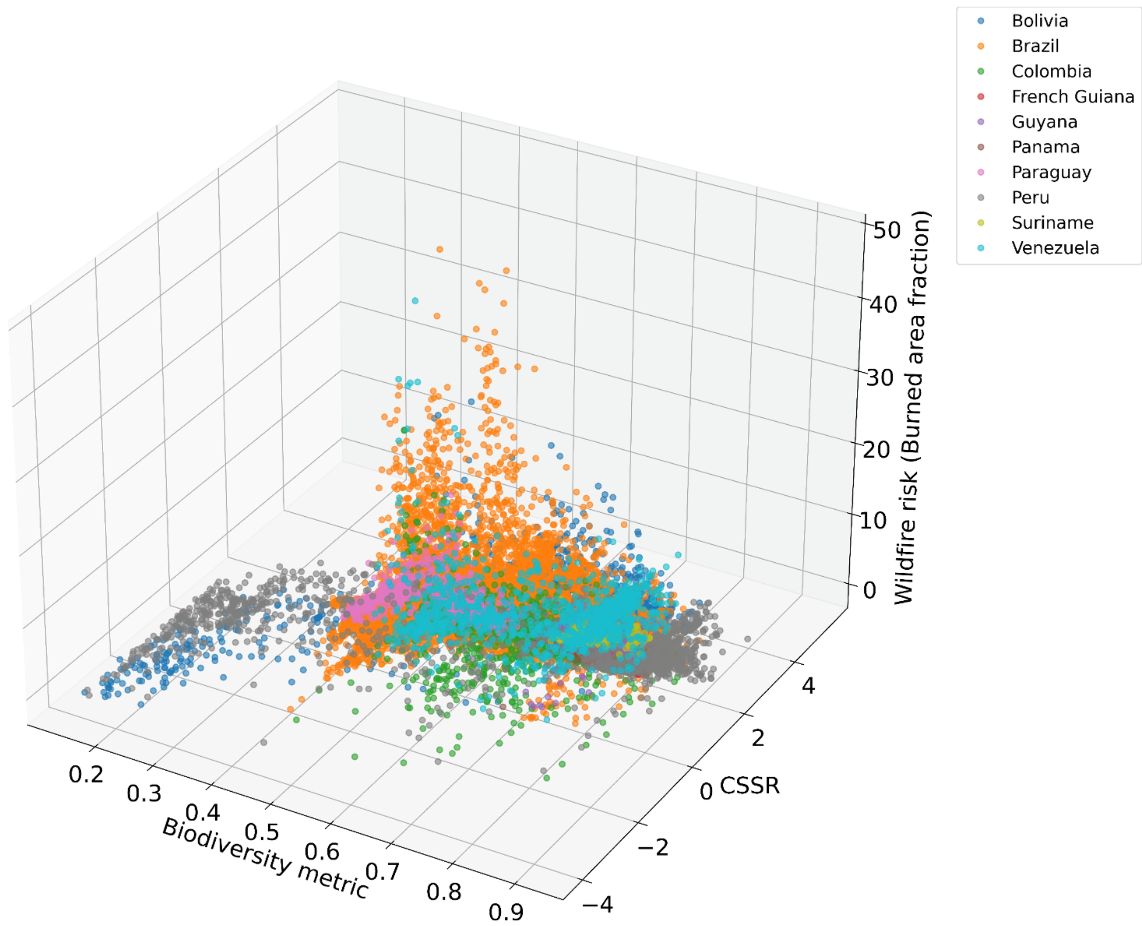

Figure 16. Carbon Sequestration Sharpe Ratio (CSSR), biodiversity score and wildfire risk exposure across the top 10 South American locations having the highest biodiversity-CSSR score. The latter is defined as the product of the biodiversity metric and CSSR.

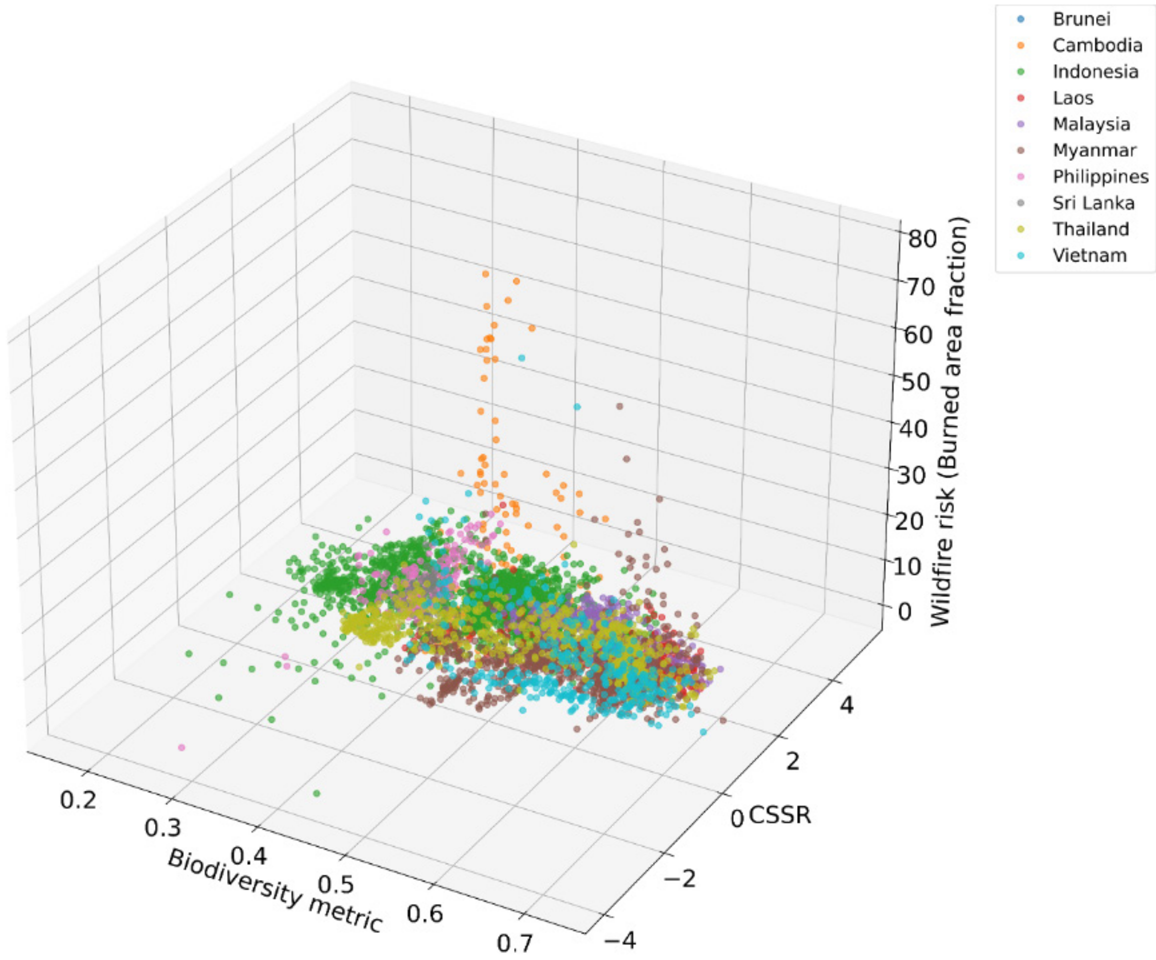

Figure 17. Carbon Sequestration Sharpe Ratio (CSSR), biodiversity score and wildfire risk exposure across the top 10 Asian locations having the highest biodiversity-CSSR score. The latter is defined as the product of the biodiversity metric and CSSR.

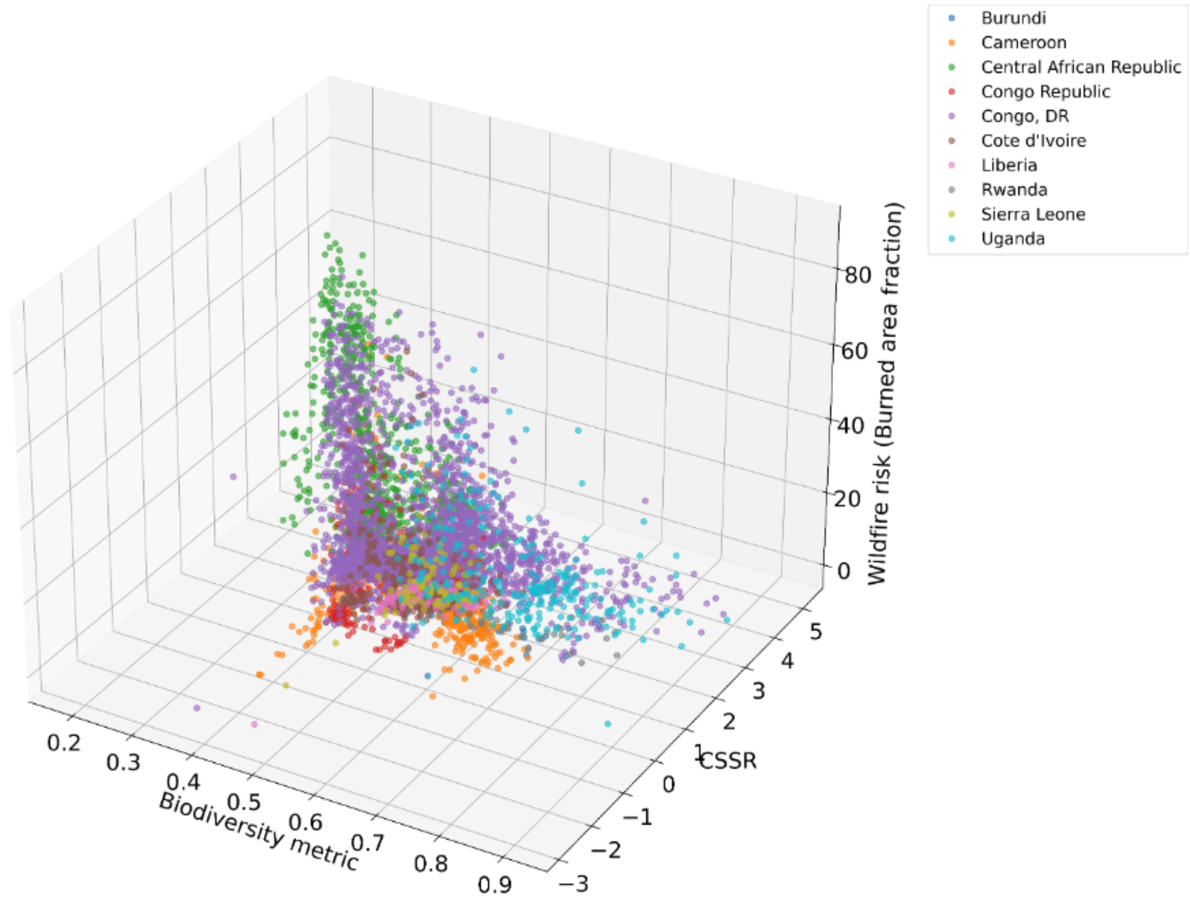

Figure 18. Carbon Sequestration Sharpe Ratio (CSSR), biodiversity score and wildfire risk exposure across the top 10 African locations having the highest biodiversity-CSSR score. The latter is defined as the product of the biodiversity metric and CSSR.

4. Building Forestry-backed Tranches

As wildfire is the main downside risk we consider in this report, the selection of bundles capping such hazard exposure to a particular target level can be mapped into tranches carrying a different rating and hence trading at a yield consistent with similarly rated asset-backed securities. Although risk could be reduced further by first bundling and then tranching the forestry pool, we focus here first on tranches targeting a maximum level of wildfire risk among a given pool of forests and then identify suitable forestry bundles within that pool delivering desired CSSR and biodiversity targets. This makes it easier to navigate the risk-return profiles of forestry assets across different locations. The exercise also offers important insights into forestry project selection which may be equally helpful to forestry managers, investors and governmental agencies in addition to originators.

To produce stylized examples of forestry-backed tranches, we use the data discussed in the previous section to design three different case studies.

- **Case study 1**. We first consider the top 10 countries (by biodiversity-CSSR score) within each of South America, Africa and Asia. We then narrow down the investment universe to target the top third (33%) of forestry projects by degree of biodiversity-CSSR score.
- **Case study 2**. We first consider the top 10 countries (by biodiversity-CSSR score) within each of South America, Africa and Asia. We then consider only those projects that have a biodiversity score and CSSR falling in the top 10% of the distribution.
- **Case study 3**. We consider the global pool of forestry projects. We then consider the top 0.3% of projects by biodiversity-CSSR score, resulting in a bundle of 16 countries.

The first two case studies start from a baseline pool of countries aimed at avoiding geographical clustering induced by the disparity in wildfire risk exposure across continents. The last case study allows the entire pool of countries to be considered, irrespective of continent, and focuses on the very top biodiversity-CSSR score, leaving a pool of forests that can still deliver sizable risk-pooling gains.

For each case study, we consider different levels of wildfire risk to mimic the tranching mechanism delivering increasingly secure investment propositions to market participants. In particular, we consider expected annualized wildfire risk losses equal to 1%, 0.5%, 0.1%, 0.01% and 0.001%[27]. To put things in perspective, regulatory banking and insurance requirements usually target capital provisions enabling institutions to be solvent with 0.5% probability over a one-year horizon.

Figure 19 reports the optimal forestry bundles for case study 1. It shows that a 1% wildfire risk target would ensure good diversification across continents. As a tighter level of wildfire risk is considered to accommodate greater investor risk-aversion, we see that the composition of the bundle changes, inducing some countries to fall out of the bundle. The relative contribution of the remaining countries to the bundle, however, is relatively stable. This suggests that aggregation could start from a core bundle of countries and then increase exposure to wildfire risk by expanding the bundle with selected countries. This would clearly have important implications for the way in which originators look at the economic value and viability of projects that can be added to the core bundle in a second stage.

Figure 20 represents the bundles for the second case study. As is apparent from the picture, the tighter biodiversity and CSSR targets considered result in a more concentrated bundle. Moreover, as the wildfire risk target becomes tighter, there is an increase in concentration, with greater contribution from some countries (e.g., Peru) relative to others (e.g., Brazil and Bolivia), while some countries drop out of the bundle (e.g., Uganda). The results suggest that tighter biodiversity-CSSR targets make bundles more concentrated and their composition more sensitive to the target level of wildfire risk.

Finally, figure 21 shows the result for the third case study. We recall that here we consider the entire forestry investment universe without imposing any balance across continents before tranching. We still obtain a well-balanced portfolio of projects featuring countries that were not

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[27] These figures are often translated in finance as leaving investors facing a total loss in case of a 1-in-100, 1-in-200, 1-in-1,000, 1-in-10,000 and 1-in-100,000 year event, respectively. This perspective should be used with caution in our context, as expected annualized losses of *x%* and a 100% loss every *1/x* years have radically different ecological implications.

appearing in the first two cases (e.g., Philippines) and mitigating the concentration in certain countries (e.g., Brazil). For example, Brazil, Indonesia, DR Congo and Venezuela now have comparable shares in the bundle. As tighter levels of wildfire risk exposure are considered, we clearly notice some changes in the relative contribution of different countries, but the most important takeaway is that African countries see their contribution shrink or completely vanish (e.g., Central African Republic, Angola, Madagascar and Ethiopia), yielding a bundle which is 90% dominated by South American and Asian projects.

In interpreting the bundles presented in figures 19 to 21, we can think of the country contribution as representing conditional probabilities of picking a forestry project within each country, given the relevant constraints on wildfire risk exposure and biodiversity-CSSR score are met[28].

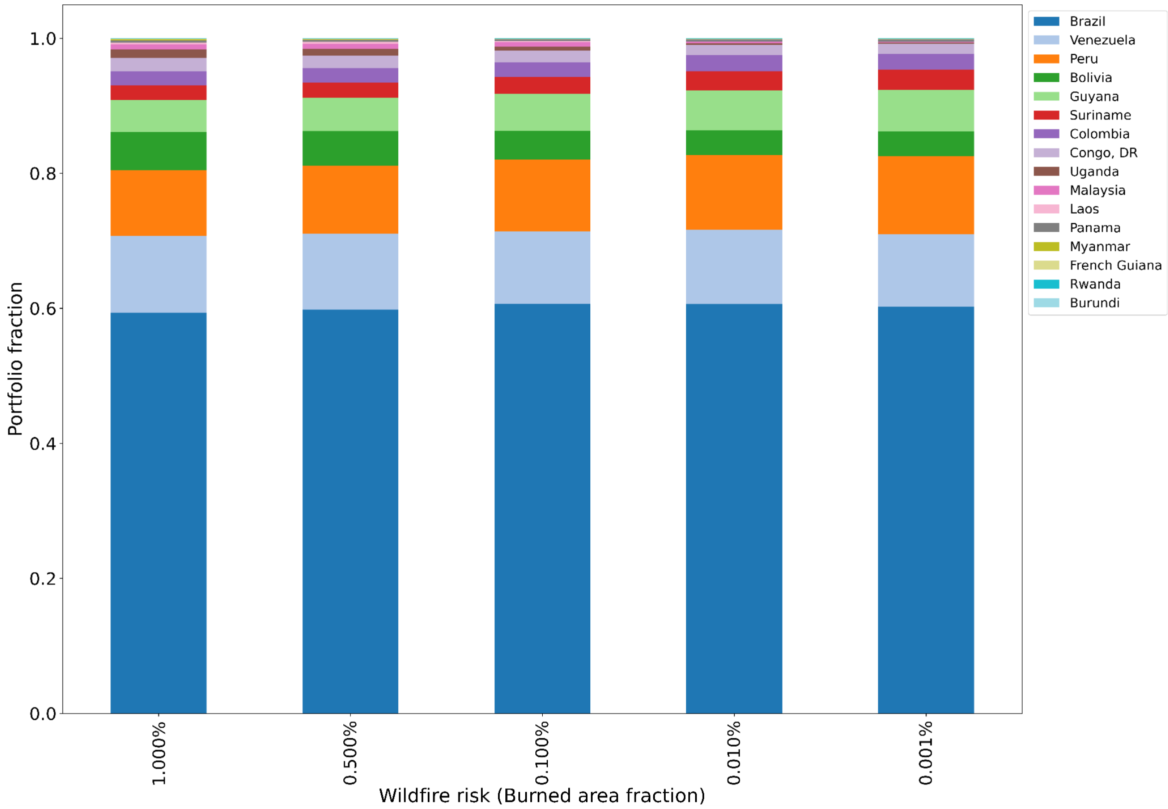

Figure 19. Case study 1. Forestry bundle composition for different expected annualized wildfire risk losses.

[28] The probabilistic interpretation explains the normalization of the sum of all country contributions to 100%. Although this angle is not explored in this study, the approach lends itself naturally to valuation exercises based on expected values of discounted cashflows.

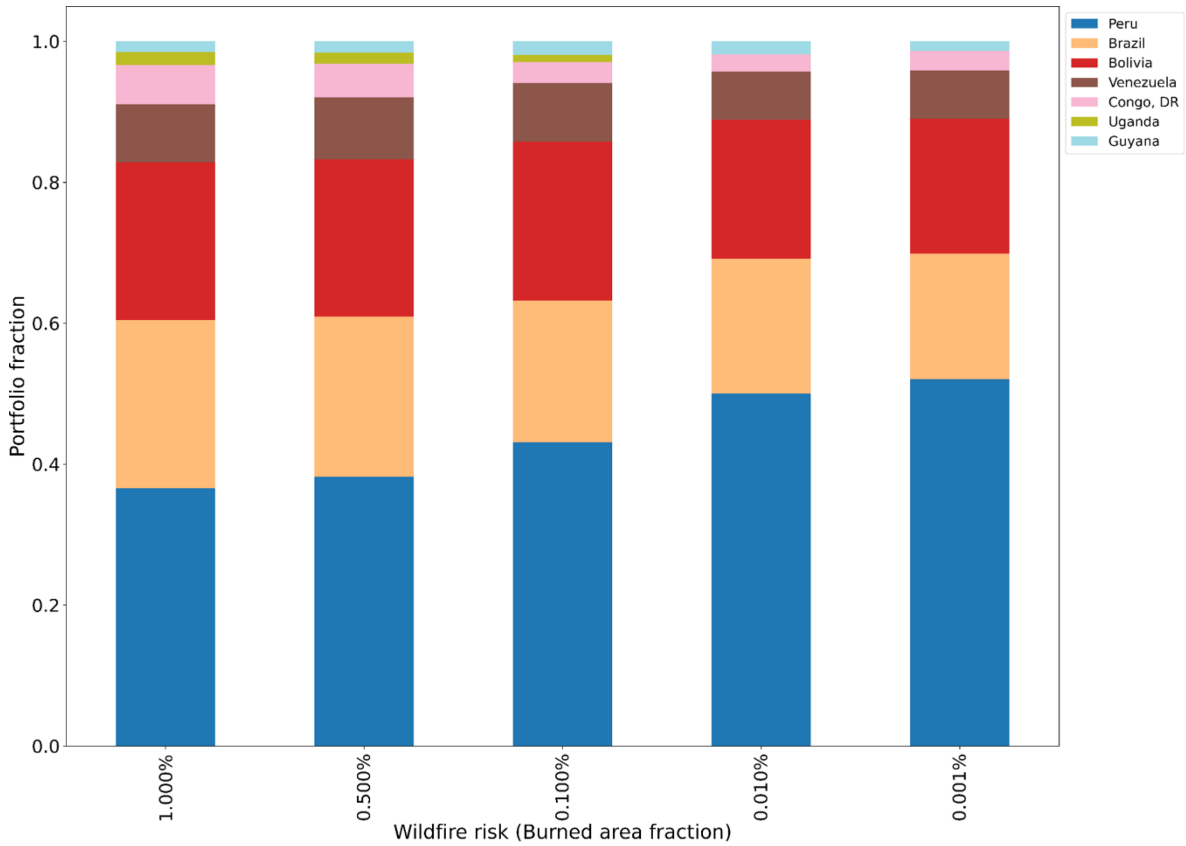

Figure 20. Case study 2. Forestry bundle composition for different expected annualized wildfire risk losses.

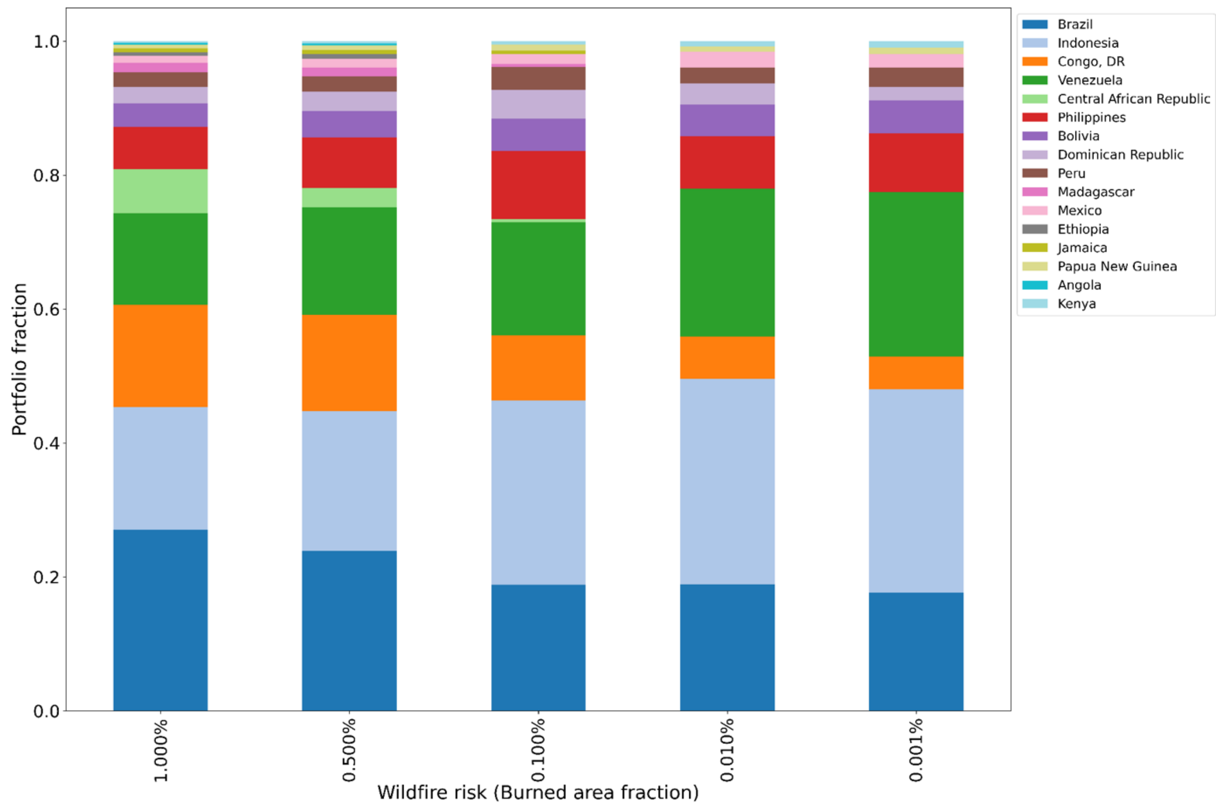

Figure 21. Case study 3. Forestry bundle composition for different expected annualized wildfire risk losses.

Boosting geographical diversification

The results presented above are influenced by the ability of countries of different sizes to host different numbers and varieties of forestry projects, Brazil being a notable example. We would like to approach more structurally now the idea of engineering geographical diversification in the bundle construction. Using the probabilistic interpretation of the bundle composition, we would like to allow the bundle to underweight the countries with higher relative frequency and overweight those with lower relative frequency, so as to ensure a more balanced spread of locations within the bundle. A simple way to engineer this outcome is by weighting the number of projects in each country by the inverse of the relative frequency (see the appendix for details).

Figures 22, 23 and 24 present the counterpart of the results originally depicted in figures 19, 20 and 21, respectively, after implementation of the weighting scheme allowing countries underrepresented in the sample to make a more material contribution to the forestry bundle. As can be noted from the pictures, we can now see a more balanced spread of country contributions in the bundle, with smaller countries (e.g., Rwanda) now emerging due to the high-quality forestry assets they host. If we consider case studies originally characterized by greater geographical concentration due to the stringent biodiversity-CSSR objectives (see figures 20–21), we can now see a very different picture, with a number of countries now contributing to the forestry bundle (see figures 23–24). As we increase the tightness of the wildfire risk exposure, it still occurs that some countries are excluded from the bundle, but we are left with a fairly diverse mix of forestry asset locations even at the 1-in-10,000 year level.

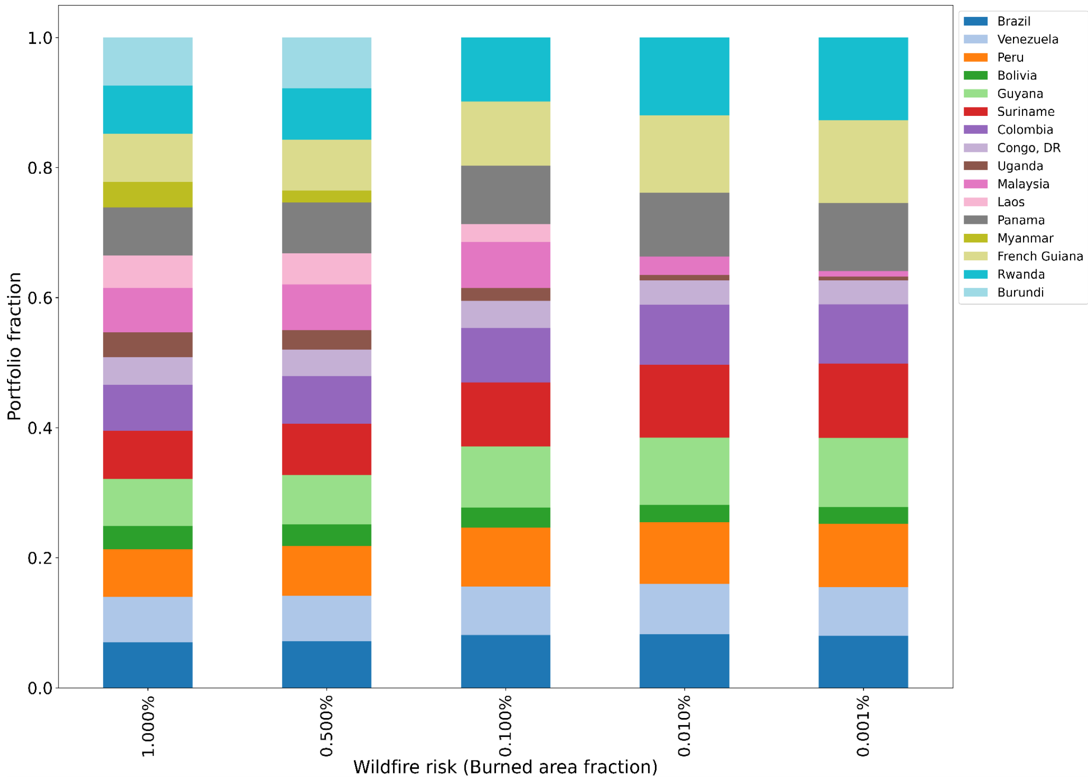

Figure 22. Case study 1. Forestry bundle composition for different expected annualized wildfire risk losses, after the reweighting scheme outlined in the appendix is implemented.

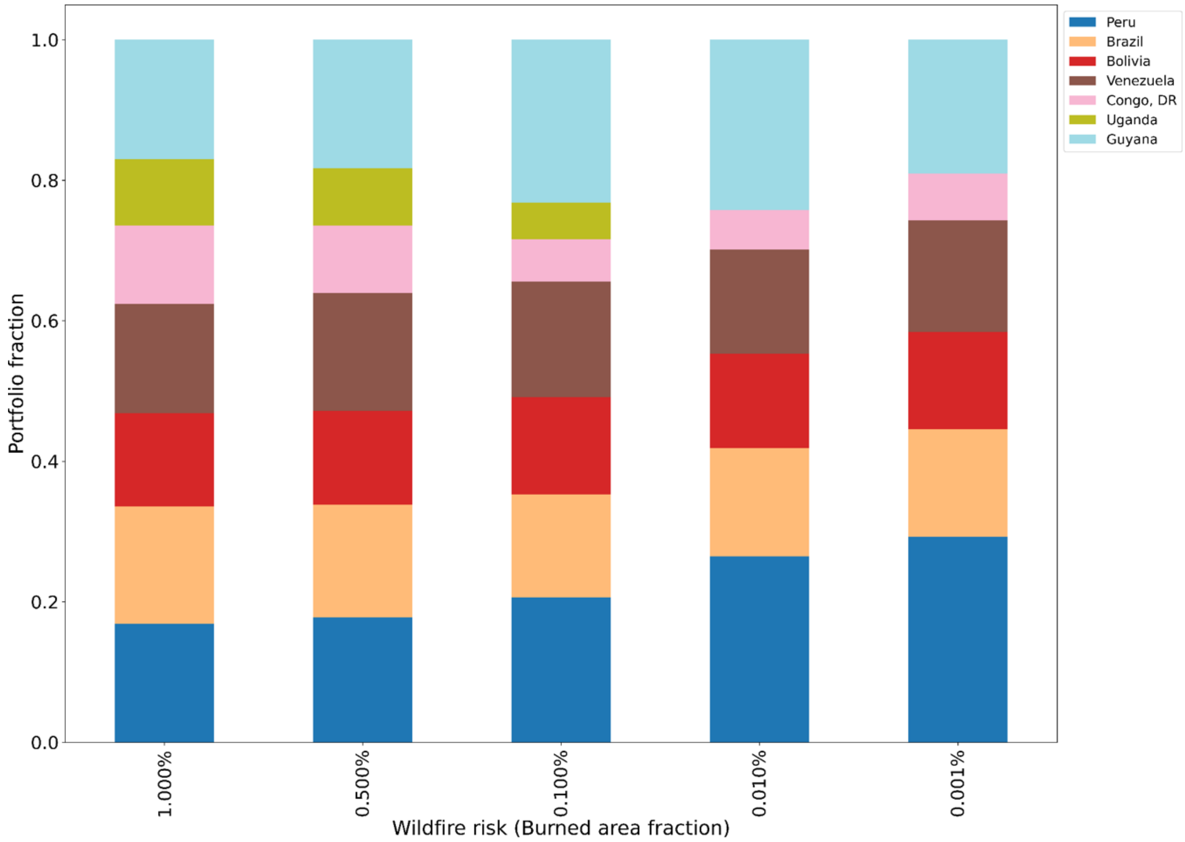

Figure 23. Case study 2. Forestry bundle composition for different expected annualized wildfire risk losses, after the reweighting scheme outlined in the appendix is implemented.

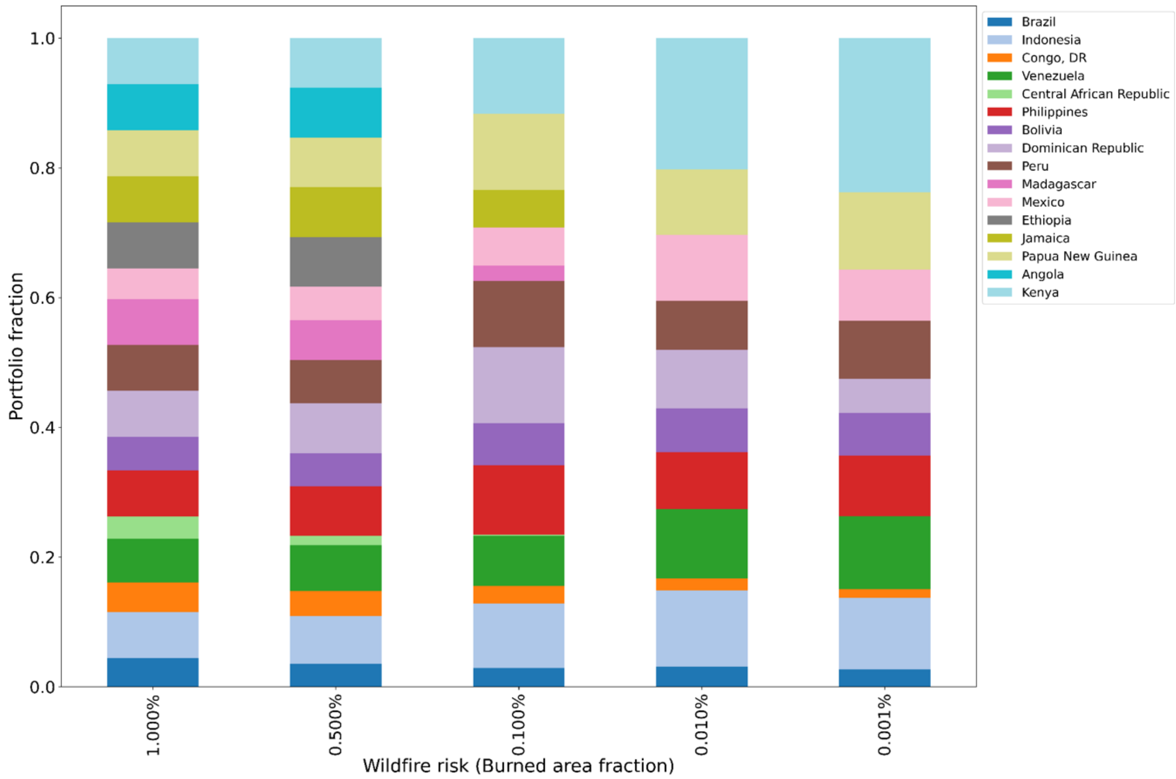

Figure 24. Case study 3. Forestry bundle composition for different expected annualized wildfire risk losses, after the reweighting scheme outlined in the appendix is implemented.

5. Conclusion

In this work we have taken a novel look at the design of forestry-linked securities, exploring in particular opportunities for risk pooling offered by forestry assets presenting different attributes at a geographical, vintage, biodiversity and carbon sequestration potential level. The exploration of multidimensional project selection has revealed interesting opportunities for creating forestry bundles and tranches targeting different levels of biodiversity and carbon sequestration while capping investors' exposure to wildfire risk within a desired level. The results presented are important for forestry asset originators, as well as investors and forestry management companies interested in articulating project selection beyond traditional metrics associated with the timber market and instead focusing on the biodiversity and carbon sequestration potential of forestry assets. The results are also relevant to policymakers and governmental agencies interested in understanding which forestry assets may need tailored intervention to make them more appealing to market participants interested in carbon-based assets. We have offered a number of case studies supported by historical data. An important dimension which is left for further research is how climate change will shape the relative attractiveness of certain locations relative to others. This important aspect will be discussed in future research. A forthcoming companion paper will instead address the carbon and timber revenue dimensions.

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Appendix

Geographical subregion coding for section 3

BONA	Boreal North America	NHAF	Northern Hemisphere Africa
TENA	Temperate North America	SHAF	Southern Hemisphere Africa
CEAM	Central America	BOAS	Boreal Asia
NHSA	Northern Hemisphere South America	CEAS	Central Asia
SHSA	Southern Hemisphere South America	SEAS	Southeast Asia
EURO	Europe	EQAS	Equatorial Asia
MIDE	Middle East	AUST	Australia and New Zealand

Geographical diversification boosting procedure for section 4

The table below offers a stylized example of calculations allowing one to engineer a more diversified forestry project bundle based on the data available for six countries labelled X1 to X6. The original bundle is composed for more than a third by country X1 (columns A and B). After taking into account the fact that 57% of overall forestry projects are located in country X1 (columns C and D), we can apply a weighting scheme rescaling each country's contribution by the inverse of the relative frequency of projects appearing in the dataset. The results are presented in columns F and G, which report the outputs of the products of columns A and E and columns B and E, respectively.

	A	B	C	D	E	F	G
Country code	Number of projects in the bundle	Proportion in the bundle	Number of available projects	Relative frequency	Weights (Inverse of relative frequency)	Adjusted number of projects in the bundle	Rescaled proportion in the bundle
X1	35	35%	570	57%	1.75	61	5%
X2	20	20%	100	10%	10.00	200	17%
X3	10	10%	60	6%	16.67	167	15%
X4	15	15%	200	20%	5.00	75	7%
X5	8	8%	20	2%	50.00	400	35%
X6	12	12%	50	5%	20.00	240	21%
Total	100	100%	1000	100%	103.42	1143	100%