Pricing and Restoring Natural Capital: A Case Study on Mining and Vegetation

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EXECUTIVE SUMMARY

Natural resources often come for free to the companies that use them. Natural resources have a large economic value. For example, pollination enables between US$235 and US$577 billion of the global agricultural output [1] and the total value of forests is estimated to be around US$4.7 trillion per year [2]. However, most often companies are allowed free use of vegetation and other natural resources in their production processes [3]. This is a major problem, as natural resources are being consumed 1.75 times faster than the planet can regenerate [4], which endangers the ecological foundations of society [5].

We provide a centralized, satellite-based methodology to estimate the cost of vegetation loss and apply it to the mining sector. We show that by using satellite images that are publicly available we can assess the impact of companies on natural resources and estimate the related cost. To showcase how this system works, we focus on the case of the Antamina mining site in Peru and the associated loss of vegetation, with three main steps:

1. We use an established satellite-based approach to compute an index that tracks the type of light emitted by plants during photosynthesis to measure vegetation's intensity.
2. We link the index to the mining activity in Antamina, as the impact of vegetation is evident and visible from space.
3. We consider the amount of money that would be required to restore a similar amount of vegetation, and we use it to value the vegetation loss in the Antamina site.

We find that the "vegetation debt" of the Antamina site for the period 1998-2012 amounts to around US$5.7 million.

Current investments into nature restoration must increase, especially from the private sector. While funding reforestation is key to reach climate goals [6], [7], funds are currently missing. Investments for nature preservation and restoration are currently in the range of US$ 124 – 143 billion a year, mostly coming from the public sector (86%) [8], [9]. If we are to reach these climate goals, these investments need to at least quadruple by 2050 [9]. This paper provides a mechanism for the private sector to step in and help closing this financing gap for nature.

We show how to use the proposed methodology to create a centralized, polluter-pays fund for the private sector to restore vegetation. In this system, companies would pay for both the past and present use of vegetation by transferring the due amounts into a fund, which would then be reinvested in restoration projects. Following our case study, the owner of the Antamina site could repay its vegetation debt by transferring US$5.7 million into this fund, and this sum would be used to fund new reforestation projects. This centralized system allows efficiency in restoration outcomes and the pursuit of pre-determined restoration objectives, which is the same approach followed by the Global Biodiversity Framework (GBF) Fund of COP 15. Indeed, our methodology could also be used to regulate payments from the private sector into this and other existing centralized financing systems for nature restoration.

1 INTRODUCTION: THE VALUE OF NATURAL CAPITAL

Natural capital, or natural assets, are the natural resources available in an economy (e.g. [10]). They can be either renewable assets, such as fisheries and forests, or non-renewable assets, like fossil fuels and minerals [3].[6] Natural capital provides services such as energy, water, plant and fibre growth, from which people derive benefits, also called ecosystem services (e.g. [17]). While it is acknowledged that firms use natural capital, for a long time this aspect has not been a matter of concern, as the "usage rate" was lower than the rate at which natural capital was naturally regenerated. However, in the past 30 years this logic has flipped, as we started using more natural capital than what is being regenerated. It is thus necessary to move from a gross measure of value creation (like GDP) to a net one, accounting for the losses of natural capital.

Natural assets are largely undervalued. While people and organizations may value natural assets in different ways, the way they manage these assets boils down to a matter of cost minimization. The problem with natural assets is that companies can often use them for free. Companies only need to minimize the extraction and harvesting costs for natural resources, like minerals, but they are not required to pay for the resources themselves (e.g. [11]). Furthermore, natural capital is often not only free, but can even have a "negative" price because of government's subsidies - such as the subsidies for oil and mining companies. The absent or negative price of natural assets no longer reflects their large social value and leads to a price gap. Specifically, there is a gap between the market price of natural assets, i.e., how much they are valued by economic agents, and their accounting price, i.e., the value they have as a public good for society, mostly coming from their scarcity [3].

Estimating the accounting price of natural assets is difficult. Market prices are often used to approximate accounting prices, though most of the time market prices for natural capital are simply missing. Economists have thus focused on measuring ecosystem services, which are the benefits that we derive from natural capital. For example, these benefits can be measured with questionnaires asking participants to place a value on such benefits (e.g. [12], [13]).[7] However this methodology is very complex and results can vary widely depending on the assumptions. Another way to value natural capital is considering the cost it would take to mitigate and restore the amount of natural capital that was lost. For example, the accounting price of a road includes the cost of building ways for animals to cross around the road (mitigation) and, if the road in question damages natural habitats, the cost of recreating these natural habitats elsewhere (restoration).

In this study we focus on a specific type of natural capital, namely vegetation. Plants, and more in general vegetation, are a type of natural capital that is tangible and alienable [3]. The variability among plants and other living organisms, and the ecological complexes of which they are part of, is referred to as biological diversity, or biodiversity [16]. [8] Biodiversity can thus be considered as the living part of nature,

[6] Note that natural capital can be tangible and alienable (plants), tangible and often non-alienable (pollinators), intangible and alienable (the view from one's sea-front home), intangible and non-alienable (global climate) [3]. This introduction draws broadly from the Dasgupta report.

[7] These benefits can be both direct and indirect, i.e. water filtered by wetlands that is used for breeding of animals. Aside from methods relying on the indirect use value (stated and revealed preferences), there are methodologies that focus on the direct-use value, namely the value of ecosystem services that can be inferred from existing markets. For a review of current methods to value nature and ecosystem services, see [14], [15].

[8] There is a difference between capital goods and enabling assets. Enabling assets are public knowledge, institutions and mutual trust that enable capital goods. For example, peace enables education, or taking care of the atmosphere. The accounting price of capital goods largely depends on these enabling assets. Biodiversity is an enabling asset for natural capital, so its value is embedded in the accounting prices of items of natural capital, such as ecosystems.

which also includes other types of life on Earth, such as geology, water, climate and all other inanimate components that comprise the planet [17].

Our estimate for the cost of vegetation loss is the amount of money that is needed to restore it. In this study, we propose a simple methodology to estimate the accounting price of vegetation. Rather than attempting to price all the ecosystem services that stem from vegetation, we will estimate the loss of vegetation that is due to an economic activity, with its price given by the cost of restoring it. We will then propose a funding mechanism based on the polluter-pays principle by which companies that have used vegetation in their production processes must pay for it. A simple example is a mining company that cuts trees to build an extraction site, which will be the focus of our case study. In this funding mechanism, nature-negative companies pay the price of the vegetation they have damaged by financing restoration projects.

In recent years, governments have put in place the first funding mechanisms for natural capital. In Section 2, we summarize their main characteristics, with the goal of making a parallelism between the existing systems and the system that we will propose (also described in Section 2). Section 3 reports a case study on the mining sector showing how we can measure the impact of mining companies on vegetation and estimate the related costs. Section 4 will discuss how we can apply this methodology to create a centralized, polluter-pays fund for the restoration of vegetation. Finally, Section 5 concludes by discussing the policy implications of this financing mechanism and next steps.

2 FUNDING MECHANISMS FOR NATURAL CAPITAL

As investing in natural capital is generally not profitable, regulators have created artificial market and financing systems to price natural assets and either preserve or restore them.[9] Here we will refer to "markets" for natural capital mostly as systems based on units of natural capital with a related price, given mainly by the interacting demand and supply of such units (trade). Differently, we will use the term "financing systems" for natural capital to refer to more general (financial) infrastructures that allow investments in natural assets.

Today, there are several market and financing systems for natural capital in place. Both the public and the private sector use these systems to channel money towards the preservation and restoration of natural assets. At the moment, the largest resources are allocated towards climate-related objectives (climate finance), with an overall amount of US$579 billion invested annually [9]. Approximately half of it is coming from the public sector (56%) and half from the private sector (44%). When it comes to nature-related objectives (nature finance), the overall amount is much lower, around US$133 billion per year [9]. Furthermore, there is a much larger imbalance between the contributions of the public and private sector, with the latter contributing only to 14% of these funds. [10] Our study provides a methodology and a financing system in the form of a fund, with the goal to increase the participation of private entities in the effort of preserving and restoring natural capital. In this section we briefly describe the current state of the existing systems to finance the preservation of the atmosphere and nature more in general, highlighting the main advantages and issues of each system and thus setting the stage to

[9] For example, the Dasgupta Report (2021) mentions the low profitability of preservation and restoration activities, and therefore the lack of a case for private investments to finance them.

[10] Currently, 36 countries are using the UNDP's Global Biodiversity Finance Initiative (BIOFIN) to understand how much of the public budget is being spent on conservation and restoration of biodiversity (UNDP, 2018).

propose a centralized, polluter-pays fund for nature restoration for the private sector.

2.1 EXISTING MECHANISMS

There are several existing market systems and funding mechanisms for natural capital, especially for carbon and biodiversity. We will start with the market systems, and specifically carbon markets, which can be differentiated between compliance and voluntary markets.

2.1.1 Market systems for natural capital

Compliance carbon markets are mechanisms created by governments and multilateral organizations to reduce countries' carbon emissions using carbon allowances, i.e., rights to emit. Each country has an allocated amount of such allowances, which is set in international agreements such as the Kyoto Protocol of 1992 and the Paris Agreement of 2015 [18]. Following these agreements, single countries established compliance carbon markets in the form of cap-and-trade systems, also known as Emission Trading Schemes (ETS). In this overall mechanism, countries allocate rights to emit to companies, which can emit carbon up to a certain threshold ("cap"). Beyond this cap, companies must buy allowances from either companies below the cap or certified carbon-capture projects in emerging economies that issue carbon allowances.[11] Today, ETS are present in 23 countries and cover around 15% of global emissions [19]. One tonne of carbon in the EU ETS market costs around 85-95 Euros [20].

Voluntary carbon markets allow companies to voluntarily reduce their carbon emissions by purchasing carbon offsets. Carbon offsets differ from carbon allowances, or credits, in that they are not used to fulfil emissions requirements set by international and national authorities [21].[12] Furthermore, voluntary markets do not have official regulations, and market standards are set by private certifiers, such as the American Carbon Registry, Verified Carbon Standard (Verra), the Gold Standard Impact Registry, and the Climate Action Reserve. Today, one tonne of carbon in the voluntary carbon market costs around US$3 [22].

Borrowing from these frameworks, practitioners have started developing new funding and market systems for natural capital in general, and biodiversity more specifically [23]. As it is for carbon, also for biodiversity there are compliance and voluntary systems. However, compliance systems are predominant, and include both cap-and-trade and offsetting schemes.

Cap-and-trade markets for specific aspects of biodiversity, like fish species, are regulated under the binding system of Individual Transferable Quotas (ITQs), also referred to as biodiversity permits, or allowances. In this system, a regulator sets a limit to the use of a specific natural resource (e.g., fish), which is then divided into allowances, or permits, that are distributed among companies or individuals. These tradable permits represent policy instruments that governments use to prevent biodiversity loss often related to species overexploitation due to fishery or hunting [24]. For instance, one permit corresponds to one tonne of fish. Following the same mechanism as carbon, actors can trade these instruments. There are currently 42 tradable permit schemes in 26 countries,

[11] More precisely, the Kyoto Protocol established three market-based mechanisms to introduce more flexibility on allowable emissions and allow signatory countries to add to, or subtract from, their initial assigned amount by trading emission allowances on a global scale [23]. The first mechanism, called Emission Trading, enabled countries that have unused emission allowances - those that have been allotted to them but not utilized - to trade their surplus to countries that have exceeded their emissions targets. The other two mechanisms, the Clean Development Mechanism (CDM) and Joint Implementation, were designed to incentivize developed countries to invest in emission-reducing projects in developing countries and thereafter issue carbon offsets. These credits must be certified by official organizations. For example, credits in the CDM are certified by the CDM Executive Board, an institution set up by the United Nations Framework Convention on Climate Change (UNFCCC) [26]. A platform to find the UNFCCC-certified credits is here: https://unfccc.int/climate-action/united-nations-carbon-offset-platform. For other types of units that could be traded under the Kyoto agreement, see here: https://unfccc.int/process/the-kyoto-protocol/mechanisms/emissions-trading.

[12] For example, the Verra credits can be used in compliance carbon markets only in Colombia and South Africa, and within the Carbon Offsetting and Reduction Scheme for International Aviation (Verra).

which have been recognized as significant for biodiversity [24].[13]

National schemes for biodiversity offsets aim to limit their impact on biodiversity of new infrastructure projects. There is usually a hierarchy of actions to achieve such a goal, namely avoid possible impacts, mitigate if they cannot be avoided (e.g. minimization or on-site rehabilitation), and lastly offset any residual impact. In this last level, biodiversity-negative companies can either offset their impact themselves or outsourcing the offsetting activity to owners of biodiversity-positive projects, so called bio banks, by purchasing specific credits from them, so called bio credits.[14] There are currently around 100 countries with such schemes [26] and there are around 12,983 (mostly small) offset projects in 37 countries [27].[15] For example, in Switzerland the accounting price of building a road includes the cost of building ways for animals to cross around the road (mitigation) and, if the road in question damages natural habitats, the cost of recreating these natural habitats elsewhere [29]. Finally, outside of these compliance programs, the demand for bio credits led to voluntary biodiversity markets, some of which are regulated at the national level.[16]

Carbon and biodiversity markets are proper markets that work with a price-setting mechanism, given by the supply and demand of allowances. Schemes for biodiversity offsets are a bit of a hybrid system, in between a market (bio banks and bio credits) and a financing system. The system we will propose aims to serve as a substitute to the outsourcing of offsetting actions, by promoting centralization. This system can be considered a financing system for natural capital (not a market), which will complement the existing financing systems that are described in the next section.

2.1.2 General financing systems for natural capital

Financing systems for natural capital include all systems and tools put in place by both public and private institutions to finance the preservation and restoration of natural capital, that do not have a price-setting mechanism.

Carbon taxes and funds for negative emissions. As a complement to the mentioned Emission Trading Schemes, 36 countries currently have in place a carbon tax, which is a tax on companies' emissions [30]. For example, Switzerland has a "CO2 levy" of 120 CHF per ton since 2022 [31]. A new proposition to tackle the aspect of negative emissions – removing more CO2 than what is emitted – are polluter-pays sovereign funds that receive money from polluters (via a carbon-tax like system) and invest them into projects for negative emissions [32]. These polluter-pays funds are very much in line with the funding mechanism for natural capital that we will propose in what follows.

The public sector disposes of several financing systems to finance nature restoration. Some examples are Payments for Ecosystem Services (PES), biodiversity-relevant taxes and subsidies, and Official Development Assistance – summarized in Box 1. One interesting tool that is related to our analysis is the Global Biodiversity Framework (GBF) Fund, established during the last Conference of the Parties on biodiversity, COP 15. The fund will complement existing financing systems,

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[13] These countries are Argentina, Australia, Canada, Chile, Denmark, Estonia, Finland, Iceland, Lithuania, Malta, Mauritius, Mexico, Morocco, Mozambique, Namibia, Norway, New Zealand, Peru, Spain, Sweden, South Africa, the United Kingdom and the United States. For critiques of this system, see [25].

[14] Such as the ones used by the California Department of Fish and Wildlife.

[15] As offsetting can give an incentive to companies to degrade the environment, the IUCN stated that offset projects must now provide a net gain, as it's already being done in the UK [28].

[16] For instance, the Australian government is at the forefront of developing legislation to support a national, voluntary biodiversity market, with approved certification and monitoring. For more information, see here: https://www.dcceew.gov.au/environment/environmental-markets/biodiversity-market.

with the goal to mobilize at least US$200 billion per year by 2030 [33, p. 15]. The funding mechanisms that we will propose below can regulate and channel payments from the private sector into this fund.

The private sector contributes only marginally. The private financial sector is currently investing in biodiversity restoration, with investments between US$ 6 and 13 billion a year [34], [35]. However, this is very little compared to the loans and underwriting services to sectors that harm biodiversity, which amounted to US$2.6 trillion in 2019 alone [36]. While this is the case, there are some signals that efforts are increasing.

The private sector too disposes of several financing mechanisms for investing in natural capital. At the moment, most of the sustainability-related investments from the private sector focus on transitioning towards more sustainable practices, such as sustainable agriculture and low-carbon energy production [37]. This is different from investing in actual nature restoration. This trend is partially explained by the lack of profitability of the restoration activities, driven by the mentioned wedge between market and accounting prices (or the true cost). Tools available for the private sector to invest in nature are green bonds, sustainability-linked bonds, private equity funds in supporting biodiversity, and environmental impact bonds [34], [38]–[40]. The low financial returns, the small size of restoration projects and the lack of data and transparency on impact are clear barriers to bring these private funds to scale [37], [41], [42]. Alternative mechanisms that address these barriers are blended finance, pooled funds and private funds for nature like the one of HSBC [43].

Overall, governments have put in place several systems to price and preserve natural capital. The most advanced systems are the ones related to climate objectives, with a fair degree of centralization, achieved via international carbon markets. On the other hand, systems for the preservation and restoration of nature and biodiversity are currently quite heterogeneous and decentralized. This is partially due to the lack of a commonly accepted unit of measure for biodiversity.[17] Possible shortcomings are a low degree of coordination on the choice of restoration projects to be financed, and a low involvement of the private sector in contributing to the restoration efforts. In the next section we propose a centralized, polluter-pays funding system that aims to increase the contribution of companies in efficiently financing restoration programs.

[17] Among the ones available, there is the Mean Species Abundance (MSA) indicator, which is the mean abundance of species in disturbed habitat relative to their abundance in undisturbed habitat, and the Biodiversity Intactness Index (BBI), which is the fraction of naturally present terrestrial biodiversity that still remains (e.g. [74,75]). Recently, market participants have proposed methodologies to measure the impact of firms on these indicators, such as the Biodiversity Footprint for Financial Institutions (BFFI) [76] and the Global Biodiversity Score [77].

Box 1: Financing systems for natural capital for the public sector

There are several financing systems that are used to channel public funds (either exclusively or for the major part) into the preservation and restoration of natural capital.

1. **Payments for Ecosystem Services (PES)** run on the principle that beneficiaries of ecosystem services should pay people and businesses who are providing them. It creates a system of financial incentives for local actors who provide these services, such as forest managers that preserve mangrove coastal forests. There are currently several PES programs, which are mainly based on the costs of maintaining the ecosystem service (e.g. [44]–[46]). In all PES systems, the beneficiary of the ecosystem service pays for it. These beneficiaries can be tourists, governments, or citizens. Currently there are more than 550 PES schemes around the world, with annual transactions estimated to be between US$ 36 and 42 billion, mostly coming from public funds [47], [48].[18]

2. **Biodiversity-relevant taxes** are aimed at activities with a negative impact on nature such as pesticides, fertilizers, forest products and timber harvests. There are currently around 206 biodiversity-relevant taxes in 59 countries [24].

3. **Biodiversity subsidies** include programs for forest management and reforestation, agriculture, and land conservation, and are currently in place in 24 countries [38].

4. **Green and blue bonds** are also used to restore nature, though their focus remains climate - it is estimated that only 4% and 2% of the bonds' proceeds go to, respectively, biodiversity and sustainable land use [49].

5. **Official Development Assistance (ODA)** is an international funding scheme targeted for developing countries [35]. USA, Germany, France and Japan are the main donors of biodiversity-related ODA, with the main projects being about the sustainable management of forestry, water supply, agriculture and fishing in African countries [34]. Multilateral ODA are possible thanks to the mediating and financing role of Multilateral development banks (MDB), with the formula of blended finance. International schemes catalyse a significant part of the public money allocated to biodiversity restoration (around 5-12% of the overall funds spent) [35].

6. **Debt-for-nature swaps** can be used by developing countries to receive a debt or interest discount, and in exchange must invest the related savings into nature preservation and restoration. Countries have been using these instruments quite successfully, leading to around US$1 billion of cancelled debt so far, and approximately US$500 million of savings reinvested in conservation [50].

[18] They focus on different ecosystem services, namely biodiversity conservation, carbon sequestration, landscape amenities and hydrological services [47]. PES have 4 main problems. First, the landowners could have protected these ecosystem services in any case for their own interest. Second, protecting an ecosystem service covered by the PES might mean destroying another one that is not covered. Third, PES create an incentive to landowners to degrade ecosystems in anticipation of a PES scheme being put in place. Fourth, reforestation (ecosystem function) may not always lead to an increase in ecosystem services [46].

2.2 PROPOSAL: A POLLUTER-PAYS FUND FOR NATURE RESTORATION

Centralizing financing systems for nature is key. In current nature markets based on bio credits, companies can outsource restoration efforts by acquiring these credits from bio banks, which are owners of nature-positive projects. In this system, companies have their own targets on nature restoration, and purchase credits in order to achieve them. As there are no common objectives, investments can be very heterogeneous and their effectiveness in protecting and restoring animal and plant species at risk can be limited. To address these challenges, COP 15 has created a centralized fund to invest in nature preservation and restoration, with the clear objective of restoring, or start restoring, at least 30% of damaged ecosystems by 2030 [33]. In this system, the selection of projects is "centralized" in the figure of the fund manager, who decides which are the critical projects to invest in to achieve this objective.

We propose a centralized, polluter-pays fund for nature restoration for the private sector. In this mechanism, a centralized monitoring system measures the past and present impact of companies on natural capital, and related cost (or price). These "nature-negative" companies then pay this price into a fund for nature restoration – so the term "polluter pays". Specifically, there are two types of payments that would go into the fund:

- Payments for Past Impacts (PPI), related to all the natural capital companies have damaged up to today;
- Payments for New Impacts (PNI), related to all the new natural capital companies will damage from today onwards.

For example, an extraction company operating since the '80s, should repay for the trees it has cut down until today to make space to its extraction sites – what we can refer to as its "natural debt". Second, for any new extraction site, the company should pay the price of the trees it will cut to make room for the site. The fund we propose here aims to reach a high level of centralization of investments from the private sector. Such investments could either add up in the fund of COP 15 or being organized through a new fund for the private sector.

First, we propose to consider the local negative impact of a company's facility on natural assets. Companies' facilities can be factories, mining sites, infrastructure projects, and other assets needed for production. Because of the nature of their activity, some companies need to place their facilities inside natural habitats. When this is the case, companies modify or destroy natural habitats to make room for the facilities needed for production. A classic example is a mining company that cuts trees to make room for an extraction site. Note that this approach focuses only on the direct, local impact of a company's facility on nature, and excludes all indirect impacts related to the company's business.[19] The literature currently reports some techniques to estimate these indirect impacts, such as the Biodiversity Footprint for Financial Institutions (BFFI) and the Global Biodiversity Score mentioned above, which are not included in our methodology. In a parallel with accounting of CO_2 emissions, we could say that we are only considering a Scope-1 effect on nature (direct), and not Scopes 2 and 3 (indirect).

Second, we propose to measure the value of this nature loss by considering how much it would cost to restore it. We then need to estimate the value of the natural capital companies "use", or damage, to make room for their facilities. To do that, we could either estimate the value of all ecosystem services stemming from a natural asset or consider how much it would cost to restore the same natural asset. As the first methodology is too complex to be generalized, we propose to follow the second approach, as it is

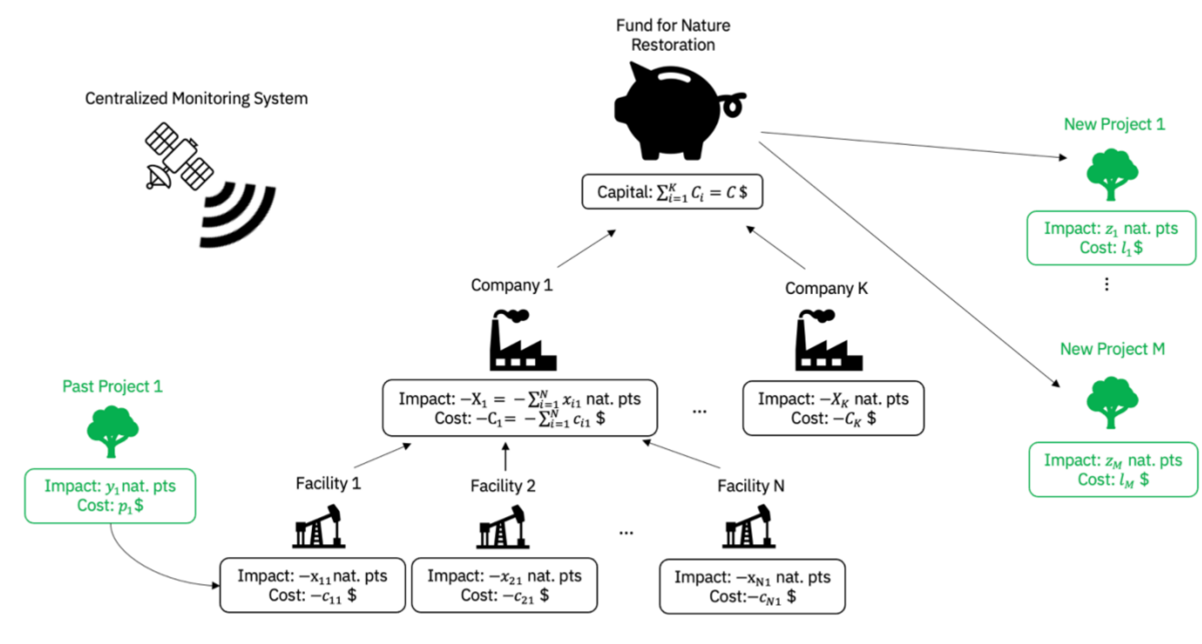
[19] The indirect impacts are those impacts produced by the company's supply chain. For example, the impact on nature of a Swiss coffee producer includes the land impact of its coffee suppliers in third countries.

currently being done in biodiversity offset schemes (e.g. [29]).

This system can be represented as in Figure 1. A centralized monitoring system measures the local, negative impact of Facility 1 of Company 1 on a natural asset ($-x_{11}$ nature points). The same monitoring system measures the equivalent positive impact of Past Project 1 on the same natural asset ($-y_1$ nature points). The cost of restoration for this project ($-p_1$ \$) is considered as estimate for the value of the natural asset that Facility 1 has damaged ($-c_{11}$ \$). This process is repeated for all *N* facilities of Company 1. The sum of all impacts and costs is the estimate for the impact on, and cost of, the natural asset damaged by all the facilities of Company 1 in the past, respectively $-X_1$ nature points and $-C_1$ \$. Company 1 then needs to transfer the due amount for Payments for Past Impact (PPI), namely C_1 \$, to the fund. This holds for all companies that have a negative impact on the natural asset considered, for an overall amount C, which is the fund's capital. This capital is then reinvested into new projects for nature restoration (right side of the figure).

In this paper we report a case study showcasing how this financing system would work for the impact of mining companies on vegetation. First, we observe the trend of the Enhanced Vegetation Index (EVI) in the location of an extraction facility, and we compare it with a control location to estimate the net impact. Second, we use the EVI to measure the vegetation gain of an equivalent reforestation project, and we interpret the cost of restoration as an estimate for the cost of the vegetation loss. These estimates of vegetation impact and cost of a company's facility can be used as a basis for a pilot fund for vegetation restoration.

Figure 1: Centralized Polluter-Pays Fund for Nature Restoration



Notes: This figure reports a representation of how the centralized polluter-pays fund for nature restoration for the private sector would work. The focus here is payments for past impacts (rather than payments for new impacts). The impact of companies' facilities is estimated via a centralized monitoring system. The cost of such impact is estimated by looking at the cost of equivalent restoration of past projects (left side). The fund then reinvests the Payments for Past Impacts in new projects for nature restoration (right side).

Section 3 explains how we compute the EVI and its meaning, and reports trends in this vegetation index in the location of the Antamina mine in Peru. In addition, it shows how we can look at the income statement of companies that successfully restored vegetation to estimate the restoration cost and thus price the loss of vegetation capital due to the extracting activities. Finally, Section 4 discusses how the market system would work in this specific case study.

3 CASE STUDY: VEGETATION LOSS IN THE MINING SECTOR

3.1 USING SATELLITES TO TRACK CHANGES IN VEGETATION

3.1.1 The Enhanced Vegetation Index

The Enhanced Vegetation Index (EVI). This study uses satellite imagery to analyse the impact of companies on vegetation. As a starting point, we retrieve satellite images around the location of companies' facilities, from a publicly available databased called Landsat 5, with images at 30-meter resolution covering all locations on the planet over the period 1984-2012. We use these images to compute the Enhanced Vegetation Index (EVI), which is an image-based measure for vegetation density. Intuitively, when plants do the photosynthesis, they scatter near-infrared light and absorb red light [51]. The EVI captures the difference between these two types of light at the pixel level. The higher the EVI, the higher is the photosynthesis, and therefore the higher is the density of plants. The EVI can go from -1 to 1, with positive values indicating the presence of vegetation - healthy tropical forests have values around 0.7 [52]. The EVI is a corrected variation of the well know Normalized Difference Vegetation Index. For more information, see Section 1 of the Technical Appendix.

3.1.2 Linking the Enhanced Vegetation Index to Companies' facilities

The literature of spatial finance estimates the impact of companies' activities on surrounding natural habitats. We need a methodology to link the EVI with companies' facilities. One of the strands of the literature that attempts to do just that is called spatial finance, which merges remote sensing with financial practice to monitor the impact of businesses and their supply chains on natural assets (e.g. [53]).[20] Another strand of recent literature uses satellite images to associate forest loss to economic activities. A specific focus is on mining activities, as they cause the loss of habitats for microorganisms, macroorganisms, and plants, removing the fertile topsoil needed for agriculture (e.g. [54]).[21]

We propose a simple methodology to link the construction of a company's site with vegetation loss. First, we select the location of the facility of interest, and we draw a radius of 3 kilometres around it. This will be our area of analysis. We then observe the difference in EVI values in this area before and after the facility was built.[22]

[20] For example, the WWF has used satellite images to monitor mining and other environmentally harmful activities in the natural World Heritage Sites [85].

[21] For example, Curtis et al. 2018 use satellite images and a decision-tree model to predict the causes of forest loss [87]. They show that permanent changes in land use for commodity extraction are responsible for 27% of the global decrease in forested areas. In another study, Sun et al. 2022 consider a satellite-based vegetation index around 3 mining sites in China and estimate the depth of the environmental damage related to the mining activities [88]. They found that the radius of damage is around 1 or 2 kilometres around the analysed mines, and that the loss in vegetation was mainly caused by dust pollution, decreases in groundwater levels, and waterborne pollution.

[22] To compute these EVI values, we consider images in windows of 3 years each. First, we select all images in the 3 years just preceding the construction of the facility and we compress them with the methodology described in the Technical Appendix to obtain one reduced image and compute one EVI value. Second, we do the same for a 3-year window at the end of our image dataset, to obtain the most recent EVI value, which will represent the status of vegetation after the facility was built. This computation could be done in many ways, though we picked this one as our baseline for two main reasons. First, the availability

This is a simplistic approach, which may result in including areas that were not touched by the facility of interest. A better approach would be using computer-vision methods to identify affected regions (e.g., object detection and image segmentation) [55], which will be the scope of future work.

The methodology includes a comparison with an untouched location, to control for the natural causes of vegetation loss. The mentioned time-trend analysis gives us a broad idea of the evolution of vegetation around the facility of interest. However, observing the mere time trend is not enough to infer any causal link between the construction of the facility and the related loss of vegetation. Indeed, there is no way of knowing if such loss would have materialized anyway due to, say, natural causes such as wildfires or plant diseases. One way to address this problem is comparing the location of interest with a "control", untouched location.[23] Specifically, we select an untouched control area of 3-km radius by minimizing the difference between this area and the area of interest around two key characteristics, namely distance and difference in altitude. We thus compare the change of the EVI in the location of the facility with the change of the EVI in the nearby, untouched location, and compute the difference. This "adjusted" change is a better estimation of the potential impact of the facility on the surrounding vegetation, as it factors out other natural drivers of vegetation loss.

3.2 IMPACT OF THE ANTAMINA MINE

We propose a case study of mining sites. We start our case study with a mining site that had a potentially negative impact on vegetation. The scope of our exercise is to illustrate how we can use satellite images to link a company's facilities and activity to vegetation loss. The most obvious starting point is focusing on a sector that has an evident impact on the surrounding environment, that can be easily picked up by satellites with a fairly low image resolution. Mining is one of the most harmful activities for the environment and especially forests. Indeed, permanent changes in land use for commodity extraction are responsible for 27% of the global decrease in forested areas [56].

We focus on the mining sector in Peru. Peru's mining industry is crucial for the country's economic growth, accounting for nearly 10% of GDP. In 2021, mineral exports generated US$27.2 billion in revenue, representing 60% of Peru's total exports. The country is a major global producer of copper, silver, and zinc, as well as the largest producer of gold in Latin America [57]. On the one hand, mining plays a significant role in Peru's economy, but on the other, mining companies are causing the destruction of entire landscapes, flora, and fauna, leading to large losses of natural capital (e.g. [58]).

Specifically, we consider the mining site of Antamina, one of the largest copper and zinc mines in the world. The Antamina mine is located in the Puna grassland approximately 270 kilometres north of

of satellite images in Landsat 5 is not always very good and reducing images around a 3-year window assures a minimum number of images and thus quality of the EVI value - vis à vis 2-year or 1-year windows. Second, computing the before value with a window ending just before the site was built reduces the probability of picking up external factors that influenced the site before the mining company started drilling. In addition, computing the after value with a window ending at the end of the dataset allows us to grasp the impact of the facility on nature cumulated through time.

[23] This technique of comparing trends in two similar locations is not new. For example, the same principle is applied in the Mean Species Abundance (MSA) indicator mentioned above, which measures the mean abundance of species in disturbed habitat relative to their abundance in undisturbed habitat. This concept is also largely applied in carbon markets, which rely on the principle of additionality - with the only difference that in carbon markets business-as-usual scenarios are usually computed with the help of environmental models. As an example, see the guidelines for the CDM system here: Introduction Guide Clean Development Mechanism Projects in the Early Transition Countries. Finally, this principle is largely used in the literature of natural experiments and empirical policy studies. This literature compares trends in units of interest (treated) with trends in control units, with very similar characteristics to the treated units - in our case, it would be a "twin" location (e.g. [89]). In these experiments, scientists observe the differences between these two groups of units over time, i.e. before and after the event of interest happened - so called difference in the differences. The literature provides several approaches to select these control units, i.e. via either randomization (randomized control trials, i.e. [90]), matching (propensity score matching, e.g. [91]) or simulation (synthetic controls, e.g. [92]).

Lima at an average elevation of 4,200 meters. This area is a hotspot for biodiversity, with species of endangered fauna and flora. For more information on the biodiversity in this region, see Box 2. Given these characteristics, we expect that the impact of the mining activity on nature will be evident and can be grasped also with low-resolution satellite images. In addition, this site serves well to the scope of our analysis as the history of the mining activity is very well documented. In 1998, the miner underwent extensive drilling and sampling to determine if the project was viable. Once it was deemed feasible, the building phase started in 1999 and by 2001 the site was ready for mineral-resource extraction [59].

Box 2: Characteristics of Natural Habitat of the Puna Region

The Puna grassland is one of the eight natural regions of Peru. Puna can be found at elevations of 3,000 to 5,000 meters above sea level, above the tree line, and below the permanent snow line. The Puna can be further divided into three subregions, with different flora:

- *The Central Andean Wet Puna*, which stretches from north-central Peru to the south-eastern Altiplano of Bolivia, is characterized by grasses mixed with herbs, lichens, mosses, and ferns. Many areas are used for farming.
- *The Central Andean Puna*, found mainly in southern Peru, is dominated by shrublands and thickets of tola shrubs.
- *The Central Andean Dry Puna* is located primarily in the southern part of the Central Andes along the Cordillera Occidental in Bolivia.

The Puna grassland hosts a large diversity of species. The animals of the Puna region must be able to survive in an environment with low oxygen levels, prolonged drought, and cold temperatures. Native camelids such as vicunas and guanacos graze on the high pastures of the Puna. Other mammals that can be found in the Puna include viscachas, chinchillas, and Andean hairy armadillos. The Andean fox, the small and rare Andean cat, and the puma are predators that live in the Puna. The flightless Darwin's or Lesser Rhea and the poor-flying Puna Tinamou are also found in this region. A variety of flamingos, including the endangered James Flamingo and Andean Flamingo, and Chilean Flamingo, visit the salt pans with briny lakes in the Puna [60].

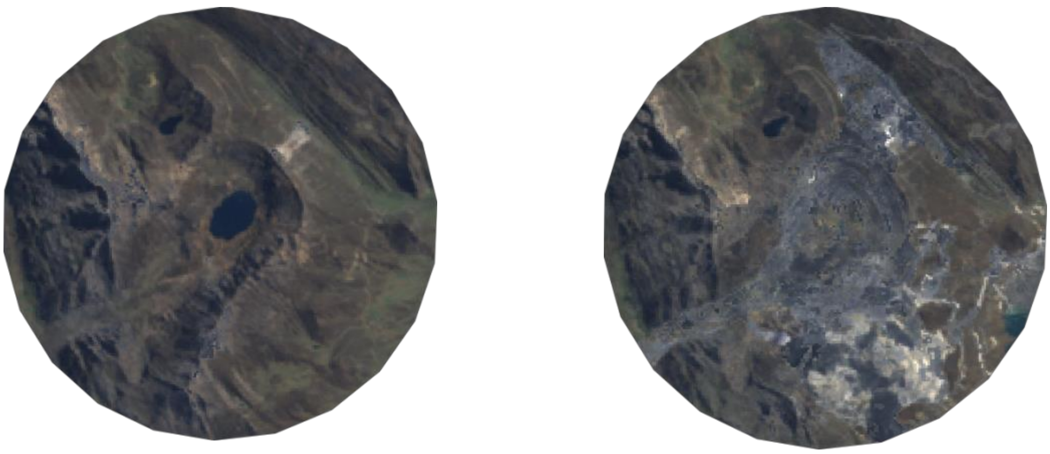
3.2.1 Trends for the Enhanced Vegetation Index

We compute values of the EVI before and after the Antamina site was built, respectively 1997 and 2012. As the Antamina site is quite large, we consider a specific mining concession inside the site, with latitude -9.53663 and longitude -77.06248, at an altitude of 4,242 meters above sea level. We then draw a circle with a 3-km radius around this point, which will be our study area. Our goal is to compute the EVI before and after the mine was built and observe the difference. First, we select all images in the window 1994-1997 - just before the drilling activities started - and we filter and reduce them as explained in the Technical Appendix, to obtain a single, reduced image for this period. We then obtain the EVI by averaging the EVIs at the pixel level in this image. We repeat the same procedure for the period 2009-2012 to obtain the EVI representative for the most recent situation in the aftermath of the construction. We also run a set of robustness checks changing windows and parameters, which we describe in the Technical Appendix.

Figure 2 gives a sense of the loss in vegetation in the Antamina site. As mentioned, the hand-collected reports of the Antamina site show that most of the drilling and construction operations took place between 1998 and 2001. Panel (a) and (b) show the composite images for periods, respectively, 1994-1997 (before) and 2009-2012 (after). The satellite images clearly show the development of the mining site on the mountain and the vast reduction of vegetation that occurred.

Figure 2: Antamina - Composite Images

(a) 1994-1997 (b) 2009-2012



Notes. This figure reports the composite images for the Antamina site before and after the site was built (3-km radius). The first image was obtained by compressing all images available in the window 1994-1997. The compression minimized the presence of clouds. The same procedure was applied to obtain the second image over the window 2009-2012 (end of the dataset).

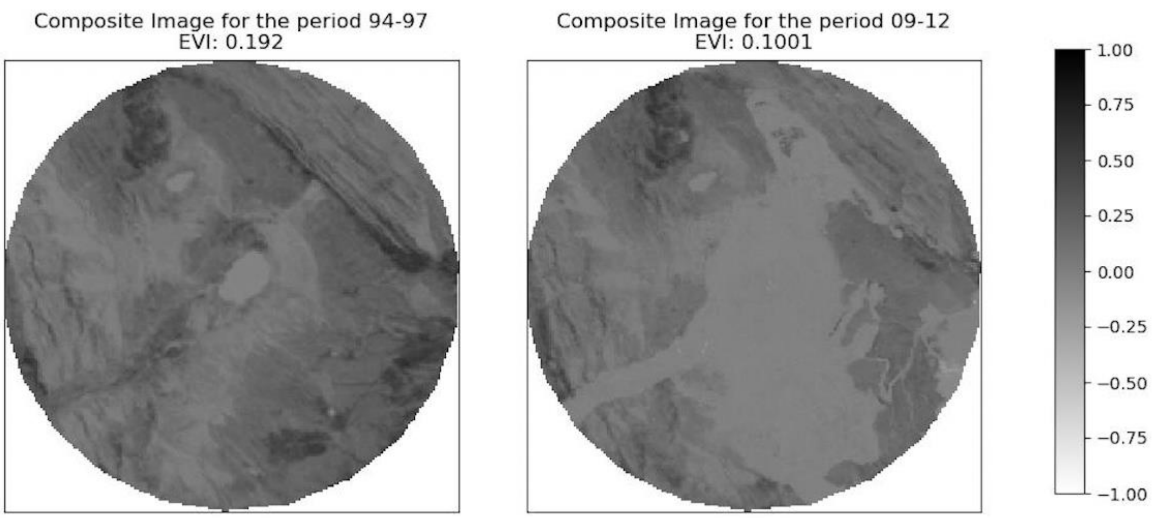
Figure 3 reports a visualization of the EVI values in the area before and after the mine was built and shows that there was a reduction of 0.09 EVI points (48% loss). Darker and clearer pixels are for, respectively, positive EVI values (presence of vegetation) and negative EVI values (absence of vegetation). The average of pixel-level EVI values for the reduced image for 1994-1997 is 0.192. On the other hand, the EVI average for the period 2009-2012 is 0.1001, which still shows the presence of vegetation, though to a much lower degree than in the starting period. Overall, the comparison of the EVI values shows a reduction of about 0.09 EVI points in the considered area, corresponding to a 48% decrease in the vegetation index.

By construction, these results depend on the area of study and the time windows considered in this baseline approach. In Section 2 of the Technical Appendix, we present a set of checks to see how much results change as we change some of these parameters.

It is difficult to interpret what these numbers mean in absolute values. There is no clear range of EVI values that unequivocally define healthy vegetation, as values may vary largely across locations, as they depend on the type of plants, altitude, temperature, etc. Nonetheless, it is not surprising that the value of the EVI for the first image (0.19) remains in the low range, as the typical vegetation in the Puna grassland at an altitude of around 4,000 meters is not as dense as in tropical forests. With this given, Huete et al, 2002 [61] report that images of desert locations can have aggregate EVI values of around 0.1. Following this reference, we could say that the EVI value in the Antamina location dropped close to the one for deserts after the construction of the mine. In the next section we will offer a comparison with a control area, which can provide a realistic reference for this drop.

Figure 3: Antamina - Changes in the Enhanced Vegetation Index

(a) 1994-1997 (b) 2009-2012



Notes. This figure reports the values at the pixel level for the Enhanced Vegetation Index in images of the area of the Antamina site before (panel a) and after (panel b) the site was built (3-km radius). Darker pixels are for positive EVI values (presence of vegetation), while clearer pixels are for negative EVI values (absence of vegetation).

3.2.2 Comparison with a control location

The weakness of this general approach is that we have no way of knowing how much of the loss of vegetation in the considered area is attributable to the mining activity, and how much is attributable to, say, natural causes. We thus cannot unequivocally associate the loss of 48% in vegetation to the activity of the mining site. In the next section, we propose a methodology to address this issue.

We partially address causality with the comparison with an adjacent control location. In our attempt to partially address the "causal" link between the mining activity and the vegetation loss, we consider the logic of natural experiments. For our case study, we take inspiration from the matching literature, and we manually choose our control location by minimizing the difference between two key characteristics. Specifically, we look for an area that is adjacent to the Antamina location (difference in distance) and with a similar altitude (difference in altitude). Following these two criteria, we select a point reference with latitude -9.6012 and longitude -77.0717, which is 7.21 kilometres away from the Antamina location, and at an altitude of 4,271 meters above sea level (Antamina is at 4,242 meters above sea level). We then draw a 3-kilometre radius around this point reference to obtain our control area for comparison. In the Technical Appendix we report anecdotal evidence that this control can be considered a "good" control, as the time trends of the EVI in both locations behave similarly, aside from the major drop in the Antamina location around 1998-2001.

Table 1 reports the EVI values before and after the mine was built, for both the Antamina and control locations, and shows that the "adjusted" vegetation loss is 0.0899 EVI points. As mentioned, the EVI in the Antamina location decreases by around 0.09 points, which is a 48% decrease with respect to the period before the site was built (Column 1). Differently, the EVI in the control location remains approximately constant, moving from 0.2144 to 0.2122, which is a 1% loss, presumably due to natural causes (Column 2). We can thus compute the "adjusted" change, which is the difference between the change in the Antamina location (-0.0921) and the change in the control location (-0.0022), namely -0.0899 (bottom of Column 1). Intuitively, this is the loss of EVI points in the Antamina location "adjusted" for any trend in the control location. Our methodology relies on the assumption that these two locations are comparable and that the control location shows what would have happened to the Antamina location if the mine was not built. If this assumption is satisfied, we can say that the construction of the Antamina mine caused an adjusted loss in vegetation of around 0.0899 EVI points (rather than 0.0921 EVI points).

Table 1: Adjusted Difference in Enhanced Vegetation Index for Antamina

	Site Location (1)	**Control Location (2)**
1994-97	0.1916	0.2144
2009-12	0.0995	0.2122
Change	-0.0921	-0.0022
Change %	-48.0689	-1.0261
Adjusted Change	**-0.0899**	

Notes. This table reports the values and differences in the Enhanced Vegetation Index (EVI) in both the Antamina location and in the considered control location, before and after the Antamina mine was built. The considered area has a radius of 3-km radius around the coordinates for the Antamina location. "Change" is the difference between the EVI value for 2009-12 (after) and the EVI value for 1994-97 (before). "Change %" is the percentage change between these two values. "Adjusted Change" is the difference in the differences between locations, i.e., the difference between the change for Site Location and the change for Control Location.

Note that these values and differences are dependent on the parameters we chose for our analysis, such as the radius of the studied area and the time windows for the satellite images. In Section 2 of the Technical Appendix, we report a set of checks obtained when we change these parameters.[24]

The vegetation loss that can then be associated to the companies that own the Antamina site on an ownership basis. The most straightforward approach would be to allocate the loss to companies proportionally to their shares in the ownership of the mine. For example, if one company holds 100% of the property, then the entirety of the vegetation loss could be assigned to that company (0.09 EVI points). Differently, if the ownership is split between, say, two companies, at, respectively 40% and 60%, then the vegetation loss that can be associated to the first and the second company is, respectively, 0.036 and 0.054 EVI points.

3.3 PRICING THE VEGETATION LOSS OF THE ANTAMINA MINE

In this section, we propose a methodology to estimate the cost of such negative impact on vegetation, by considering how much money is needed to finance a nature-positive project that led to an almost "offsetting" vegetation gain. To do that, we focus on a project in Brazil that created an evident vegetation gain that can be grasped with low-resolution images. The local dimension in vegetation, and biodiversity in general, is a very important aspect, and replanting a specific type of trees in Brazil cannot be considered equivalent to "compensate" for the vegetation loss that took place in Antamina. With that given, the scope of our exercise here is merely to illustrate how the methodology we propose can work. This methodology must then be extended to address the complex differences between plant species, and biodiversity more in general. In the last section of this paper, we discuss how we plan to do this, and other, important extensions.

As an example on how to value the mentioned vegetation loss, we consider a reforestation initiative in Brazil called Instituto Terra. The Instituto Terra was founded by Lélia and Sebastião Salgado in April 1998 and it aims to support the environmental restoration and sustainable rural development of the Rio Doce Valley, which was once originally part of the Atlantic Forest [62]. The bulk of the reforestation effort started in 2001 and covered an area of 710 hectares of rainforest [63]. Today, this project is considered a large success and it has recently received substantial funds by Zurich Insurance to continue the preservation and restoration efforts.

We apply the same methodology explained for the mining site to this reforestation initiative. As the geographical centre for our analysis, we consider the northern part of the area managed by the Instituto Terra, with latitude of -19.52724 and longitude of -41.07454, and we draw a circle with 3-kilometre radius around it to define the area of analysis. Then, as reforestation started in 2001, we consider images in the window 1997-2000 as informative of the natural habitat of the site before the restoration activities took place. In addition, and consistently with the nature-negative scenario, we consider images in the window 2009-2012 as our reference for the most recent status of the area in our database. We thus reduce all images available in the Landsat-5 database for these windows to obtain two composite images of the site before and after the reforestation process took place.[25]

[24] Overall, the "adjusted" value increases when we reduce the area radius to 2 KM (0.10 EVI points). This is intuitive, as a smaller radius implies a larger focus on the mine itself and less on surrounding areas, thus making the change more evident. Moreover, the adjusted value increases when we select the beginning of the dataset as our starting period (0.10 EVI points). Again this is intuitive, as pre trends are included. For the scope of our analysis, we keep our estimate of 0.09 EVI points as baseline for the adjusted value, which seems to be the middle ground between estimates obtained with other parameters' combinations. For more information, refer to Section 2 of the Technical Appendix.

[25] Figure 3 in the Technical Appendix shows the pictures before and after with the infrared bands.

The adjusted vegetation gain in the area of the Instituto Terra is 0.0832 EVI points. We apply the same methodology explained above for the Antamina site to estimate the change in vegetation in the area of analysis for the Instituto Terra. The time-trend methodology shows that the EVI increased from 0.29 to 0.41 EVI points (43% increase). To estimate the "adjusted gain", we select a control location distant 15.21 kilometres from the Instituto Terra, with a similar altitude.[26] We compute the difference with this control location as explained above and we obtain an adjusted vegetation gain for the Instituto Terra of 0.0832 EVI points. If we believe that the control location is representative of what would have happened in the location of the Instituto Terra if the restoration did not take place, then we can say that the Instituto Terra had a positive impact on vegetation of 0.0832 EVI points.

While we can apply the same methodology to measure the impact, the analysis for nature-positive projects is less straightforward than for nature-negative companies. In Section 4 of the Technical Appendix we study these complications in the case of a reforestation in the aftermath of a wildfire, and provide some solutions.

The operating expenses of the Instituto Terra during 2001-2012 amount to US$5.3 million, or about US$637,000 per 0.01 EVI points. Intuitively, we can use the costs paid by the Instituto Terra to restore this area as an estimate of how much the owner of Antamina would need to pay to restore the vegetation that it used. We thus consider the financial reports published by Instituto Terra since the beginning of the restoration activity in 2001, until the end of our dataset in 2012. Section 5 of the Technical Appendix explains how we collected the data and reports the full figures.[27] The centre's activities include reforestation as the main focus, and other auxiliary activities such as administration and education. As all these activities play a key role in allowing the reforestation process, we consider all expenses of the Instituto as a reasonable estimate of how much it comprehensively costs to restore a given amount of rainforest in Brazil.[28] The expenses paid by the Instituto Terra over the period 2001-2012 amount to approximately 28 million reais, which is about US$5.3 million.[29] As the EVI gain is 0.0832 EVI points, we can say that a gain of 0.01 EVI points of vegetation costs about US$637,000.

On that basis, the cost of the vegetation loss produced by the Antamina site is about US$5.7 million (= .637 x 0.0899). Following this illustrative matching logic, we could say that the estimated cost of restoring an amount of vegetation equivalent to the one damaged by the Antamina site, i.e., 0.0899 EVI points, is US$5.7 million. This cost can be assigned to the companies owning the Antamina site through the principle of ownership shares. In the case a single company owns the site, then the vegetation debt of such company would be of US$5.7 million. On the other hand, following the example above of two companies owning respectively 40% and 60% of the site, the vegetation debt of these two companies would amount to, respectively, US$ 2.28 and 3.42 million.

This illustrative example bears some important caveats. First, nature and biodiversity are local aspects, with very different characteristics across locations. Ideally, by the principle of equivalence, we would need to consider restoration projects that happened nearby Antamina, of possibly the same type of vegetation. Second, this principle also holds when considering restoration costs, which can vary largely across locations.[30] To partially

[26] The resulting control area is an area of 3-km radius centred in a reference point with latitude -19.46730 and longitude -41.20490, just 15.21 km away from the Instituto Terra, and with a similar elevation - the Instituto Terra location is at 293 meters above sea level, while the control location is at 212 meters above sea level.

[27] Financial reports can be found here: https://institutoterra.org/relatorio-financeiro/.

[28] The expenses are split between operating expenses, including reforestation, and administrative expenses, including salaries.

[29] Exchange rate of 0.19 on 10.02.2023.

[30] For example, for the Fountain wildfire mentioned in the Appendix, the company Sierra Pacific spent around US$ 3 million to restore 11,000 burned acres, which is US$ 272 per acre (https://archive.redding.com/news/forest-debates-rage-on-after-a-fire-

address this problem, in a follow-up study we will consider a sample of nature-positive projects and compute averages for EVI gains and costs, possibly for different countries and types of restoration. In addition, we will subset our sample to create country-adjusted averages of gains and restoration costs. Second, there are likely differences in considering decreases and increases of EVI in different ranges of the index. For example, it is likely that producing an EVI gain from 0.2 to 0.3 is very different than producing an EVI gain from 0.3 to 0.4. Presumably, the costs of such operations could also be very different. Ideally, as a good example to estimate the cost of the vegetation loss in the Antamina mine – with an EVI going from 0.20 to 0.10 – we would need to consider a vegetation-positive project (possibly in the Puna grassland) that brought the EVI from 0.10 to 0.20. Addressing these issues will be part of future work

4 APPLICATION: A POLLUTER-PAYS FUND TO RESTORE VEGETATION

Regenerating degraded forests is key to both reach the net-zero targets and support biodiversity on land. Approximately 30% of the world's land is covered by forests [64]. However, our planet is currently losing an alarming amount, with a forested area equivalent to Belgium being cleared each year (15-18 million hectares). This equates to approximately 2,400 trees being cut down every minute [65]. 95% of deforestation takes place in the tropics, particularly in Brazil, which is responsible for more than a third of all tropical-forest loss globally [66]. Reforestation is urgently needed to avoid large extinction of endemic species and respect the carbon-sequestration targets [6].[31] Indeed, regenerating or creating an additional 24 million hectares of forest every year until 2030 would contribute to storing a quarter of the carbon necessary to keep global warming below 1.5C [7]. Lewis et al. (2019) [67] compare the restoration of natural forests to agroforestry and plantation, and find that restoring and preserving natural forests is by far the best solution to both store carbon and restore biodiversity. The preferred approach is therefore to target degraded forests for regeneration and protect natural forests once restored.

The methodology and case study reported above can serve as a basis to create a centralized, polluter-pays fund to restore vegetation for the private sector. This fund is an application of the more general financing system explained in Section 2. In this case, the centralized monitoring system would be the methodology that relies on EVI values to estimate the impact of mining sites on vegetation, and financial-statement information to estimate the cost of such vegetation loss. The companies owning the mining sites would then need to re-pay such cost by transferring the estimated amount into the fund. They should do it in two main ways, namely with Payments for Past Impacts (PPI) to cover for their vegetation debt, and Payments for New Impacts (PNI) to cover for any new damage to vegetation.

The owner of the Antamina site would pay US$5.7 million into the fund, which would reinvest it in new reforestation projects. In this polluter-pays scheme, the mining company of Antamina would need to re-pay its vegetation debt by transferring the

ep-377593423-355688741.html/). As the total restored area is about 64,000 acres, we can estimate a total restoration cost of around US$ 17.4 million. Considering that the total adjusted gain in vegetation after restoration is about 0.30 EVI points, a related gain of 0.01 EVI point would cost about US$ 580,000. If we use this as a reference, the cost of the vegetation used by the Antamina site would be around US$ 5.12 million, instead of US$. 5.7 million.

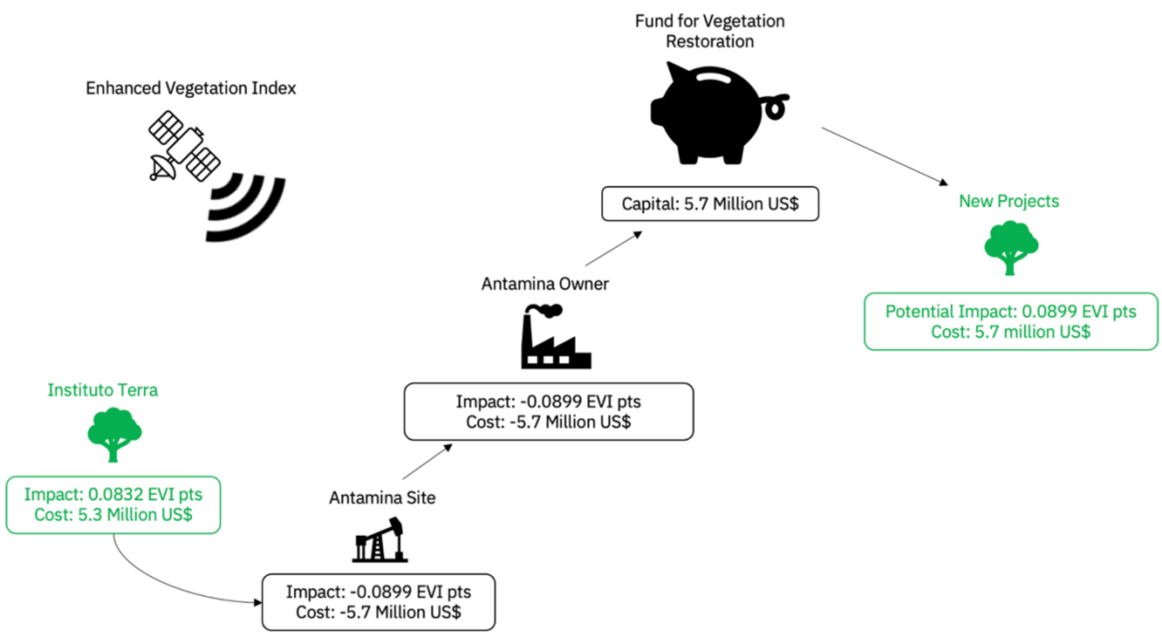
[31] The authors highlight the urgency by showing that, if the needed reforestation is delayed by 10 years, it would be too costly and unfeasible. Also, the social cost for reaching biodiversity intactness by 2050 is calculated to be US$7 trillion dollars, and it could increase to US$15 trillion if action is delayed by 10 years [6].

overall amount of US$5.7 million into a fund. The fund manager would then reinvest this amount into reforestation projects, similar to the Instituto Terra, that would produce a vegetation gain of 0.0889 EVI points. The fund manager could use existing platforms, such as Restor and the System Explorer of Open Forest Protocol, to select such projects. The centralized monitoring system could also be used to monitor that the vegetation gain is effectively produced.

Figure 4 illustrates how this polluter-pays fund would work. In this representation, the monitoring system is based on the Enhanced Vegetation Index, and the unit of analysis is the owner of the Antamina site. The Antamina owner would pay its vegetation debt with a Payment for Past Impact (PPI) into the fund, which would reinvest it in restoration projects that can produce a potential vegetation gain of 0.0899 EVI points (right side).

Overall, this application shows how we can use the proposed methodology to create a fund for vegetation restoration for the private sector. This example is mainly for illustration purposes, as several steps need to be achieved to put this system into practice – some of these steps are discussed in the following section. Nonetheless, it gives a sense of how the system would increase the participation of private companies in the restoration efforts. As overall private investments for nature are currently at US$ 18 billion per year and need to at least triple by 2030, this fund would contribute to closing this financing gap.

Figure 4: Illustration of a Polluter Pays Fund to Restore Vegetation



Notes: This figure illustrates how the centralized polluter-pays fund for vegetation restoration would work. The focus here is payments for past impacts (rather than payments for new impacts). The impact of companies' facilities is estimated via the Enhanced Vegetation Index. The cost of such impact is estimated by looking at the cost paid by the Instituto Sierra to finance the restoration efforts (left side). The fund then reinvests the Payments for Past Impacts in new projects for nature restoration (right side).

5 DISCUSSION

We have proposed to create a centralized monitoring system to transparently track the damage on nature of companies' facilities and create a polluter-pays financing system to restore this damage. Nature-restoration projects will play an important role in reducing emissions and halting biodiversity loss [7]. However, investments in these solutions today are not nearly close to the level they should be in order to reach the 2050 climate and nature objectives [9]. In this study, we propose to use a centralized monitoring system to create a financing mechanism for nature that would help closing this financing gap. This system relies on the polluter-pays principle, by which nature-negative companies would have to pay for the amount of natural assets they damage with their physical facilities. This "price" equals the cost of restoring an equivalent amount of natural assets. In the proposed system, nature-negative companies would pay the due amount into a fund that would finance projects that can restore the estimated loss of natural capital.

We have reported an example of how this system would work considering the impact of mining companies on vegetation, measured with the satellite-based Enhanced Vegetation Index. This paper reports a case study showing how this system would work when considering a specific type of natural asset, vegetation, which we can measure with a vegetation index computed with satellite images - the Enhanced Vegetation Index (EVI). Specifically, we study trends in EVI around extraction sites to estimate the impact of mining companies' facilities on vegetation. Furthermore, we illustrate how we can use the same technique to estimate the positive impact on vegetation of restoration projects. Importantly, we consider the overall funding of these projects as an estimate for the value of the vegetation loss produced by the mining companies. We finally use this methodology to propose a funding system for vegetation, in which mining companies would pay the cost of vegetation loss by transferring the due amount to a fund, which would then reinvest it into projects that restore vegetation.

This methodology could also be applied to regulate the payments into the Global Biodiversity Framework fund of COP 15. The system we propose would have direct implications for policy making. In the last United Nation Biodiversity Conference (COP 15), countries have decided, among others, to mobilize at least US$200 billion per year in biodiversity-related funding by 2030 and raise international financial flows from developed to developing countries to at least US$20 billion per year by 2025, and to at least US$30 billion per year by 2030 [68]. To achieve these goals, COP 15 proposes the creation of a trust fund called Global Biodiversity Framework (GBF) fund. The GBF fund could use the proposed methodology to generalize and increase the payments coming from the private sector for vegetation restoration. In addition, the fund manager could use the proposed methodology to efficiently select restoration projects. For example, estimates on past vegetation gains for reforestation projects in a specific region can give a prediction on how much vegetation gains will be produced by funded initiatives in the same region. In addition, these estimates can be combined with estimates around carbon sequestration to select projects with the highest capacity for both carbon sequestration and vegetation restoration.

This methodology currently presents some limitations, which we will address in future work. One of the limitations lies in the data needed to compute our measure of the overall impact on vegetation of a company. One approach would be to use existing databases with information on the location of companies' assets, such as the Trucost database by S&P. However, the Trucost database does not report the year of construction of companies' facilities, nor the percentages of ownerships in joint ventures. In future work, we plan to complete this information, which is key to consistently estimate the impact of companies on vegetation. In addition, research is needed to extend our methodology to take into account capital allocation and thus allocate part of a company's vegetation debt to its stakeholders (including stock and bond holders), who would also contribute to pay for the restoration efforts.

Another limitation of our methodology is that we have considered only one restoration project to estimate the cost of vegetation assets. To obtain more precise estimates, in a coming study we will consider a much larger sample of restoration projects, with initiatives covering different countries. We will thus be able to compute both an average price for vegetation and differentiated average prices by geographical area. In addition, the granular estimates could be used to predict the future EVI gains of new restoration projects, thus giving a tool to the fund manager to select the restoration projects. We will also do further work to combine these measures with indicators of physical risks - such as risk of wildfires - to address the principle of permanence and potentially rate the restoration projects.

Finally, our focus on vegetation is just a starting point. Potentially, our methodology can be extended to any indicator of biodiversity. Generalizing this methodology to all aspects of biodiversity is key, as the local impact of companies on ecosystems may go far beyond trees and plants. Thanks to this generalization we would be able to provide a financing system by which companies would need to internalize the nature cost of their facilities. Research will then be needed to link this direct impact on biodiversity (i.e. Scope 1) with indirect impacts (i.e. Scope 2 and 3), making the bridge with methodologies that measure the negative spillovers on nature of full supply chains, such as the Biodiversity Footprint for Financial Institutions (BFFI) and the Global Biodiversity Score.

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