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CAN NATURAL CLIMATE SOLUTIONS RESOLVE KEY TRADE-OFFS WITHIN THE SUSTAINABLE DEVELOPMENT GOALS?

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CAN NATURAL CLIMATE SOLUTIONS RESOLVE KEY TRADE-OFFS WITHIN THE SUSTAINABLE DEVELOPMENT GOALS?

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Executive summary

The Sustainable Development Goals (SDGs)[1] aspire to make major strides on human development and environmental protection, across multiple sectors and spatial scales. Yet, there is an intense debate around whether the SDGs are achievable.[2] Are there fundamental trade-offs between economic and environmental SDGs? The past suggests so. Economic development has come at the cost of perilous environmental degradation and increasing climate risks.

The first part of this policy brief critically examines the trade-offs and synergies between the 17 SDGs. We use evidence gathered as part of recent progress assessments.[3] These assessments show that high-income countries perform well on socioeconomic goals, but all countries perform poorly – sometimes very poorly – on environmental goals. We find strong synergies within the socioeconomic goals, and strong synergies within the environmental ones. But importantly, our analysis also suggests that the countries that perform best on the socioeconomic SDGs also tend to perform poorly on environmental SDGs.

The second part of this brief delves into a possible resolution to these trade-offs: Natural Climate Solutions (NCS). NCS consist of approaches to tackle global warming with natural and managed forests, agriculture and grasslands, and wetland systems to lower greenhouse gas emissions and/or increase carbon sequestration[4]. These natural pathways comprise a combination of conservation, restoration, and improved land management interventions on natural and agricultural lands. Scientific assessments indicate that these pathways offer significant CO_2 mitigation potential[5], and have demonstrable co-benefits for other environmental SDGs. Do they also represent an opportunity to create synergies between environmental goals and economic goals? Our review of the literature suggests that, via the provision of ecosystem services, NCS pathways provide several co-benefits by interconnecting the environment and human well-being across social, cultural and economic dimensions[6]. We conclude that, with careful design and implementation, NCS may have the potential to strengthen the linkages between climate mitigation and sustainable development.

We make five recommendations – which we describe in detail in our conclusions – to fully take advantage of NCS in the context of the SDGs:

1. **Employ spatial approaches to identify candidate areas with the greatest potential for synergies**
2. **Manage NCS projects dynamically with multiple goals in mind, and set minimum thresholds to facilitate prioritization**
3. **When there are trade-offs, ensure that NCS projects include measures that compensate negatively affected stakeholders**
4. **Analyse the impact of NCS on vulnerable communities**
5. **Consider prioritizing protection efforts over restoration efforts**

1 The 2030 Agenda for Sustainable Development was set by the United Nations (UN) in September 2015, establishing 17 goals 169 targets and 232 indicators centred on people, planet and prosperity (United Nations, 2015).
2 See (Lim, Søgaard Jørgensen and Wyborn, 2018; Scherer *et al.,* 2018; Selomane *et al.,* 2019)
3 OECD (2019) and the UN Sustainable Development Solutions Network (SDSN; Schmidt-Traub *et al.,* 2017)
4 Griscom *et al.,* 2017
5 Fargione *et al.,* 2018, Fuss *et al.,* 2018
6 de Groot, Wilson and Boumans, 2002; Folke *et al.,* 2016; Millennium Ecosystem Assessment (MEA), 2005; The Economics of Ecosystems and Biodiversity (TEEB), 2010

I. Trade-offs between socioeconomic and environmental SDGs

I.A. Qualitative evidence

The SDGs are, in theory, indivisible and should be pursued in an integrated manner (United Nations, 2015). However, the risk of trade-offs and the potential for synergies between different SDGs – as well as the Paris Agreement – are widely recognized (Nilsson, Griggs and Visbeck, 2016; Sperling *et al.*, 2016). To assess the sustainability of development pathways and take effective corrective action, it is important to identify and map these trade-offs across different scales.

Several pieces of work have started this task. ICSU (2017) provides a detailed account on the strength of interdependencies between SDGs based on a systematic literature review, informed by the qualitative framework of Nilsson, Griggs and Visbeck (2016). The OECD (2019) and the UN Sustainable Development Solutions Network (Schmidt-Traub *et al.*, 2017, Sachs *et al.*, 2019) provide assessments of progress towards the SDGs. These progress assessments show a clear imbalance between socioeconomic development and environmental performance. Overall, the highest rankings are achieved by high-income countries, while the lowest scores are for low-income countries, particularly from Sub-Saharan Africa (Schmidt-Traub *et al.*, 2017, Sachs *et al.*, 2019).

At a more disaggregated level, OECD countries often place in the highest (green) or second highest category (yellow) for the key SDGs concerned with meeting basic human needs or advancing prosperity. However, no OECD country achieves a high ranking in SDGs focused on the sustainability of climate, terrestrial or marine systems (i.e. SDGs 13-15), or sustainable consumption and production (SDG12) (see Figure 1)[7]. On the other hand, countries that rank high concerning SDG12 (Responsible Consumption and Production), SDG 13 (Climate Action) and 15 (Life on Land), tend to be developing countries and predominantly from Sub-Saharan Africa. This group of countries simultaneously ranks as low scoring concerning meeting basic human needs and building prosperity.

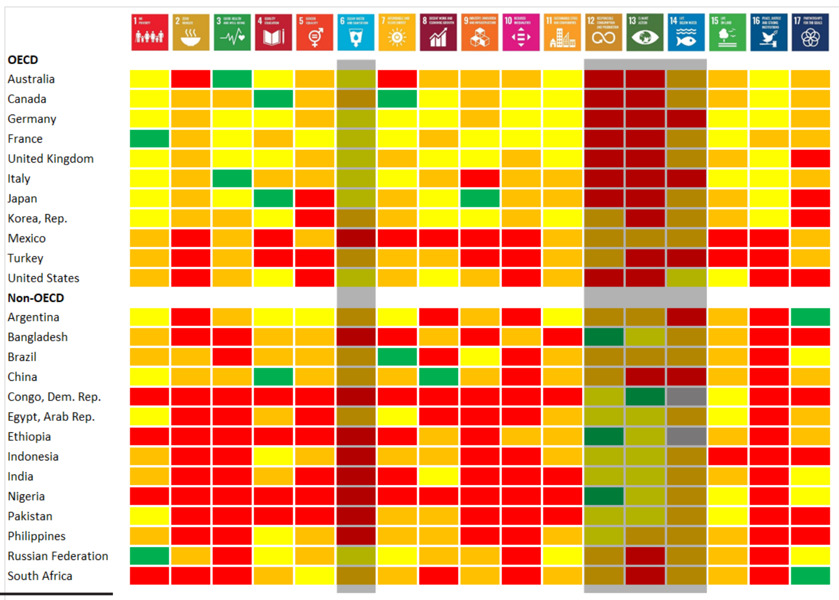

Figure 1: Country performance and the SDGs
Source: , Sachs et al., 2019
Notes: The highest rank is green, followed by yellow, orange and finally red. Gray is for missing data. We have also used gray shading to highlight the SDGs most related to environmental performance (goals 6, 13, 14 and 15).

7 With regards to natural capital, an interesting exception to this pattern is the performance on SDG 6 (clean water and sanitation), where several OECD countries also place in the highest category (Schmidt-Traub et al., 2017). The performance here reflects in part the capability of countries to provide a service, i.e. universal access to the resource, and the fact that several OECD countries are at least partially located in more temperate regions with more abundant supply of freshwater resources.

I.B. A quantitative assessment of trade-offs and synergies across SDGs

In this section, we produce a cross-country analysis of correlations in achieving some SDGs versus others. Without making assumptions about causality, we can observe whether the progress on particular goals are close or distant to one another, and assess the ease of completing one goal if another goal has been completed.

The Interagency Expert Group (IAEG) on SDG indicators, created by the United Nations Statistical Commission, has proposed 232 indicators for assessing progress towards the 17 SDGs and their associated targets. However, not all of these indicators are readily available for all countries or collected on a regular basis. To reduce complexity, we have chosen a subset of 17 indicators to each correspond to a single goal.

Since we are interested in the correlation across goals, and not within goals, we choose to simplify in this manner and make the basic assumption that success in one target within one goal will contribute to achieving the other targets of the same goal. Annex A displays the full list of representative indicators used in this section, and the rationale behind the choice of indicators. For a simple measurement of the closeness or distance separating progress on any two goals, we use the pairwise Pearson coefficient correlations between the 17 selected indicators. Results for pairwise correlations between indicators are displayed in Table 2. Positive values (up to 1) show synergies between the goals, whereas negative values (up to -1) show trade-offs.

Table 2: Synergies and trade-offs between SDG goals

Goal	1†	2†	3	4	5	6	7	8	9	10	11*†	12†	13†	14*	15*	16*†	17*
1†																	
2†	0.69																
3	0.84	0.55															
4	0.71	0.51	0.80														
5	-0.07	-0.11	0.17	0.04													
6	0.74	0.63	0.79	0.80	0.09												
7	0.90	0.67	0.85	0.84	0.07	0.83											
8	0.52	0.44	0.60	0.33	0.26	0.46	0.41										
9	0.10	0.22	0.53	0.24	0.25	0.41	0.30	0.56									
10	0.34	0.10	0.24	0.15	0.10	0.25	0.26	0.28	0.19								
11*†	0.74	0.65	0.71	0.80	0.07	0.80	0.80	0.62	0.36	-0.43							
12†	-0.45	-0.40	-0.51	-0.40	-0.04	-0.38	-0.46	-0.42	-0.44	-0.21	-0.44						
13†	-0.53	-0.35	-0.49	-0.39	-0.03	-0.47	-0.49	-0.56	-0.37	-0.33	-0.54	0.66					
14*	0.19	0.09	0.27	0.19	0.31	0.19	0.20	0.32	0.34	-0.14	0.28	-0.09	-0.13				
15*	0.12	-0.03	0.18	0.10	0.27	0.12	0.10	0.20	0.23	-0.27	0.12	-0.02	-0.04	0.37			
16*†	0.16	0.15	0.38	0.29	0.15	0.46	0.33	0.41	0.34	-0.30	0.24	-0.33	-0.23	0.45	0.42		
17*	-0.16	-0.03	0.07	0.15	0.21	0.03	0.10	-0.06	0.22	-0.37	0.34	0.27	0.09	0.35	0.09	n.a.	

Notes: The figures correspond to the value of the Pearson correlation coefficient between each pair of representative indicators, as listed in Table 1. Correlation coefficients have been built using exclusively data for 2010, except for SDGs 11 and 14-17 (marked with an asterisk [*]). For these goals, data was lacking and the correlation coefficient has been calculated with all years available. Therefore, this table only uses cross-country variation to identify correlations between goals, except for goals 11 and 14 to 17. For some indicators, their associated goal would be attained if their respective value were reduced, not increased e.g. SDG 1 (No Poverty) is achieved if the share of people living with less than $1.90 goes to 0. These indicators are marked with a cross [†] and the sign of the correlation coefficient displayed in the table has been inverted to properly reflect synergies and trade-offs. For example, the share of the population living with less than 1.90 dollars per day (goal 1) is negatively correlated with life expectancy: the Pearson correlation coefficient between the indicators of goal 1 and 3 is -0.84. In the table, the sign was been inversed to display that less poverty is associated with a higher life span (+0.84 in the table).

Globally we find that there are strong and positive associations between SDGs 1, 2, 3, 4, 6, 7, 8 and 11. However, in the countries that have achieved these goals, domestic material consumption and CO_2 emissions per capita are higher. We clearly observe a dichotomy between countries with low poverty and hunger, quality education, affordable energy and water, decent housing and economic growth, on one side, and countries with low environmental footprints, on the other. This is in line with the findings of Schmidt-Traub *et al.* (2017). A related finding is the negative correlation between SDG 10 (Income Inequality) on the one hand and the environmental SDGs 11-15 on the other. It follows that more equal societies may tend to have higher environmental footprints per capita.

An essential question for sustainable development is whether apparent tensions between reaching environmental and development goals can be reconciled. The increasing nature of the ambitions around limiting climate change, in the form of the Paris Agreement's Nationally Determined Contributions (NDCs) that rise over time, presents a risk that these rising ambitions might affect economic development particularly acutely for the poorest areas of the globe. The agricultural sector in particular is of great importance for these low-income and lower-middle income countries – meaning that for these countries, land-based solutions and agricultural management is at the cornerstone of both environmental and economic SDGs.

The second part of this paper focuses on the potential for Natural Climate Solutions that deal with land-use, forestry and agriculture to deliver simultaneously on climate change mitigation and on other SDGs.

II. The contribution of Natural Climate Solutions

II.A. Natural Climate Solutions and Climate Action (SDG 13)

Nature Climate Solutions (NCS), as defined by Griscom *et al.* (2017), are composed of 20 different types of interventions across three categories: agriculture and grasslands; forests; and wetlands (Annex B). For climate action, the aggregate potential of these pathways has been assessed as being significant. A comprehensive study with global coverage estimated that NCS have the potential to provide 37% of cost-effective carbon dioxide equivalent (CO_2e) mitigation between now and 2030 for a 66% chance of stabilizing warming to below 2°C (Griscom *et al.,* 2017). NCS can be implemented at a cost less than US$100 per tonne of CO_2e whilst contributing to 11.3 GtCO_2e per year of climate mitigation (Turner, 2018). At the country level, NCS could deliver a large amount of established NDCs: for example, NCS are equivalent to up to 28% of the current NDC reduction target in the United States and 43% in Brazil (486 MtCO2e and 2,716 MtCO2e per year respectively) (Nature4Climate, 2018).

These findings indicate that countries may have considered only a small portion of the contribution that NCS could make to climate mitigation (i.e. 11.3 GtCO_2e per year), highlighting the untapped potential of NCS pathways in achieving both SDG13 and the Paris Agreement. In addition, NCS can be strategically integrated with fossil fuel mitigation actions and investments in negative emissions technologies (NETs) to stabilise warming to below 2°C and pursuing efforts to limit it to 1.5°C in the long run.

II.B. Benefits of NCS beyond Climate Action

NCS pathways provide ecosystem services (Griscom *et al.* (2017), and it is *via* these services that, if properly implemented, NCS pathways could present a framework for achieving both environmental and socioeconomic SDGs (Figure 2). Ecosystem services refer to the goods and services people obtain from ecosystem functions (de Groot, Wilson and Boumans, 2002). MEA (2005) and TEEB (2010) have classified ecosystem services in four categories: "provisioning" (material or energy outputs from ecosystems, such as food and freshwater); "regulation" (benefits obtained from ecosystem processes, such as air quality regulation); "supporting" (ecological functions underpinning ecosystem services production, such as habitat and biodiversity maintenance); and "cultural" (intangible benefits from ecosystems, such as recreation and tourism).

Ecosystem services enhance the feedbacks between social and ecological systems across all SDG indicators (Selomane *et al.,* 2019). In some circumstances, ecosystem services are even essential to the attainment of socioeconomic SDGs, particularly those related to poverty, hunger, health and well-being, and sustainable cities (SDGs 1, 2, 3, 11) (IPBES, 2019). For instance, the poorest people on earth largely rely on subsistence agriculture and therefore depend on the quality of land and availability of water. Prior analyses on the relationships between ecosystem services and SDGs suggest a number of key groupings: for instance, Wood *et al.* (2018) attempted to map ecosystem services and SDG interactions, with a large expert survey to identify and evaluate experts' perceptions on the linkages between 44 SDG targets and 16 ecosystem services. The survey covered all the ecosystem services categories we have considered for NCS (i.e., provisioning, regulation, supporting and cultural) as well as the environmental and socioeconomic SDGs. Their findings concluded that SDGs 1 (No Poverty), 2 (Zero Hunger), 6 (Clean Water and Sanitation) and 15 (Life on Land) obtained the highest number of ecosystem services contributions. Out of the mapped ecosystem services, food provision, water provision, and habitat and biodiversity maintenance were regarded as central to achieving these four SDGs. They conclude that there is a poverty-agriculture-water-nature nexus that can be exploited in the context of the SDGs to foster ecosystem services provision.

Smith *et al.* (2019) have also identified the interactions between the SDGs and land-based greenhouse gas removal (GGR)[8] options, using Nature's Contribution to People (NCP, a classification for ecosystem services recently adopted by IPBES) as a framework for analysis. They found that all land-based GGR options have some positive impacts on ecosystem services and the SDGs, particularly wetland restoration and soil carbon sequestration.

In Figure 2, we have mapped out some of the essential ecosystem services that NCS can provide. For example, reforestation can convey several co-benefits such as improved air filtration; habitat maintenance and preservation; or water retention and flow regulation. We have linked NCS pathways to ecosystem services based on four generalised types (air; biodiversity; soil; water). These linkages were only established where one or more peer-reviewed publication identified at least one type of ecosystem service enhanced by a pathway activity (Griscom *et al.*, 2017). Then we have highlighted the SDGs directly impacted by the ecosystem services derived from the NCS pathways, as identified by Smith *et al.* (2019). For example, agriculture and grasslands pathways contribute to achieving SDGs 1 (No Poverty) and 2 (Zero Hunger) by improving soil quality (i.e. a regulation ecosystem service), which in turn result in (i) healthier soils for food production and (ii) food security as well as income generation for poorer populations. These interactions provide the evidence for the NCS-SDG synergies, since all ecosystem services identified are derived from NCS pathways.

The linkages presented in Figure 2 are based on the demonstrated co-benefits that specific measures can convey. For example, in mineral soils, increased carbon sequestration can increase soil quality (Smith *et al.,* 2013; Annabi *et al.,* 2007; Lal, 2016) and health (Reeves, 1997). It has also been established that increased soil carbon sequestration increases yields on agricultural land (Pan, Smith and Pan, 2009). Soil carbon sequestration can therefore be associated with negative marginal costs of implementation even in the absence of a carbon price (Enkvist et al 2007; Hepburn *et al.,* 2019). Consequently, improved soil quality alone is a key supporter of multiple SDGs: it leads to better food security (Keesstra *et al.,* 2016; Smith *et al.,* 2019), improved nutrient recycling (UK National Ecosystem Assessment, 2011), increased biodiversity levels (Erber et al 2010), and reduced erosion (Lal, 2016). These indirect benefits have concrete value: for instance, soil erosion due to agriculture costs the UK around £100m a year (Defra, 2009).

Increased amounts of carbon stored in trees also come with multiple co-benefits. Increased tree cover can be valued via multiple ecosystem service points, including maintaining biodiversity and habitat, building and conserving soil and storing water, providing cultural and tourism services, and providing better air quality. Globally the value of forest ecosystem services (including tropical,

8 Land-based GGR options include afforestation or reforestation (AR), wetland restoration, soil carbon sequestration (SCS), biochar, terrestrial enhanced weathering (TEW), and bioenergy with carbon capture and storage (BECCS).

temperate and boreal forests) ranges from US$1,338 to US$3,800/ha/year (estimates are for 1997 and 2011 respectively and provided in 2007 dollars) (Costanza *et al.,* 2014). Thanks to the removal of air pollutants such as ozone, sulphur dioxide and nitrous oxide, the health value of trees and forests is particularly significant across the globe; in the US it has been calculated to be around US$6.8bn (Nowak *et al.,* 2014).

Sustainably managed forestry, like soil carbon sequestration, can be seen as a carbon removal strategy that has negative marginal costs even in the absence of a carbon price (Hepburn *et al.,* 2019). Forests of maximal value for biodiversity (Mohren, 2019) and the climate (Houghton, Byers and Nassikas, 2015) are often located in high-poverty areas of the world in which there is a high dependence on natural resources including biomass for energy, food, feed, and other material products. This means sustainable and adaptive forest management is key to achieving multiple socio-economic and environmental SDGs (FAO, 2018; Swamy *et al.,* 2018).

Finally, freshwater and coastal wetlands make up less than 9% of the global landscape but are estimated to deliver up to 23% of global ecosystem service values (Costanza *et al.,* 2014). Wetlands have key roles in water regulation and filtration, which are seen as crucial for fisheries productivity. Several papers have assessed the economic value of such ecosystem services. At the global level, wetland ecosystem services range from US$20,404 to US$140,174/ha/year (estimates are for 1997 and 2011 respectively and provided in 2007 dollars) (Costanza *et al.,* 2014). Wetland ecosystem services also encompass hydrologic services (e.g. water supply and regulation), water quality (e.g. waste treatment) and biodiversity services (e.g. habitat and disturbance regulation), altogether contributing to over US$33 bn/year according to Zedler (2003). Because of the high value nature of wetlands, there may be significant future job creation opportunities related to wetland restoration, both directly through the construction of wetlands and indirectly through the yield improvements of native fisheries and coral reefs (Smith *et al.,* 2019).

II. C. Trade-offs associated with the implementation of NCS

Ecosystems are complex, dynamical systems, and implementing solutions based on complex biogeochemical interactions always poses the risk of altering other parts of the system. The carbon cycle is intricately linked to the nitrogen cycle and implementing natural methods of carbon sequestration may increase emissions of other types of greenhouse gases. For instance, wetland restoration may increase levels of methane emissions (Hemes *et al.,* 2018). NCS can also affect the climate on a large scale via, for instance, the effect of increased vegetation on albedo, heat and moisture transfer (Baldocchi and Penuelas, 2019). Although forests assist with water regulation via flood control and drought mitigation, carbon assimilation by an ecosystem follows a tight relationship with water requirements (Smith *et al.,* 2015; Baldocchi and Penuelas, 2019), and some studies have shown a negative effect on water yield following recent reforestation (Filoso *et al.,* 2017).

In general, the impact of implementing an NCS on the ecological system will be a function of time since implementation (for instance, the age of the forest, or the starting level of degradation of soil), the land-use history, and the changing climate itself. Once instigated, the long-term

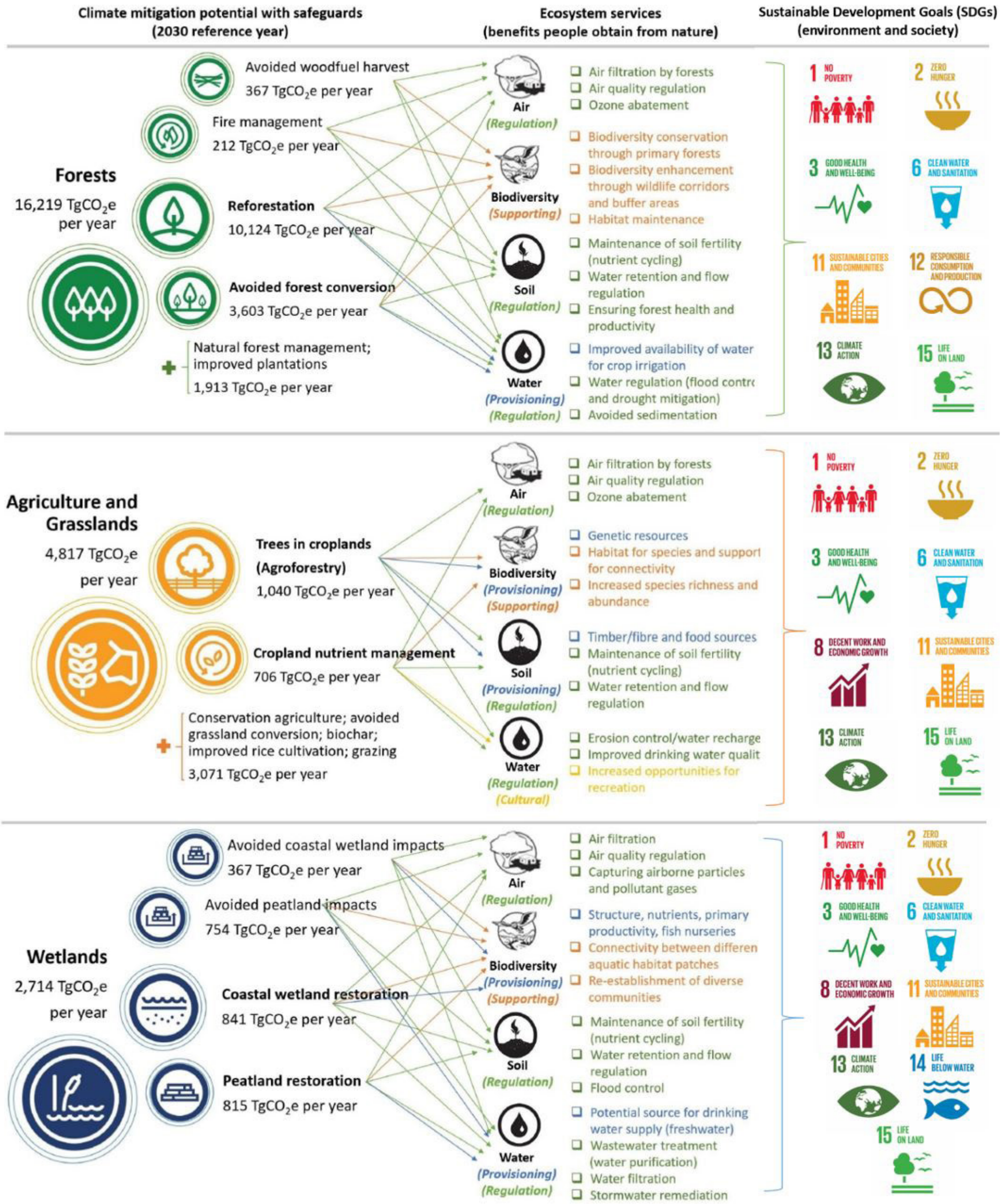

Figure 2. Climate mitigation potential with safeguards (in teragrams of carbon dioxide equivalent, $TgCO_2e$, per year) at a 2030 reference year and the interactions between ecosystem services of Natural Climate Solutions (NCS) pathways (classified as forests; agriculture and grasslands; wetlands) and the UN Sustainable Development Goals (SDGs). Safeguards refer to food security, wood production and biodiversity. We prioritised NCS pathways based on their simultaneous contribution to climate mitigation potential and ecosystem services provision. We have linked NCS pathways to ecosystem services based on four generalised types (air; biodiversity; soil; water). The arrows indicate the contributions of each pathway to ecosystem services as well as their categories. We have identified NCS ecosystem services under the following categories: "provisioning" (material or energy outputs from ecosystems); "regulation" (benefits obtained from ecosystem processes); "supporting" (ecological functions underpinning ecosystem services production); and "cultural" (intangible benefits from ecosystems) based on MEA (2005) and TEEB (2010). The ecosystem service-NCS pathway linkages were established where one or more peer-reviewed publication identified such link. We have highlighted the environmental and economic SDGs directly impacted by the ecosystem services derived from the NCS pathways based on Smith *et al.* (2019). For the full account of NCS ecosystem services, please refer to Table S5 in the Supplementary Materials of Griscom *et al.* (2017). For the full account of SDGs, please refer to Smith *et al.* (2019). (NCS icons by The Nature Conservancy; ecosystem services icons by TEEB and Free Icons from www.freeiconspng.com; SDG icons by the United Nations).

management of the ecological system requires careful calibration for multiple goals. For instance, managing a forest resource to maximise both carbon sequestration and product yield is possible under highly specific circumstances (Lippke *et al.,* 2011; Pingoud *et al.,* 2018), but may often in practice trade one off against the other (Gutiérrez Rodríguez *et al.,* 2016). Similarly managing wetlands solely for their exceptionally effective water treatment capability may provoke trade-offs with biodiversity (Keenan and Lowe, 2001). The longevity of the carbon storage will also differ, particularly for carbon in soils (Smith *et al.,* 2019), meaning that relative synergies and trade-offs will change over time.

Trade-offs in NCS are often more likely at scale. To reach the level of climate mitigation impact as assessed in Griscom *et al.* (2017), large tracts of land are required. 40% of the reforestation mitigation potential estimated in Griscom *et al.* (2017) implies reducing land use for pasture, which could only be possible if beef production became less land-intensive or if dietary changes curbed beef consumption (Griscom *et al.,* 2017). Carbon dioxide removal techniques such as afforestation and reforestation could impose significant constraints on human development via increased food prices and competition for arable land (IPCC, 2018). Such competition could cause disproportionately negative impacts on poor and vulnerable communities such as rural or indigenous populations.

Restoration also provokes trade-offs between the existing use of the land in question. For instance, freshwater wetlands and mangroves have in the past often been converted for agricultural or aquaculture purposes and now provide products with high yields per unit hectare of food, feed or energy (Zedler, 2003). This represents high opportunity costs of restoration. NCS pathways that involve the protection rather than the restoration of natural carbon will still require assessments in terms of alternative uses of land, but there is strong evidence to support the particular value of protection over restoration (albeit both need to be pursued particularly where cost-effective) (Busch, *et al*., Forthcoming). This is particularly the case for biodiversity for which restoration is a complex and gradual process in both forests (Takano *et al.,* 2014; Watson *et al.,* 2018) and wetlands (Smith *et al.,* 2019), and for soils, because soil carbon losses are generally faster than soil carbon gains (Johnson *et al.,* 2009).

In parallel, the poor execution of NCS could create new trade-offs, particularly when safeguards are not properly designed into voluntary standards. Site-specific forest carbon projects, like some projects promoting reforestation actions for carbon offsetting in Uganda's Mount Elgon National Park, may have historically resulted in uncompensated dispossession of local residents and smallholder farmers (Cavanagh and Benjaminsen, 2014). Such negative consequences can often be avoidable with a careful investigation on a system-wide basis. Scientific analysis and econometric assessment tools are becoming increasingly sophisticated in this regard. Well-designed integrative frameworks for implementation and incentives are required, as are coherent links between research and policy frameworks (Ferraro *et al.,* 2011; Smith *et al.,* 2015). Within the framework of reforestation for carbon offsetting, a series of procedures should be considered for proper implementation, especially when it comes to the monitoring of projects and the provision of guarantees of additionality (Bumpus, 2011). National-level REDD+ programs have safeguard requirements around interactions with people.

It is increasingly possible to move beyond the traditional opposition between socioeconomic and environmental goals for humanity (Miteva, 2019). Integrating development and ecological conservation or mitigation goals is achievable. There are large-scale examples of positive synergies from sustainable land management projects leading to both greenhouse gas mitigation and food security benefits, such as Ethiopia's Productive Safety Net Programme, which reduced over 3 million $MgCO_2e$ per year in greenhouse gas emissions at the national scale (Woolf, Solomon and Lehmann, 2018). Decentralised approaches can be effective: a recent paper examining the impacts of more than 18,000 projects across Nepal has shown that community forest initiatives have simultaneously reduced deforestation and poverty (Oldekop *et al.,* 2019). Multi-decadal forest restoration efforts in China provide opportunities to examine evidence of wider benefits of afforestation programmes: systematic reviews have shown that these programmes led to increased income opportunities for rural landowners, better control of soil erosion, and better local flood control (Huang, Shao and Liu, 2012; Gutiérrez Rodríguez *et al.,* 2016).

Conclusions

The first part of this policy paper found evidence that there may be a trade-off between the socioeconomic SDGs and the environmental SDGs. The second part of our paper finds strong synergies between NCS and ecosystem services that provide support for food production (SDG 2), water quality (SDG 6), and human health (SDG 3). Since the agricultural sector is of particular importance for the economic development of low- and middle-income countries, NCS may provide the synergies that are necessary to reconcile environmental SDGs with socioeconomic ones in emerging countries, particularly SDG 1 (No Poverty) and SDG 8 (Work and Growth). At the same time, we identified several trade-offs, especially if NCS are implemented at scale and if they convey large changes in land use, i.e. in the framework of restoration initiatives. Managing resources in the long-term for multiple goals would reduce the risk that trade-offs outweigh the benefits of NCS.

To fully take advantage of the potential that NCS may offer in the context of the SDGs, we make the following recommendations:

1. **Employ spatial approaches to identify candidate areas with the greatest potential for synergies:** The effectiveness of NCS as a tool to achieve SDG 13 (climate action) is location-specific, and synergies with other SDGs will also vary geographically according to different drivers. For example, the health benefits of trees on filtering air strongly depend on local pollution levels and population density. Spatial analyses could identify candidate regions where biophysical, historical and infrastructural features can support the implementation of NCS with maximum co-benefits.
2. **Manage NCS projects dynamically with multiple goals in mind, and set minimum thresholds to facilitate prioritisation:** Ecological systems need to be managed for the long term and with multiple objectives in mind: carbon sequestration is only one possible objective, and trade-offs between objectives may change over time. When trade-offs do exist between objectives (e.g. water availability vs. carbon sequestration), prioritisation may be facilitated by setting minimum thresholds. For example, if a minimum amount of water availability is necessary, and if carbon sequestration requires water, then carbon sequestration could be fostered up to that pre-determined threshold.
3. **Where there are trade-offs, ensure that NCS projects include measures that compensate negatively affected stakeholders:** With trade-offs, the full economic cost of NCS deployment per ton of carbon sequestered may be higher than the mere implementation cost of NCS. It is however possible to consider these trade-offs prior to implementation and factor in their economic costs as part of the cost of NCS project development. For example, the cost of carbon offsetting initiatives can include compensation efforts towards the stakeholders losing out from the implementation of NCS.

4. **Analyse the impact of NCS on vulnerable communities:** The deployment of NCS could affect vulnerable communities in either positive or negative ways. In certain areas, a detailed assessment may be required to identify the costs incurred or the opportunities at hand. The involvement of local communities in NCS-related projects is likely to be a requisite factor for the correct identification of trade-offs and synergies between environmental goals and economic development.
5. **Consider prioritising protection efforts over restoration efforts:** Particularly from the perspective of biodiversity, overall gains from protecting ecosystems such as forests are likely to be higher than those from restoration. Restoration may also come at higher opportunity costs than those of protection.

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Annexes

Annex A: indicators used in the assessment of trade-offs and synergies across SDGs

SDG	Name	Selected indicator
1	No Poverty	Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
2	Zero Hunger	Prevalence of undernourishment (% of population)
3	Good Health and Well-Being	Life expectancy at birth, total (years)
4	Quality Education	Primary completion rate, total (% of relevant age group)
5	Gender Equality	Proportion of seats held by women in national parliaments (%)
6	Clean Water and Sanitation	Improved water source (% of population with access)
7	Affordable and Clean Energy	Access to electricity (% of population)
8	Decent Work and Economic Growth	GDP per capita (constant 2010 US$)
9	Industry, Innovation and Infrastructure	Research and development expenditure (% of GDP)
10	Reduced Inequalities	Income share held by lowest 10% / highest 10%
11	Sustainable Cities and Communities	Population living in slums (% of urban population)
12	Responsible Consumption and Production	Domestic material consumption (metric tons) per capita
13	Climate Action	CO_2 emissions (metric tons per capita)
14	Life Below Water	Marine protected areas (% of territorial waters)
15	Life on Land	Terrestrial protected areas (% of total land area)
16	Peace and Justice, Strong Institutions	Bribery incidence (% of firms experiencing at least one bribe payment request)
17	Partnerships for the Goals	Net official aid received (constant 2014 US$) per capita

To select the indicators, we proceeded as follows. Among the list of 232 indicators, we selected one representative indicator for each goal. The selection was qualitative and based on two criteria: direct relevance to the goal and data availability. For example, we selected the quantity of people living on less than $ 1.90 per day as the indicator for SDG 1 (No Poverty). This indicator was also proposed as an official indicator for SDG 1. It is relevant to the analysis of poverty, widely used and generally available. For three goals (SDGs 3, 11 and 13) though, we preferred to choose a representative indicator outside of the official list of 232 indicators. For SDG 3 (Good Health and Well-Being), health indicators typically consist of mortality rates by death cause. We thought that the cumulative effect of these mortality rates could be better summarised using life expectancy at birth, which is one of the most commonly used health indicators for cross-country comparisons. SDG 10 (Reduced Inequalities) tackles both within-country and cross-country inequalities. Our selection focuses on within-country inequalities and we decided to use a standard metric of inequality: the ratio of income earned by the first decile over the last decile. The closest indicator in the official list for this goal would be the share of people living below median national income. This indicator provides information on relative poverty, but it does not consider that inequalities may rise if a small share of the population has very high incomes. Our preferred indicator encompasses information on the two extremes of income distribution. For SDG 13 (Climate Action), the official indicators focus on climate change adaptation and agreements across countries to combat climate change. The description of SDG 13 includes the following acknowledgement: “the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change”. We should therefore be using one of the primary indicators used by UNFCCC to look at countries’ effort to combat climate change instead of the official SDG ones. This is why we picked out carbon dioxide emissions per capita to assess progress on SDG 13.

After selecting these indicators, we extracted the data from the World Development Indicators dataset of the World Bank. However, the data for domestic material consumption for SDG 12 (Responsible Consumption and Production) comes from the SDG indicators database of the UN. Our dataset of 17 indicators covers most countries and, for some indicators, it goes back to the 1960s. However, for most indicators, data is only available since the 1990s or the 2000s.

Annex B: Description of the 20 Natural Climate Solutions pathways for climate mitigation across three categories—agriculture and grasslands, forests, and wetlands. Cost-effective mitigation is set at a threshold defined as < US$100 $MgCO_2e^{-1}$, meeting <2°C mitigation. It accounts not only for CO_2, but for other greenhouse gases. Areas included in each pathway calculation are defined. Although there may be spatial overlaps amongst pathways, there was no double-counting in the calculations.

Pathway	Pathway definition	Cost effective mitigation ($TgCO_2e\ y^{-1}$)	Areas included in the pathway
Forest			
Avoided forest conversion	Emissions of CO_2 avoided by avoiding forest conversion.	2,897.00	Limited to predominantly tropical and sub-tropical climate domains where forest conversion is most active.
Reforestation	Additional carbon sequestration by converting non-forest (less than 25% tree cover) to forest (more than 25% tree cover).	3,037.00	Areas where forests are the native cover type. Boreal zones are excluded from reforestation.
Natural forest management	Additional carbon sequestration in above- and below-ground tree biomass.	882.00	Native forests under non-intensive management for wood production.
Improved plantations	Additional carbon sequestration in above- and below-ground tree biomass by limited extension of economically optimal rotation lengths to biologically optimal yield rotation lengths.	266.00	Even-aged intensively managed wood production forests.
Avoided woodfuel harvest	Avoided emissions due to reduced harvest of woodfuel used for cooking and heating, without reducing heating or cooking utility.	110.00	There may be potential spatial overlap with savanna burning, but no double-counting given that improved savanna fire management is additive. The non-spatial extent is based on number of people, mostly in Africa.

Pathway	Pathway definition	Cost effective mitigation ($TgCO_2e\ y^{-1}$)	Areas included in the pathway
Fire management	Additional sequestration and avoided emissions in above- and belowground tree biomass due to three forms of additional fire management: (i) prescribed fires applied to fire-prone temperate forests; (ii) fire control practices applied to edges of moist and wet tropical forests in the Amazon region; (iii) use of early season fires in savanna ecosystems to avoid higher emissions from late season fires.	127.00	Includes naturally fire-prone forests in North America and Europe, forests adjacent to pasture in the Brazilian Amazon, and global savannas.
Agriculture and grasslands			
Avoided grassland conversion	Avoided soil carbon emissions by avoiding the conversion of grasslands (including savannas and shrublands) to cropland.	35.00	Includes avoided conversion to cropland of tropical, subtropical, and temperate native grasslands.
Biochar	Additional carbon sequestration by amending agricultural soils with biochar, which increases the agricultural soil carbon pool. Source of biochar production limited to crop residue.	331.00	Spatial extent assumed to be all global croplands. There is spatial overlap with three pathways - cropland nutrient management, conservation agriculture, and trees in croplands.
Trees in croplands	Additional carbon sequestration in above- and below-ground tree biomass and soil carbon due to the integration of trees into croplands at levels that do not reduce crop yields. It is usually referred as agroforestry in the literature.	439.00	Includes windbreaks, alley cropping, and farmer managed natural regeneration, all of them restricted to non-overlapping relevant cropland areas. Applicable area for windbreaks and/or alley cropping includes annual croplands with <10% tree cover, excluding African cropland.
Cropland nutrient management	Avoided N_2O emissions due to reduced fertilizer use and improved application methods on croplands.	635.00	Applicable extent includes all global croplands, except those already using best nutrient management practices.
Conservation agriculture	Additional soil carbon sequestration by planting cover crops during the time of the year when the main crop is not growing.	372.00	Limited to active global cropland areas where crops are not currently used but could be given climatic and crop system context. There is spatial overlap with biochar, nutrient management, and trees in croplands.

Pathway	Pathway definition	Cost effective mitigation ($TgCO_2e\ y^{-1}$)	Areas included in the pathway
Grazing (improved feed; animal management; optimal intensity; legumes in pastures)	Grazing has been grouped into four categories (the first two refer to livestock and the last two to rangelands/pasture). Cost-effective mitigation values are the sum of all categories. For livestock, grazing refers to avoided methane emissions due to reduced enteric fermentation and reduction in total animal numbers needed for the same level of meat and milk demand. For rangelands/pasture, grazing refers to additional carbon sequestration due to (i) grazing optimisation and (ii) sowing legumes in planted pastures.	485.00	Areas with livestock production, global rangelands and planted pastures. There may be some spatial overlap with other grazing pathways and reforestation. Added benefit of sparing land given the reduction of land needed for livestock.
Improved rice cultivation	Avoided emissions of methane and N_2O associated with anaerobic decomposition by employing periodic draining of rice soils and removal of rice residues in flooded and upland rice production lands.	159.00	Included global upland and flooded rice lands. Limited spatial overlap with biochar, trees in croplands, and nutrient management.
Wetlands			
Coastal wetland restoration	Avoided oxidation of soil carbon and enhanced soil carbon sink due to soil re-wetting in mangroves, salt marshes, and seagrass beds. Additional sequestration included for mangroves due to restored tree growth.	200.00	Includes restoration of global mangroves, salt marshes, and coastal seagrass.
Peatland restoration	Avoided oxidation of soil carbon due to soil re-wetting in freshwater wetlands (tropical, temperate, and boreal peatlands).	394.00	Includes restoration of global non-tidal freshwater forested and non-forested wetlands.
Avoided peatland impacts	Avoided emissions of above- and below-ground biomass and soil carbon due to avoided degradation and/or loss of freshwater wetlands (tropical, temperate, and boreal peatlands).	678.00	Includes all non-tidal freshwater forested and non-forested wetlands.
Avoided coastal wetland impacts	Avoided emissions of above- and below-ground biomass and soil carbon due to avoided degradation and/or loss of salt-water wetlands (mangroves, salt marshes, and seagrass beds).	273.00	Includes restoration of global mangroves, salt marshes, and coastal seagrass.

Source: adapted from Table S2 and Table S4 of the Supplementary Material (Griscom *et al.*, 2017).