PBL Netherlands Environmental
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THE GLOBAL POTENTIAL FOR LAND RESTORATION: SCENARIOS FOR THE GLOBAL LAND OUTLOOK 2

MAIN MESSAGES AND EXECUTIVE SUMMARY

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The global potential for land restoration: Scenarios for the Global Land Outlook 2

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Main messages

Land restoration has the potential to deliver multiple benefits simultaneously, making it a highly integrated solution for sustainable development. The way that land is used, managed and protected is central to achieving the goals of the UN Conventions on land degradation and desertification, climate change and biodiversity, as well as many of the Sustainable Development Goals. This is because the choices, synergies and trade-offs between sustainability ambitions often materialise on land. Over the past years, attention to and ambitions for restoration have gained momentum, culminating in the UN Decade on Ecosystem Restoration (2021–2030).

This study quantifies the potential effects of land restoration at the global and regional levels. Three global land-use scenarios up to 2050 were constructed and analysed to provide a view of the extent and risks of land degradation, and to estimate the potential of land restoration compared to a future without restoration. These three scenarios are the *Baseline*, *Restoration* and *Restoration & Protection* scenarios. The effects of land restoration were assessed for natural area, biodiversity, soil organic carbon, agricultural yields, water regulation and carbon storage.

The *Baseline* scenario shows what would happen between 2015 and 2050 without land restoration measures. Land management negatively affects soil and biomass productivity on an estimated 12% of the global land area. Agricultural productivity is projected to increase, but current land management practices have an average negative effect of 2%, rising to 6% to 10% in some regions. Cropland expands by about 20% (~300 million ha), at the expense of natural areas. Of the remaining biodiversity, 6% is lost due to land-use change, intensive production and climate change. Average annual carbon emissions between 2015 and 2050 from land-use change and land management amount to 16% of current annual emissions.

In the *Restoration* scenario, around five billion hectares are restored using potential land restoration measures. Land condition and ecosystem functions improve between 2015 and 2050 due to the implementation of these measures. The measures include agroforestry, conservation agriculture, silvopasture, grazing management, grassland improvement, forest plantations, assisted natural regeneration and cross-slope barriers. Restoration boosts agricultural yields globally by 2% and by up to 10% in some regions, compared to the *Baseline* scenario. Conversion of natural land to agriculture is reduced and biodiversity loss is 11% less in 2050 compared to the *Baseline* scenario. Carbon storage in soils increases and loss of carbon in vegetation is reduced, resulting in a net gain of 17 GtC between 2015 and 2050. This can make a substantial contribution to meeting climate ambitions, when compared to current global emissions of 11 GtC/yr.

In the *Restoration & Protection* scenario, restoration measures are combined with protection of areas that are important to maintain ecosystem functions. This translates into 400 million hectares more natural land, and the prevention of one third of the global biodiversity loss in the *Baseline* scenario. However, food prices increase relative to the *Restoration* scenario and agriculture is required to intensify faster due to limited available land. Compared to the Baseline scenario, an additional 83 Gt of carbon is stored in soils and vegetation, equivalent to more than 7 years of current global emissions.

Current global restoration commitments cover around one billion hectares and therefore one fifth of the potential for restoration in the scenario projections. Almost half of all commitments are found in sub-Saharan Africa. There are also large commitments in South Asia and Central and South America, relative to the total land area. Other regions report much smaller commitments to land restoration.

Implementing the current commitments requires investments estimated at 0.04% to 0.21% of annual global GDP for 10 years (USD 300 billion to USD 1,670 billion). Estimated costs are highest for sub-Saharan Africa due to the large restoration commitments in this region. The costs of implementing the restoration commitments are likely to be prohibitive for developing countries, unless international cost-sharing mechanisms for restoration are developed.

The benefits of agricultural restoration measures to household incomes remain without firm evidence. Better land management by landowners is hoped to deliver higher agricultural productivity and improved farmer household incomes. Too few studies exist to firmly assess the direct benefits of land restoration to farmer household incomes, and the existing studies provide little to no evidence of short-term effects on household income. Given the large land restoration commitments by countries, this knowledge gap is problematic.

The multiple benefits of restoration draw in a variety of actors but can result in fragmentation, making investment decisions complex. Fragmented planning, funding and implementation are underscored by the lack of coherence between national plans for land restoration. While private investors need to rely on bundling of projects to attain profitable scale and reduce risks, transaction costs increase with the number of actors involved. Knowledge on effective policy and governance approaches to bridge this complex distribution of costs and benefits remains scarce.

Restoration measures can prevent future land degradation, and this should be accounted for when assessing investment in restoration measures. Not accounting for prevented impacts would underestimate the potential benefits of land restoration. Prevention is crucial because land restoration is generally a long-term process.

The stimulation of land restoration measures requires countries to integrate restoration into existing policies and institutions. Given the large commitments that countries are making, in particular in improved land management, effective governance requires policy interventions across multiple levels and sectors. While there are many different policies and institutions to build on or to newly develop, there is no one-size-fits-all policy. Policymakers require evidence of what works under which conditions, and such information is imperative for making the UN Decade of Restoration a success.

Combining land restoration and protection measures with changes to production, supply chains and consumption patterns can achieve larger benefits. These measures can have synergy with land restoration, as reducing pressure on land can further improve the potential for land restoration.

Executive summary

Land, and the way it is used, managed and protected, is central to achieving global sustainability ambitions and the goals of the three Rio Conventions covering land degradation and desertification (UNCCD), biodiversity (CBD) and climate change (UNFCCC). Many of the Sustainable Development Goals have clear links to land, and the choices, synergies and trade-offs between sustainability ambitions often materialise on land. Land restoration is seen as a means to provide multiple benefits. Restoration measures can contribute to better soil quality, higher agricultural productivity and improved water regulation, as well as to biodiversity conservation and climate change mitigation and adaptation.

This study provides a quantitative estimate of the global and regional potential of land restoration until 2050 using a comparative scenario analysis. This restoration potential is expressed in terms of changes to a set of biophysical indicators for land and soils, biodiversity, climate, water and agriculture, and is subsequently compared to projected future changes to land over the coming decades, in the absence of restoration. The current restoration commitments made by countries, and the costs of and policies required for their implementation, are compared to the restoration potential.

The scenarios presented in this study provide a first approximation of the global potential of land restoration. The quantitative results are based on a large set of assumptions, a combination of models, and a limited set of scenarios, resulting in a high degree of uncertainty. Furthermore, the study's objectives and method require a focus on biophysical effects and agro-economics at global and regional scales, which means that limited attention is paid to local complexities and governance of land rights, land distribution and access. These are, obviously, also highly important, but fall outside the scope of this scenario study. Still, the findings of this study can provide a background to discussions on the future of land governance and land markets.

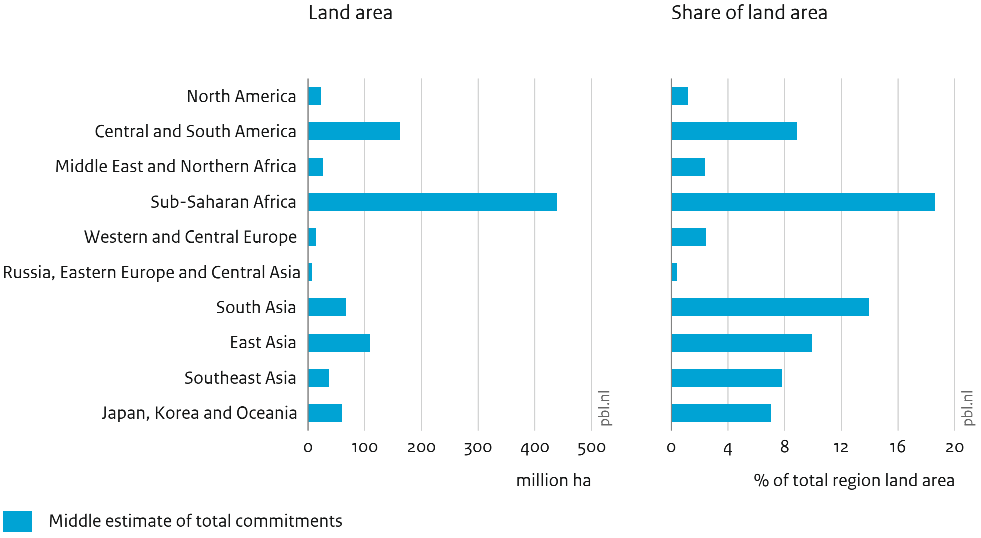
Land restoration and current restoration commitments

Land degradation is defined as a negative trend in land condition and persistent loss of ecosystem functions that cannot be reversed unaided. This study quantifies changes in land condition and ecosystem functions, using a set of indicators. The indicators for changes in land condition include land use, primary productivity, soil organic carbon and biodiversity. Agricultural yields, water regulation (in terms of water holding capacity) and carbon stocks are used as indicators for changes in ecosystem functions. This report provides estimates of future trends for each of these indicators, but no estimate of the total degraded area, as decisions on land management often result in a trade-off between individual ecosystem functions, rather than a negative trend across all indicators (Section 2.1.1).

Land restoration provides multiple potential benefits and thus draws interest from various stakeholders. Over the past years, attention to and ambitions for restoration have gained momentum. This has culminated in the UN Decade on Ecosystem Restoration (2021–2030), an array of global and regional restoration goals, and the inclusion of land restoration measures in many countries' national policy plans. In this report, *restoration* covers a range of measures that improve land condition through changes to physical land management, including improved management of land under human use, rehabilitation of degraded lands to a productive status, and ecological restoration, where the aim is to restore degraded land to its natural state (Section 2.1.2).

Countries' restoration ambitions are already significant. At least 115 countries have committed a total of close to 1 billion hectares to land restoration. Commitments are combined from national plans under the UNCCD, CBD and UNFCCC conventions and the Bonn Challenge. Almost half of all restoration commitments are found in sub-Saharan Africa. South Asia and Central and South America also have large commitments relative to their land area (***Figure 1***) (Sections 2.2 and 2.3).

Figure 1
Total restoration commitments per region, 2020



Source: UNCCD, UNFCCC, CBD, Bonn Challenge, FAO; collected and adapted by PBL for Global Restoration Commitments database, August 2020

Countries' current restoration commitments cover natural areas and areas under human use, in equal measure. Total commitments are almost equally divided between the ecological restoration and protection of natural areas on the one hand, and improved land management and the rehabilitation of degraded land on the other. The current commitments cover roughly about one fifth of global cropland, one tenth of all forest area, and a small share of pastures (Section 2.3.3).

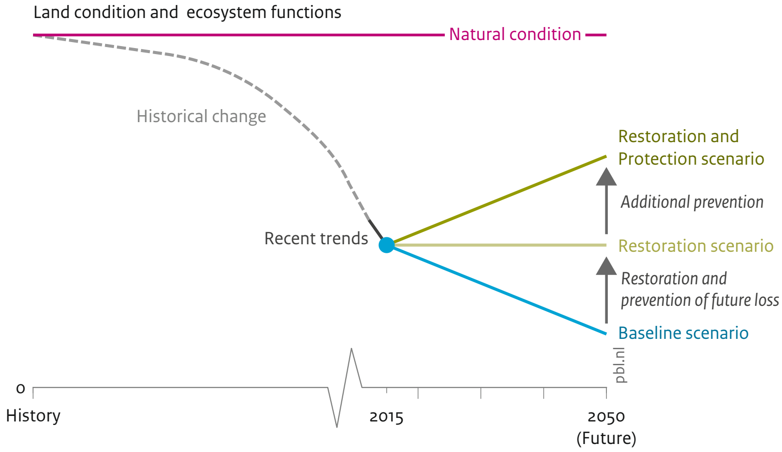
Three scenarios to explore the potential of land restoration

Three global scenarios up to 2050 provide a view of the future impacts of land degradation and the potential benefits of land restoration and prevention of future land degradation. The scenarios include a *Baseline* scenario, a *Restoration* scenario, and a *Restoration & Protection* scenario (***Figure 2***). The effects of restoration measures can take a long time to fully materialise, which is why the restoration potential is assessed in scenarios up to 2050. Meanwhile, demographic, economic and environmental factors continue to develop (Section 2.4).

The *Baseline* scenario projects future changes in land condition and ecosystem functions up to 2050, without land restoration. In the *Baseline* scenario, there are three main factors that affect land condition and ecosystem functions: land-use change (due to the increasing global demand for food, feed, fibre and bioenergy crops), climate change effects, and the impact of current land management practices. The *Baseline* scenario provides the reference against which the effects of the restoration scenarios are compared. This makes it possible to estimate the potential of land restoration measures to prevent losses in land condition and ecosystem functions that would otherwise take place (**Figure 2** and Section 2.4).

The two restoration scenarios project the potential effects of land restoration measures and the protection of ecosystem functions up to 2050. The *Restoration* scenario assumes the implementation of eight potential land restoration measures on cropland, grazing land and natural land. The *Restoration & Protection* scenario assumes the same potential restoration measures and adds the safeguarding of natural areas that are important for water regulation, biodiversity, carbon stocks and the prevention of soil erosion through protection measures, and assumes that these natural areas will not be converted for human use in the future. This scenario shows to what extent the future decline in land condition and ecosystem functions can be prevented if key areas are protected (Section 2.4).

Figure 2
Illustration of scenarios to assess potential benefits of land restoration

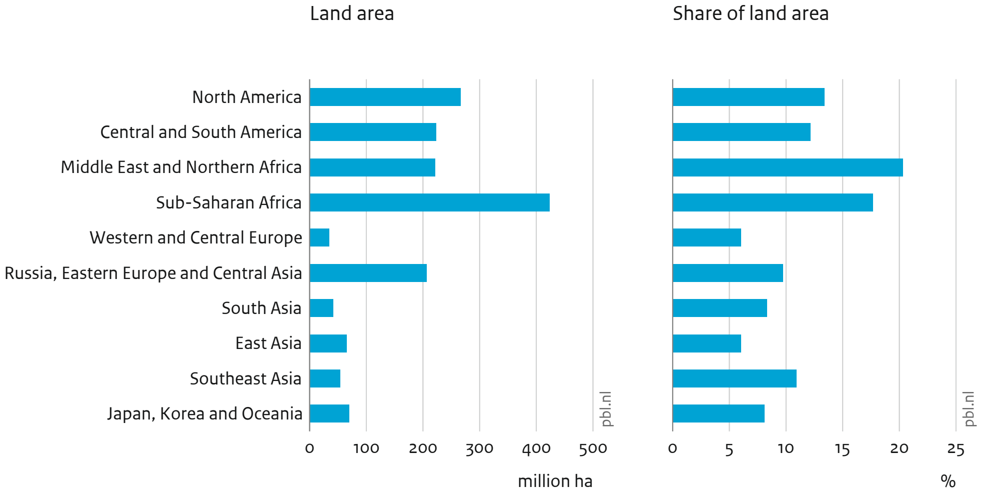


Source: PBL

The *Baseline* scenario projects a continued global decline in land condition and most ecosystem functions

Worldwide, a persistent decline in primary productivity is taking place, attributed mainly to land management practices on an estimated 1.6 billion ha (12%) of the total land area. This estimate is based on satellite observations of the normalised difference vegetation index (NDVI) between 2001 and 2018 and is corrected for long-term climatic effects. The regions that are most affected are sub-Saharan Africa, the Middle East and North Africa, and North America (***Figure 3***). This decline in NDVI affects 14% of the total cropland area, 13% of all grazing land and 12% of all natural areas (Section 3.2.2).

Figure 3
Area with negative productivity trend, corrected for climate change, 2001 – 2018



Source: PBL, NASA/MODIS

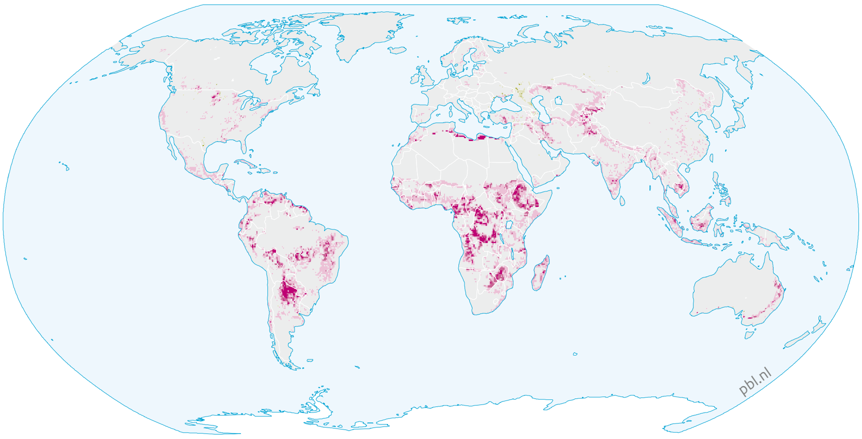
In the *Baseline* scenario, pressure on land increases at the expense of natural areas. Land use for agricultural production increases, in particular in sub-Saharan Africa and Central and South America (***Figure 4***). In most other regions, the availability of natural land suitable for agricultural expansion is very limited and food production increasingly relies on intensification. Under this scenario, the global demand for crops increases by some 45% and cropland expands by close to 20% (~300 million hectares), between 2015 and 2050. Agricultural expansion comes at the expense of natural areas, with biodiversity declining by an estimated 6% compared to 2015 (in mean species abundance), mainly due to more intensive production in existing agricultural areas and climate change (Sections 3.2.1 and 3.2.5).

Soil health is projected to further decline in many regions, under the *Baseline* scenario. Soil organic carbon is an important indicator of soil health as it contributes to soil fertility and water-holding capacity. Most regions have already seen significant losses of soil organic carbon due to the conversion of natural land to agriculture. The majority of losses have occurred in highly productive agricultural regions, most notably in North America, Europe, India and China. An estimated 7%, or 140 Gt, of soil carbon has been lost due to historical changes in land use, such as the conversion of natural land to cropland and land management practices (Section 3.2.4).

Under the *Baseline* scenario, projected soil carbon losses amount to 32 GtC between 2015 and 2050, as a consequence of land conversion and ongoing land management practices. Declining soil health increases vulnerability to dry spells, as it reduces water-holding capacity and may also negatively affect agricultural yields through the loss of nutrients, as well as having wider effects on hydrology, biodiversity and carbon stocks.

Deterioration in land condition affects agricultural yields, water regulation and carbon storage in soils and vegetation. This exacerbates the challenge of attaining the goals of the three Rio Conventions and the SDGs. While average agricultural yields are projected to increase globally, degradation processes reduce these increases in all regions. This is most pronounced in the Middle East and Northern Africa, sub-Saharan Africa and Central and South America, with a 6% to 10% negative impact on yields attributed to land degradation. Compensating these losses by taking more land into production is responsible for about 20% of agricultural land expansion, under the *Baseline* scenario. In addition, climate change has a negative impact on yields in tropical regions, due to reduced precipitation and higher average temperatures, with an up to 4% reduction in yields in sub-Saharan Africa. Both of these effects reinforce the existing need to significantly improve agricultural yields, especially in sub-Saharan Africa. Both effects also come with high uncertainties. There are few other estimates of the impact of land degradation on agricultural yields and projections of climate change impacts vary greatly. Livestock areas are projected to become increasingly densely used, increasing the risk of overgrazing, especially in the Middle East and Northern Africa as well as in South Asia (Sections 3.2.1, 3.2.2 and 3.3.1.2).

Figure 4
Land-use change in baseline scenario, 2015 – 2050



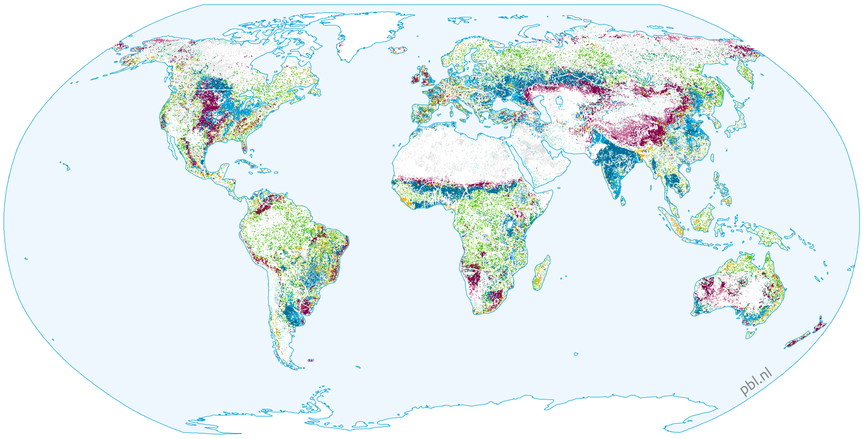
Source: PBL/IMAGE

The water-holding capacity of soils is particularly important for the cultivation of rain-fed crops and grazing land in dryland areas, which require moisture to be stored for long periods without rain. Under the *Baseline* scenario, areas where crop production is already limited by low water availability are projected to be particularly affected, including large areas in East and West Africa and in South America (Section 3.3.2).

Average annual carbon emissions from land-use change and land management, over the period covered by the *Baseline* scenario, amount to 17% of current annual emissions. Changes in carbon stocks in soils and vegetation affect carbon dioxide concentrations in the atmosphere. Under the *Baseline* scenario, the amounts of emissions from soil and vegetation are comparable. Average annual emissions due to loss of soil organic carbon amount to 8% of current global annual emissions (total of 32 GtC over the 2015–2050 period), about a third of which in sub-Saharan Africa. Estimated average annual emissions from vegetation loss due to land-use change, over the *Baseline* scenario period, amount to some 7% of current global emissions (total of 27 GtC over the 2015–2050 period). Continued agricultural activity on peat soils, mostly in Europe and Russia, as well as further conversion of peatlands in tropical regions, results in substantial carbon emissions from degrading peatlands, and amount to 2% of current emissions when averaged per year (total of 10 GtC over the 2015–2050 period). In total, projected average annual carbon emissions from land-use change and land management amount to 17% of current annual emissions (Section 3.3.3).

Figure 5

Locations of improved land management and restoration measures as applied in the restoration scenarios



Measures and combinations of measures

- Agroforestry; Conservation agriculture
- Conservation agriculture
- Cross-slope barriers; Agroforestry; Conservation agriculture
- Cross-slope barriers
- Grazing management; Silvopasture
- Grazing management; Grassland improvement
- Grassland improvement
- Assisted natural regeneration
- Forest plantations
- Assisted natural regeneration; Forest plantations
- Other combinations
- Restoration potential, but no measure possible
- No restoration potential

Source: PBL/WUR

The benefits of improvements in land management and prevention of land degradation

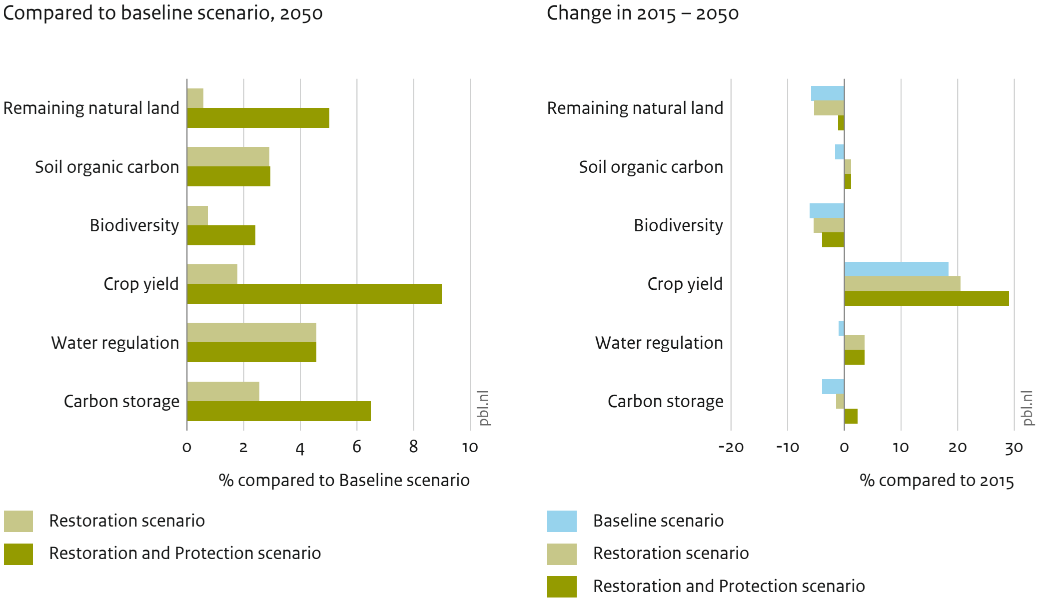
Under the *Restoration* scenario, land is restored where there is potential to do so, and part of the future negative impacts on land condition as projected under the *Baseline* scenario is prevented, through the implementation of eight types of restoration measures. Under the *Restoration & Protection* scenario, the same measures are implemented and, in addition, natural areas that are important for specific ecosystem functions are protected from land conversion. Under both restoration scenarios, restoration measures are assumed to be appropriate for current and future land use. This means that, for instance, measures for conservation agriculture are taken on croplands, and measures for grazing management on pastures. No agricultural or forest land is assumed to be taken out of production for restoration. Agroforestry measures are not applied in intensive production areas where there is little productivity potential left to compensate for possibly reduced agricultural yields.

Under both restoration scenarios, land restoration measures are implemented on around five billion hectares. On this land area, soils are estimated to have potential to be restored and one or more restoration measures are applicable. The measures include conservation agriculture, agroforestry on cropland and grazing land, grazing management, grassland improvement, forest plantations on degraded land, assisted natural regeneration, and cross-slope barriers. In many areas, multiple measures are possible and, in practice, could be combined (***Figure 5***). Restoration measures are estimated to be possible on 1.6 billion ha of cropland, 2.2 billion ha of grazing land, and 1.4 billion ha of natural areas. The regions with the largest area with restoration measures are sub-Saharan Africa and Central and South America.

Natural areas serve both biodiversity and key ecosystem functions, indicating the multiple benefits of conserving and protecting these areas. Under the *Restoration & Protection* scenario, there is no conversion of areas that are important for biodiversity and the provision of key ecosystem functions. This is in line with proposals by Parties to the CBD and other

Figure 6

Global effect of restoration scenarios on land condition and ecosystem functions



Increase in crop yields in the Restoration and Protection scenario beyond the Restoration scenario effect is caused by the additional protection of areas constraining agricultural expansion. Therefore, this additional increase in yields is a requirement in this scenario, not a benefit of restoration.

Source: PBL/IMAGE/GLOBIO, Stoorvogel et al. 2017, Utrecht University

stakeholders for the post-2020 global biodiversity framework to protect 30% or more of land by 2030. Implementation of protected areas under the *Restoration & Protection* scenario reaches close to 50% of the terrestrial area by 2050, based on assumptions regarding which areas are important for water regulation, biodiversity, carbon stocks and prevention of soil erosion. Such far-reaching protection of areas for ecosystem functions significantly limits agricultural expansion in Southeast Asia, South Asia and East Asia (Section 4.2.3)

The *Restoration* scenario shows significant gains from the restoration measures by 2050, compared to under the *Baseline* scenario. The type and size of impacts differ per region. Under the *Restoration* scenario, land condition and ecosystem functions are projected to improve between 2015 and 2050. Restoration of soil health leads to crop yields that are, averaged globally, about 2% higher by 2050 than they are under the *Baseline* scenario (***Figure 6***). Benefits to crop yields by 2050 are the greatest in the Middle East and Northern Africa, Central and South America and sub-Saharan Africa, with increases of 10%, 5% and 5%, respectively, compared to under the *Baseline* scenario (Section 4.3.4).

The extent of natural land continues to decline under the *Restoration* scenario, due to the expansion of agricultural land and urban areas. This expansion is slightly less than under the *Baseline* scenario, due to improvements in agricultural productivity from restoration measures. By 2050, the largest effects are in Central and South America, where natural areas are some 3% larger, compared to under the *Baseline* scenario. Biodiversity also continues to decline, but restoration measures prevent some 11% of the loss under the *Baseline* scenario. This is due to reduced conversion of natural land and increased agroforestry. The effect on biodiversity is underestimated in this analysis, as the *Restoration* scenario does not quantify the biodiversity benefits of the 1.4 billion hectares of natural area that are restored, due to difficulties in estimations (Sections 4.3.1 and 4.3.3).

Under the *Restoration* scenario, wide-scale implementation of land restoration measures has a large effect on soil organic carbon. This leads, globally, to an additional 55 Gt C stored in soils by 2050, compared to under the *Baseline* scenario. When measured in tonnes, the largest gains are projected in the regions of Russia, Eastern Europe and Central Asia and in Central and South America, while the strongest prevention of soil organic carbon loss takes place in sub-

Saharan Africa. Particularly large relative improvements in soil organic carbon are projected for West Africa, India, Southeast Asia and parts of Brazil. Restoration can be crucial in areas with lower levels of natural soil organic carbon, such as marginal agricultural areas where smallholder livelihoods depend on the sustainable use of soils. Here, maintaining soil fertility, water-holding capacity and soil stability may do less in absolute terms of storing carbon, but be all the more important in sustaining livelihoods and small-scale agriculture. Restoring soil organic carbon requires input of organic matter, but this is also used for fuel or fodder in many areas. The use of fertiliser seems therefore necessary in many cases, to produce organic matter at high enough levels for soil carbon restoration, while avoiding trade-offs with biomass use required for livelihoods (Section 4.3.2).

As a consequence of soil carbon improvements, soil water-holding capacity increases. This is especially relevant for rain-fed agriculture in arid areas, where the buffering capacity of soils can help plants to bridge dry spells. Under the *Restoration* scenario, the average water-holding capacity in rain-fed croplands improves by over 4%. The effect is strongest in parts of East and West Africa and in parts of South America, as well as in parts of South and Southeast Asia. The effects on water-holding capacity are only projected for current rain-fed croplands, and are thus the same under both restoration scenarios (Section 4.3.5).

Compared to 2015, carbon storage on land leads to a net increase of 17 GtC under the *Restoration* scenario. This is the balance of a net increase in soil organic carbon, increased carbon in agroforestry and a continued loss of vegetation carbon due to land conversion, although this loss is smaller than under the Baseline scenario. With global emissions from all sources currently at 11 GtC/year, this increased storage can make a substantial contribution to achieving climate ambitions. The difference between the *Restoration* and the *Baseline* scenarios is 66 GtC in 2050, a much higher figure as this includes the carbon emissions that are prevented by the restoration measures compared to a situation without restoration. Carbon storage on land is improved by restoring soils and vegetation, and by limiting land conversion (***Figure 6***; Section 4.3.6).

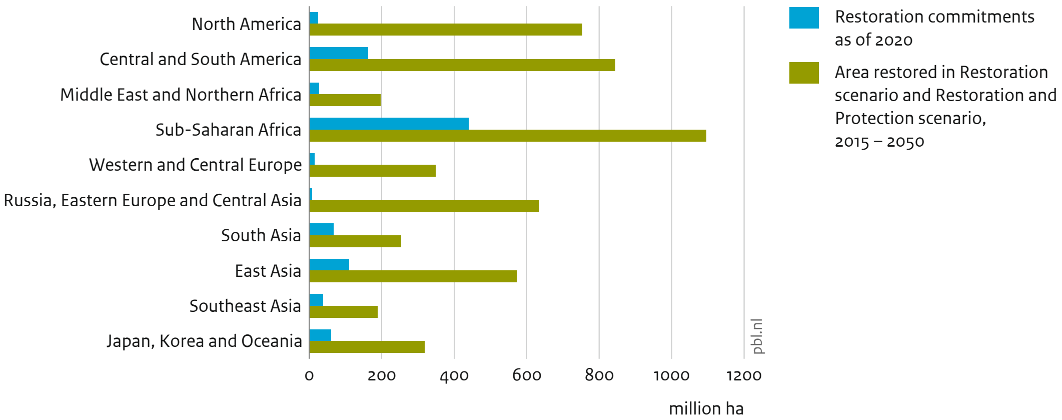
The *Restoration & Protection* scenario shows larger gains than the *Restoration* scenario, especially for remaining natural areas, biodiversity and carbon storage. However, this requires much larger yield increases and pushes up food prices. By conserving natural areas for their biodiversity and ecosystem functions, space for agricultural expansion is much more limited under the *Restoration & Protection* scenario than it is under both the *Baseline* scenario and the *Restoration* scenario. As a consequence, agriculture is forced to intensify. This requires yields of some 9% above levels under the *Baseline* scenario, in 2050. This is significantly beyond what is achieved through the restoration of soils. Contrary to the *Restoration* scenario, this has an upward effect on food prices, implying reduced food security, especially in South Asia and Southeast Asia where agricultural land is already scarce.

The extent of natural land by 2050 is much larger under the *Restoration & Protection* scenario than under both the *Baseline* and the *Restoration* scenario. Compared to the *Baseline* scenario, in 2050, there are close to 400 million hectares more natural land. The largest gains are in South Asia, Southeast Asia and Central and South America. Biodiversity is still projected to decline up to 2050, under the *Restoration & Protection* scenario, but the combination of restoration measures and protection prevent over a third of the biodiversity loss that occurs under the *Baseline* scenario. There are also potential biodiversity benefits in the restored 1.4 billion hectares of natural area, but as previously noted, these are difficult to quantify and have therefore not been included.

For soil organic carbon, the effects under the *Restoration & Protection* scenario are comparable to those under the *Restoration* scenario. Under the *Restoration & Protection* scenario, the combination of restoration measures and protection leads to a difference of 56 GtC with the *Baseline* scenario, over the period between 2015 and 2050. This small difference has three reasons: (1) most of the improvements in soil carbon come from restoration measures on existing agricultural or natural lands, (2) any agricultural expansion is mostly on soils that are lower in soil carbon, and (3) new agricultural land is assumed to be managed under the best available land management practices, under both restoration scenarios.

Carbon storage in above-ground vegetation is 16 GtC higher under the *Restoration & Protection* scenario than under the *Restoration* scenario. Crucially, while soil organic carbon levels hardly differ between the two restoration scenarios, the protection of peatlands and high-carbon forest areas in particular leads to a significant positive change in vegetation carbon, under in the *Restoration & Protection* scenario. As under the *Restoration* scenario, this estimate includes the effect of restoration measures and agroforestry, but does not account for the potential of forest restoration. Compared to the *Baseline* scenario, the *Restoration & Protection* scenario projects 83 Gt more carbon storage in soils and vegetation, by 2050. This is also

Figure 7
Restoration commitments compared to areas restored in restoration scenarios



Source: UNCCD, UNFCCC, CBD, Bonn Challenge; collected and adapted by PBL for Global Restoration Commitments database, August 2020

the result of emissions under the *Baseline* scenario that are prevented through restoration measures and reduced land conversion.

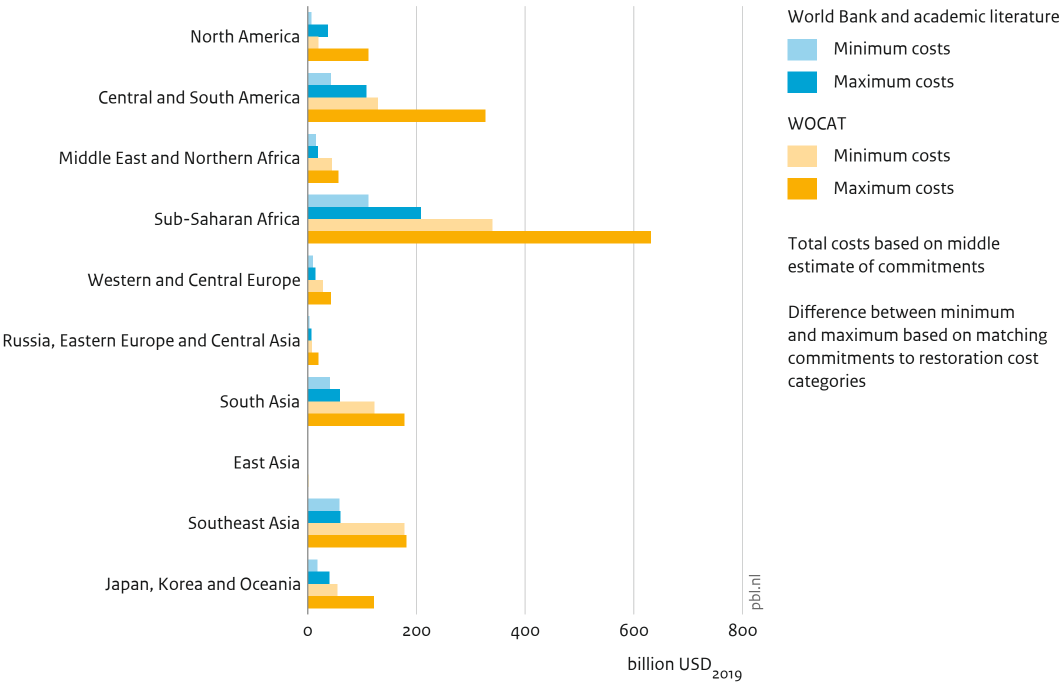
Restoration can increase resilience to sudden environmental shocks and contribute to longer term climate change adaptation. Environmental shocks, such as drought, flooding, pests and diseases, may increase in intensity or frequency, as a result of climate change. The effects of restoration on agricultural yields and water-holding capacity may serve as a first estimate of how, where and to what extent land restoration can help to mitigate environmental shocks and adaptation to a changing climate. In most regions, climate change is projected to negatively affect yields, which may be counterbalanced through restoration. The degree to which these changes might mitigate the impacts of environmental shocks is not further quantified.

Of the potential area under the restoration scenarios that is suitable for restoration measures, around 20% is covered under countries' current restoration commitments. Globally, these restoration commitments cover about a billion hectares, and potential area for restoration is estimated at 5.2 billion hectares, under the restoration scenarios. In sub-Saharan Africa, current restoration commitments add up to about half of the estimated area with potential for restoration (***Figure 7***). Sub-Saharan Africa is one of the regions with the largest share of land showing negative trends in primary productivity caused by land management, and it is also the region that is projected to have the highest degree of land-use change up to 2050. These commitments, therefore, appear to be focused on the right place. The other regions show much lower coverage by current commitments relative to the potential restoration area. Countries' commitments to land restoration and the expansion of protected areas could increase in response to ambitious targets in the CBD post-2020 framework for biodiversity restoration.

Global costs of land restoration and benefits to households

The benefits of land restoration are significant, but implementation of measures is complex due to high costs and their distribution. The potential benefits of restoration as shown by the *Restoration* scenario are significant, although some potentially negative effects could not yet be incorporated in the modelling. However, implementing current commitments, or going beyond that, requires addressing how such implementation should be financed, how to balance private and public costs and benefits, and how to enable effective governance mechanisms.

Figure 8
Total costs of restoration commitments as of 2020



Source: PBL, Verhoeven et al. in prep.

Implementing current land restoration commitments requires investments that are estimated at 0.04% to 0.21% of annual global GDP, if implementation would be spread out over 10 years. The total costs range from USD 300 billion to USD 1,670 billion. The large spread is mainly due to large differences in the cost data available from various data sources. The estimate accounts for differences in labour and investment costs between countries, based on their GDP. It also accounts for specific types of restoration measures. The median restoration cost for all restoration types comes to USD 1,464/ha, with the highest median restoration costs found in cross-slope barriers, irrigation, silvopasture and agroforestry, and with the lowest median costs recorded for forest management, grazing management and passive regeneration. Not included are learning curve effects, the potential benefits of scale and opportunity costs. The costs are only calculated for the current commitments by countries, not for the restoration scenarios (Section 5.3).

Most restoration costs for current commitments will be incurred in developing countries, where costs are likely to prohibit full implementation. The largest share of restoration costs appears to occur in sub-Saharan Africa (USD 112–631 billion) and Central and South America (USD 43–327 billion), in part due to the higher level of commitments made in the global south (***Figure 8***). The costs of implementing the restoration commitments in sub-Saharan Africa, with estimates of 0.8% to 3.7% of GDP, annually, up to 2030, are likely to prohibit implementation in this region. Unless international cost-sharing mechanisms for restoration are developed, such as through climate, biodiversity or private finance measures, it seems likely that countries that have made a large part of the current commitments will lack the required resources (Section 5.3).

The large ambitions related to land restoration and improved land management make it imperative to know how restoration can benefit land users. Better land management is viewed as the key to unlocking multiple benefits for land users, including better soil quality, higher levels of agricultural productivity and higher incomes. Many of the interventions are based on a plausible theory of change. However, the empirical evidence based on private benefits of land restoration by landowners is ambiguous. If restoration practices increase on-farm productivity and farm income but also demand more labour and thus lock out other sources of income, the overall effects on farmer household income could be negligible (Section 5.1).

The benefits of agricultural restoration measures to farmer household incomes remain without firm evidence. Too few studies are available to firmly assess the direct benefits of land restoration for household incomes. Existing studies provide little to no evidence of short-term effects on household income, and many studies report no findings on the impact of restoration on households and provide little information on the institutional and governance environment in which the measures were implemented. Given the large land restoration commitments by countries, policymakers need advice on incentivising land restoration by landowners to create net societal benefits, especially in agricultural land management. This is a key knowledge gap to be addressed (Section 5.2).

Restoration measures can prevent future land degradation, and this should be taken into account when assessing investments in restoration measures. The negative impacts that are avoided by preventing future land degradation are a benefit of the implementation of restoration measures. This requires an estimate of the potential future impact in the absence of restoration measures. Not accounting for prevented impacts would underestimate the potential benefits of land restoration. Prevention is also crucial because, while deterioration of land condition can be rapid (in the case of land conversion) or slow (in the case of slow but persistent degradation processes), land restoration is generally a long-term process (Section 5.4).

Land restoration's strength in creating multiple benefits for many actors is also its weakness. How private actors, such as smallholders, can be rewarded for providing public benefits, in the short or long term, is a key challenge. Adding to the complexity is the number of actors involved. Scaling up restoration projects requires engaging millions of smallholders across many regions of the world. While private investors need to rely on bundling of projects to attain profitable scale and reduce risks, transaction costs increase with the number of actors involved. Knowledge of effective policy and governance approaches to bridge this complex distribution of costs and benefits remains scarce (Sections 5.5 and 5.6).

Balancing the public and private benefits of land restoration requires effective governance

Effective governance of land restoration efforts requires policy interventions at micro, meso and macro levels. While land restoration often starts with micro-level restoration projects, there is scope for enhancing the incentives by landowners by considering complementary national policies. Such policies may further leverage private investment by providing better safeguards and legal certainty for private investors.

The stimulation of land restoration measures requires countries to integrate restoration into existing policies and institutions. There is a large variety of policies and institutions to support and shape incentives for land restoration, such as agricultural and land-related policies, nationwide economic policies, and policies in several non-agricultural sectors. These policies include the implementation and enforcement of local rules and regulations, participatory decision-making, capacity building for cooperatives to implement restoration, responsive extension services, effective land policy frameworks that govern tenure and land markets, and agricultural taxes and subsidies. For some of these instruments and institutions, it is clear under which conditions they can help to provide enabling conditions for restoration — for others, much less so.

Fragmentation amongst actors makes public or private investment decisions complex. Because restoration can provide a range of benefits, rather than being a focused solution for a single goal, it can result in fragmented planning, funding and implementation. The onset of the UN Decade on Ecosystem Restoration, and the inclusion of a complementary and consistent set of restoration targets in the Rio Conventions and the SDGs that are subsequently translated into the national plans (LDN, NDCs, NBSAPs), may help create more coherence between various goals and ambitions.

Combining land restoration and protection measures with changes in production and consumption patterns can achieve larger benefits and enable implementation. The restoration scenarios account for changes in land restoration and management, and the protection of key ecosystem functions. Larger improvements to land condition, biodiversity and ecosystem functions could be achieved by avoiding ongoing degradation and conversion. Scenarios can be designed where restoration and protection are combined with concurrent food system transformations, such as consumption shifts to less meat-intensive diets, reductions in food waste, and the more sustainable sourcing of agro-commodities. Increasing efficiencies in production chains, for instance through improved livestock efficiency or reduced losses of food in the supply chain, would reduce the pressure on land. If less land would be needed for the production of land-based products and, thus, would become abandoned, this land could be restored.

There are no silver bullets for choosing the right mix of policies or projects to incentivise land restoration at scale. There is a paucity of empirical evidence on combinations of policies and projects that have proved successful for land restoration. Such information is urgently needed as the required interventions are site- or country-specific, and also as benefits take decades to materialise. This finding implies a need for more policy experimentation and evaluation to better understand how land restoration can be achieved at scale, at the lowest possible cost to societies. Such information is imperative for making the UN Decade of Restoration a success.

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