The potential effects of land-based mitigation on the climate system and the wider environment: A synthesis of current knowledge in support of policy

Land-based options to mitigate climate change are expected to deliver approximately a quarter of emissions reductions pledged by countries in their Nationally Determined Contributions (NDCs) under the Paris Climate Agreement, and is key to achieving the zero balance target between anthropogenic emissions and removals in the second half of the 21st Century. We review new scientific knowledge on land-based mitigation options, the effect of these options on land-use and land-cover change (LULCC) and their interplay with other environmental concerns. Land-based mitigation provides policy-makers with competing demands and trade-offs, but also possible co-benefits, and it is through this policy lens that we synthesise the state of the current knowledge. The primary mitigation options considered in this summary are: (i) afforestation-reforestation and avoided deforestation, and (ii) bioenergy with carbon capture and storage (BECCS)*.

Message 1: Land-based mitigation competes for land with food production, other ecosystem services & biodiversity

There is evidence to suggest that land-based mitigation has already increased food prices, and models predict further increases, due to the competition for land and the direct use of food crops as a bioenergy feedstock. The land area required to achieve emission reductions from land-based mitigation consistent with most 2°C scenarios, is substantially higher than the available land area currently identified as marginal or abandoned. However, potential land allocation for climate change mitigation depends on other claims on the same lands, the degree of climate change, technological developments and dietary preferences. Intensification of agricultural land use could free up more land for climate mitigation, but this can have other environmental impacts if not done sustainably.

Land-based mitigation policies and strategies in one location affect land use elsewhere due to displacement; an example of indirect land-use change (iLUC). iLUC can be a major source of GHG emissions that are not always reported, particularly when the displacement happens in countries with limited reporting of GHG fluxes. When iLUC is included in life-cycle analyses of different bioenergy feedstocks, it alters the feedstock's relative GHG mitigation performance, which has the potential to undermine conventional bioenergy crops as a sustainable energy source. EU legislation assumes that the biomass used for electricity generation is carbon-neutral, as it assumes that the land sector captures both direct and indirect LUC emissions. Not reporting the land sector emissions embodied in the goods produced within a country can lead to substantial emissions under-reporting. Labelling and certification schemes for biofuel feedstocks could decrease iLUC and embodied emissions. Furthermore, recent changes in EU policy seek to limit the share of food-based biofuels and to promote advanced feedstocks.

* A third important option, reducing greenhouse gas emissions (esp. N2O and CH4) through agricultural practices was not within the remit of the LUC4C project.

Terrestrial ecosystems provide a range of ecosystem services, but land-based mitigation impacts on the ability of ecosystems to provide both the amount and the quality of some of these services. For instance, bioenergy production has a higher water demand than any other alternative energy source, and can compete with other water uses unless managed carefully. Intensification of food production could lead to more land being available for other uses, but is associated with large nitrogen losses to the atmosphere and water pollution from fertilisers. Provisioning services, such as food and biomass production, and regulating services, such as carbon sequestration or flood protection, are currently often not compatible, but could be with more integrated approaches to land management. Provisioning services are often more tangible and easier to exchange in the market than regulating services, cultural services or the protection of biodiversity. European policies and emissions targets raise the demand for woody biomass, consequently reducing forest carbon sinks. However, the carbon sink reduction would be small if advanced bioenergy crops rather than forest removals were used to meet energy demand.

Land-based mitigation competes for land with biodiversity, but there is potential for achieving co-benefits. Some land-based mitigation options are incompatible with biodiversity goals. Afforestation using monoculture plantations reduces species richness when introduced into (semi-)natural grasslands; a habitat that is prioritised by EU policies on biodiversity. Evidence suggests that when faced with conflicting mitigation and biodiversity goals, biodiversity is typically given a lower priority, especially if the mitigation option is considered risk-free and economically feasible. Approaches that promote synergies, such as avoided deforestation, land sparing and sustainable farming practices in bioenergy production, and longer rotation-times and mixed-species forests in afforestation-reforestation, can avoid the loss of biodiversity from land-based mitigation. Systematic land-use planning would help to achieve land-based mitigation options that also limit trade-offs with biodiversity.

Message 2: Biophysical effects are significant and can have important co-benefits

LULCC affects climate not only through greenhouse gas emissions and uptake, but also through biophysical effects, especially at the regional scale. Biophysical effects include the reflectance of sunlight from the Earth's surface (albedo), cooling from evapotranspiration and the absorbance of wind energy. Changes in vegetation cover alter the reflection of sunlight (albedo); crops and pastures tend to be more reflective than darker forests, and this has a cooling effect. However, forests have higher evapotranspiration rates than crops and pastures, which cools the land surface as well as recycling water to fall as rain. Forests also absorb wind energy and this has implications for local surface temperatures. The net effects of these processes play out differently in different parts of the world. Satellite observations show that large-scale regional deforestation has a predominantly warming effect in the tropics, and parts of the temperate zone, due to reduced evapotranspiration. However, deforestation causes cooling in the boreal regions, due to increased reflection of sunlight, especially in winter and spring, but unlike the tropics, in boreal regions the agreement between measurements and models is less clear. Uncertainties remain regarding the magnitude of the effect, especially for seasonal variables (e.g., maximum summer temperatures), and for the effects on precipitation, but it is now well established that the regional biophysical effects of land-cover change are substantial. Furthermore, biophysical effects on local temperature are more rapid than warming arising from global atmospheric CO2 levels. Thus, mitigation actions taken at the regional level would benefit from considering the consequences of biophysical effects on local temperature as well as the impacts of GHG emissions. There are major benefits in doing so, since accounting for the biophysical climate effects of LULCC can support both mitigation and adaptation objectives and thus, make policy more effective.

Current global, policy frameworks do not consider biophysical effects, and hence opportunities exist for policy to realise co-benefits. Although local biophysical climate impacts from LULCC are large, they tend to be much smaller when aggregated globally and this has implications for global policy. The process of including land-based mitigation in the UNFCCC context has been a matter of long and complex negotiations. Hence, the relatively small and currently uncertain global biophysical effects make it difficult to justify efforts to include these effects in the complex negotiations of the UNFCCC process, at present. However, it is now possible to evaluate the regional biophysical impacts (changes in local temperature)

of land cover transitions, following a tiered method similar to that of the IPCC to estimate the effects of GHG emissions. The method applies three levels of increasing complexity, from Tier 1 (i.e. default method and factors) to Tier 3 (i.e. country-specific methods and factors). The procedures proposed for each tier method are transparent, taking into consideration the UNFCCC reporting principles and could inform mitigation efforts at regional or national scales to realise the co-benefits of accounting for biophysical effects.

Policies that support avoided deforestation, especially in tropical regions, have especially large co-benefits. Avoided deforestation mitigates global climate change by reducing CO_2 emissions. It also affects the local climate in a positive way by maintaining cooler surface temperatures through biophysical effects. Future climate change will also increase vegetation growth through the effect of atmospheric CO_2 fertilisation and this will further enhance the biophysical cooling effects of forests. Thus, avoided deforestation as a land-based mitigation option benefits from positive effects on both the regional and global climate systems.

Message 3: Time lags and multiple goals strongly limit the effectiveness of land-based mitigation, but there is potential for improvement and co-benefits can be achieved

The relative contribution to climate mitigation of different land-based mitigation options changes through time. Avoided deforestation provides immediate mitigation gains by reducing rapid carbon emissions that take place when forests are cut or burnt (as well as having co-benefits with multiple ecosystem services). Afforestation-reforestation can take-up carbon immediately upon planting, but with varying, relatively small annual gains due to the slow rate of forest growth, especially as forests approach maturity. The current carbon sink of EU forests due to past afforestation will likely decline due to forest ageing. Harvesting and replanting, with carbon storage in harvested wood products or use as bioenergy, can enable the same land to continue to contribute to mitigation, but care has to be taken to sustainably manage repeated harvesting in order not to deplete soil carbon stocks. Overall, bioenergy (especially lignocellulosic) is expected to contribute more to mitigation scenarios in the second half of the century, but this will depend on the availability of advanced technologies.

Time lags in policy implementation and uptake strongly influence the effectiveness of land-based mitigation policy. There are large uncertainties associated with the development and implementation of BECCS, and other land-based mitigation options. Barriers arising from the rate of technological development and the considerable need for financial investment mean that the large scale implementation of BECCS is not likely until around the middle of the 21st century, at the very earliest. Furthermore, the rate of uptake of bioenergy crops by farmers can be slow in spite of the existence of financial support. Such barriers could limit the success of bioenergy as a land-based mitigation option. This demonstrates the importance of immediate policy action, and measures to support more rapid policy intervention and uptake.

The success of afforestation-reforestation and avoided deforestation as mitigation options are subject to the changing risks from disturbances that affect forest permanence and depend on continued monitoring and management of forest stands over the long term. Disturbances arising from climate extremes, wild fires, pest and diseases affect afforestation-reforestation and avoided deforestation, but also yields of bioenergy crops. The risk of these disturbances will also change with future climate

change. Better understanding disturbances and how to manage them in a changing climate would reduce uncertainty and therefore the risks associated with investment in mitigation options. Monitoring, Reporting and Verification (MRV) of forest carbon and other land based mitigation schemes need to be able to account for disturbances (and associated carbon losses) to provide confidence that land-based mitigation projects will meet their long-term objectives. Recent advances in satellites and modelling capabilities can support MRV, along with capacity building in developing countries.

There are potential synergies between land-based mitigation and adaptation that would allow co-benefits to be achieved. Primary forests, in contrast to monoculture plantations, provide a wide range of ecosystem services and have more biodiversity, which are characteristics of a resilient forest ecosystem. Hence, avoided deforestation of primary forests could benefit both mitigation (retaining carbon) and adaptation (greater resilience) to climate change. Furthermore, planting trees in urban areas has mitigation benefits (carbon storage) as well as adaptation benefits (cooling effects, and reducing surface water run-off and flooding). Changing food consumption patterns (e.g. through low-meat diets, reducing over-eating and waste, and eating alternative protein sources) reduces the land area needed for food production providing opportunities for land-based mitigation. This also builds resilience to climate change, since the additional availability of land could offset the negative impact of climate change on crop yields and thus food production. These examples demonstrate potential opportunities, but there is little scientific evidence to support understanding of the full extent of mitigation-adaptation synergies (or trade-offs), which is a major knowledge gap.

Developing policies that systematically cut across policy sectors would achieve co-benefits for multiple policy goals. Co-benefits are not always realised, and a single sector focus can often cause unintended negative impacts on other sectors, e.g. by promoting land clearing, which is associated with negative impacts on carbon and flooding. Well-grounded, land-based mitigation strategies can have positive social benefits, but conversely, land-based mitigation can have negative environmental and social impacts if poorly planned. There is considerable potential for rural development and job creation linked to European bioenergy markets. However, entry into the sector often requires economies of scale (excluding smallholders) and time lags in implementation and up-take are also constraints (as outlined above).

In Summary

Land-based mitigation is not a 'silver-bullet' to avoid climate change, but alongside drastic reductions in fossil fuel emissions, it can contribute to delivering the "balance of sources and sinks" in the Paris Agreement. Land-based mitigation is currently the only way to remove CO_2 from the atmosphere at a scale that is potentially relevant to climate mitigation. The land sector will not be emissions free due to the emissions necessarily associated with food production. Moreover, there is a real danger that land-based mitigation will compete with food production, the provision of other ecosystem services and biodiversity. Further analysis is required to understand fully the many trade-offs, beyond climate mitigation that arise from land management and to identify policy options that support co-benefits. Land-based mitigation could potentially enable the land sector as a whole to approach a balance of sources and sinks, and, if barriers are overcome and sustainability ensured, it could further offset some of the more unavoidable emissions from fossil fuels.

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