POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Policy brief

The potential of forests and trees in addressing climate change

Policy recommendations for the Ethiopian context

Julia Tomalka, Sarah Bereswill, Lisa Murken, Kirsten Thonicke, Christoph Gornott

January 2024

Background

Ethiopia is highly vulnerable to climate change, the impacts of which can be felt across different sectors. In particular forests are threatened by rising temperatures, shifting precipitation patterns and extreme weather events. Human activities like deforestation and land-use change further exacerbate climate impacts, increasing the risk of wildfires and reducing the potential of forests for carbon sequestration. However, forests and trees are of major importance for ecosystems and local communities, providing plant and animal habitat, protection against soil erosion, provision of sufficient water resources, wood for fuel and construction, and various non-timber products. In addition, climate change is increasingly impacting water resources through prolonged and more frequent droughts, leading to water scarcity, crop failures and food insecurity for millions of people in Ethiopia. At the same time, erratic and heavy precipitation events lead to increased instances of flooding and soil erosion, further compromising water availability and quality. In a similar way, soils are impacted by climate change, with temperature increases and shifting precipitation patterns leading to soil degradation and reduced soil fertility, making it harder for smallholder farmers to pursue agriculture as a livelihood.

Forests and trees are particularly threatened by climate change. At the same time, they are key in both climate change mitigation and adaptation efforts. Against this background, this policy brief discusses the potential of forests and trees in addressing climate change, specifically looking at natural forest regeneration as a mitigation strategy and at agroforestry as an adaptation strategy, highlighting the unique potential of forests and trees to achieve a dual benefit for climate action. Although these strategies are considered in greater detail, it should be noted that there is no single best mitigation or adaptation strategy, but rather different mutually complementing strategies.

Mitigation describes efforts to reduce greenhouse gas emissions as well as measures to enhance greenhouse gas sinks. Forest and tree-based mitigation options can be classified as efforts to *maintain* the remaining forest cover (reduce deforestation and degradation), and measures to *increase* forest cover (natural regeneration and reforestation) (Nabuurs et al., 2007). We briefly describe each strategy but focus on natural regeneration later on.

Reducing deforestation and forest degradation

Natural forests in Ethiopia have declined by 16% between 1990 and 2020 (FAO, 2020). The pressure on remaining forests is high, with agricultural expansion and wood fuel demand acting as the most prominent drivers of deforestation and forest degradation[1] (MEFCC, 2018). Disturbed or degraded forests have limited carbon storage capacity and are more susceptible to fires, wind, drought as well as other environmental and human-driven stressors, and are less capable to adapt to climate change. Between 2000 and 2020, emissions from deforestation and land degradation ranked second in Ethiopia, following emissions from the agricultural sector (FDRE, 2023). Halting the decline and degradation of remaining forest ecosystems should therefore be a priority, as it has the potential to contribute substantially to climate mitigation and to safeguard species habitats.

Reforestation and afforestation

Reforestation and afforestation both describe the seeding or planting of trees in non-forested areas. Specifically, reforestation refers to areas where forest has been removed or reduced (e.g. from logging or degradation), but which were recently covered with forest, while afforestation describes the establishment of trees in areas that have long not been or have never been forested (IPCC, 2000). The contribution of reforestation to climate mitigation depends on the ability of planted forests to store carbon and their long-term survival (Pennisi, 2022). Native species and combinations of different species should be considered, as biodiverse forests can store more carbon than planted monocultures and better withstand environmental change (Di Sacco et al., 2021). Reforestation of formerly lost natural forests also helps to restore biodiversity, thus contributing to the Montreal-Kunming Global Biodiversity Framework (CBD 2022[2]). To ensure long-term maintenance of reforestation efforts and benefits to communities, local actors need to be involved from the beginning (Di Sacco et al., 2021).

Natural and assisted natural forest regeneration

Natural regeneration (NR) describes successional processes that return disturbed and degraded forests or deforested areas towards a stable and productive forest ecosystem naturally over time. NR can occur without human influence, based on seeds available in the soil or dispersed from surrounding forest areas, or by resprouting from remaining roots or stumps. NR is an inexpensive and easy-to-implement measure to recover vegetation structure, biodiversity and ecosystem services of forests (Crouzeilles et al., 2017). NR potentially offers a higher carbon sequestration potential (Lewis et al., 2019) and advances for biodiversity, compared to planted forests (Di Sacco et al., 2021). However, NR can be prevented, for example, by limited seed availability, unfavourable climatic conditions and disturbance, such as grazing, burning or logging. In such cases, human intervention is required to ensure regeneration success. Assisted Natural Regeneration (ANR) describes practices where humans support natural regeneration processes. ANR is required especially in areas with high grazing pressure, human disturbances and encroachment of shrubs. For example, area enclosure can help protect regenerating forest from grazing animals.

[1] Forest degradation describes the "reduction of the capacity of a forest to provide goods and services" (FAO, 2011). Forest degradation also refers to changes in forest structure and functional composition (Chazdon, 2014), a loss of carbon storage capacity and resilience (Ghazoul et al., 2015).

[2] See https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf.

Additional targeted planting of (native) tree species' seedlings can be required to ensure regeneration success (Aerts et al., 2008). A prominent example of ANR is the Humbo Project which focuses on the restoration of native tree species in south-western Ethiopia. The approach involves farmer-managed natural regeneration and traditional forest establishment techniques, promoting native vegetation and biodiversity (World Vision Ethiopia, 2018).

Potential of natural forest regeneration for climate mitigation and biodiversity recovery in Ethiopia

Natural forest regeneration offers a high mitigation potential in areas where carbon accumulation rates are high and the local climate is suitable for forest regrowth. Synergies can be achieved when also considering recovery of biodiversity. In contrast to species richness, which only considers the number of species, functional diversity (FD) provides a more comprehensive understanding of how forests function and respond to environmental changes (see definitions of functional diversity and key plant traits in the green box below). FD is derived from the range of functional traits[3] of the trees present in a forest. Traits allow for a categorization of trees according to, for example, their carbon sequestration capacity, drought and fire resistance or nutrient deficiency tolerance (Díaz et al., 2011). High FD increases the resilience of forest ecosystems to climate change and other environmental stressors (Aguirre-Gutiérrez et al., 2022), which is important for the long-term stability of carbon sinks in recovering forests. Consequently, NR should also aim at restoring FD of forests (Di Sacco et al., 2021).

To project the future potential of natural forest regeneration for carbon sequestration and biodiversity recovery in Ethiopia, the Potsdam Institute for Climate Impact Research (PIK) carried out a modelling analysis using a flexible trait-based Dynamic Global Vegetation Model (LPJmL-FIT, Lund-Potsdam-Jena managed Land model with Flexible Individual Traits, Sakschewski et al., 2015, 2021). LPJmL-FIT simulates the Potential Natural Vegetation (PNV) that is established under local climatic and soil conditions (not considering historical, present or future land use). The model represents complex forest ecosystems composed of individual trees with different functional trait combinations[4]. Carbon accumulation rates and recovery of FD were assessed by simulating recovery of forests from bare ground for 100 years (2000-2100) under present-day (baseline) and future climate change scenarios (SSP126 and SSP585)[5]. Atmospheric CO_2 concentrations were fixed at the 2015 value for the consecutive simulation years of the future scenarios because of the model's uncertainty regarding potential carbon gain in tropical vegetation under rising atmospheric CO_2.

Key plant traits and functional diversity

Specific Leaf Area (SLA): The ratio of leaf area to leaf dry mass ($mm^2\ mg^{-1}$) indicates the efficiency of photosynthesis and resource-use strategies. Fast-growing, high-SLA leaves are highly efficient in photosynthesis, but less durable than more conservative, low-SLA foliar strategies.
Wood Density (WD): Reflects a tree's mechanical and hydraulic properties and its growth rate. Species with higher WD tend to be more drought-tolerant and have greater resistance to mechanical damage, while lower WD species are often faster-growing, but less durable.
Tree Height (TH): Influences competition for light and is strongly affected by resource limitations and environmental conditions.
Functional Richness (FR): Measures the extent to which a community of species occupies different functional niches or roles within an ecosystem (Schneider et al., 2017; Villéger et al., 2008). FR was calculated as described in Thonicke et al. (2020).
Functional Evenness (FE): Is a complementary concept that focuses on the evenness of the distribution of species abundance in functional niches (Mouchet et al., 2010). FE was calculated as described in Thonicke et al. (2020).
Functional Diversity (FD): In this work, FD is defined as the sum of FR and FE (normalized to values between 0 and 1).

[3] Functional traits are any measurable morphological, physiological, phenological or behavioral characteristics of organisms at the individual level that influence their overall fitness (Carmona et al., 2016).
[4] Selected key functional traits in LPJmL-FIT are: Specific Leaf Area (SLA, $mm^2\ mg^{-1}$), Wood Density (WD, $g\ cm^{-3}$) and Tree Height (m) (see green box for definitions).
[5] SSP = Shared Socioeconomic Pathways. SPP126: sustainable and "green" pathway, with 2.6 W/m^2 radiative forcing by 2100; and SSP585: fossil-fueled development, with 8.5 W/m^2 radiative forcing by 2100. For further information see: https://www.dkrz.de/en/communication/climate-simulations/cmip6-en/the-ssp-scenarios.

FD was derived from the trait distributions present in the simulated forests: Each individual tree in the simulation was categorized based on the combination of the key functional traits SLA, WD and TH (Thonicke et al., (2020).

Future climate projections predict a strong increase in mean annual temperatures, especially in northern and central Ethiopia (by more than 4.5°C, SSP585, Figure 1a). The climate model ensemble also projects an increase in mean annual precipitation towards the end of the 21st century under the strong emissions scenario (SSP585), but no clear trend for SSP126 (Murken et al., 2020). The Maximum Climatic Water Deficit (MCWD[6]), i.e. the difference between precipitation and potential evaporation, is a key indicator of water availability for vegetation, and a predictor of forest growth and recovery. MCWD is projected to decrease in parts of the southern highlands, eastern Oromia and parts of Afar (SSP585, Figure 1b), which indicates a decrease of water stress for vegetation in these regions.

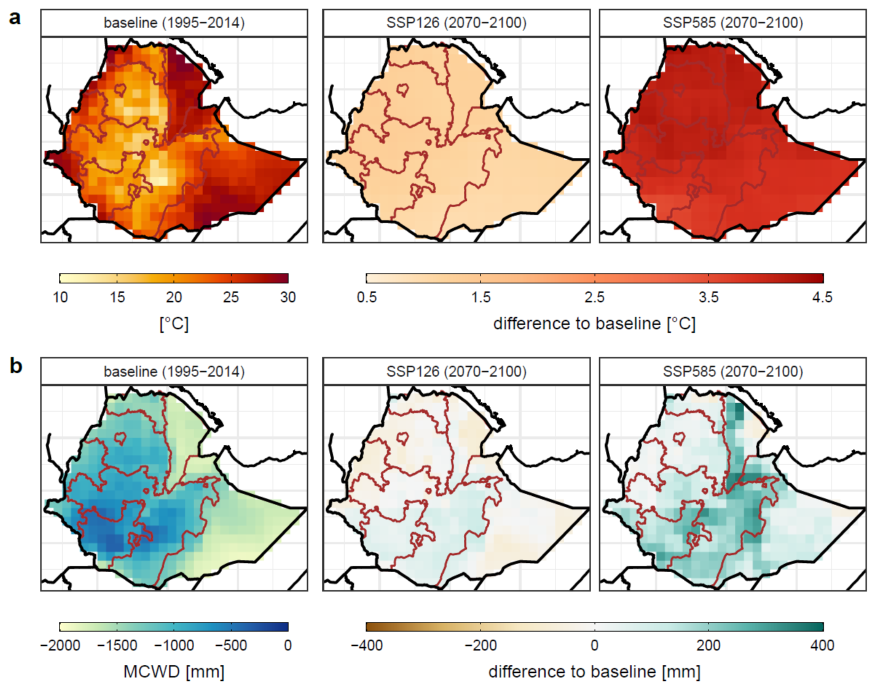

Figure 1: Projected changes in a) mean annual temperature, and b) MCWD (Maximum Climatic Water Deficit) from a CMIP6-multi-model ensemble mean[1] for SSP126 and SSP585. Where MCWD is 0, precipitation equals or exceeds potential evapotranspiration, a more negative MCWD indicates more severe water stress. A positive change of MCWD indicates a decrease in water stress, compared to the baseline climate (mean 1995-2014)

Climate change impact on carbon sequestration potential

Assuming present-day climatic conditions until the end of the 21st century, simulated carbon accumulation rates (in Mg carbon ha^{-1} $year^{-1}$) in recovering forests are highest in the SNNR region and parts of Oromia (Figure 2a, left, next page) and overlap with regions with the highest water availability (MCWD close to 0, Figure 1b, left). Under SSP126, recovering forests in SNNR and southern Oromia, the regions where a moderate increase in temperatures and water availability is projected, could potentially sequester up to 20-30% more carbon. Carbon sequestration rates are projected to rise under SSP585 for these regions as well, but decline in western and north-western Ethiopia (strongest warming, Figure 2a, centre and right panel, next page).

Climate change impact on functional diversity recovery

Hotspots of FD in naturally recovering forests are located in south-western Ethiopia, where moist, evergreen Afromontane forests grow, and in parts of the northern and southern highlands, where dry Afromontane forests occur (Figure 2b, left panel, baseline scenario, next page). While FD reaches similar levels under both scenarios in the highlands, FD in western and north-western Ethiopia (part of Combretum-Terminalia woodland ecosystem) stays below baseline values. Lower FD could increase the vulnerability of these ecosystems to disturbance and environmental stress.

[6] MCWD is a metric for the intensity and severity of drought, defined as the most negative value of the climatological water deficit (CWD) within each hydrological year (here: Sept-Oct). CWD is the difference between precipitation and PET (potential evapotranspiration). MCWD was calculated as in Malhi et al., (2009) as the minimum value from CWD_1 … CWD_{12} for each year.

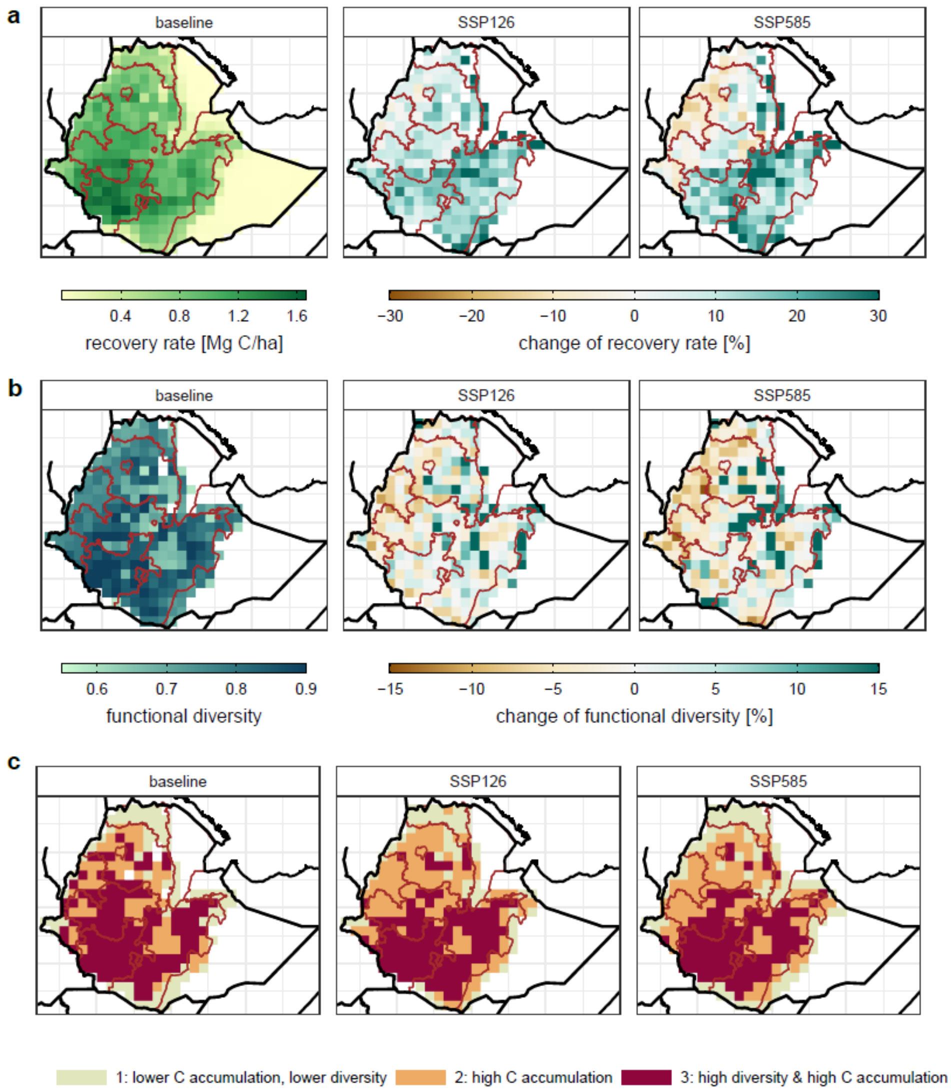

Figure 2: Natural forest regeneration, simulated with the trait-based Dynamic Global Vegetation Model LPJmL-FIT (50x50km² spatial resolution). Forest regrowth was simulated for 100 years starting from bare ground in the year 2000. a) Left: Carbon accumulation rate in recovering forests (in Mg C ha^{-1} yr^{-1}), averaged over a recovery time of 100 years, assuming present-day climatic conditions as a baseline. Centre and right: Difference of carbon accumulation rate for a best-case and a worst-case emissions scenario (SSP126 and SSP585) vs. the baseline. b) Left: Functional Diversity (FD) after 100 years of recovery assuming present-day climatic conditions as a baseline. Centre and right: Projected changes in FD until the end of the 21st century under SSP126 and SSP585 vs. the baseline. c) Left: Combined potential of natural forest recovery (simulated as potential natural vegetation) under baseline climate. Centre and right: SSP126 and SSP585. Thresholds for high carbon accumulation potential and FD for all scenarios were based on the median values from the baseline scenario simulations. The presented results do not consider past, present-day or future land use.

Potential for natural forest recovery

Regions where both carbon accumulation rates and FD in recovering forests are high[7] are potentially promising for achieving the dual target of mitigating climate change and restoring biodiversity. Such regions are located in the south-western and southern highlands (moist Afromontane forests), but also the northern and north-western highlands (baseline scenario, Figure 2c left). Ethiopia's moist and dry Afromontane forests are severely affected and degraded by human activities, however, they are mostly located within areas with high potential for NR. The projected future decline in functional diversity, especially in the SSP585 scenario, leads to a decline in regeneration potential in northern Ethiopia (Figure 2c, right). However, even under future climatic conditions, carbon can be sequestered in recovering forests across large parts of the Ethiopian highlands (potential class 2, Figure 2c centre and right).

Overall, natural forest regeneration bears a great potential to sequester carbon and restore biodiversity in Ethiopia. Climate change enhances the carbon accumulation rate in some regions, but strong warming could limit forest regrowth. Functional biodiversity recovery in the northern highlands was negatively impacted by climate change in our analysis. As the presented results refer to the potential natural vegetation, they can be understood as an additional perspective to the priority map for tree-based landscape restoration in Ethiopia published by the Ethiopian Ministry of Environment, Forest and Climate Change (MEFCC, 2018), which considers, for example, human population density or land use. Identifying areas where natural forest recovery can be successful and beneficial for all livelihoods requires a comprehensive analysis of ecological as well as socio-economic factors (Di Sacco et al., 2021). In addition to the approach presented here, which focussed on forest recovery and biodiversity, provisioning services such as food and fodder resulting from changing land-use patterns are equally important for people's livelihoods and well-being and can be a focus of future studies.

[7] Highest 50% of baseline carbon accumulation rate and FD.

In addition to their mitigating role, forests and trees are also key in climate adaptation, in particular where climate change negatively impacts natural resources like water, soils, and agricultural and food systems. Forests and trees can support adaptation efforts in various ways, including as buffers against extreme weather events, for erosion control and as part of agroforestry systems. The latter shall be discussed in more detail.

Defining agroforestry

In the context of climate adaptation, agroforestry has gained particular prominence in recent years. It is a sustainable land management practice that involves the intentional integration of trees or woody vegetation with crops and/or livestock within the same piece of land. While different definitions exist, the World Agroforestry Centre (ICRAF) defines agroforestry in the following way, "Agroforestry is the interaction of agriculture and trees, including the agricultural use of trees. This comprises trees on farms and in agricultural landscapes, farming in forests and along forest margins and tree-crop production, including cocoa, coffee, rubber and oil palm" – or, in short, as "agriculture with trees" (ICRAF n.d.).

Benefits of agroforestry

Scientists and practitioners alike consider agroforestry as a pragmatic solution to addressing the multifaceted impacts of climate change, in addition to other connected challenges. For example, as a climate adaptation strategy in smallholder agriculture, agroforestry can improve soil fertility (e.g. with falling leaves acting as mulch) and reduce erosion, particularly on steep slopes, both of which can contribute to better soil health and thus increase agricultural productivity. In this way, agroforestry can also aid in restoring degraded lands and vegetation cover. Furthermore, agroforestry systems enhance water retention by reducing runoff and increasing infiltration, which is critical for managing both droughts and heavy precipitation events. Finally, trees can serve as protective structures in the case of extreme weather events like storms, but also provide shade, thereby creating cooler microclimates and reducing heat stress on crops, livestock and humans (Lasco, Delfino, and Espaldon 2014). This is especially important in more urbanized areas where heatwaves tend to be more pronounced. With regards to food security, the integration of trees and crops can diversify food sources and reduce smallholder farmers' dependence on single crops, ideally allowing them to generate additional income through the production of tree products like fruits, nuts and timber, alongside traditional crops and livestock. In the context of sustainable land management, agroforestry can contribute to a diversification of landscapes, thereby enhancing the ability of ecosystems to withstand climate-related stresses such as droughts, floods and extreme temperatures. Diversified landscapes also promote biodiversity by creating habitats for various plant and animal species, supporting pollinators, natural pest control and wildlife. The practice of agroforestry is unique in that it not only contributes to adaptation efforts, but also to mitigation efforts through carbon sequestration, thereby helping to reduce greenhouse gas concentrations.

Types of agroforestry

Agroforestry is a practice that is particularly widespread in the tropics, including many countries in sub-Saharan Africa, which have a rich tradition of agroforestry due to their diverse ecosystems and reliance on agriculture (Muthee et al. 2022). Like other countries in the region, Ethiopia has implemented different types of agroforestry systems, with agroforestry being deeply rooted in local culture and traditional agricultural production. Jemal et al. (2018) find for south-western Ethiopia that multi-story, coffee-based systems (MCS), multi-purpose-trees-on-farmlands (MTF) and home garden agroforestry (HG) are the main agroforestry systems. Multi-story systems have at least three layers of plants of different heights, with each layer partially shading the layer below. In the case of coffee production, shade trees like Acacia and Cordia are planted to improve the microclimate for shade-tolerant coffee plants. These agroforestry systems are often used for income generation. MTF systems are grown to make more than one contribution to the production or service function of a land-use system, although any tree species can be multi-purpose in one setting and single-purpose in another setting. In these types of agroforestry systems, trees like mango, avocado and papaya are typically intercropped with leguminous crops to improve soil fertility and diverse yields. HG systems complement the two previous types. They are common in both rural and urban areas, typically including a mix of trees, shrubs, vegetables and small livestock, contributing to household food security and nutrition. Oftentimes, households use all of those systems in combination, with each of them serving different purposes. Another way of distinguishing between agroforestry types in Ethiopia is between high-value agroforestry for food, fibre (mainly timber for construction), fuelwood or fodder production, and farmer-managed natural regeneration of trees (Amare et al. 2019; Iiyama et al. 2017). Many different tree species are used in Ethiopian agroforestry systems. The species composition of an agroforestry system in Ethiopia depends on characteristics of the respective household, e.g. gender, market access and local social capital, as different agroforestry systems require different amounts of labour. Furthermore, market access may determine whether high-value crops like coffee are grown (Jemal et al. 2018). Agroforestry can be integrated with further adaptation practices, which complement agroforestry or can enhance its effect. For example, different water or soil conservation practices like terracing in hilly areas and rainwater harvesting can further improve soil health and ensure that there is sufficient water during dry periods for trees, crops and livestock alike.

Results from the climate risk analysis for Ethiopia

PIK conducted a climate risk analysis of the agricultural sector in Ethiopia, including an evaluation of agroforestry as a climate adaptation strategy (Murken et al. 2020).[8] In a first round of analysis, agroforestry was evaluated in terms of its risk mitigation potential for maize production. The evaluation was based on a simulation of solar radiation and its effect on local temperatures. Although shading can help to improve soil quality and regulate the microclimate, it can also have negative effects on plant photosynthesis and thereby on plant growth and crop yields. Therefore, the analysis evaluated agroforestry by simulating 10% and 20% of shade on maize yields. These values were based on the findings by Jonsson et al. (1999), who identified 25% shading as the threshold at which adverse effects of shading on crop productivity start.

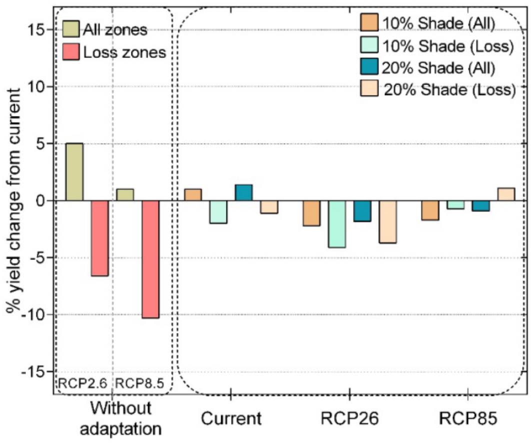

Figure 3: Effect of agroforestry shading on maize yield changes in Ethiopia (see Chemura et al., 2021).

The results show that agroforestry in Ethiopia has the potential to stabilise maize yields in zones which are projected to experience yield losses under climate change. For these zones, 10% shade will reduce the national yield loss from a loss of 10% to a loss of 4% (RCP2.6) or to 1% (RCP8.5). When shade is increased to 20%, at national level, maize yields will increase by 1% under current climatic conditions for all zones (Figure 4). Hence, 10% or 20% shade levels can reduce projected yield losses, but negatively affect yields in zones which are projected to benefit from climate change. This highlights that agroforestry as an adaptation strategy needs to be carefully evaluated and its adaptation potential is context-specific. These are however conservative results, since not all possible factors were considered, as for example benefits of enhanced soil organic carbon from agroforestry.

[8] For more details on the assumptions underlying this analysis as well as the data, models and methods, please see the full Climate Risk Analysis for Ethiopia.

In addition to the biophysical assessment, a cost-benefit analysis (CBA) was performed, which compared the costs for establishing an agroforestry system, including costs for seedlings, labour and material, with its benefits. When integrating shade-providing mango trees into a maize farming system, the CBA shows that after a short initiation phase, when costs arise from the removal of maize plants and for the establishment of the agroforestry system, the economic situation starts to improve, with a steadily growing economic margin. Thus, the CBA shows that adapting maize production with agroforestry is highly beneficial, compared to the inaction scenario. It has a positive return on investment, paying off after just a few years and leading to high economic gains under future climate change, a result which is partly driven by additional income from mango sales that can be realized in such a system (Figure 5).

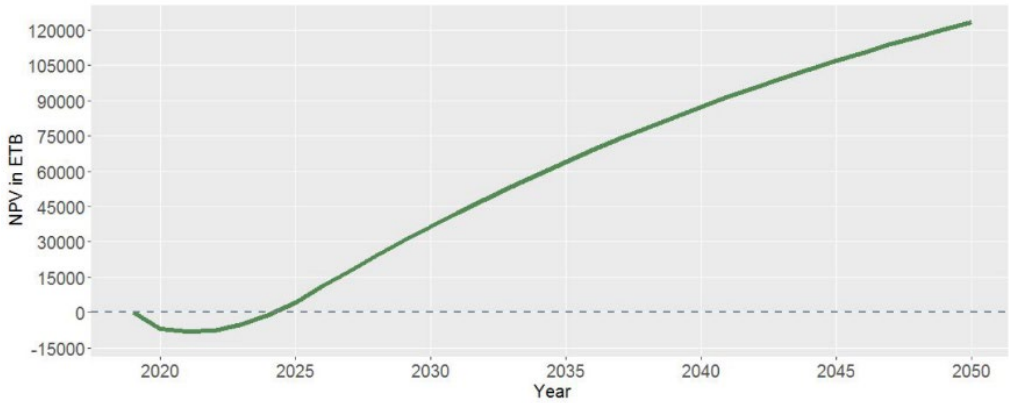

Figure 4: Development of the net present value (NPV) from 2020 to 2050 when switching from maize monoculture to maize production within an agroforestry system under future climate change impacts (in Ethiopian Birr, ETB).

Challenges in implementing agroforestry systems

Despite its many benefits, the implementation and maintenance of agroforestry systems bears several challenges. As agroforestry systems rely on tree growth, agroforestry becomes profitable only after a couple of years, depending on the growth period of a tree species. Farmers may therefore lose income from the land dedicated to agroforestry in the meantime. This is particularly an issue for smallholder farmers, whose land tends to be small in size and increasingly fragmented (Yigezu Wendimu 2021). Another barrier related to the implementation of agroforestry is the question of land rights, which are often not secured or tend to be in the hands of men, thus limiting access for women and marginalised groups in establishing agroforestry systems (Gebrehiwot, Elbakidze, and Lidestav 2018). Once in place, the maintenance of agroforestry systems requires much labour (e.g. regular pruning of trees or harvesting of fruits), which especially in home gardens could increase the burden on women who are frequently in charge of this type of agroforestry and of securing food for their families (ibid).

Synthesis and policy recommendations

This policy brief highlights the role of forests and trees in addressing climate change. In terms of mitigation, natural forest regeneration can contribute to carbon sequestration and biodiversity restoration in Ethiopia and consequently contribute significantly to climate mitigation. Simulations by PIK show the potential of natural forest regeneration based on projected future vegetation dynamics under two emissions scenarios. Especially in the southern and south-western highlands, natural forest regeneration could sequester high amounts of carbon, while restoring the functional diversity of forests. (Functional) diversity contributes to the stabilization of forests under climate change and should always be considered when prioritizing climate mitigation strategies. However, the success of natural forest regeneration depends greatly on human influences such as the expansion of land use and the protection of recovering forests from further destructions or perturbations. On the adaptation side, forests and trees can support adaptation efforts through their capacity to provide shade and absorb and water. They can also act as natural buffers against extreme weather events, such as floods and storms. This policy brief highlights agroforestry as one possible adaptation strategy. Agroforestry can achieve both climate adaptation and mitigation objectives, making it a key adaptation strategy for the agricultural sector. Analyses conducted by PIK show that agroforestry can stabilize crop yield losses, where negative climate impacts are expected, and can benefit farmers financially with a high positive return on investment.

Based on the scientific findings generated by PIK and based on input by local experts and stakeholders, the following policy recommendations can be given to strengthen the role of forests and trees in climate mitigation and adaptation efforts in Ethiopia:

Mitigation

- Natural forest regeneration in Ethiopia has a high potential to achieve both the goals of carbon sequestration and the restoration of functional biodiversity, especially in the highlands, also under projected future climatic conditions. As extreme weather events such as droughts or heatwaves can negatively impact forest recovery, their consequences need to be assessed in a regional analysis.
- Recovering natural forests must be protected from further perturbations (e.g. deforestation, degradation, overgrazing, shrub encroachment, human-caused fires and land-use change) to ensure long-term success of natural forest regeneration. Assisted forest regeneration (e.g. through area enclosures) or targeted planting of native tree species might be required to enable forests and woodlands to recover.
- Local communities must be involved in forest regeneration decisions and activities, as their livelihoods are closely linked to these natural resources.
- Natural forest regeneration cannot replace the vital role of safeguarding existing forests, as they serve as substantial carbon reservoirs and host a high level of biodiversity. Countering deforestation by addressing the root causes is therefore of highest priority.

Adaptation

- Implementing agroforestry systems can be recommended in parts of Ethiopia where negative crop yield losses are projected, e.g. in Gamo-Gofa, Western Tigray, Metekel and Guraghe.
- Where future yield increases are projected, the implementation of agroforestry needs to be carefully evaluated beforehand. Selected tree species may be beneficial across Ethiopia despite projected crop yield increases without adaptation.
- Decisions regarding particular tree species and intercropping should be based on local suitability, preferences and opportunities for further benefits, e.g. for sale at the market or fodder trees for livestock production.
- Concrete policy recommendations could include the provision of tree seedlings to farmers and corresponding trainings on the establishment and maintenance of agroforestry systems.

General recommendations

In addition to specific recommendations related to mitigation and adaptation, the following more general recommendations can be given:

- Planning for mitigation and adaptation should be regionally specific, as different areas in Ethiopia will be impacted by climate change differently.
- Strategies related to other natural resources like soil and water should be mainstreamed into all efforts to address climate change and considered wherever possible.
- Combinations of strategies, whether on the mitigation or adaptation side, are often more effective than single approaches.
- Smart mitigation and adaptation incentives are key to induce uptake of suitable strategies. Possible incentives include better access to credits or markets.
- Local communities need transitional financial support in bridging the gap between the initial investment and the break-even point, where a strategy becomes profitable.

References

Aerts, R., November, E., Hermy, M., Deckers, J., Haile, M., & Muys, B. (2008). Assisting natural forest regeneration in Northern Ethiopia: One measure is not enough. *Nature Precedings*.

Aguirre-Gutiérrez, J., Berenguer, E., Oliveras Menor, I., Bauman, D., Corral-Rivas, J. J., Nava-Miranda, M. G., Both, S., Ndong, J. E., Ondo, F. E., Bengone, N. N., Mihinhou, V., Dalling, J. W., Heineman, K., Figueiredo, A., González-M, R., Norden, N., Hurtado-M, A. B., González, D., Salgado-Negret, B., … Malhi, Y. (2022). Functional susceptibility of tropical forests to climate change. *Nature Ecology and Evolution*.

Amare, D., Wondie, M., Mekuria, W. & Darr, D. (2019). 'Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits'. *Small-Scale Forestry* 18(1):39–56.

Carmona, C. P., de Bello, F., Mason, N. W. H., & Lepš, J. (2016). Traits Without Borders: Integrating Functional Diversity Across Scales. In *Trends in Ecology and Evolution* 31(5):382–394.

Chazdon, R. L. (2014). *Second Growth*. University of Chicago Press.

Chemura, A., Yalew, A. W. & Gornott, C. (2021). 'Quantifying Agroforestry Yield Buffering Potential Under Climate Change in the Smallholder Maize Farming Systems of Ethiopia'. *Frontiers in Agronomy* 3:609536.

Crouzeilles, R., Ferreira, M. S., Chazdon, R. L., Lindenmayer, D. B., B Sansevero, J. B., Monteiro, L., Iribarrem, A., Latawiec, A. E., & N Strassburg, B. B. (2017). *Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests*.

Díaz, S., Quétier, F., Cáceres, D. M., Trainor, S. F., Pérez-Harguindeguy, N., Bret-Harte, M. S., Finegan, B., Peña-Claros, M., & Poorter, L. (2011). Linking functional diversity and social actor strategies in a framework for interdisciplinary analysis of nature's benefits to society. *Proceedings of the National Academy of Sciences of the U.S. of America*, *108*(3), 895–902.

Di Sacco, A., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Cecilio Rebola, L., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G., Shaw, K., Smith, P., Smith, R. J., & Antonelli, A. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. *Global Change Biology*, *27*(7):1328–1348.

FAO (2011). *Assessing forest degradation: Towards the development of globally applicable guidelines*.

FAO (2020). Global Forest Resources Assessment 2020: Main report. In *Global Forest Resources Assessment 2020*. FAO.

FDRE (2023). *Ethiopia's long term low emission and climate resilient development strategy (2020-2050)*.

Gebrehiwot, M., Elbakidze, M. & Lidestav, G. (2018). 'Gender Relations in Changing Agroforestry Homegardens in Rural Ethiopia'. *Journal of Rural Studies* 61:197–205.

Ghazoul, J., Burivalova, Z., Garcia-Ulloa, J., & King, L. A. (2015). Conceptualizing Forest Degradation. In *Trends in Ecology and Evolution,* 30(10):622–632.

ICRAF (n.d.). 'What Is Agroforestry?' Retrieved 7 September 2023 (https://new.worldagroforestry.org/about/agroforestry).

Iiyama, M., Derero, A., Kelemu, K., Muthuri, C., Kinuthia, R., Ayenkulu, E., Kiptot, E., Hadgu, K., Mowo, J. & Sinclair, F. L. (2017). 'Understanding Patterns of Tree Adoption on Farms in Semi-Arid and Sub-Humid Ethiopia'. *Agroforestry Systems* 91(2):271–93.

IPCC (2000). *Land Use, Land-Use Change, and Forestry*.

Jemal, O., Callo-Concha, D. & Van Noordwijk, M. (2018). 'Local Agroforestry Practices for Food and Nutrition Security of Smallholder Farm Households in Southwestern Ethiopia'. *Sustainability* 10(8):2722.

Jonsson, K., C. K. Ong & J. C. W. Odongo (1999). 'Influence of Scattered Néré and Karité Trees on Microclimate, Soil Fertility and Millet Yield in Burkina Faso'. *Experimental Agriculture* 35(1).

Lasco, R. D., Delfino, R. J. P. & Espaldon, M. L. O. (2014). 'Agroforestry Systems: Helping Smallholders Adapt to Climate Risks While Mitigating Climate Change'. *WIREs Climate Change* 5(6):825–33.

Lewis, S., Wheeler, C. E., Mitchard, E. T. A., & Koch, A. (2019). Regenerate natural forests to store carbon. *Nature*, 568:25–28.

Malhi, Y., Aragã O A, L. E. O. C., Galbraith, D., Huntingford, C., Fisher, R., Zelazowski, P., Sitch, S., Mcsweeney, C., & Meir, P. (2009). *Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest*.

MEFCC (2018). *National Potential and Priority Maps for Tree-Based Restoration in Ethiopia.*

Mouchet, M. A., Villéger, S., Mason, N. W. H., & Mouillot, D. (2010). Functional diversity measures: An overview of their redundancy and their ability to discriminate community assembly rules. *Functional Ecology*, *24*(4), 867–876.

Murken, L., M. Cartsburg, A. Chemura, I. Didovets, S. Gleixner, H. Koch, J. Lehmann, S. Liersch, S. Lüttringhaus, M. Rivas-Lopez, S. Noleppa, F. Roehrig, B. Schauberger, R. Shukla, J. Tomalka, A. Yalew, & C. Gornott (2020). *Climate Risk Analysis for Identifying and Weighing Adaptation Strategies in Ethiopia's Agricultural Sector*. Potsdam, Germany: PIK.

Muthee, K., Duguma, L., Majale, C., Mucheru-Muna, M., Wainaina, P. & Minang, P. (2022). 'A Quantitative Appraisal of Selected Agroforestry Studies in the Sub-Saharan Africa'. *Heliyon* 8(9):e10670.

Nabuurs, G. J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, & X. Zhang. (2007). *Forestry*.

Pennisi, E. (2022). How to regrow a forest? Scientists aren't sure. *Science*, *378*(6622):816–817.

Sakschewski, B., von Bloh, W., Boit, A., Rammig, A., Kattge, J., Poorter, L., Peñuelas, J., & Thonicke, K. (2015). Leaf and stem economics spectra drive diversity of functional plant traits in a dynamic global vegetation model. *Global Change Biology*, *21*(7):2711–2725.

Sakschewski, B., Von Bloh, W., Drüke, M., Sörensson, A. A., Ruscica, R., Langerwisch, F., Billing, M., Bereswill, S., Hirota, M., Oliveira, R. S., Heinke, J., & Thonicke, K. (2021). Variable tree rooting strategies are key for modelling the distribution, productivity and evapotranspiration of tropical evergreen forests. *Biogeosciences*, *18*(13):4091–4116.

Schneider, F. D., Morsdorf, F., Schmid, B., Petchey, O. L., Hueni, A., Schimel, D. S., & Schaepman, M. E. (2017). Mapping functional diversity from remotely sensed morphological and physiological forest traits. *Nature Communications*, *8*(1).

Thonicke, K., Billing, M., Bloh, W., Sakschewski, B., Niinemets, Ü., Peñuelas, J., Cornelissen, J. H. C., Onoda, Y., Bodegom, P., Schaepman, M. E., Schneider, F. D., & Walz, A. (2020). Simulating functional diversity of European natural forests along climatic gradients. *Journal of Biogeography*, *47*(5):1069–1085.

Villéger, S., Mason, N. W. H., & Mouillot, D. (2008). New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology*, *89*(8), 2290–2301.

World Vision Ethiopia, K. of S. P. E. C. O. E. P. Co.,Tokyo E. P. C. H. (2018). *Humbo Ethiopia Assisted Natural Regeneration Project*.

Yigezu Wendimu, G. (2021). 'The Challenges and Prospects of Ethiopian Agriculture' edited by M. Tejada Moral. *Cogent Food & Agriculture* 7(1):1923619.

This policy brief was developed as part of the AGRICA Ethiopia project and is based on findings from the Climate Risk Analysis for Identifying and Weighing Adaptation Strategies in Ethiopia's Agricultural Sector from the GIZ-funded project AGRICA and analyses conducted for the module on forests and biodiversity from the IKI-funded project B-EPICC at PIK.

The authors are grateful to Paula Castro for supporting the development of this policy brief.

Photo on title page: Natasha Elkington/CIFOR

Illustrations: Sarah Heuzeroth