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Ethiopia’s Path to Net Zero and Climate-Resilient Development: Policies, Costs, and Co-benefits

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EXECUTIVE SUMMARY

Highlights

- This paper considers the co-benefits for economic development of achieving Ethiopia’s net zero emissions and climate resilience ambition by 2050.
- Results from Ethiopia’s Green Economy Model showed the net zero emissions (NZE) pathway increasing average real annual gross domestic product (GDP) growth rate by 1.4 percent from 2020 to 2050, relative to a business-as-usual (BAU) scenario.
- Implementation of NZE is estimated to raise cumulative investment costs by US$66.98 billion (net present value) compared to BAU by 2050; however, this investment creates cumulative co-benefits for development of $111 billion from 2020 to 2050 in the form of increased real GDP compared to BAU and avoids costs of $89 billion (largely avoided energy costs).
- Other co-benefits include, on average, 672,000 additional green jobs relative to BAU; a faster reduction of extreme and moderate poverty and higher disposable incomes, with the latter rising 10.5 percent by 2030 and 53.1 percent by 2050, compared to BAU; also better air quality and related health benefits and potential benefits from nature-based solutions and ecosystem services.
- Overall, the cumulative monetized results suggest a benefit-cost ratio (BCR) of 1.04, such that by 2030, each dollar invested in mitigation and adaptation generates $1.04 in economy-wide benefits; the cumulative BCR rises to 2.17 by 2040 and 2.99 by 2050.

About this working paper

This research focuses on climate change mitigation and adaptation in Ethiopia, estimating the costs of action and the benefits of a range of economic, social, and environmental impacts. Notably, it considers how climate change action, aiming to achieve the ambitious goal of net zero greenhouse gas (GHG) emissions by midcentury, will impact income inequality, poverty, employment, and ecosystem services. It also considers impacts on air pollution and how this affects human health.

The paper specifically explores the corollary benefits for economic development and environmental sustainability of a low-carbon, climate-resilient, green pathway for Ethiopia—a pathway that is consistent with attaining the country's medium- and long-term development goals. The analysis compares an NZE scenario with a BAU scenario. The BAU scenario embeds optimistic (high) economic growth assumptions from Ethiopia's 10-Year Development Plan, and it incorporates the gradual and early incremental adoption of several climate initiatives proposed in the Climate Resilience and Green Economy Strategy. The NZE scenario builds on the implementation of Ethiopia's nationally determined contribution (NDC) by 2030. The NZE scenario also incorporates additional climate policy options (adaptation and mitigation), resulting in net zero emissions by 2050.

The paper highlights how investments in climate mitigation and adaptation can create synergy for national development along an NZE pathway, helping deliver net zero GHG emissions in Ethiopia by 2050. It demonstrates the tangible economic, social, and environmental benefits, or "co-benefits," of this pathway. Given the optimistic growth assumptions in the BAU scenario, the benefits of NZE compared to BAU estimated in this paper may be considered conservative estimates. Overall, higher levels of investment in the NZE scenario, compared to the BAU scenario, lead to higher levels of growth and better-quality growth (i.e., growth that is more environmentally sustainable and inclusive); the co-benefits of NZE would be even higher if estimated from a comparison with a lower-growth BAU scenario.

Summary of key findings

The study indicates that despite Ethiopia's low GHG emissions and small (0.04 percent) contribution toward global emissions, significant investment will be required to shift the country onto a net zero emission, climate-resilient pathway and to achieve its developmental ambitions over the next 30 years (Federal Democratic Republic of Ethiopia 2021). The adverse impacts of climate change are rising in Ethiopia and will require targeted attention.

The implementation of NZE policies and related investments are estimated to generate additional and faster growth. Specifically, GDP growth averages 8.1 percent per year from 2020 to 2050 in the NZE scenario compared to 6.7 percent per year in the BAU scenario. This reflects total development co-benefits of $111 billion by 2050 (in the form of added GDP above BAU in cumulative discounted terms). Poverty is projected to decline along with economic growth in both the NZE and the BAU scenarios, but the NZE scenario accelerates poverty reduction compared to BAU: the share of those in extreme poverty decreases from 16.7 percent in 2020 to 2.1 percent in the BAU scenario by 2050 and to 1.3 percent in the NZE scenario; moderate poverty reveals a rapid decline from 46.0 percent in 2020 to 11.2 percent in the BAU scenario by 2050 and to 9.2 percent in the NZE scenario.

Early introduction of NZE policies in land use, forestry, and energy sectors can deliver significant near- and long-term economic, ecosystem, and social co-benefits, resulting in improved development outcomes. Delaying interventions in these sectors will create new risks for growth, slowing progress in Ethiopia's implementation of ambitious plans to modernize and green its economy.

Economic performance under the NZE scenario is, however, uneven across sectors when compared to BAU. Over the period 2020–50, a notable decline in the agriculture sector's real GDP of $8.71 billion is estimated, while growth is generated in the industry and service sectors (where additional total real GDP amounts to $60.33 billion and $59.45 billion, respectively).

Clean energy and land-use interventions both create synergies for development in the short to long term. On the clean energy side, these actions reduce emissions, unlock additional growth, and help reduce poverty; they also make energy more affordable and lower air pollution levels to deliver health benefits. The energy intensity of GDP (in megajoules to gross domestic product, or MJ/GDP) at the national level drops by 52 percent in 2050 under the NZE scenario compared to BAU, making the economy more competitive and more productive. Relative to BAU, NZE clean energy interventions create jobs, including for the rapidly growing youth population. There is an overall net gain in employment for both the BAU and NZE scenarios, with an additional 672,000 green jobs in the NZE on average relative to BAU from 2020 to 2050; the share of green jobs in total employment rises from 0.6 percent in BAU to 1.6 percent in the NZE scenario over the period. These jobs are created in the power generation and the supply chain surrounding electric vehicles. Land-based interventions also create a significant number of green jobs and increase provision of essential ecosystem services. Identifying which types of specific jobs and sectors are expected to grow can help identify skills gaps and enable the government to plan and implement appropriate education and training programs to support the decarbonization transition.

Overall, the broad economy-wide analysis shows cumulative BCR greater than 1 by 2030, with $1.04 of benefits generated for every dollar invested. This benefit-cost analysis shows that the co-benefits of decarbonization policies grow over time, with more considerable benefits materializing in the medium and long term (2040–50) compared to the near-term period (2020–30). By 2040, the BCR is 2.14, and by 2050 it is estimated at 2.99, thus nearly triple the BCR in 2030. The interventions needed to implement Ethiopia's NDC by 2030 and to reach the 2050 NZE goals will require a system-wide, collaborative approach and multilevel governance to ensure timely and well-targeted policy reforms, particularly at the sector level. They will also require a dedicated financing strategy for implementation, a topic that is ripe for future work.

INTRODUCTION

Ethiopia is recognized as a leader on climate ambition in Africa and for over a decade has been working to mainstream climate change mitigation and adaptation into its overarching development goals (Dagne et al. 2022). During recent national planning processes, the government developed a comprehensive Green Economy Model (GEM) as a tool for policy analysis and a basis for exploring potential scenarios that achieve both emission reduction and development objectives (Dagne et al. 2022). This paper highlights the costs and benefits of adaptation and mitigation policies designed to deliver a net zero greenhouse gas (GHG) emissions pathway in Ethiopia by 2050. The focus of the paper is on the "co-benefits" of such a 2050 net zero emissions (NZE) pathway for Ethiopia's development and its economy.

Ethiopia is a large, landlocked country in northeastern Africa with several unique socioeconomic and environmental characteristics. It is considered a least developed country (UN DESA 2021). In 2021, its gross national income (GNI) per capita was US$832, whereas the average GNI for least developed countries is $1,274, and for developing countries it is $6,666 (UN DESA 2021; USAID 2020). In 2022, Ethiopia's gross domestic product (GDP) was equivalent to $126.8 billion. Before the COVID-19 pandemic, Ethiopia was among the fastest-growing economies in the world—with an average annual growth rate of close to 9 percent—which had slowed down to 5.6 percent in 2021 (World Bank 2022b; World Bank Knowledge Portal 2021). Close to 40 percent of GDP and 80 percent of exports are derived from the agricultural and forestry sectors (UN DESA 2021; USAID 2020), and almost 80 percent of the population resides in rural areas (CIA 2023). The country has the 13th-largest population in the world and second-largest population in Africa, with approximately 60 percent of its citizens under 25 years of age (CIA 2023; World Bank 2022a).

On the adaptation and impacts side of climate change, Ethiopia is exposed to significant climate impacts and climate-related disaster risks. These include high risks of severe drought, riverine and urban floods, landslides, extreme heat, dust storms, and wildfires (World Bank 2023). The risk of water scarcity in Ethiopia is currently assessed at the medium level, and access to land and water could be a factor in recent conflicts between pastoralists (Beyene 2017; Burka et al. 2023). Another climate-related threat to food security and agriculture in Ethiopia comes from locust swarming triggered by hot temperatures and precipitation following the dry season—both exacerbated by climate change (Youngblood et al. 2023). Even before large regional locust swarming in 2019, about 8.5 million people in Ethiopia experienced acute food insecurity and were in need of humanitarian assistance; over 70 percent of these people live in areas now exposed to locust infestation, which can only exacerbate food insecurity (IFRC 2022). Building resilience to climate change through adaptation and better development is thus a high priority of the Ethiopian government.

Regarding mitigation of GHG, Ethiopia has historically low rates of GHG emissions; thus, its climate mitigation efforts will have only limited global impact compared to other larger emitters.[1] However, GHG emissions in Ethiopia are expected to grow at a considerable rate in the future, and mitigation of GHG could also transform development in the country to provide a pathway toward a cleaner, more equitable and sustainable future.

The average annual income per person in Ethiopia has more than quadrupled in the past four decades in real (constant dollar) terms, while the annual population growth rate in the country is about 2.6 percent, and child and maternal mortality has been steadily decreasing since 1980 (World Bank 2022a). However, extreme poverty levels remain high in Ethiopia, and poverty eradication is a key national development priority. The population in Ethiopia is projected to nearly double by 2050. The combined effect of improved standards of living, increases in per capita income, urbanization (annual urban population growth of 4.8 percent), population growth, and increased carbon intensity of GDP means that GHG emissions are expected to grow rapidly (USAID 2016; World Bank 2018). Despite its minimal historic contributions to global climate change, Ethiopia is politically committed to climate action.

In January 2023, Ethiopia's prime minister publicly confirmed that Ethiopia has developed a long-term net zero and climate-resilient 2050 strategy, which was submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in June 2023 (Abera 2023; PDC 2021).

This long-term strategy is in addition to the 2021 updated nationally determined contribution (NDC) and 10-Year Development Plan (10YDP), and together with other climate-related policies, it signals Ethiopia's commitment to climate action. In addition to political commitment, Ethiopia is also committed to mobilizing 20 percent of the investment finance needs for climate mitigation and adaptation actions from domestic sources and is requesting the remaining 80 percent of support needed for implementation from the international community (Federal Democratic Republic of Ethiopia 2021).

The objective of our analysis is to demonstrate the tangible social, economic, and environmental corollary benefits—referred to here as the development co-benefits or simply co-benefits—of realizing Ethiopia's climate policy ambition. Specifically, we explore the co-benefits of a low-carbon, green, climate-resilient pathway for Ethiopia, a pathway that is consistent with the attainment of national medium- and long-term development goals. To our knowledge, this study of climate policy co-benefits for development in Ethiopia is the first of its kind. It thus fills a gap in the literature and contributes empirical evidence to support decision-making in Ethiopia.

While there is general agreement among policy practitioners on what constitutes co-benefits of climate policy (IPCC 2022), the nuances and interpretations as well as methodologies for accurately accounting the value of the co-benefits are continually evolving. If the main purpose of the investment or policy is to mitigate climate change or adapt to it, then the reduction of GHG emissions and the increase in resilience to climate change will be the main direct outcomes. For co-benefits to be recognized and classified as such, specific indicators are required to track change. The indicators could take the form of a binary, quantitative, qualitative, or percentage change. In the context of Ethiopia and for this study, we focus on co-benefits for development, dividing these into socioeconomic and environmental outcomes. For further details of different types of co-benefits, based on a review of the literature, see Appendix B.

When discussing co-benefits, it is important to keep in mind the trade-offs between climate change mitigation or adaptation in a net zero economic transition on the one hand and other development goals on the other. In some cases, climate change mitigation could lead to negative economic impacts. For example, in Ethiopia in the short term, shifting to more sustainable land management and sustainable forest management typically will permit less farming or forest yield than concentrated farming operations and commercial timber production; yet in the longer term, agricultural and forest harvest productivity may rise. Agricultural and forestry productivity reductions could in turn have negative effects on incomes and slow down poverty alleviation or eliminate jobs in some sectors and locations during a period of transition. Sustainable land management can also result in lower availability of water—for example, for irrigation and urban centers in some colocated areas—by increasing water retention in natural ecosystems and thus reducing local water yield (Cohen et al. 2021); at the same time, it can increase water yield for upstream and downstream users over the longer term. Another possible set of trade-offs comes in the labor sector, where transitioning to clean energy—the related increase in green jobs, for example—would increase demand for skilled jobs, but not necessarily for unskilled jobs. This change can create tension and a need for the government to actively manage the transition for workers.

At the international level, changes in cross-border trade are expected, as countries become more self-sufficient in producing goods to meet domestic consumption needs in the transition to NZE economies. In the case of Ethiopia, agriculture trade dynamics may be impacted, with reduced imports but possibly higher exports. Despite their relevance, these issues were not within the scope of this research. Trade-offs such as these will need to be considered in future research to support the design of just transition policies that balance development goals such as poverty alleviation, job creation, and gender equity, among other development and climate goals.

In this paper, we focus on studying the effects of climate change mitigation and adaptation in Ethiopia. We simulate policy action across sectors to achieve NZE and build resilience to climate change by 2050 (see Appendix A, Table A1). In terms of development co-benefits, we assess poverty alleviation, changes in income inequality, and employment. We also assess co-benefits from ecosystem services generated through scaling of nature-based solutions (NBS) that contribute to habitat quality, water and soil quality, and management of climate-related extremes such as drought, dust storms, and floods. NBS also contribute carbon capture and storage services.

This analysis was done through model-based economic analysis using the Ethiopia GEM (see "Conceptual framework, methods, and data" and Figure 1) and by constructing feedback loops in causal loop diagrams to underpin the modeling). Additionally, special analysis was commissioned for this study, including using the Sustainable Asset Valuation (SAVi) and Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) models to specifically assess sustainable land management policies, as well as the Global Income Distribution Dynamics (GIDD) models, to examine distributional impacts (see details in "Conceptual framework, methods, and data" as well as Appendix A).

While this study considers a relatively long list of co-benefits quantitatively in physical units and or monetary units, we did not monetize all of them; thus, the economic analysis is partial. Specifically, ecosystem services from NBS are not monetized but are estimated here in physical units; health benefits from lower levels of air pollution are not all explicitly quantified or monetized. Moreover, the economic impact of several decarbonization benefits materializes through improvements in total factor productivity, which in turn drives economic growth. When a range of multipliers for the quantification of benefits was available, we opted to use the lower-end multipliers. This means that the benefit-cost analysis results can be considered conservative or initial lower-bound estimates on which future work can build.

The rest of this paper is organized as follows. "Conceptual framework, methods, and data" lays out methods. "Results" describes results from the GEM modeling of NZE versus business-as-usual (BAU) scenarios to 2050 for different categories of co-benefits and costs, starting with macroeconomic growth, employment, and poverty reduction benefits, before turning to NBS and ecosystem service benefits.[2] "Results" also highlights the overall costs as investment requirements, as a share of GDP, and avoided costs of NZE, compared to BAU. In "Discussion/conclusion," we build on these results to compare benefits and costs and to construct benefit-cost ratios (BCRs). This allows us to consider the overall economic performance of a 2050 NZE pathway for Ethiopia. The "Discussion/conclusion" section also concludes and points to areas of future work.

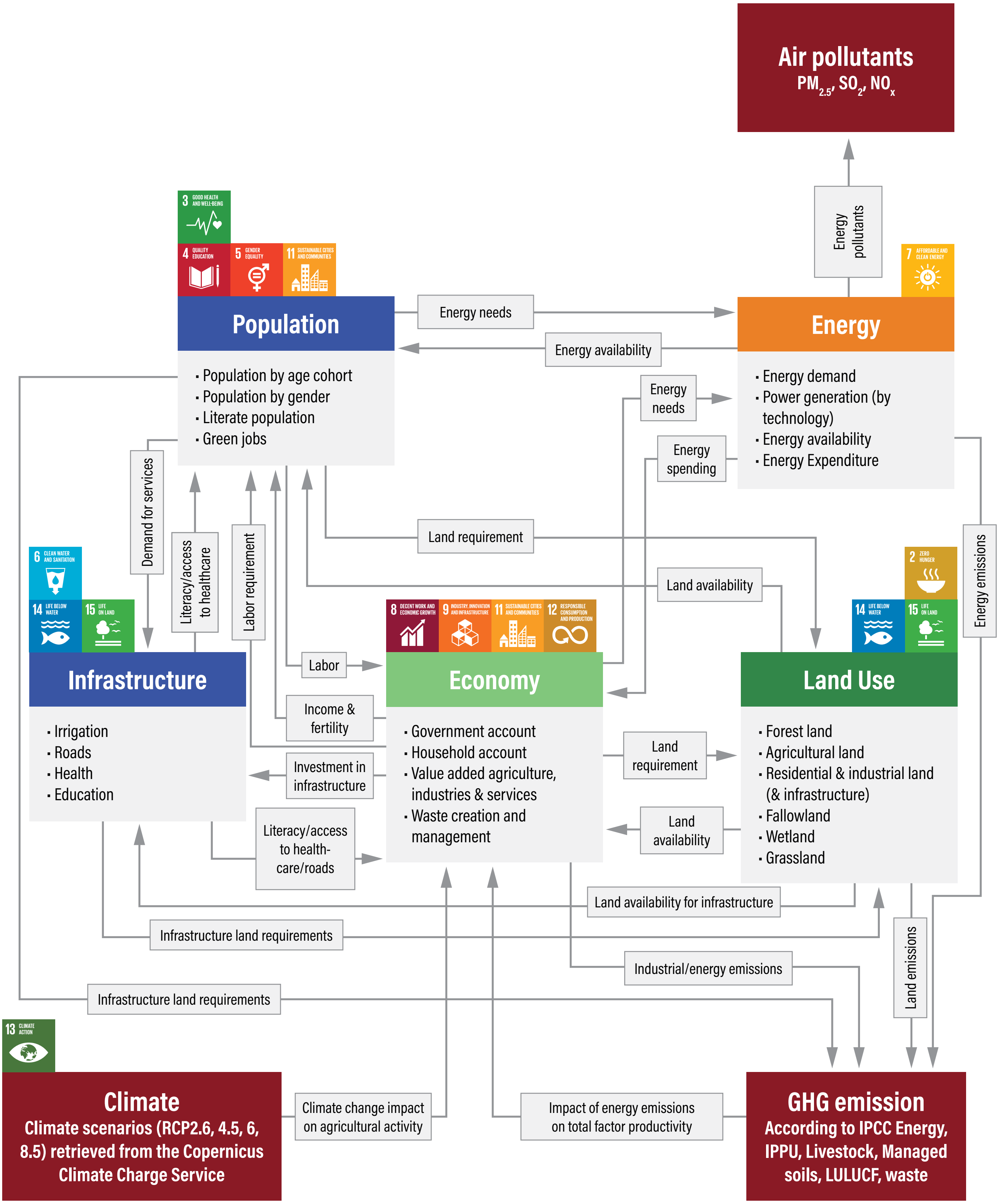
CONCEPTUAL FRAMEWORK, METHODS, AND DATA

This study explores the co-benefits for development of a low-carbon, green, climate-resilient pathway for Ethiopia that is consistent with the attainment of national medium- and long-term development goals. Results are derived from a participatory modeling framework based on systems thinking and system dynamics, and an economic assessment approach that was designed in close cooperation with Ethiopia's Ministry of Planning and Development (MoPD) and the direct engagement of government experts from various sector ministries. The participatory system dynamics modeling approach is embedded in the Ethiopia GEM. The aim was to work with local ministry officials and experts to identify science-based, economically rigorous, politically, and institutionally feasible policies and other interventions (e.g., regulations and priority investments) to shift Ethiopia to a net zero, climate-resilient, green economy. In this way, both the modeling results and the model itself are coproduced by the Government of Ethiopia and World Resources Institute (WRI). The analytical and engagement processes that underpin this study also contribute to the development of institutional and human competencies for effective design, assessment, prioritization, and implementation of climate policies in Ethiopia.

National economies are complex systems, composed of a large range of economic sector activities, each of which often competes for the same strategic resources and capital. Policymakers need reliable analytical tools and methods to forecast the effect of proposed policy interventions on citizens' well-being and on a country's economy overall. Such instruments should capture the multitude of interactions between key elements of the national economy. Economy-wide models that capture economic and population indicators as well as climate, environmental, and social conditions are often used for environmentally sustainable and NDC-aligned climate and development policy assessment and planning. Numerous models are in use around the world, including GEMs, which are based on systems thinking principles and system dynamics modeling approaches (UNEP 2014). System dynamics modeling is a form of computer simulation modeling designed to facilitate a comprehensive, systemic approach to development planning in the medium to long term (Randers 1980; Richardson and Pugh 1994; Sterman 2002). In 2020, the first country-specific GEM for Ethiopia was developed, and it is the model that we refined and employed in this study.[3]

The Ethiopia GEM uses Vensim software and includes all sectors of relevance for development planning in Ethiopia (Figure 1). The GEM captures causal relationships across social, economic, and environmental dimensions of the systems it models. Feedback loops are built into the model structure and highlight system interactions, which enables users to explore potential impacts that result from different policy interventions across sectors (Dagne et al. 2022). Please refer to Figure 1 and Appendix A for further details.

Figure 1 | **GEM Ethiopia: Model overview**



Notes: PM = particulate matter. SO$_2$ = sulfur dioxide. NO$_x$ = nitrogen oxides. RCP = Representative Concentration Pathway. GHG = greenhouse gas. IPCC = Intergovernmental Panel on Climate Change. IPPU = industrial processes and product use. LULUCF = land use, land-use change, and forestry.

Source: Authors, based on Ethiopia GEM.

Since its introduction in late 2020, the Ethiopia GEM model has been used to support national planning efforts, including preparation of Ethiopia's 10YDP, Ethiopia's updated NDC under the UNFCCC, and initial efforts to explore 2050 mitigation and adaptation strategies for Ethiopia's long-term low emission development strategy (Federal Democratic Republic of Ethiopia 2021; MOPD 2023).[4]

Results from the GEM generated for Ethiopia's updated NDC were used as a basis for this study. The 2050 NZE scenario includes the implementation of climate policies to 2030, with the NZE pathway adding policies to the NDC scenario as needed to reach net zero GHG emissions by 2050. The updated NDC, and the related emission scenario, was used as a basis for BAU for this study for several reasons: the updated NDC is the latest officially published Ethiopian national climate plan, and the NDC scenario is the latest fully validated national GHG emission scenario; it incorporates both national climate and national development objectives as outlined in Ethiopia's 10YDP; and it includes near-term milestones in 2030 as well as the beginning of a longer-term pathway to decarbonization around midcentury.

This modeling exercise assesses a 2050 NZE pathway scenario against the BAU scenario. Choices in GEM model design and assumptions, for both the BAU and the 2050 NZE scenarios, were determined in close consultation with our partners in the Government of Ethiopia. The BAU scenario embeds high economic growth assumptions that come from Ethiopia's 10YDP and includes the incremental implementation of some early climate policies identified in the Climate Resilience and Green Economy Strategy. The ambitious growth targets for the 10YDP are also achieved in the BAU scenario. By comparison to BAU, the NZE scenario adds all the policy intervention options (adaptation and mitigation) leading to NZE by 2050. See Appendix A for a list of 2050 NZE scenario mitigation and adaptation interventions used in this modeling exercise.

The NZE scenario assumes the creation of a significant carbon sink in the land-use sector, through reforestation, afforestation, forest and land restoration, and reduced deforestation. The NZE scenario also assumes the electrification of end-use sectors such as transport, residential, commercial and industry, replacing fossil fuels (and biomass use), combined with the expansion of renewable power production.[5] Finally, the NZE scenarios reduce livestock-related emissions using a range of interventions, such as increased productivity of livestock. (Please see Appendix A for an overview of the main interventions covered in this study and the associated types of co-benefits.)

Underlying data inputs were collected from the Central Statistical Agency in Ethiopia and from relevant sector ministries. This includes sectoral and national growth rates, population dynamics, and resource and energy data. These data inputs and expert views on system interactions and feedback were gathered through a series of online meetings from April 2020 to August 2020.[6]

In addition, a number of other models are part of the GEM framework for this Ethiopia assessment:

- The GIDD model was used to assess the potential microeconomic, distributional impacts of Ethiopia's net zero pathway.[7] The GIDD was linked to the GEM for assessing microeconomic interactions with the macroeconomic assessment. Four modules of the GIDD framework were used, covering changes in the demographic and education structure; sectoral reallocation of labor; relative labor income for different types of workers; and economic growth (see "Co-benefits from low carbon, climate resilience interventions").
- The GEM Ethiopia model results are also combined with an SAVi financial analysis, developed by the International Institute for Sustainable Development (IISD 2023), as well as spatially explicit analysis using a suite of models known as InVEST to assess nature-based solutions.[8] The InVEST models are developed by the Natural Capital Project (2019) and are parametrized for Ethiopia. They take land-use/land cover maps as input and quantify a wide range of ecosystem services. Specifically, using the InVEST spatial models, we assess the direct co-benefits of land restoration as well as other changes in habitat quality, sediment retention, water retention, and carbon storage deriving from NZE policies. Restoration of landscapes, for example, improves ecosystem service provisioning and generates a range of co-benefits that InVEST quantifies (see "Cost of interventions").

It is important to note that the characterization of BAU is a critical input to this GEM model–based assessment and underlies the cost and co-benefit results that we present here. The BAU scenario used in this analysis is based on optimistically high economic growth assumptions from Ethiopia's 10YDP. The BAU scenario also incorporates the anticipated incremental implementation of some early climate policies. The NZE scenario reflects both the implementation of the NDC scenario from 2020 to 2030 and an NZE pathway from 2031 to 2050. Using an alternative BAU scenario with lower growth assumptions would provide a different set of results. See Appendix E for an overview of how baseline economic growth could be lower, which in turn would make estimated co-benefits even more significant.

RESULTS

Ethiopia's planned climate policies and ultimate achievement of net zero GHG emissions around midcentury generate both climate change benefits and a range of other co-benefits. These results derive from the macro- and microeconomic simulations of the models noted above as part of the GEM Ethiopia framework and as such represent aggregate outcomes associated with 2050 NZE policy interventions.[9]

Co-benefits from low-carbon, climate resilience interventions

Co-benefits of climate action capture a range of economic, social, and environmental impacts of a 2050 future with ambitious climate policy (NZE) compared to a baseline (BAU).

Macroeconomic benefits and impacts on economic growth

The economic benefits of Ethiopia's transition toward a low-carbon, climate-resilient economy include higher economic growth in the NZE scenario compared to BAU. From 2020 to 2050, real GDP growth per year averages 6.7 percent in the BAU scenario and 8.1 percent in the NZE scenario, despite additional GHG mitigation and adaptation policies and higher investments required for climate action. The average real GDP growth rate in the NZE scenario, compared to BAU, increases by 1.4 percent per year from 2020 to 2050, which overall is about 20 percent higher than BAU annual average growth. Average annual real GDP growth in the NZE scenario is 1 percent higher compared to the BAU scenario from 2020 to 2030, 1.6 percent higher from 2030 to 2040, and 1.8 percent higher from 2040 to 2050. Because of higher growth, total real GDP in the NZE scenario is projected to be 10.3 percent higher by 2030 and 52.5 percent higher by 2050, relative to the BAU scenario. From 2020 to 2050, the cumulative additional real GDP generated in the NZE scenario totals $2.13 trillion (undiscounted), which is equivalent to an average additional real GDP of $71.07 billion per year.[10] The additional growth induced by the implementation of NZE measures also translates into higher per capita income: real disposable income per capita in the NZE scenario reaches $1,093.06 per person per year in 2030 (+10.5 percent over BAU) and further increases to $3,340.1 per person per year in 2050 (+53.1 percent over BAU).

The economic growth benefits in the NZE scenario come from various channels in the economy (represented as feedback loops in the model) and from economy-wide multiplier effects that capture the beneficial impacts of investments in decarbonization and resilience. Transitioning to clean energy unlocks GDP growth and reduces energy-related emissions (–65.5 percent in 2050 compared to BAU). Investments in energy efficiency and in the transition to electric vehicles (EVs) reduce the energy footprint of the economy and drive strong economic performance though productivity gains due to improved human health conditions, innovation, investment, and income. The energy intensity of GDP at the national level drops by 52 percent in 2050 under the NZE scenario compared to BAU, making the economy more energy efficient and productive. Furthermore, by ensuring a share of renewable power generation above 70 percent over the next few decades, it becomes possible to boost use of off-grid renewables such as solar, wind, and biogas and to simultaneously phase out diesel generators, while keeping electricity cost reliably low. Increased reliance on renewables (other than hydropower) also helps deliver rural electrification, a key development target. Finally, the clean energy transition delivers a range of other development co-benefits such as better human health due to lower levels of air pollution and creation of additional jobs in power generation and the supply chain surrounding EVs.

The 2050 NZE scenario policies and investments are also designed to boost climate adaptation and resilience. For example, adaptation investments in the agriculture sector are estimated to reduce production losses 6.5 to 10.1 percent per month during the dry season, hence maintaining overall agricultural productivity above BAU levels to 2050. Beyond this, all interventions in the land-use sector yield both mitigation and adaptation benefits to increase Ethiopia's resilience in the face of climate change.

Our analysis also includes climate impacts on the economy, specifically looking at the power generation sector, water scarcity impacts on crop production, and the impacts of extreme precipitation on industry and services capital. To assess the cumulative impacts of climate change, the BAU and NZE scenarios were simulated with and without these climate impacts for comparison. Climate change impacts on total real GDP stem in part from the forgone production of the agriculture sector, as well as from the loss of productive capital in the industry and services sectors. The GEM projects that cumulative forgone real GDP due to climate change from 2020 to 2050 will be 2.93 percent of GDP in the BAU scenario and 2.71 percent of GDP in the NZE scenario (see Table 1).[11] Under both scenarios, close to three years of current economic activity will be lost between now and 2050 due to climate change. However, the 2050 NZE scenario results show that NZE policies already begin to limit the economic impacts of climate change in Ethiopia's agriculture sector in the coming decade (see Appendix D for details). The differences between the two scenarios are minimal however, due to the early stages of adaptation policy in Ethiopia, and climate damages in Ethiopia will be driven in any case to a great extent by global developments.

Table 1 | **Climate change impacts as share of GDP for BAU and NZE scenarios by decade, 2020-50**

	2020-30 (%)	2030-40 (%)	2040-50 (%)	2020-50 (%)
Net zero	3.27	2.56	2.25	2.71
BAU	3.33	2.79	2.60	2.93

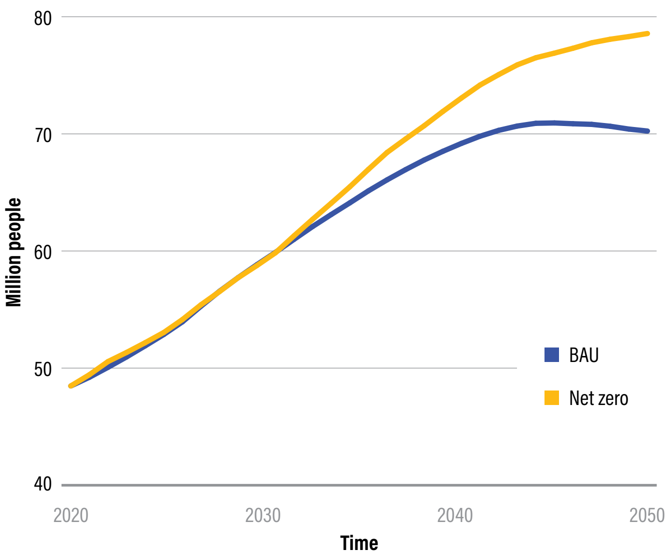
Source: Authors, based on Ethiopia GEM.

Employment and labor productivity

The NZE scenario drives additional growth of the economy and generates a higher number of jobs relative to the BAU scenario. Accounting for population growth, the job generation in the model includes direct, indirect, and induced jobs created as a result of higher growth and resulting capital accumulation. In both scenarios, the GEM models the creation of additional green jobs—including electrification of vehicles and the installation of EV chargers, renewable energy technologies (centralized and decentralized), and jobs to conduct reforestation and waste management activities—to implement climate change mitigation measures. Under the BAU scenario, taking into account population growth and demographic change, total employment is projected to increase from 49.22 million jobs in 2022 (37 percent of total active population employed) to 70.24 million jobs in 2050 (34 percent of total active population employed). As some climate and other environmental policies are already in place in this baseline, the total number of green jobs doubles in the BAU scenario, from 227,200 (2020) to 455,400 (2050), slightly increasing from 0.5 percent of total employment in 2020 to 0.7 percent of total employment in 2050. However, employment gains are even higher in the NZE scenario.

Under the NZE scenario, the mitigation and adaptation interventions reduce the unemployment rate from 2020 to 2050 by 3.6 percent compared to the BAU scenario. The total number of jobs in the NZE scenario is 78.57 million in 2050—which is 11.9 percent higher than in the BAU scenario—and corresponds to 8.33 million additional jobs (Figure 2). From 2020 to 2050, NZE related interventions generate on average 672,000 additional green jobs relative to the BAU scenario. Almost two-thirds of additional green jobs are generated from land-based interventions like reforestation measures, and around a quarter (27 percent) of green jobs result from the expansion of renewable energy capacity due to fuel switching. The share of green jobs in total employment in the NZE scenario averages 1.6 percent from 2020 to 2050, which is 1 percent higher than under BAU (0.6 percent).

Figure 2 | **Total employment in Ethiopia under BAU and NZE scenarios, 2020–50**



Note: BAU = business-as-usual.

Source: Authors, based on Ethiopia GEM.

Poverty and income inequality

Pursuing an NZE pathway will impact key development goals in Ethiopia, including poverty reduction and income inequality. The New Climate Economy Ethiopia project commissioned a separate analysis of the distributional impacts of the NZE scenario compared to BAU outcomes. This analysis used the GIDD model for macro-micro simulations, originally developed by the World Bank (Bussolo et al. 2012).[12] The GIDD analysis uses microdata from the Ethiopian Household Consumption and Expenditure Survey, collected in 2015 and 2016 from an estimated 30,229 households consisting of 125,098 individuals.

Both the BAU and NZE scenarios show strong economic growth in the next decades, which helps reduce extreme poverty. Roughly 30 percent of Ethiopia's population today were living in extreme poverty in 2010, and the share is estimated to have dropped to 16.7 percent by 2020. The GIDD estimates that extreme poverty in real terms will be eradicated across all scenarios. In the NZE scenario, however, higher growth contributes to eradicating extreme poverty six years sooner than in the baseline BAU scenario: in 2041 versus 2047 (Figure 3). Overall poverty will also decline in both scenarios by 2050. Per capita consumption across all income groups will increase due to economic growth. In both the BAU and NZE 2050 scenarios, inequality increases very slightly, as labor does not transition from unskilled to skilled.[13]

In this analysis, the GIDD model holds constant demographic and education structure across both scenarios and there is no assessment of changes in consumer prices. Thus, the distributional effects results are driven solely by the differences in labor market dynamics and economic activities in each of the scenarios. Results are also driven by relative differences in wages of skilled and unskilled workers. The model does not allow movement of workers from unskilled to skilled, which could be refined in future analysis.[14]

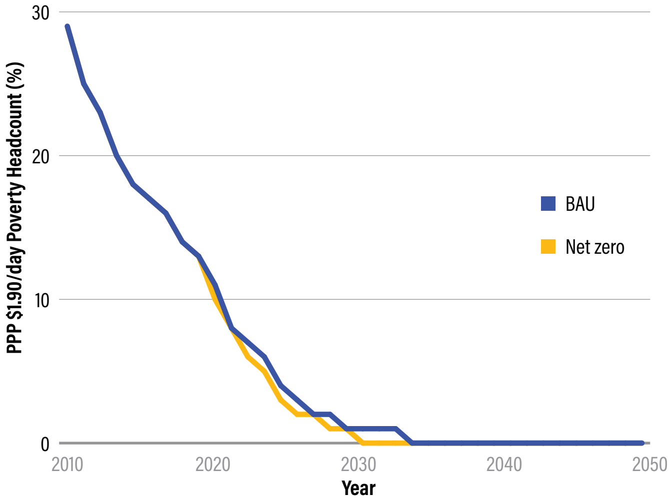
Nature-based and air quality co-benefits

The GEM modeling presented here integrates spatially explicit analysis, which is particularly relevant to the assessment of policies targeting NBS. (See Appendix C for detailed results, including maps for each category of NBS co-benefit.) As noted, this spatially explicit part of the analysis relies on the InVEST suite of models developed by the Natural Capital Project (2019); The InVEST models take land-use/land cover maps as input and quantify a wide range of ecosystem services. Based on the causal loop diagram for land use (see Appendix A), we identified habitat quality, sediment retention, and water retention as well as carbon storage as relevant regulating ecosystem services to be quantified, using the InVEST spatial models.

LAND RESTORATION: CO-BENEFITS FOR SMALLHOLDER INCOMES

In the NZE scenario, additional restoration of forest land is assumed to contribute to the rehabilitation of degraded forest and agriculture areas. This contributes to reducing carbon dioxide (CO_2) emissions through additional biomass growth and carbon storage (Cutler and Guzzetti 2022).[15] Also, if the restoration is combined with the establishment of agroforestry systems, the land restored generates additional economic benefits on top of the carbon sequestration provided by biomass growth (see Appendix A for more modeling detail, specifically on the causal loop diagram used for this analysis).

Figure 3 | **Extreme poverty headcount under BAU and NZE scenarios, 2020–50**

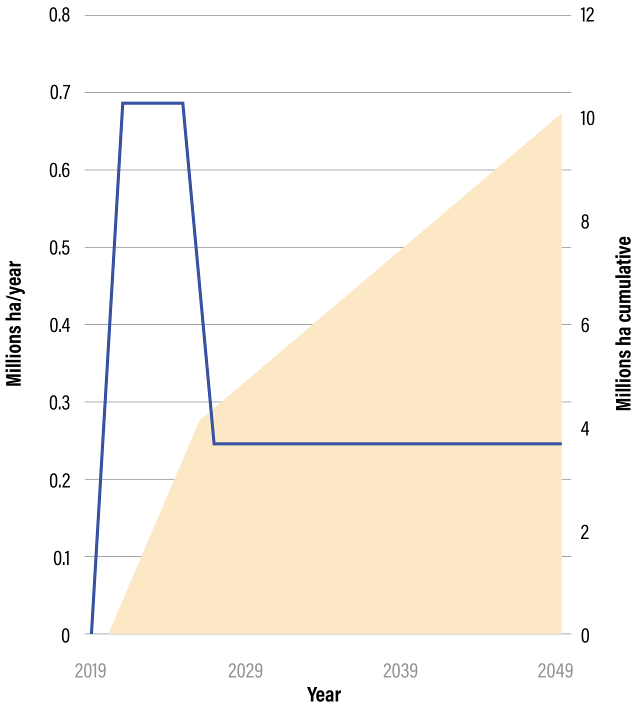


Notes: PPP = purchasing power parity. BAU = business-as-usual. NZE = net zero emissions.

Source: Medelin, based on GIDD analysis (see endnote 12).

As seen in Figure 4, from 2020 to 2050, a total of 10 million hectares are assumed for restoration, half of which is implemented from 2020 to 2030 and the rest from 2030 to 2050. A range of co-benefits is assessed for this large-scale land restoration effort. In addition to ecosystem services (e.g., see "Habitat quality"), these include local financial benefits—that is, income generated from the production and sale of grass grown on restored land; labor income from maintaining and operating the land; and the value of additional carbon sequestration, if sold, in carbon markets (Cutler and Guzzetti 2022). However, we also consider the forgone agriculture value from crop production if these 10 million hectares were used for crop production. Forgone cropping revenues present the opportunity cost if we assume that this area is no longer available for conventional agriculture purposes but rather goes into grassland production, which is an activity that has relatively low value. In addition to benefits and opportunity cost, we also assess the investment costs of this intervention (these are summarized in "Economy-wide benefit-cost analysis").

Figure 4 | **Annual and cumulative restoration of hectares in Ethiopia, 2019–49**



Source: Authors, based on Ethiopia GEM.

By 2050, the tangible income generated totals $582.8 million per year (labor) and $28.5 million per year (grass sales); the value of avoided CO_2 emissions is an intangible benefit, or not realized as a monetary benefit, unless carbon markets for this emerge. If these avoided CO_2 emissions are accounted for, these show an increase to $1.71 billion per year by 2050 (Table 2). At the same time, the forgone crop production revenues increase from around $100,000 per year in 2020 to $9.2 million per year in 2050. These estimates also take into account lost revenues due to climate change impacts. Cumulatively, the added benefits from land restoration generated from 2020 to 2050 total $42.97 billion, while cumulative forgone revenues from crop production by 2050 total $170 million. This indicates that the cumulative net co-benefits of restoration, from 2020 to 2050, total $42.8 billion.

For more conservative estimates, we can exclude the value of CO_2 emissions avoided from these benefits, while also deducting the value of forgone revenues from crop production; this shows that cumulative net benefits of land restoration are estimated at $11.3 billion for the period 2020 to 2050, and this drops to $11.1 after forgone crop revenues are deducted (Table 2).[16]

HABITAT QUALITY

Habitat quality (HQ) is important to livelihoods and well-being in Ethiopia because it is the foundation for a range of ecosystem services. HQ is represented through changes in—or shifting away from—land use that typically has a negative influence on ecosystem services; a range of land classes are identified (e.g., agriculture, urban land) that would otherwise provide habitat benefits (e.g., as forest or grassland). This analysis maps and quantifies habitat quality using an indexed approach.[17] It then steps through the range of other co-benefits (or potential losses) in ecosystem services that influence HQ. Specifically, these include annual freshwater yield; soil nutrient retention and sediment export; and flood, drought, and dust storm risk management (see next subsection).

In the BAU scenario, the HQ index is projected to decline by 7.4 percent from 2015 to 2050 due to land-use changes, notably expansion of agriculture and decline of forest land (Table 3 and Figure C2 in Appendix C). In the 2050 NZE scenario, however, there is an increase in HQ by 14.2 percent compared to 2015 in the same period. This increase in HQ in the NZE scenario is driven by an increase in forest cover, restoration of degraded forest and grassland, and the retirement of agriculture land.

Table 2 | **Co-benefits of land restoration 2020–50, annual and cumulative (million USD)**

CO-BENEFITS OF LAND RESTORATION	2020 MN USD/YR	2030 MN USD/YR	2040 MN USD/YR	2050 MN USD/YR	CUMULATIVE 2020 TO 2050 MN USD
Benefits					
Grass income	0.3	14.3	21.4	28.5	527.3
Labor income	5.2	291.6	437.2	582.8	10,774.2
Value of avoided emissions (CO_2 storage)	15.3	857.2	1,285.1	1,713.0	31,671.2
Gross benefits total	20.80	1,163.10	1,743.70	2,324.30	42,972.7
Gross benefits (conservative—without value of avoided emissions					11,301.5
Trade-offs					
Forgone crop revenues	0.1	4.6	6.9	9.2	170.2
Net benefits (with value of avoided emissions)	**20.70**	**1,158.50**	**1,736.80**	**2,315.10**	**42,802.5**
Net benefits (most conservative estimate—without value of avoided emissions and minus value of avoided revenues					**11,131.3**

Notes: Here the (intangible) value of avoided emissions is calculated on the basis of (the lowest cost of) all other available options to reduce emissions (e.g., energy efficiency). USD = U.S. dollars. mn = million. yr = year. CO_2 = carbon dioxide.

Source: Authors, based on Ethiopia GEM and building on results and data inputs from Cutler and Guzzetti (2022).

Table 3 | **Habitat quality statistics—2050 change in HQ index compared to 2015 under BAU and NZE scenarios**

	MEAN (FROM 0 TO 1)	CHANGE FROM CURRENT (%)
Current, 2015	0.449	
BAU, 2050	0.416	–7.39
Net zero, 2050	0.513	14.19

Notes: "Current" refers to the historical base year that serves as benchmark for the latest year data. HQ = habitat quality. BAU = business-as-usual. NZE = net zero emission.

Source: Authors, based on Ethiopia GEM.

FLOOD RISK MANAGEMENT AND OTHER ECOSYSTEM SERVICES

Flood risk and drought risk management are two essential ecosystem services that are associated with levels of sediment and nutrient export, as well as runoff retention on the land. These ecosystem services also contribute to adaptation and resilience derived from the expansion of forest and grassland cover in Ethiopia.

This analysis estimates a range of physical benefits (i.e., changes in sediment and nutrient export, and runoff retention volumes) under each scenario to assess ecosystem benefits (see Appendix C). The results for runoff retention illustrate flood risk mitigation potential benefits: scenario results show that in the NZE scenario, the amount of water retained on the land increases slightly (+0.9 percent) by 2050 compared to 2015 (see Appendix C, Figure C7 and Table C7). By comparison, retention volumes decline slightly (–0.8 percent) in the BAU scenario relative to the 2015 landscape. These changes relate to changes in future land covers: in the BAU scenario, as forest cover is displaced by agriculture, the flood risk mitigation potential (runoff retention) is lower compared to the NZE scenario.

Policies that promote afforestation, forest and land conservation, and regeneration will contribute to the co-benefits of flood risk and dust storm risk mitigation because trees typically retain larger volumes of water in the soil. Protecting forests and other vegetated natural ecosystems, such as grasslands and wetlands, through reforestation and afforestation and through sustainable pasture and grassland management systems can also reduce soil erosion and the risk of climate-related extremes such as drought.

AIR POLLUTANT REDUCTION AND HUMAN HEALTH CO-BENEFITS

Decarbonization of the economy in the NZE scenario benefits air quality by significantly reducing polluting emissions—including methane, sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter 2.5 microns or less in diameter ($PM_{2.5}$) by 51 percent relative to the BAU scenario by 2030 and by nearly 100 percent by 2050, depending on the pollutant (see Appendix C, Figure C1, and Table C1). Some of these air emissions, like $PM_{2.5}$, are known to have direct human health impacts, and others, like SO_2 and NO_x, have a negative impact on ecosystem health and agricultural productivity, while also impacting human well-being (Sharma and Kumar 2020). $PM_{2.5}$ pollution has long been known to be a factor contributing to respiratory and cardiovascular diseases (Osipov et al. 2022). Recent studies show that higher COVID-19 hospitalization and mortality rates were observed in areas with high $PM_{2.5}$ pollution levels (Harvard T.H. Chan School of Public Health 2020; Mendy et al. 2021; Shao et al. 2022).

The health and environment scorecard prepared by the World Health Organization (WHO 2022a) for Ethiopia in 2022 shows that 41 percent of deaths from stroke and ischemic heart diseases are caused by air pollution, and an additional burden of disease exists among the population with respiratory diseases. Ethiopia's levels of $PM_{2.5}$ pollution are six times higher than the current WHO air quality guideline values. Air pollution co-benefits from GHG mitigation thus deliver direct near- and long-term benefits for Ethiopian people and their economy.

Under the 2050 NZE scenario, the concentration of air pollutants from fossil fuel combustion and from woodstove cooking drops to zero or near zero. This is expected to drive a linear drop in respiratory illness and related deaths in Ethiopia in the same period.

A steady decline in air pollution is thus projected from 2020 to 2050 in the NZE scenario (see Appendix C for details). This is largely due to energy sector decarbonization policies that drive fuel switching from petroleum and biomass use to electricity, and a shift to 100 percent renewable energy generation. The decline in pollutants, particularly $PM_{2.5}$ from 2020 to 2030, is driven by the electrification of households (e.g., clean stoves); the decline after 2030 is attributable to fuel switching across all sectors. This, alongside increased energy efficiency and a transition to EVs (15 percent market share by 2030, 75 percent by 2050), enables a continued decline in air emissions in the NZE scenario. By comparison, in the BAU scenario, annual air emissions continue to grow until total energy demand peaks in 2040 (largely supplied by fossil fuel and biomass), after which air emissions slightly decline. Although total energy demand in the NZE scenario remains roughly constant, electrification across all sectors enables further GHG and air emission reductions. By 2030, 54 percent of baseline petroleum and 51 percent of baseline biomass demand will be electrified in the NZE scenario, which is expected to lead to significant health benefits due to lower levels of air pollution.

Cost of interventions

While Ethiopia's emissions are extremely low, significant investment will still be required to achieve mitigation, adaptation, and development ambitions in Ethiopia in the coming 30 years. Although the investment required to reach net zero and improved climate adaptation may be small from a global perspective, it represents a significant portion of Ethiopia's GDP. The total estimated cost for the NZE scenario, relative to the BAU scenario, averages 8.0 percent of total investment or 4.7 percent of total real (inflation adjusted) GDP from 2020 to 2050 (Table 4). This is based on a comparison of total climate mitigation and adaptation investment to total investment flows and the total real GDP in the NZE scenario compared to the BAU scenario over the period. Mobilizing such investment will require a concerted effort on the part of national policymakers, international partners, and the private sector. And although these are costly investments, the benefits from these investments are estimated here to be large, multidimensional, and central to achieving the development targets set out by the Ethiopian government. This is demonstrated in the benefit-cost analysis presented in "Economy-wide benefit cost analysis."

Economy-wide benefit-cost analysis

An economy-wide benefit-cost analysis (BCA) provides a way to integrate both positive and negative externalities, alongside avoided costs and direct costs arising from a particular set of policies or a policy pathway. Here the BCA is used to provide an overview of the additional costs and co-benefits resulting from implementing the national climate policies required for the 2050 NZE pathway. The integrated BCA summarizes the additional investment, avoided costs, and added benefits materializing at the system level in the NZE scenario relative to the BAU scenario. The cost figures are additional investment cost to implement NZE and are projected across different parts of the economy to 2050. Additional costs are also considered, as noted previously; for example, in forgone crop revenues due to land-use policies. These additional costs are embedded in the forecast changes in GDP and in the case of agriculture lead to a decline in its contribution to GDP (see Table 5a). On the benefits side, avoided costs derive from lower energy costs, fertilizer inputs, and internal combustion engine vehicle costs under NZE;[18] these are combined with other added benefits due to increases in real GDP (which largely includes increases in government revenues and labor income).[19]

The BCA ratio results are presented in two different ways here—in both annual and cumulative terms (see Figure 5 and Table 5c, respectively). Overall, the BCA ratio shows that the development co-benefits of decarbonization policies grow over time, with larger benefits materializing in the medium and long term (2040–50) compared to the near-term period (2020–30).

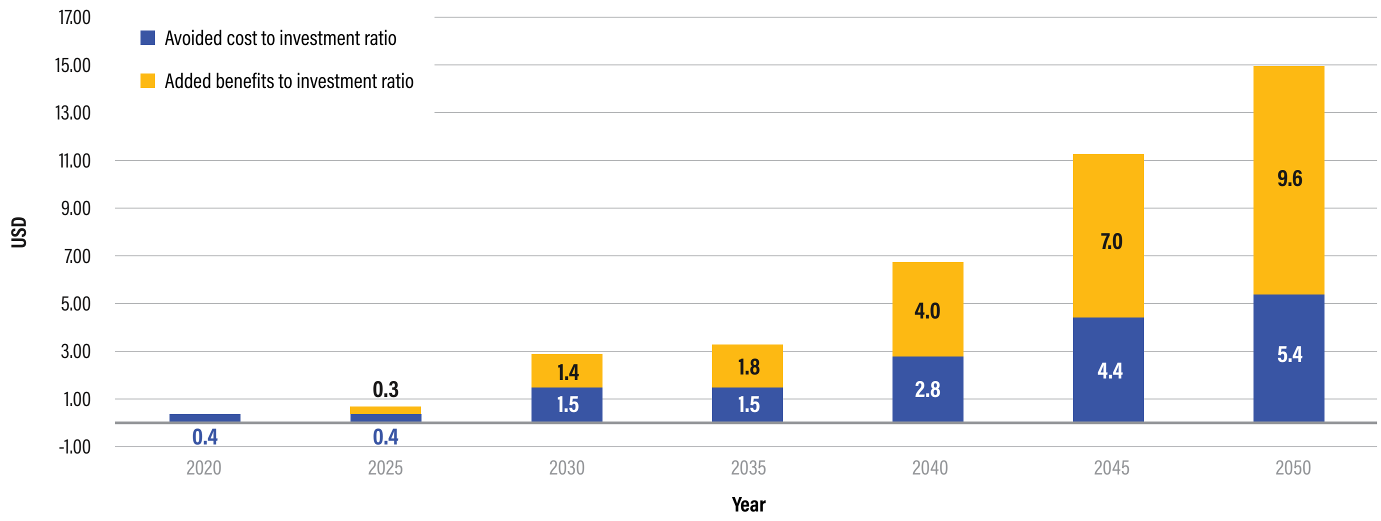
Table 4 | **Total NZE added investment as a share of total investment and as share of real GDP, by decade (annualized) and cumulative**

ADDITIONAL NZE INVESTMENT AND CHANGE IN GDP		2020–30 (%)	2030–40 (%)	2040–50 USD/YR (%)	2020–50 USD (%)
NZE investment as share of total investment	%/period	12.2	10.2	6.8	8.0
NZE investment as a share of total GDP	%/period	5.6	5.7	4.1	4.7

Notes: NZE = net zero emissions. GDP = gross domestic product. USD = U.S. dollars. yr = year.

Source: Authors, based on Ethiopia GEM.

Figure 5 | **Benefit to cost investment ratio (BCR), 2020–50**



Source: Authors, based on Ethiopia GEM.

The annual benefit-cost ratio (BCR), shown in Figure 5, indicates the breakdown of avoided costs and added benefits per dollar invested for selected years. It shows rapid improvement over the period. Here, benefits exceed the break-even point already in 2026 (not shown), with a BCR of $1.01 per dollar invested in 2026 rising to nearly $3 per dollar invested by 2030. Further, in 2040 and 2050, the annual BCR increases to nearly 7 and 15, respectively. The figures underlying this trend show total annual investment increasing significantly in the 2050 NZE scenario year on year, driven by economic growth; by 2050, annual investment costs are 61.1 percent higher than in the BAU scenario. The increase in investment costs due to NZE policies are, however, increasingly outweighed over time by a rise in corollary benefits (co-benefits). The ratio of the two aggregate sums—co-benefits and direct investment costs—yields the annual BCR, which is shown in Figure 5. This shows co-benefit externalities separately from avoided costs (and when combined, these comprise the full set of co-benefits in this analysis).

Table 5 shows a full set of results for the BCA estimates in cumulative terms for 2020 to 2050, with investment costs in net present value (NPV) discounted at a rate of 15 percent. The choice of discount rate is based on the average inflation rate from 2005 to 2021, according to the World Bank, and 21.8 percent inflation indicated for 2021,[20] with an expectation for lower inflation in the decade to come. The cumulative NPV of additional investment is $66.98 billion compared to BAU; this is required in 2050 to implement planned NZE climate change policies and measures to achieve overarching and sector climate targets and goals (Table 5a). Overall, the cumulative results suggest a BCR of 1.04 per dollar invested for 2030, indicating that by 2030, each dollar invested in mitigation and adaptation generates $1.04 in economy-wide benefits. Results show a higher BCR of 2.17 for 2040 and 2.99 for 2050 (Table 5c).

Most of the additional investment is needed in the energy sector, with a total of $42.45 billion required by 2050 (Table 5a). Of this additional energy investment, 73 percent is for power generation, 25 percent for transport electrification, and the remaining 2 percent for energy efficiency. Additional investment requirements also exist in the agriculture sector ($12.92 billion), in land-use and forestry sectors ($6.47 billion) and in waste management ($5.82 billion). These investment estimates track the policy objectives set out by the government as outlined in its updated NDC 2030 targets.

Cumulative avoided costs resulting from implementation of climate policies total $129.32 billion relative to the BAU scenario from 2020 to 2050 (Table 5b). These economy-wide avoided costs outweigh the costs of implementation of NZE policies in this period. Of the total, cumulative avoided energy expenditure is $80.08 billion (or 62 percent of the total).

The implementation of NZE policies and related investments is also estimated to generate a cumulative total added economic (co-)benefits of $111.06 billion from 2020 to 2050 (Table 5b). To avoid double counting with government revenues and labor income, additional total real GDP is the key part of these benefits. While total real GDP is considered as the main benefit in the BCA, many of the impacts realized by NZE interventions culminate into higher GDP. For instance, investments in electrification and renewable energy lead to higher electricity demand (which increases employment and hence stimulates economic growth) and reduce the cost of production and hence the market price of electricity (which increases capital productivity). As a second example, investments in sustainable agriculture management practices increase climate resilience, land productivity, and crop yield and thereby increase sectoral value added as a result of investments in climate adaptation. The results indicate a cumulative net reduction of $8.71 billion in agriculture real GDP in the NZE scenario compared to BAU, which is attributable to the productivity-induced reduction in agriculture land and slightly lower agricultural production. This change reflects structural change in Ethiopia's economy, a change that is underway also in the BAU scenario, where there is a shift away from agriculture toward industry and service industries. Thus, by comparison, the cumulative additional real GDP generated in the industry and service sectors totals $60.33 billion and $59.45 billion, respectively, for the NZE compared to BAU from 2020 to 2050, outweighing the losses in agriculture (Table 5b).[21] Additional government revenues are also estimated to rise in the NZE scenario, notably from $2.07 billion in 2030 to $13.46 billion by 2050, which is equivalent to 5.5 percent of the total investment required by 2030 rising to 20.1 percent by 2050.

The increased economic performance of the economy also contributes to higher disposable income, which in turn increases total consumption and investment above BAU levels (not shown in Table 5; please refer to the endnote for more information).[22] Total national additional labor income increases overtime in the NZE scenario from 16,024 mn USD in 2030, to 39,899 mn USD in 2040, and 61,549 mn USD in 2050. This indicates that spending for basic needs will increase, as well as spending for other social activities and needs, and poverty will decline (see "Co-benefits from low-carbon, climate resilience interventions").

Table 5a | **Economy-wide summary: investment costs in USD M**

TOTAL NZE ADDITIONAL INVESTMENT	2030	2040	2050
Investment in power generation	17,641	25,781	27,270
O&M cost power generation	1,236	3,077	3,953
Total power generation	**18,876**	**28,858**	**31,223**
Investment in chargers	266	358	372
Investment in EVs	6,461	9,272	9,687
O&M cost EVs	120	244	298
Investment in electronic buses	96	136	142
O&M cost electronic buses	10	20	25
Total cost of transport electrification	**6,953**	**10,030**	**10,525**
Energy efficiency	**498**	**690**	**744**
Cost of crop diversification	101	155	170
Cost of livestock interventions	2,049	5,159	6,971
Cost of sustainable agriculture	2,421	4,651	5,782
Total cost of agriculture interventions	**4,572**	**9,966**	**12,922**
Industrial CCS	**0**	**0**	**16**
Reforestation	**2,826**	**3,365**	**3,541**
Restoration	**1,930**	**2,678**	**2,931**
Waste management	**1,847**	**3,711**	**4,604**
Waste prevention	**688**	**1,097**	**1,214**
Total NZE cost (cumulative investment)	**37,693**	**59,705**	**66,975**

Notes: NZE = net zero emissions. O&M = operations and maintenance. EV = electric vehicle. CCS = carbon capture and storage. USD = U.S. dollars.

Source: Authors, based on Ethiopia GEM.

Table 5b | Economy-wide summary: avoided costs and added benefits in USD M

TOTAL NZE AVOIDED COSTS AND ADDED BENEFITS[a]	2030	2040	2050
Energy cost	16,294	53,283	80,079
Cost of synthetic fertilizers	153	328	408
ICE vehicle cost	5,505	8,368	8,854
Total avoided costs	**21,953**	**61,979**	**89,341**
Agriculture real GDP	-1,137	-4,705	-8,711
Industry real GDP	8,080	35,127	60,325
Services real GDP	10,152	37,072	59,445
Total added benefits (GDP only)	**17,094**	**67,494**	**111,058**
Total benefits (avoided cost & GDP only added benefits)	**39,047**	**129,474**	**200,399**
Net total added benefits[b]	1,354	69,769	133,424

Notes: [a] TOTAL NZE Avoided Costs = (e.g., Cumulative Net Present Value Avoided Costs of NZE over BAU). NZE = net zero emissions.

[b] Net total added benefits = avoided costs + GDP only added benefits – total investment costs. The table's units are U.S dollar figures in millions, and all U.S. dollar figures in this table are cumulative—for example, 2030 figures represent the cumulative total from 2020 to 2030, net present value (so discounted to 2016 U.S. dollars).

ICE = internal combustion engine. GDP = gross domestic product.

Source: Authors, based on Ethiopia GEM.

Table 5c | BCA ratios

	2030	2040	2050
Total NZE cost (cumulative investment) USD M	**37,693**	**59,705**	**66,975**
Total avoided costs USD M	**21,953**	**61,979**	**89,341**
Total added benefits USD M (GDP only)	**17,094**	**67,494**	**111,058**
Avoided cost to investment ratio	**0.58**	**1.04**	**1.33**
Added benefits to investment ratio	**0.45**	**1.13**	**1.66**
Total benefit to cost ratio	**1.04**	**2.17**	**2.99**
Government revenues USD M	2,072	8,181	13,461
Government revenues to investment	**5.5%**	**13.7%**	**20.1%**

Note: BCA = benefit-cost analysis. Government revenue = net present value additional government revenue from NZE over BAU.

Source: Authors, based on Ethiopia GEM.

DISCUSSION/CONCLUSION

This paper demonstrates how decarbonization and resilience strategies—notably centered on land use, forestry, and energy policies—are vital to generating climate and development co-benefits. However, decarbonization and resilience strategies need to be coupled with agricultural and urban policy reforms to succeed. In the medium term, implementation efforts focused on achieving ambitious 2030 NDC development goals and emission targets offer a considerable step toward Ethiopia's 2050 NZE decarbonization pathway.

The interventions needed to implement Ethiopia's NDC and 2050 NZE goal will require collaborative approaches and multilevel governance to ensure timely and well-targeted policy reforms, particularly at the sector level (Dagne et al. 2022). Identifying which specific jobs and sectors are expected to grow across the decarbonizing economy is a key implementation step for the transition, helping identify skills gaps and enabling the government to plan appropriate labor measures, such as education and training programs.

The simulation results show that ambitious climate action can lead to large co-benefits and avoided costs. For example, investments in energy efficiency, more rapid electrification in some sectors (e.g., transport), and renewable energy, especially for those without access to electricity, lead to large productivity and economic gains in the transport and energy sectors and in household energy practices and also improve health through reduced levels of air pollution.

Investments in sustainable land management activities under the 2050 NZE pathway also generate large co-benefits for development, alongside carbon sequestration benefits. These co-benefits are due to increased forest cover, restoration of degraded forest and grazing land, and incentives that advance the retirement of agricultural land in the 2050 NZE scenario compared to the BAU scenario. The co-benefits include improved ecosystem services; notably, higher habitat quality and key nature-based resilience services, such as drought and flood risk management. The detailed land restoration part of our report provides useful lessons and data to inform decisions in Ethiopia's national efforts to achieve its ambitious landscape restoration targets (10 million to 20 million hectares nationally) in response to global calls for partnership on NBS.

These economic benefits are corollary to climate change mitigation and adaptation benefits. They lead to better development outcomes through improved productivity and growth across Ethiopia's economy, as shown in higher levels of real GDP. The additional spending to implement 2050 NZE also creates jobs and avoids higher costs across the economy. Importantly, 2050 NZE policies also decrease the number of people in extreme and moderate poverty.

The significant economic and environmental co-benefits estimated in this paper suggest there is high value to mobilizing the necessary investment to make ambitious climate policies happen. The results provide a strong evidence base to guide national policy decisions and priority budget allocations, as well as to underpin more international financial support from development partners.

Although the co-benefits are clear, mitigation and adaptation policy also create some trade-offs that need to be managed to ensure a just transition that prioritizes key development goals. This will mean balancing poverty alleviation, job creation, and income equality, alongside other development goals with climate goals. Further, as with any forward-looking modeling study, the results presented here are constrained by the accuracy of assumptions and reliability of the data used. While not a "prediction" of the future, these results are indicative of what could be possible with implementation of ambitious but feasible climate policy. The success and effectiveness of these policies heavily rely on the availability of external financial resources and the country's capacity to mobilize these along with its own domestic resources. Ethiopia aims to mobilize 80 percent of the required investment finance from external sources, with the remaining 20 percent being sourced domestically. Achieving this target will be pivotal in ensuring the robust implementation and significant impact of these policies. Overall, we show that a 2050 pathway of low-carbon, climate-resilient development is worth the investment required, as it would deliver significant near-term and long-term co-benefits in Ethiopia.

Future research priorities

This assessment points to several areas that would benefit from further research, including an effort to better understand and manage how NZE policies affect Ethiopians. Specifically, future research could usefully prioritize policy-relevant topics such as the following:

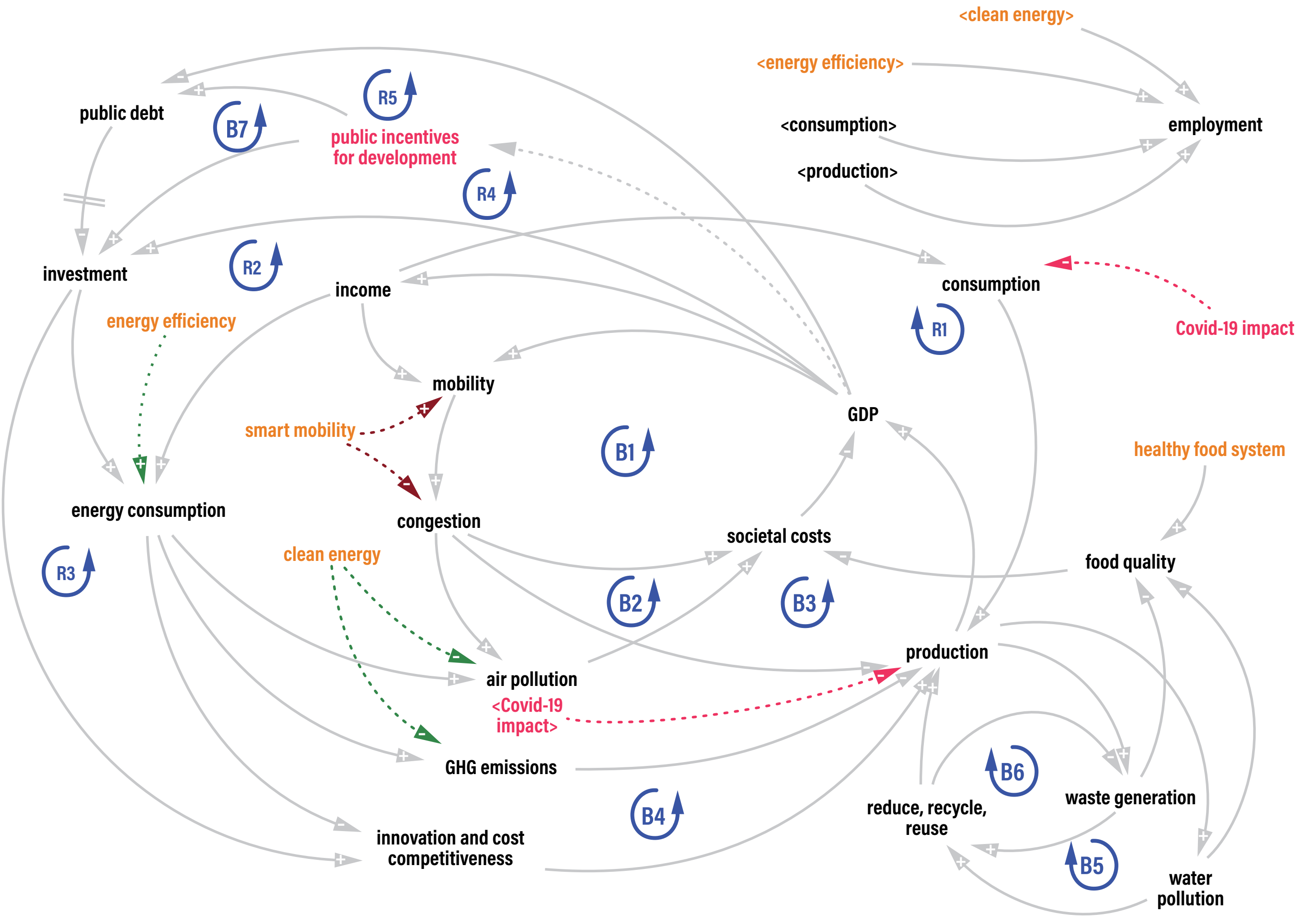
- **Distributional impacts of low-carbon policies on the labor force and the related needs for new skill sets, education, and training to address the risk of otherwise rising income inequality.** Our assessment suggests that new policies are needed to target education or vocational training for low-income and rural populations, to better transition to and benefit from a new climate economy. It will also be important to examine spatial impacts and how climate action may impact different regions in different ways, creating differences in winners and losers at a regional level with implications for policy to manage a just transition. As the gap between the richest and the poorest could widen under an NZE set of policies that could drive rising prices for household commodities, there is a need for complementary policies to reduce income inequality.
- **Possible trade-offs between food production, food security, and food and land use policy.** Given the national goal to preserve and restore forests and grasslands, there is a need to look at how, realistically, agricultural yield and animal farming production can be increased to meet the growing demand for food. Possible agricultural trade impacts should also be considered.
- **Adaptation and resilience interventions, such as through water sector policies, to better understand how these interact with development benefits as well as decarbonization goals.** Such analysis could help the government update, cost, and (re)prioritize its adaptation goals.
- **Policies to drive Ethiopia's clean energy transition, including in rural areas where access to electricity remains limited.** There is a high potential for decentralized renewables to fill the access gap, but the policies required are not yet clear.
- **Institutional reforms required to enable multilevel governance.** This includes local and international partnerships and collaboration to help implement, monitor, and improve performance of NZE policies.
- **Financial analysis on how to generate the required investment to realize the 2050 NZE pathway.** Questions include the following: How to incentivize private investments in key sectors, such as in climate smart agriculture and land management, clean energy, sustainable transport? How to strengthen local capital markets in Ethiopia to help cofinance these investments? How to generate the necessary public funding; for example, for public infrastructure such as climate-resilient roads and public transit systems? What barriers if any exist for external public finance of climate action in Ethiopia?

APPENDIX A. THE ETHIOPIA GEM MODEL AND FURTHER METHODOLOGICAL DETAILS

A simplified visual representation of the Ethiopia GEM model is presented in Figure A1 (with a focus on the energy sector and mobility services) and Figure A2 (with a focus on land use). The diagrams show how primary resources (physical, social, human, and natural capital) interact to drive future social, environmental, and economic trends. Feedback loops that are reinforcing (R) can be seen throughout the model. Reinforcing patterns of social and economic growth are enabled by the availability of natural resources, which, if not properly managed, can constrain economic growth via the balancing loops (B). Balancing loops for energy, for example, include energy spending (the more spent on energy, the less is available for other consumption and investment, curbing GDP growth) or GHG emissions (the higher the emission and air pollution, the lower labor productivity, curbing GDP growth).

Policy interventions can be explored through the model to consider sustainable consumption and production patterns and decoupling economic growth from resource use, in order to mitigate the exploitation of natural capital and generate a stronger and more resilient green growth.

Figure A1 | **Causal loop diagram representing the GEM Ethiopia model**



Source: Authors, based on Ethiopia GEM.

The GEM model establishes links between different structures that represent physical, fiscal, and other components of Ethiopia's social-environmental-economic system. Mitigation options and other interventions will impact different parts of the economy, society, environment, and GHG emissions represented in the model. For instance, when GDP increases, income and consumption increase, leading to higher GDP via production (reinforcing loop R1), and investments increase, triggering more innovation and improved cost competitiveness, which increases production and GDP (reinforcing loop R2). These two reinforcing loops (R) generate a virtuous cycle that results in continued economic growth, via production and consumption, which also leads to employment creation. On the other hand, economic growth, in addition to creating a virtuous cycle, has given rise to various balancing factors (or balancing loops) that, over time, constrain growth. In the case of mobility, for example, with economic development and income creation comes the need for mobility, resulting in more traffic and hence congestion, which forces people to spend more time in traffic than in performing other activities (B1 and B3). Further, congestion and energy consumption, stimulated by growing income and investments, lead to air pollution (B2), causing health problems and reducing labor productivity. Finally, as energy use increases through higher investment and income, the vulnerability to market dynamics and price volatility and extreme weather events impacting the supply of energy increases as well (B4), with negative impacts on production.

The system dynamics modeling for land use and agriculture also began with a causal loop diagram, to define the scope of the assessment. As noted, it is a system map that shows key pieces of the social-environmental system and how variables interact with each other. Then spatially explicit analysis, through the use of InVEST (see "Conceptual framework, methods, and data"), is used to quantify the ecosystem services that emerge from the causal loop diagram. The spatial analysis feeds into the overall integrated BCA, which includes social and environmental externalities, as well as the cash flows that are always included in any conventional economic assessment.

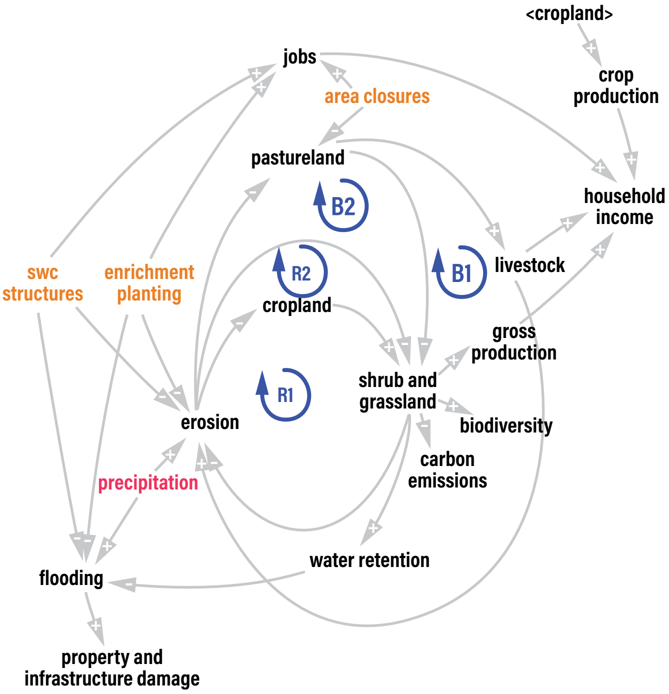
The causal loop diagram used in this study on land use is based on the one used by Cutter and Guzzetti (2022) to explain historical patterns of land degradation in Ethiopia and to reveal how NZE interventions may promote ecosystem recovery (Figure A2). Here we see that erosion has degraded land, including crops, grass, and pasture. With the loss of productivity of the cropland, which leads to a decline in household income, there is encroachment into shrublands and grasslands. As shrublands and grasslands degrade, the decrease in vegetation cover leads to more erosion, creating two reinforcing feedback loops (R1 and R2). As shrublands and grasslands are lost, carbon is emitted and biodiversity declines. There is also less water retention, which worsens flooding and damages infrastructure and property.

One driver of this land degradation is overgrazing. As the number of livestock in an area grows, erosion worsens. This lowers the quality of pastureland, which limits further livestock increases. This creates a balancing feedback loop (B1) and hurts household income.

Soil and water conservation structures and enrichment planting can mitigate erosion and flooding, promoting recovery of the ecosystem. Area closures restrict the expansion of pastureland and crops, which enables further recovery of grassland. This could have negative impacts on livestock in the short term, but it creates another balancing feedback loop (B2). Restricting the expansion of pastureland increases grassland, which mitigates erosion. Over time, this increases the area of high-quality pasture, so there is more household income from livestock production.

By restoring the land, grass is available to be harvested and sold for thatched house construction as an additional source of income. This nature-based infrastructure also creates jobs, further increasing household income.

Figure A2 | **Causal loop diagram representing the land use sector in GEM Ethiopia model**



Notes: Pink variables are climate inputs, and orange indicate possible policy interventions. Feedback loops help explain the observed patterns of declining rural livelihoods.

Source: Cutter and Guzzetti 2022.

All models, especially climate models that produce endogenous estimates over a long period (e.g., to 2050), are characterized by a high degree of uncertainty. In consequence, results reported throughout the report should be interpreted with caution, as indicative of potential realizations for core variables in absence of meaningful deviation in data and structures.

Table A1 provides a summary of the main interventions modeled in the GEM and their associated co-benefits.

Table A1 | **Summary table: Proposed thematic adaptation and mitigation interventions**

KEY SECTORS/ACTION AREAS	ACTIONS	AREA OF IMPACT AND ASSOCIATED CO-BENEFITS
Land use/land-use change (mitigation and adaptation)	▪ Sustainable agricultural land management practices ▪ Reducing preharvest losses ▪ Carbon sequestration in grassland ▪ Lowlands livelihoods resilience project ▪ Fuel switch and biomass efficiency (improved cookstoves) ▪ Reforestation ▪ Landscape restoration	▪ Ecosystem services (habitat quality, water and soil quality, water quantity) ▪ Economic productivity (GDP) ▪ Poverty reduction ▪ Employment ▪ Reduced climate impacts on production
Livestock (mitigation)	▪ Enhancing livestock productivity ▪ Agricultural mechanization ▪ Increase in the share of poultry ▪ Oilseed feeding to reduce emissions from enteric fermentation	▪ Poverty reduction ▪ Job creation ▪ Air quality ▪ Productivity
Energy (mitigation and adaptation)	▪ Renewables expansion in the power sector and off-grid uses (non-hydropower) ▪ More efficient power transmission and distribution ▪ Energy efficiency ▪ Electrification of transport ▪ Public transport expansion ▪ Industries fuel switch	▪ Air quality and health benefits through labor productivity ▪ Reduced energy cost ▪ Economic productivity (GDP) ▪ Employment (green jobs) ▪ Reduced vulnerability of power supply to climate shocks
Managed soils (mitigation and adaptation)	▪ Use of organic fertilizer and crop residues	▪ Economic growth ▪ Trade ▪ Economic productivity (GDP) ▪ Ecosystem services (air and water quality, habitat quality)
Industry (mitigation)	▪ Clinker substitution in cement	▪ Air quality and health benefits through labor productivity
Waste (mitigation)	▪ Reduction of waste per capita ▪ Waste separation and composting ▪ Wastewater management	▪ Air quality and health benefits through labor productivity ▪ Employment (green jobs)

Source: Authors, based on Ethiopia GEM.

APPENDIX B. TYPES OF CO-BENEFITS

From a global perspective, a clean energy transition is an essential part of a global NZE pathway. Such a pathway will deliver large global and local co-benefits. Replacing fossil fuel and biomass burning with clean energy reduces harmful air pollution, which improves human health by reducing mortality and morbidity rates (IPCC 2022). Cooking with biomass and other traditional fuels is one of the largest sources of deadly air pollution in developing countries; roughly one-third of the global population today cooks with biomass (WHO 2022b). Countries like Ethiopia are particularly hard hit due to heavy reliance on biomass for cooking, especially in rural areas, where there is limited access to electricity and other forms of clean energy (Fuller et al. 2022). Global economic benefits from clean energy transitions, leading to improved air quality and associated human health outcomes, are likely to be equal to or even higher than the costs of required mitigation action (IPCC 2022; Karlsson et al. 2020).

Similarly, climate mitigation through afforestation, forestry, and other land use (AFOLU) action can enhance a range of ecosystem services, bringing large co-benefits through improved food and water security and livelihoods (IPCC 2022). Co-benefits include biodiversity conservation; increased soil, nutrient, and water retention services; agricultural productivity gains; and improved land tenure benefits. AFOLU mitigation options also help limit or avoid climate change–related risks, such as increased risk of landslides, droughts, or floods, thus also delivering adaptation and resilience to extreme events alongside mitigation to climate change (IPCC 2022).

Also at the global scale, overall economic benefits from NZE 2050 pathways are expected to include job creation and lead to trillions of dollars in energy cost savings through the clean energy transition alone (Way et al. 2022). Compared to fossil fuels, investing in renewable energy and energy efficiency creates more jobs on a dollar-for-dollar basis (Jaeger et al. 2021). In Africa, investment in decentralized renewables is creating formal and informal employment for women and youth, among others (Shirley et al. 2019). Managing the transition to ensure just and equitable outcomes for everyone will be essential (Riahi et al. 2022).

The range of possible co-benefits is very wide, as illustrated in Table B1. Policymakers can decide what co-benefits to focus on, depending on the most pressing challenges in terms of developing the economy, alleviating poverty, reducing inequality, improving the health and well-being of citizens, preserving and restoring natural ecosystems to benefit from ecosystem services, or supporting specific sectors in the economy.

More elaborate approaches to classification of co-benefits identify the following classes: economic, employment, poverty, energy security, electricity access, climate resilience, political stability and democracy, noise and congestion, air quality, freshwater quality and volume, health, food and water security, and land and marine resources (Cohen et al. 2021).

Table B1 | **Comprehensive classification of climate-development co-benefits**

CLIMATE	ENVIRONMENTAL	ECONOMY AND SOCIETY
Reduced emissions of GHGs (mitigation) and adaptation to climate change *(African Development Bank et al. 2021)*	**Ecosystem and habitat, biodiversity, air and water pollution reduction**	**Economic, health impacts, equity and distributional impacts, SDG indicators**
Reduced GHG emissions from energy generation (through transition to low-carbon sources), distribution/transmission (through reduction of loss) and end use (through improved efficiency)	**Increased accumulation of aboveground and belowground woodland, savanna, and grassland biomass, allowing ecosystems to develop**	Co-benefits: improved agriculture yield
Reduced emissions of GHGs, which are also persistent organic pollutants	Conservation/preservation of biodiversity (species richness, species abundance, rarity-weighted richness (Soto-Navarro et al. 2020)	Co-benefits in the form of avoided losses: increased resilience and lower losses caused by droughts in agriculture Co-benefits: improved efficiency from climate-smart agriculture
Improved nature-based carbon capture and storage aboveground and belowground trough afforestation, reforestation, and conservation efforts, preventing land-use change in the form of deforestation	Natural habitat quality preserved and restored	Co-benefits: **green jobs created and additional revenue from green jobs**
Using nature-based and human-made solutions to prevent saltwater intrusion in coastal zones	**NBS prevent soil erosion, sediment and nutrient export from ecosystems**	Co-benefits in the form of avoided losses: increased resilience and lower losses caused by floods (infrastructure and urban setting)

Table B1 | **Comprehensive classification of climate-development co-benefits, continued**

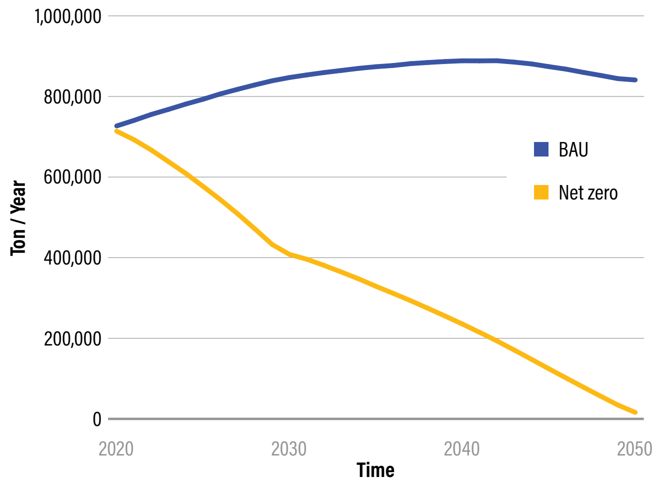
CLIMATE	ENVIRONMENTAL	ECONOMY AND SOCIETY
Reduced emissions of GHGs (mitigation) and adaptation to climate change *(African Development Bank et al. 2021)*	**Ecosystem and habitat, biodiversity, air and water pollution reduction**	**Economic, health impacts, equity and distributional impacts, SDG indicators**
Reduced GHG emissions from mining and metal production	Reduced eutrophication of freshwater reservoirs, preservation of biodiversity in aquatic ecosystems	Co-benefits: *improved labor productivity* Co-benefits in the form of avoided losses: *reduced number of hospitalizations, reduced cost of people becoming sick*
Reduced GHG emissions from industrial and manufacturing processes	NBS for flood control and reducing water yield, improved water retention by ecosystems	Co-benefits in the form of avoided losses: reduced incidence in population of chronic pollution-related or climate-related health conditions
Reduced GHG emissions from agriculture, forestry, aquaculture, and fisheries	NBS for reducing urban heat-island effect with urban tree canopy, improving air quality, reducing noise pollution, and reducing pollution in urban stormwater runoff	Co-benefits in the form of avoided losses: reduced hospitalizations and mortality in vulnerable populations: infants and children, elderly, people with chronic conditions, and pregnant women
Reduced GHG emissions from land-based and water-based transport	Wetlands restoration, protection and restoration of mangroves	Co-benefits: **reduction of poverty and improved food security**
Reduced GHG emissions from municipal solid waste, agricultural value chain waste, medical and industrial wastewater, and residential wastewater	Support and protection of healthy marine ecosystems, coral reef protection and restoration for both mitigation and adaptation goals	Co-benefits: **reduction of income inequality**
Reduced GHG emissions in communications and digital technologies and processes	Reduced water pollution	Co-benefits: improved access to potable water and water infrastructure
Contribution to climate change mitigation and adaptation through research, innovation, and development	**Reduced volume of waste through methane capture and electricity co-generation, and manufacturing of fertilizers from waste**	Co-benefits: **improved access to electricity supply, including local small-scale generation from RE sources**
	Additional ecosystem services from restored habitats	Co-benefits: **increased income, health and wellness benefits from ecosystem services**
	Reduced air pollution	**Improved visibility with better air quality**
	Preserved critical habitat for migratory, protected/endangered, and endemic species	Co-benefits: improved and more equal access to education
	Improved soil quality with higher SOM content, improved permeability (reducing runoff, flood control ecosystem service) and aeration, reducing surface crusting, reducing salinization	Co-benefits: improved inclusion of women
	Enhanced soil biodiversity, including microbial (Cornell University Cooperative Extension 2008)	Co-benefits: **protect, restore, and magnify natural capita**l
	Nature-based solutions for pest control, such as control of desert locust infestation in Ethiopia	Co-benefits: **reduced traffic congestion by supporting mass-transit systems**

Notes: The font treatments in the table indicate those co-benefits addressed (**bold**) or partially addressed (*italics*) in Ethiopia GEM modeling simulations. GHG = greenhouse gas. NBS = nature-based solutions. SOM = soil organic matter. SDG = Sustainable Development Goal. RE = renewable energy.

Sources: Authors, based on the following sources: African Development Bank et al. (2021); Cornell University Cooperative Extension (2008); Garrido et al. (2019); Mayrhofer and Gupta (2016).

APPENDIX C. DETAILED MODELING RESULTS FOR AIR POLLUTION AND NATURE-BASED SYSTEM CO-BENEFITS

Figure C1 | **Air pollution volume in $PM_{2.5}$ per year across alternative scenarios, 2020–50**



Notes: PM = particulate matter. BAU = business-as-usual.

Source: Authors, based on Ethiopia GEM.

Table C1 | **NZE scenario reduction in air pollutants compared to BAU**

AIR POLLUTANTS	UNIT	2020 (%)	2030 (%)	2040 (%)	2050 (%)
CH_4	% vs. BAU	–1.8	–51.6	–72.9	–97.1
CO	% vs. BAU	–1.8	–51.3	–72.6	–97.1
CO_2	% vs. BAU	–2.4	–54.4	–75.5	–98.6
N_2O	% vs. BAU	–1.7	–51.5	–72.7	–95.4
NH_3	% vs. BAU	–1.7	–51.3	–72.9	–96.4
NMVOC	% vs. BAU	–1.8	–51.6	–73.2	–97.5
NO_x	% vs. BAU	–1.8	–51.9	–73.7	–98.4
Organic carbon	% vs. BAU	–2.4	–57.9	–77.0	–93.9
PM_{10}	% vs. BAU	–1.8	–51.8	–73.6	–97.9
$PM_{2.5}$	% vs. BAU	–1.8	–51.9	–73.5	–98.3
SO_2	% vs. BAU	–1.8	–51.8	–73.5	–98.1

Notes: NZE = net zero emissions. BAU = business-as-usual. CH_4 = methane. CO = carbon monoxide. CO_2 = carbon dioxide. N_2O = nitrous oxide. NH_3 = ammonia. NMVOC = non-methane volatile organic compound. NO_x = nitrogen oxides. PM = particulate matter. SO_2 = sulfur dioxide.

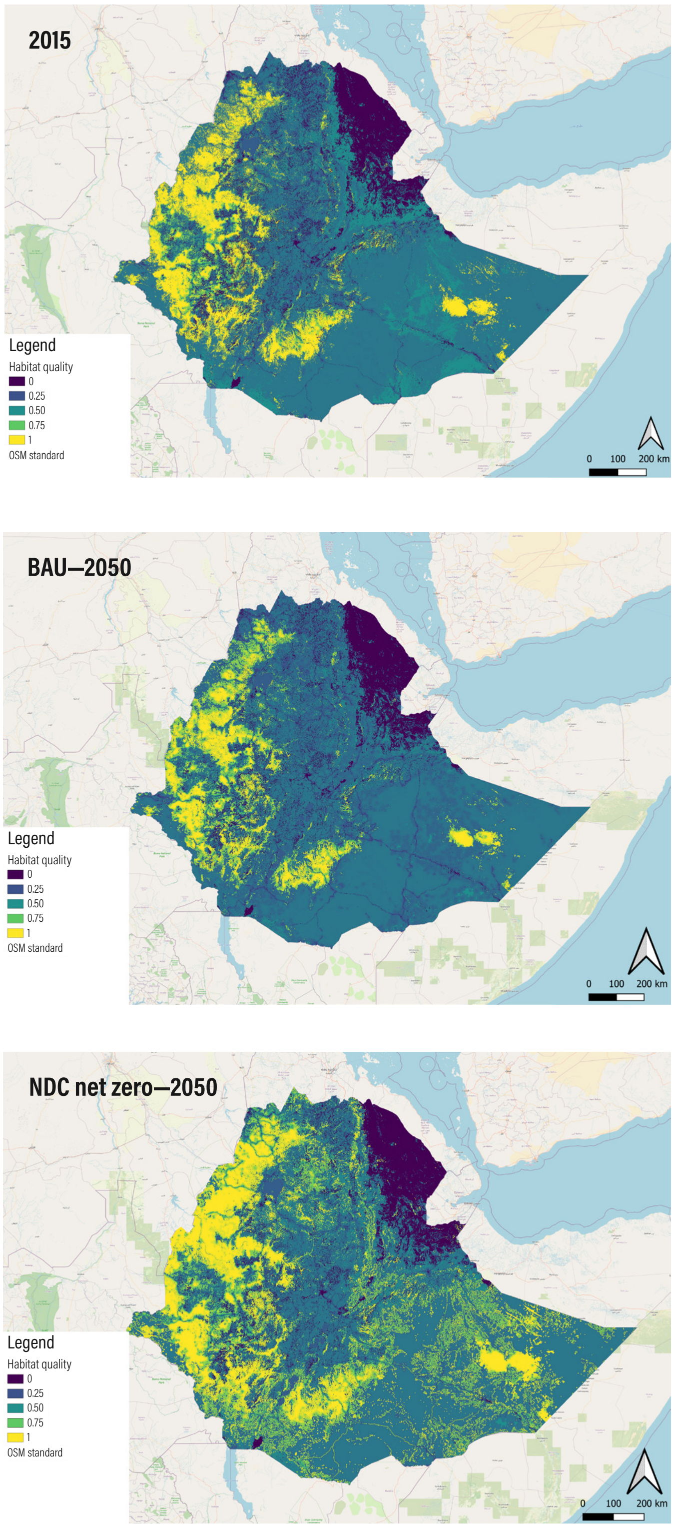
Source: Authors, based on Ethiopia GEM.

Table C2 | **Habitat quality statistics—2050 change in HQ index compared to 2015 across alternative scenarios**

	MEAN (FROM 0 TO 1)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	0.449	/
BAU, 2050	0.416	–7.39
Net zero, 2050	0.513	14.19

Notes: HQ = habitat quality. BAU = business-as-usual.

Figure C2 | **Habitat quality outputs**



Annual water yield

Water yield is expected to increase under the 2050 BAU but to decrease with 2050 NZE, compared to 2015, due to higher water retention in forested and restored lands. Results are presented in Figure C3 for the 2015 and the 2050 BAU and NZE landscapes, with numerical results in Table C3. Results show that the total volume of water yield will increase by more than 5 percent in the 2050 BAU landscape compared to the 2015 landscape; this increase is caused by the baseline decrease in forest land yielding more water as runoff and retaining less, as projected by GEM. If trees are cleared to make space for agriculture or urban land, as in the BAU scenario, then total runoff (water yield) also increases. In the NZE scenario, the total volume of water yield will decrease by almost 9 percent by 2050 compared to the 2015 landscape as there is an increase in forest and grassland cover, which retains water.

While the decline in water yield that occurs under NZE indicates that more water is retained in the landscape, we have considered only annual rather than monthly water flows due to modeling limitations. This means that, while total water yield is lower compared to BAU, land cover changes in the NZE scenario may still allow local reservoirs to recharge by improving percolation and by delaying runoff, which could in fact increase water availability during seasonally dry months relative to the baseline. Another upside of greater water retention (lower water yield) under the 2050 NZE scenario is resilience benefits that come from improvements in water quality or related flood risk management services.

In this simple modeling exercise, it was not possible to consider a number of important influences on the hydrology of the region (such as topography, soil type, vegetation type and climate) which could influence water yield and water quality among other outcomes. Further, more detailed hydrological modeling and analysis would be required to better understand the specific hydrological implications of the sustainable land use and forestry policies assessed here.

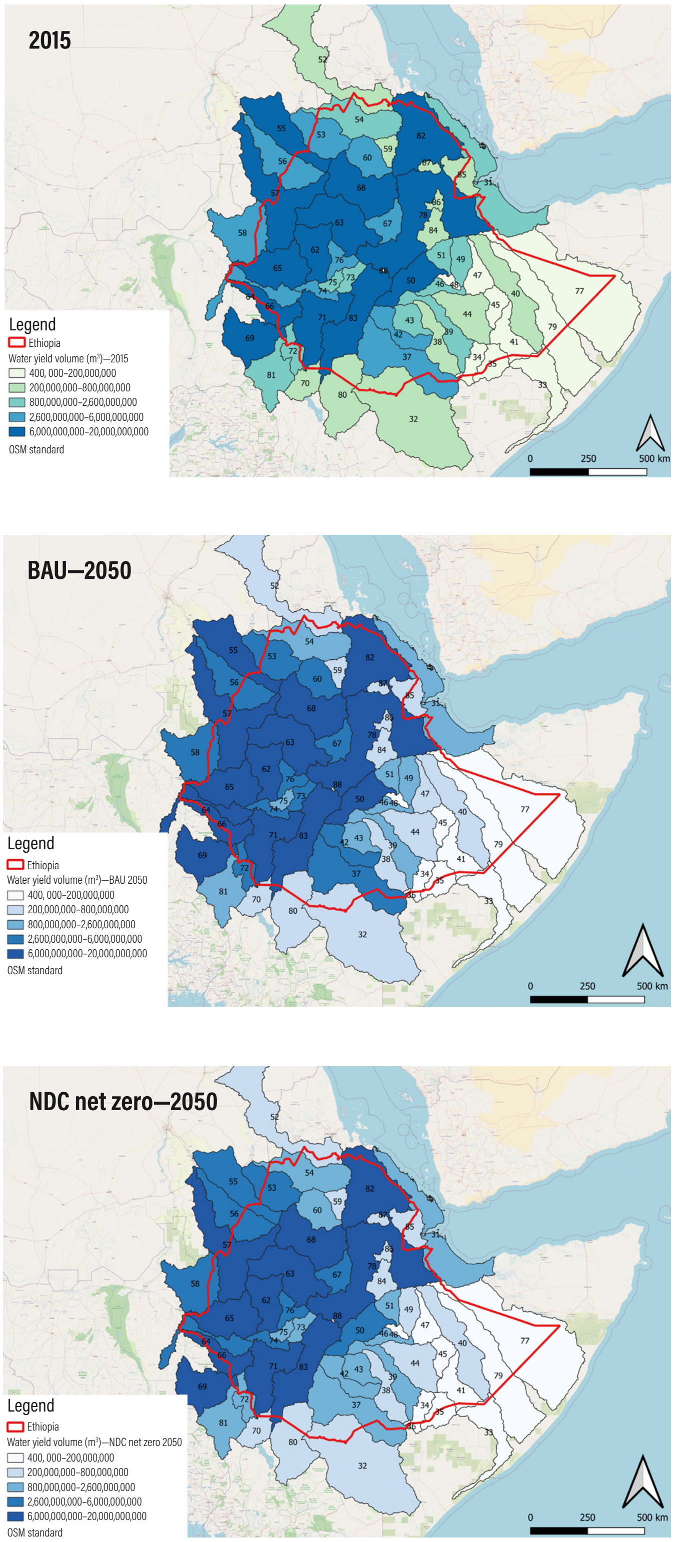
Table C3 | **Water yield results across alternative scenarios as compared to current scenario**

	WATER YIELD VOL. (M³)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	220,293,728,062	/
BAU, 2050	231,809,418,363	5.23
Net zero, 2050	200,966,917,688	–8.77

Notes: m³ = cubic meters. BAU = business-as-usual.

Source: Authors, based on Ethiopia GEM.

Figure C3 | **Water yield outputs**



Source: Authors, based on Ethiopia GEM.

Sediment and nutrient export and other ecosystem services

Reducing the export of sediment and of nutrients in any landscape helps maintain fertile topsoil. Sediment and nutrient retention also benefit potential agricultural activities while reducing the risk of landslides. Sediment and nutrient export are measured in GEM by the sediment delivery ratio and the nutrient delivery ratio; both are related to forest cover, land use, and annual water yield. As forest cover increases, annual water yield declines, and sediment and nutrient export also decline. This is also known as avoided soil erosion.

Since forest cover declines under the 2050 BAU scenario compared to 2015, sediment export increases under BAU; on the other hand, as forest and grassland cover increases in the 2050 NZE scenario, the opposite occurs, with a decrease in sediment and nutrient export, and thus reduced soil erosion. Total sediment export in the BAU scenario increases by more than 70 percent from 2015 to 2050; this compares to the 2050 NZE scenario, in which sediment export is expected to decrease by almost 32 percent compared to 2015 (Table C4). The 2050 NZE scenario also performs favorably compared to BAU to limit nutrient export (as measured by changes in nitrogen and phosphorus delivery ratio) (see Figures C5 and C6, Tables C5 and C6). However, in both 2050 scenarios, the increase in fallow land does increase nutrient export, though at a slower pace in the NZE scenario compared to BAU. These co-benefits accumulate to 2050 in the NZE scenario and are largely driven by expanded forest and grassland areas in combination with the retirement of agriculture land, compared to the BAU scenario.

Other related ecosystem services relate to runoff retention, which helps manage both flood and dust storm risk. Figure C7 and Table C7 summarize the total runoff retention volumes during a rainfall event of 125 millimeters in 2015, and in 2050 under the BAU and net zero scenarios.

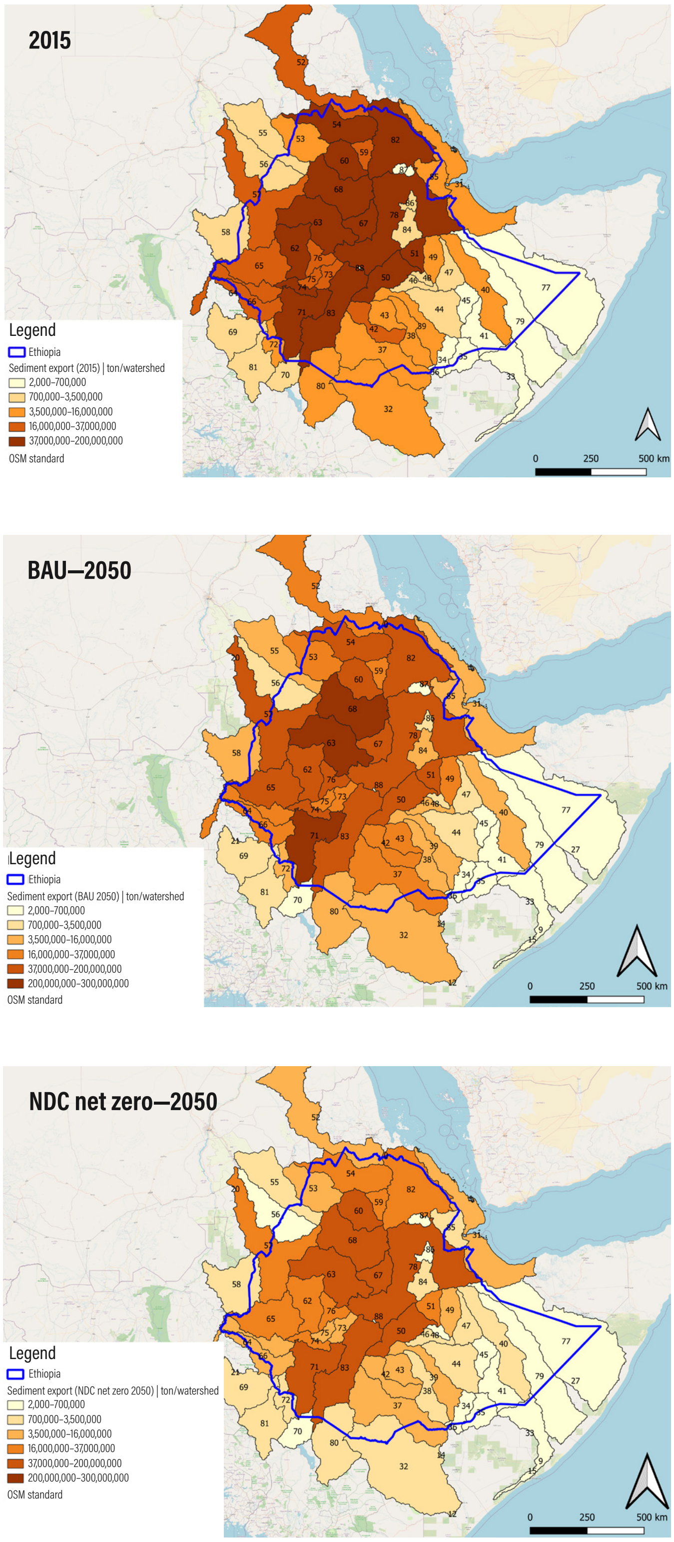
Table C4 | **Annual sediment delivery ratio statistics across alternative scenarios as compared to current scenario**

	SEDIMENT EXPORT (TONS)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	1,372,697,890	/
BAU, 2050	2,334,676,733	70.08
Net zero, 2050	934,710,645	–31.91

Notes: BAU = business-as-usual.

Source: Authors, based on Ethiopia GEM.

Figure C4 | **Sediment exports**



Source: Authors, based on Ethiopia GEM.

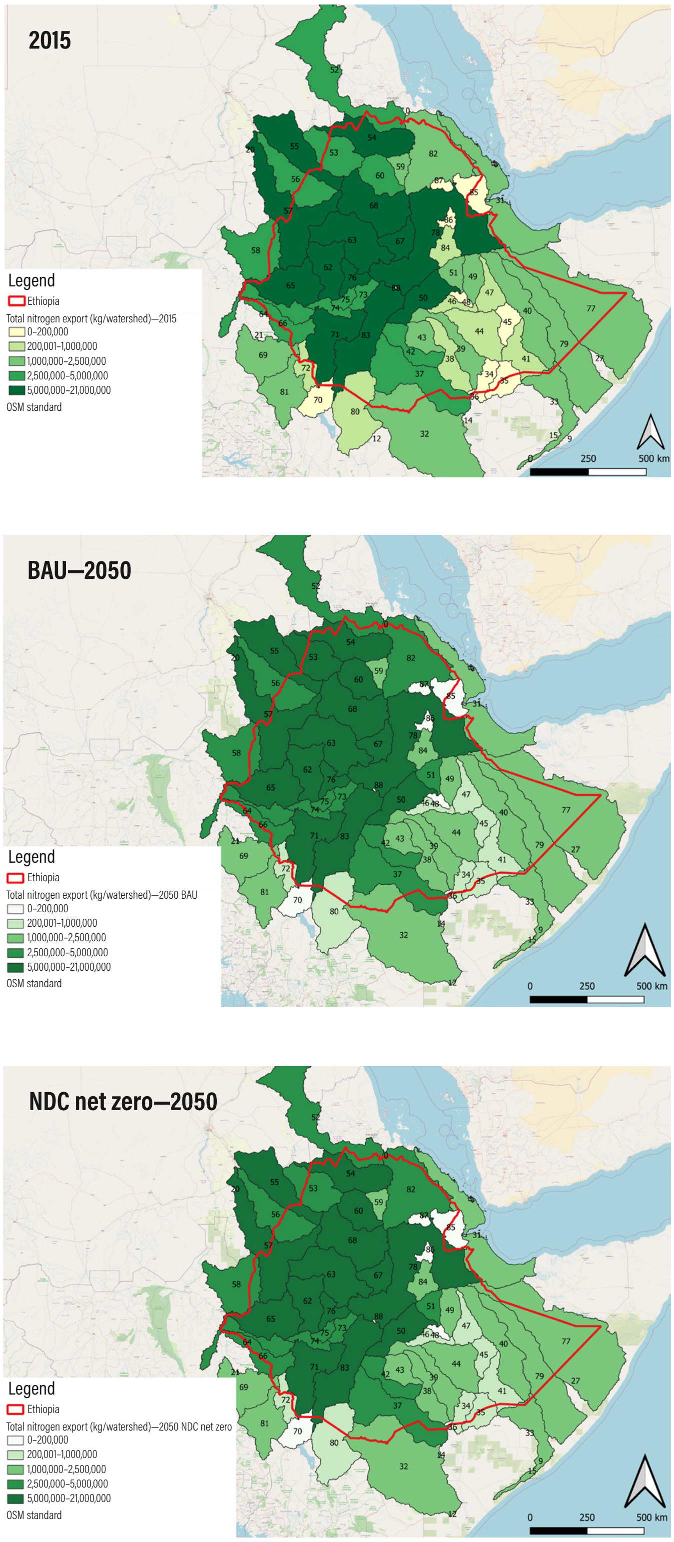
Table C5 | Nutrient export (nitrogen) statistics across alternative scenarios as compared to current scenario

	NITROGEN EXPORT (KG)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	216,643,462	/
BAU, 2050	257,467,675	18.84
Net zero, 2050	241,076,352	11.28

Notes: kg = kilogram.

Source: Authors, based on Ethiopia GEM.

Figure C5 | Total nitrogen export



Source: Authors, based on Ethiopia GEM.

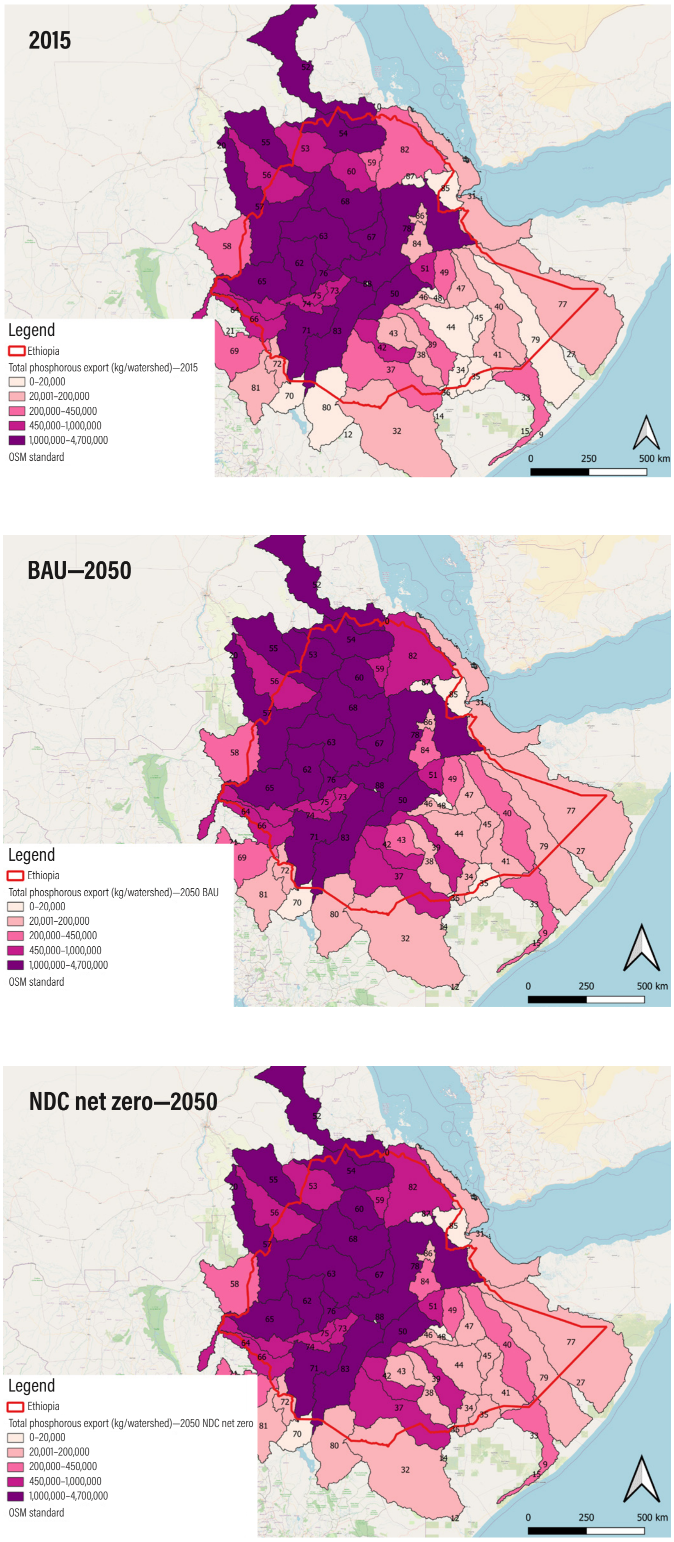
Table C6 | **Nutrient export (phosphorus) statistics across alternative scenarios as compared to current scenario**

	PHOSPHORUS EXPORT (KG)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	43,674,427	/
BAU, 2050	55,490,427	27.05
Net zero, 2050	51,116,427	17.04

Notes: kg = kilogram. BAU = business-as-usual.

Source: Authors, based on Ethiopia GEM.

Figure C6 | **Total phosphorus export**



Source: Authors, based on Ethiopia GEM.

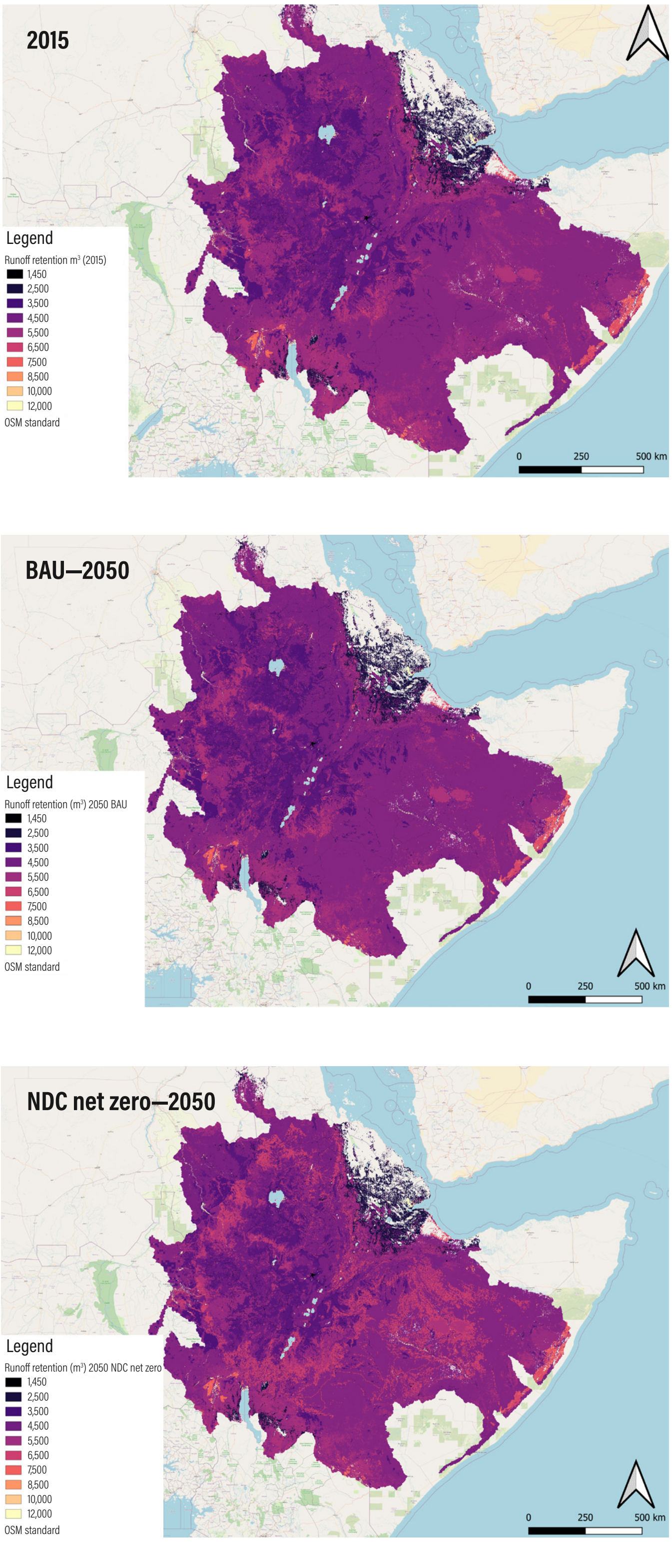
Table C7 | Flood risk mitigation runoff retention statistics across alternative scenarios as compared to current scenario

	TOTAL RUNOFF RETENTION VOLUME (M^3)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	87,915,788,464	/
BAU, 2050	87,224,038,830	−0.79
Net zero, 2050	88,676,884,647	0.87

Notes: m^3 = cubic meters. BAU = business-as-usual.

Source: Authors, based on Ethiopia GEM.

Figure C7 | Runoff retention values (m^3)



Notes: m^3 = cubic meters.

Source: Authors, based on Ethiopia GEM.

Carbon sequestration

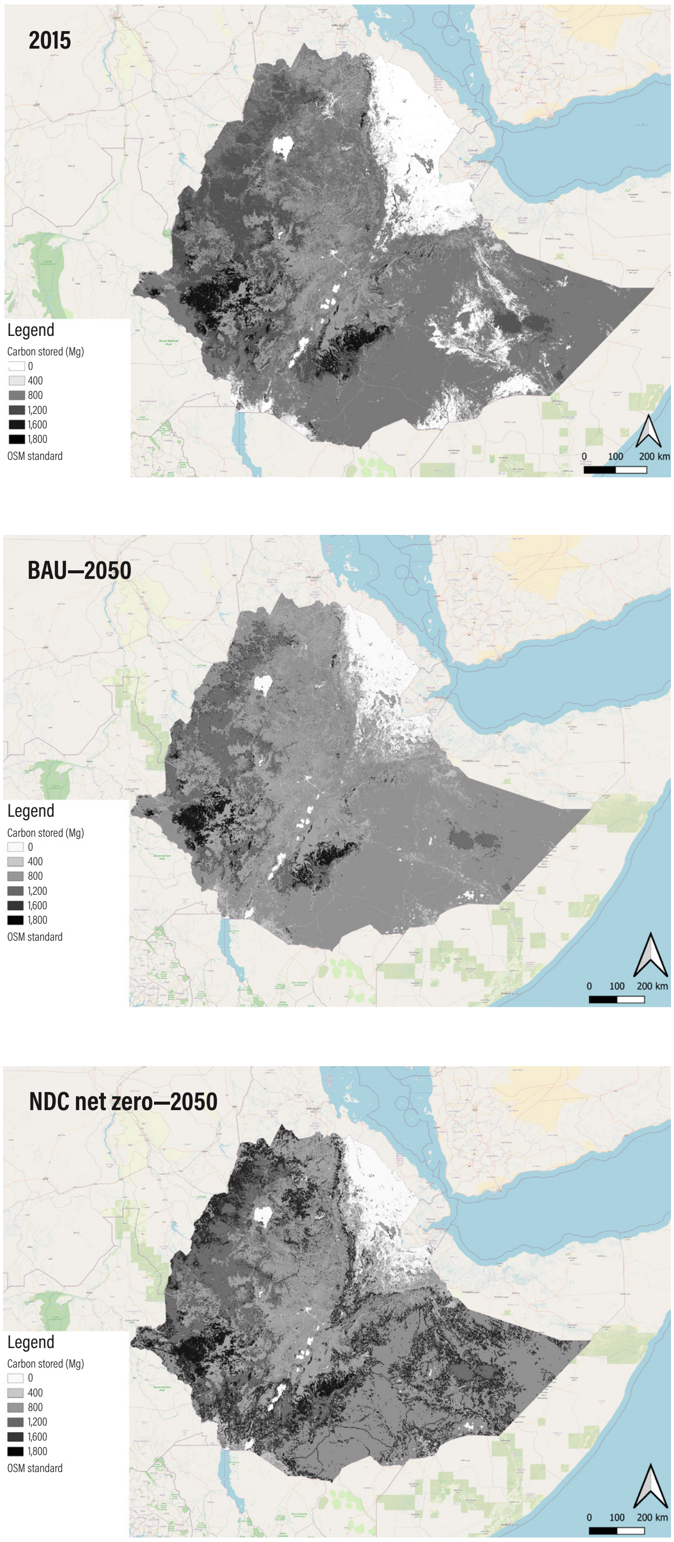
Carbon sequestration can provide development co-benefits because it can be a source of revenue through carbon market transactions. The same land-use activity that leads to carbon sequestration also generates climate resilience co-benefits (e.g., flood or dust storm buffering). According to the IPCC 2006 carbon pool inventory, agriculture land in Ethiopia's region can store large amounts of carbon in the soil, at least more than can fallow land. Our analysis of carbon sequestration compares a "current" state of land carbon sequestration in 2015 to BAU and NZE future scenarios in 2050. Figure C8 shows the amount of carbon stored in metric tons in each land area pixel in Ethiopia as of 2015 compared to the BAU and NZE scenarios in 2050. Results (see Table C8) show that, relative to 2015, an additional 4.2 percent of carbon is stored in the BAU land-use change forecast or the BAU future landscape in 2050 due to the conversion of fallow land to agricultural land. Under the NZE scenario, carbon storage increases by 22.4 percent by 2050 compared to the 2015 landscape, and by 18.2 percent compared to the BAU scenario in that same year. This increase is driven by additional reforestation and land restoration, which increases the amount of carbon stored in the landscape relative to the BAU scenario. The increased carbon storage in the NZE scenario contributes to the creation of the CO_2 sink capacity, which is required to reach net zero GHG emissions by 2050 in Ethiopia.

Table C8 | **Nutrient export (phosphorus) statistics across alternative scenarios as compared to current scenario**

	SUM (METRIC TONS)	CHANGE FROM THE CURRENT SCENARIO (%)
Current, 2015	9,219,636,682	/
BAU, 2050	9,606,178,253	4.19
Net zero, 2050	11,280,634,153	22.35

Notes: BAU = business-as-usual.

Figure C8 | **Carbon model outputs**



Source: Authors, based on Ethiopia GEM.

APPENDIX D. CLIMATE IMPACTS IN THE ECONOMY

The section entitled “Co-benefits from low carbon, climate resilience interventions” in the main paper highlights the key results of GEM modeling to assess climate impacts in the Ethiopian economy. More details of those results are described here.

Climate change impacts on total real GDP stem in part from the forgone production of the agriculture sector, as well as from the loss of productive capital in the industry and services sectors. Projections indicate that cumulative forgone real GDP due to climate change from 2020 to 2050 will be 2.93 percent of GDP in the BAU scenario and 2.71 percent of GDP in the NZE scenario (see Table 1). Relative losses due to climate change are thus slightly lower in the NZE scenario than in the BAU one (measured as a share of GDP). However, in absolute terms, they rise under the NZE scenario because GDP and productive capital at risk of climate impacts are also higher. Under both scenarios, close to three years of current economic activity will be lost between now and 2050 due to climate change.

In the agriculture sector—where most of the efforts on climate adaptation are focused—climate impacts are estimated to be slightly lower in the 2050 NZE scenario compared to BAU by 2050. The cumulative forgone value added in agriculture is estimated at $69 billion in the BAU scenario and about $62 billion in the NZE scenario. Cumulative crop production losses in the BAU and NZE scenarios for the period 2020 to 2050 total 326.3 million metric tons and 298.3 million metric tons, respectively. These losses correspond to the equivalent of 7.9 years’ worth of 2022 total crop production lost over the next 30 years in the BAU scenario, but in the NZE scenario this drops to 7.2 years. If these losses are spread equally over 30 years (2020–50), the average annual losses total 10.88 million metric tons per year for BAU (equal to 31 percent of 2022 production) and 9.94 million metric tons for NZE (equal to 28.4 percent of 2022 production). The climate impact from agriculture is lower in the NZE scenario compared to the BAU scenario for two reasons: first, there is increased climate resilience from increasing irrigation coverage (+15 percent by 2050); second, agricultural productivity gains allow retirement of some agricultural land, reducing the potential for damages.

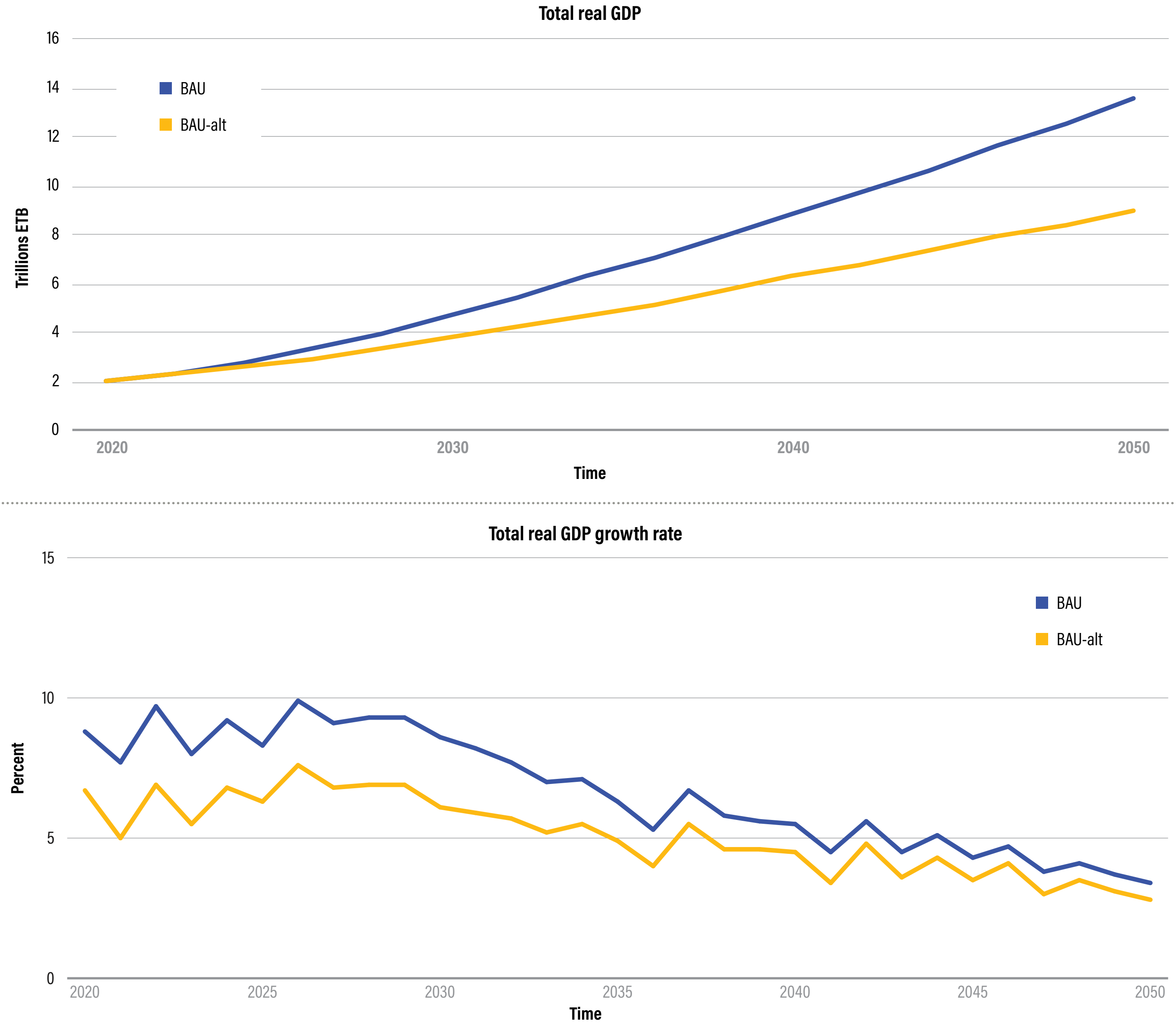
The 2050 NZE scenario results show that NZE policies already begin to limit the economic impacts of climate change in Ethiopia’s agriculture sector in coming decades. The economic gains induced by NZE policies in the agriculture sector could be expected to continue to increase over the rest of the century. However, due also to growing exposure in other parts of the economy (e.g., infrastructure) to climate change under the NZE scenario, further adaptation policies and investments will be required to limit overall damages due to climate change.

APPENDIX E. USING AN ALTERNATIVE BUSINESS-AS-USUAL SCENARIO TO DERIVE RESULTS

To test the robustness of the results in this study, it is useful to briefly consider the creation of an alternative business-as-usual (BAU-alt) scenario, one in which no additional action is taken (relative to current policies). Here, GDP growth is calibrated to match the latest forecasts of the World Economic Outlook, from October 2022 (IMF 2022), which are lower in part due to the COVID-19 pandemic and global economic slowdown. The BAU-alt scenario is lower than the ambition outlined in the 10YDP and as reflected in the BAU scenario that is used for this study.

The results for real GDP in the two simulations (10YDP = blue line, which is called BAU; the more up-to-date BAU-alt = red line) are presented in Figure E1. By 2050, total real GDP in the updated BAU-alt scenario is approximately 34 percent lower compared to the BAU scenario (i.e., the one embedded in this study). This change in economic growth has several consequences with regard to the forecasts generated with GEM across sectors, given that real GDP is one of the main drivers of energy demand and emissions, among other key variables.

Figure E1 | **Comparison of BAU and BAU-alt scenarios as total real GDP and real GDP growth rate**



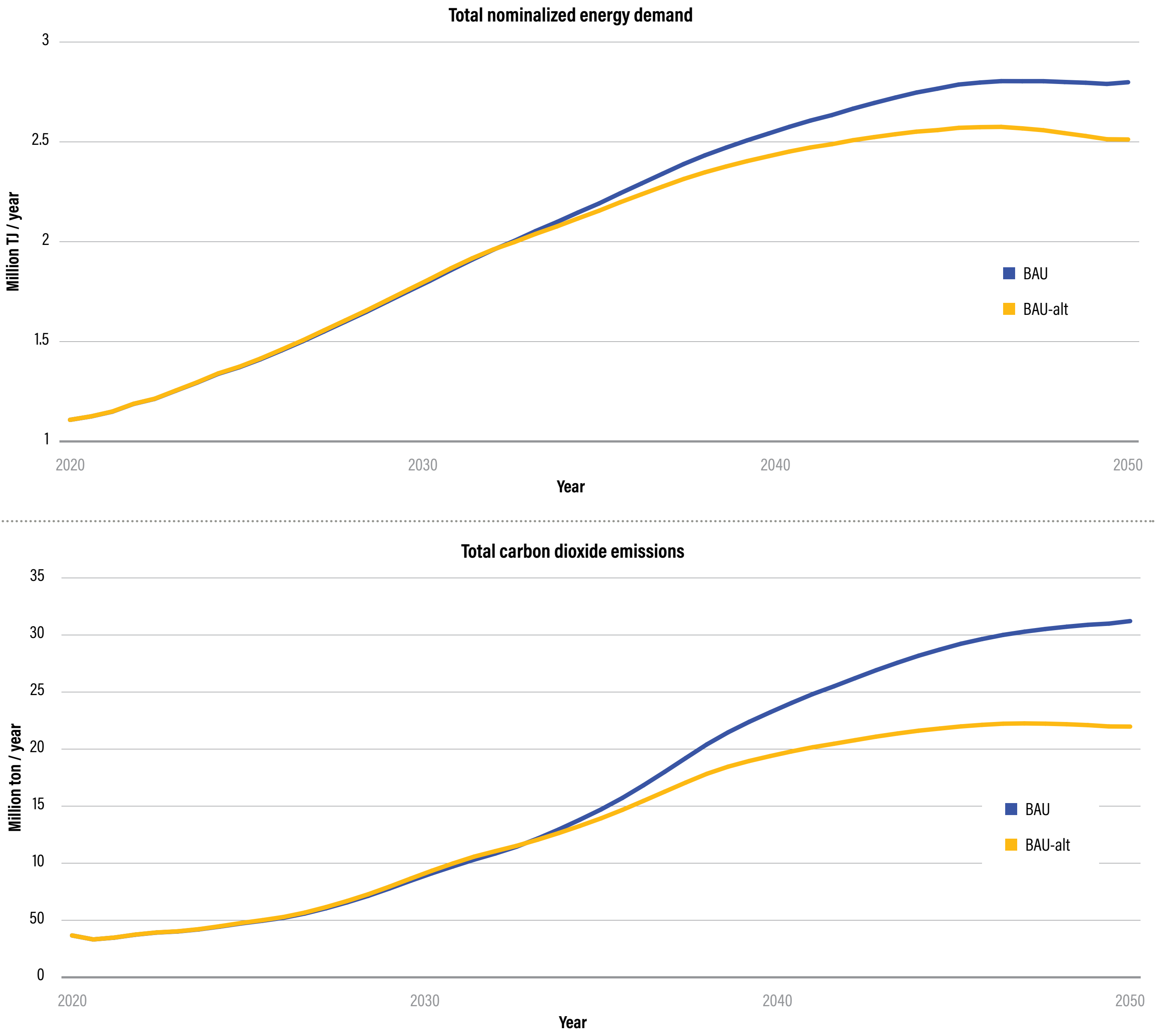
Notes: BAU = business-as-usual. BAU-alt = alternative business-as-usual. GDP = gross domestic product. ETB = Ethiopian birr.

Source: Authors, based on Ethiopia GEM.

As presented in Figure E2, the lower growth forecast for real GDP in the BAU-alt scenario leads to lower growth of energy demand and hence lower energy-related GHG emissions in the medium and longer term. By 2050, total energy demand is projected to be 10.1 percent lower in the BAU-alt scenario, while energy-related emissions decline by 29.4 percent. Despite the marked decline in energy emissions, total annual carbon dioxide equivalent (CO_2e) emissions are projected to be only 2.3 percent lower in 2050 compared to the BAU calibration. This is due to the sustained growth in emissions from livestock, which are primarily impacted by population growth, rather than by GDP.

There are several additional implications emerging from the use of a BAU-alt scenario characterized by lower economic growth. On the one hand, the absolute costs of inaction emerging over time (e.g., productivity losses from air pollution) will be lower than in the previous baseline due to lower levels of growth and a smaller economy overall. On the other hand, the relative costs of climate change will be higher, and the level of effort required to reach net zero by 2050 will be lower (because, in absolute terms, a smaller volume of GHG emissions will have to be avoided). Further, the contribution to economic growth brought by low-carbon, climate-resilient development will be more marked, with a stronger positive impact on poverty reduction.

Figure E2 | **Total energy demand and total CO_2e emissions from energy BAU update**



Notes: CO_2e = carbon dioxide equivalent. BAU = business-as-usual. TJ = terajoule. BAU-alt = alternative business-as-usua.

Source: Authors, based on Ethiopia GEM.

ENDNOTES

1. Ethiopia is estimated to have contributed only 0.04 percent of global emissions in 2019 (Federal Democratic Republic of Ethiopia 2021). Beyond this, estimates suggest that Ethiopia emitted 0.2 metric tons of CO_2 per capita in 2019, compared to a world average of 4.4 metric tons of CO_2 per capita. See Climate Watch (2020).

2. Much of the detail of quantitative co-benefits results—often in physical metrics and in the form of graphics—can be found in Appendix C of this paper.

3. In 2020, as part of the WRI project in Ethiopia, consultancy KnowlEdge Srl was contracted to develop integrated assessment tools and methods for an appraisal of expected co-benefits associated with climate action and environmental sustainability in Ethiopia. The sum of this effort was the development of a GEM. The technical system dynamics model is an empirical economic assessment tool, built drawing on consultations, data, and analytical work with Ethiopia's Planning and Development Commission (PDC) and other ministries. The GEM is designed to enhance and inform policy identification, assessment, and prioritization. It supports the PDC in the process of mainstreaming climate considerations into development planning and policy assessment. Model documentation is available by request from KnowlEdge, info@ke-srl.com.

4. The GEM has also been tailored for use in other countries. For example, see Golechha et al. (2022).

5. Hydropower is accounted for as clean, renewable energy in the GEM and in the power sector. Ethiopia is largely dependent on hydropower. However, hydropower is vulnerable to climate change. Its share of generation in the total mix is conservatively assumed to remain constant after 2020 (at 78 percent of total generation). Energy efficiency measures in the GEM are exclusively implemented for the demand side (i.e., they affect final consumption) and are not implemented in power generation or energy supply side processes.

6. WRI was able to engage with more than 11 experts selected from different ministries online over this period, including expert officials from the lead ministries (i.e., the MOPD, Ministry of Finance, and Ethiopian Environmental Protection Authority). The events were hosted by WRI and facilitated by the expert model-building team led by KnowlEdge Srl. Data for input into the model were also gathered as needed from line ministries (e.g., on agriculture, energy, and transport).

7. The GIDD framework was developed by the World Bank (Bussolo et al. 2012) and is based on previous macro-micro simulations. The GIDD follows a top-down approach in which most of the behavior is modeled by solving a macroeconomic model, which generates a series of linking aggregate variables that become the input for a microsimulation (Bourguignon et al. 2008).

8. Here we build on another study originally commissioned by this project to perform a sustainable asset valuation analysis for a land restoration assessment of the Sodo district in Ethiopia (Cutler and Guzzetti 2022). (See "Cost of interventions" and Appendix C.)

9. While we have not attempted to situate these results in the real-world context of Ethiopian life today or in the future, such a "visioning" exercise could be a useful complement to this more technical economic analysis.

10. Here and elsewhere in the document, monetary numbers are presented in U.S. dollars. The exchange rate used is 29.55 Ethiopian birr per U.S. dollar.

11. As noted in "Economy-wide benefit cost analysis," the benefit-cost analysis conducted here includes the impact of climate change, which results in lower levels of GDP for a given year.

12. WRI commissioned a consultant to conduct a distributional impacts assessment and produce a technical note to serve as a background paper to summarize and document the methodology and main results and as a guide to run the code. For the research, the GIDD model (see endnote 7) was used to assess the potential distributional effects of implementing low-carbon policies in Ethiopia, linking to results of the GEM, which was used to model the macroeconomic implications. Four of the five modules of the GIDD framework were implemented. The module considering changes in relative consumption prices of food versus nonfood products faced by consumers was not used in this analysis due to insufficient data. To access a copy of the technical note, please contact Nadin Medellin, nadin.medellin@gmail.com.

13. This result may be linked to the fact the GIDD analysis did not model transition from unskilled to skilled labor. Therefore, while income will increase at a faster pace for high-skilled labor, it will not increase as sharply for unskilled labor, resulting in greater inequality in both the BAU and NZE scenario. Impact on inequality caused by transition from unskilled to skilled labor has not been modeled at this stage; future analysis of it could link to specific policies.

14. (See also endnote 12 for initial context). The integration of GEM and GIDD is still at an early stage, and for this reason, results are partial. This GIDD exercise only models part of the effects that the implementation of low-carbon policies may have. We highlight here the labor sector rigidities that will affect the outcomes of this modeling exercise. Still, we consider that this kind of analysis is relevant and informative. If you are interested in learning more, please contact Nadin Medellin, nadin.medellin@gmail.com.

15. Land restoration benefits were the subject of a separate research report, in which the New Climate Economy team at WRI commissioned the IISD to work with local experts to carefully assess them in a local Ethiopian context. This study used the SAVi modeling tool, which combines spatial modeling (InVEST) with system dynamics modeling, and financial analysis to assess the societal costs and benefits of land restoration at the Sodo district site in southern Ethiopia (Cutler and Guzzetti 2022). (See Appendix A for more details on modeling.) It was based on local data collection and stakeholder and expert consultation facilitated by WRI; using SAVi, the IISD assessed the value of these benefits in the local context. In our own broader-scale NZE pathways modeling exercise, we build on these results to consider the potential to scale up land restoration across Ethiopia.

16. To note, the dynamics of grass production and other non-timber products that come from land restoration of this type is simplified in this modeling. Non-timber products such as honey, spices, gums, and resins are not accounted for here. We also did not account for a reduction in grass production after canopy closure, which in turn would raise the return from non-timber products.

17. This analysis is based on the InVEST Habitat Quality model, which uses land cover information and threats to biodiversity to produce habitat quality maps. See endnote 15 and Appendix A for more details on the modeling approach.

18. Avoided costs as presented in this paper also include reduced climate change damages. However, this is embedded in the results for GDP, which is more climate resilient and hence higher than in the BAU scenario. Avoided climate impacts are the second-largest share of avoided costs, estimated to be worth $39.98 billion in avoided costs compared to the BAU scenario.

19. Note all cumulative cost and benefit figures presented in this section are net present value, discounted at 15 percent. The start date for the period is 2020, so 2020–30 and so on.

20. World Bank. n.d. (Database). Inflation, GDP Deflator (Annual %)—Ethiopia. https://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG?locations=ET. Accessed 2023.

21. These results are consistent with the government's 10YDP and its NDC, which foresee an economy-wide transition toward industry and service sectors and a shift away from agriculture.

22. In the BAU scenario, total real consumption increases from $74.5 billion in 2020 to $64.3 billion in 2050 (inflation adjusted but not discounted), while 2050 consumption in the 2050 NZE scenario is estimated to be +45.9 percent over BAU in 2050 at $2.8 trillion). For the period 2020 to 2050, the results indicate that, cumulatively, total consumption is $6.35 trillion higher in the NZE scenario, which is equivalent to an additional $211.8 billion in additional consumption expenditure per year over 30 years.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

ABOUT THE NEW CLIMATE ECONOMY

The Global Commission on the Economy and Climate and its flagship project the New Climate Economy were created to help governments, businesses, and society make more informed decisions about how to achieve prosperity and economic development while addressing climate change.

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