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Integration of climate resilience and low emission pathways: Assessing the environmental and socio-economic impacts in the energy and agriculture sectors

Shivenes Shammugam[1], Basil Oberholzer[1], Andrea Bassi[2], Georg Pallaske[2], Stelios Grafakos[1]

1 Global Green Growth Institute (GGGI), Seoul, South Korea

2 Knowledge Srl, Olgiate Olona, Italy

ABSTRACT

In this paper, we present an approach and results of integrating climate impacts and climate adaptation measures in the energy and agriculture sectors in a macroeconomic top-down model. By integrating climate projections from dynamically downscaled regional climate models, we assess the impacts of changing precipitation patterns and rising temperatures on sectoral outcomes such as crop production and electricity generation, as well as on other macroeconomic socioeconomic factors such as employment and government spending for Ethiopia and Burkina Faso. The results show that neglecting climate impacts when developing long-term scenarios overestimates the evolution of economic growth in both countries. On the other hand, climate adaptation measures and adequate entitlement levels can largely offset the adverse effects of climate change in both sectors.

Keywords: climate adaptation, climate impacts, long-term low emission development strategy, greenhouse gas emissions, mitigation, climate change

NOMENCLATURE

Abbreviations	
BAU	Business As Usual
CBA	Cost-Benefit Analysis
CLD	Causal Loop Diagram
EFCCC	Ethiopian Environment, Forestry and Climate Change Commission
GDP	Gross Domestic Product
GEM	Green Economy Model
LECR	Low-emission and climate resilient scenario
LT-LEDS	Long-term low emission development strategy
NDC	Nationally Determined Contribution
PDC	Planning and Development Commission
REF	Reference Scenario
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goals
SP/CNDD	Permanent Secretariat of the National Council for Sustainable Development

1. INTRODUCTION

For developing countries and economies in transition, climate adaptation and building resilience to climate change are at least as urgent as mitigation actions, as the devastating impacts of climate change are already being felt by people in all countries. Livelihoods, culture, ecosystems, and economies are severely impacted. Currently, there is no systematic approach or framework for incorporating climate impacts and adaptation into national development strategies such as Nationally Determined Contributions (NDCs) or Long-Term –Low-Emission Development Strategies (LT-LEDS), which could help improve decision-making on climate resilient low-emission development plans and strategies and their implementation.

While different modelling approaches capture different aspects of the climate adaptation process, they do so in relative isolation without providing improved, unified representations of climate mitigation and adaptation pathways across the economy. This isolated view results in missed opportunities for important synergies between the two approaches that could drive more systematic and transformative change and increase the efficiency of mobilized investments and policy implementation.

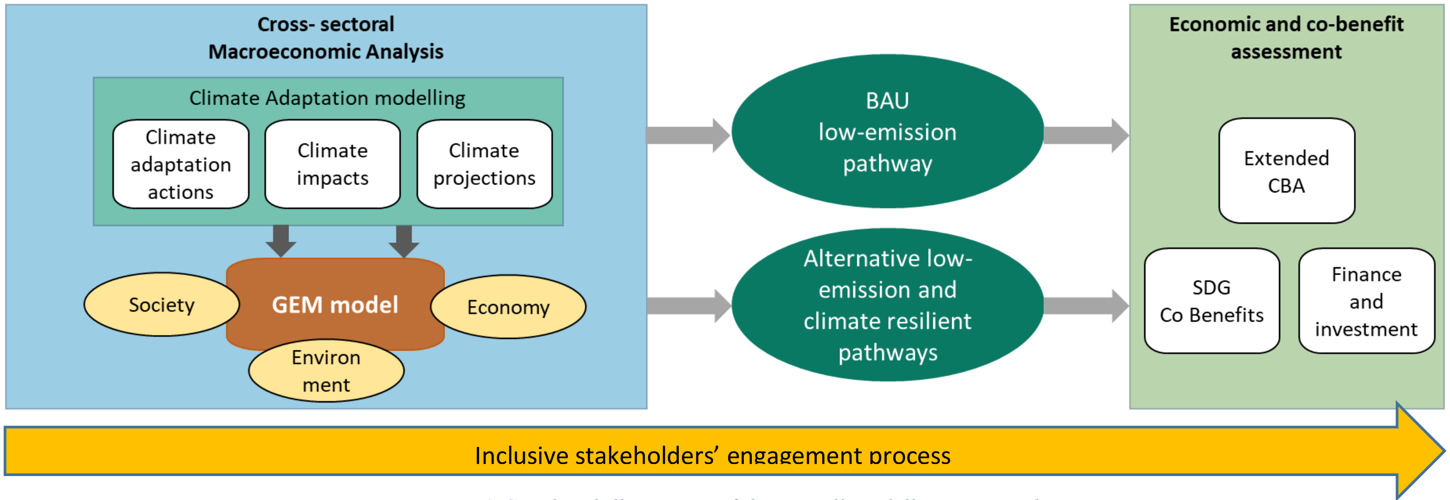

Figure 1 Graphical illustration of the overall modelling approach

Climate change adaptation goes beyond climate impact and vulnerability and assessments, considering that all sectors and the population are disproportionally exposed to the risks. There is a need to systematically integrate climate adaptation into low emission development planning and implementation processes, particularly in the context of low-income countries. This paper explores the integration of the climate dimension into a top-down macroeconomic model to assess the environmental and socioeconomic impacts of adaptation and mitigation actions with focus on the energy and agriculture sectors. We apply this approach to two case studies in Ethiopia and Burkina Faso to assist governments of both countries to develop their LT-LEDS.

2. METHODOLOGY AND DATA

2.1 Green Economy Model (GEM)

To analyse the achievement of net-zero emissions by 2050 and conduct the corresponding environmental, climate, social and economic assessment, the Green Economy Model (GEM) is applied. GEM was developed based on systems thinking, which combines knowledge in climate science, climate impacts and system dynamics. Within the framework of the systems thinking, a Causal-Loop Diagram (CLD) is first applied, which is a tool to identify causality, anticipate impacts (both desired and undesired), and the possible transformational outcomes of different ambitions (Probst & Bassi, 2014). A CLD helps select the relevant indicators, determine causality among variables, and identify drivers of change (e.g. feedback loops) that are primarily responsible for the past, present and future behaviour or trends of the system. Once the CLD has been developed, discussed and validated by relevant local stakeholders, it is modelled in GEM, where future scenarios can be simulated.

As the core mode l for the assessment of this work, the GEM is an integrated assessment model that goes beyond a linear representation of emission changes and incorporates socio-economic and environmental trends based on system dynamics models to enable simulation of the whole country's economy and its interactions in terms of emissions. In short, this means that the GEM considers feedback mechanisms between the economy and the various social and environmental subsystems in which it is embedded. The GEM presents a country's economy as a complex, adaptive system that includes demography, labour supply, fiscal space, domestic and foreign sectors, and biophysical modules such as carbon stocks and land cover. A comprehensive explanation and fundamentals of GEM are explained elsewhere in the literature (see [1]).

In this paper, the GEM is further developed and applied to Ethiopia and Burkina Faso. This is done as part of the development of the LT-LEDS for both countries. The Ethiopian GEM was originally developed and used to support initiatives of the former Ethiopian Environment, Forestry and Climate Change Commission (EFCCC) and the former Planning and Development Commission (PDC) and has since been used to support the NDC update process and the development of the country's Ten-Year Development Plan. For the development of the long-term LEDs, the GEM for Ethiopia was expanded to include climate impacts and climate adaptation measures (see Chapter 2.4). The GEM for Burkina Faso was developed from scratch under the guidance of the Permanent Secretariat of the National Council for Sustainable Development (SP/CNDD) and the Ministry of Economy, in close consultation and collaboration with local government officials and sectoral stakeholders.

2.2 Inclusive stakeholders' engagement process

An important feature of the overall modelling approach was the establishment of an inclusive stakeholders' engagement process in both countries. The inclusive stakeholders' engagement process consisted of the establishment of sectoral and cross-sectoral working groups (including the macroeconomy and climate adaptation working groups) and the organization of a series of national stakeholders workshops. The working group throughout the LT-LEDS process provided continuous inputs, guidance and support to the modelling process and regularly validated the scenarios' assumptions and results. In addition, in both countries several stakeholders' workshops were held so that a broader set of stakeholders, such as different government agencies and departments, regional authorities, academia, civic society organizations, etc. would have the opportunity to provide feedback on the development of the LT-LEDS pathways.

2.3 Future climate projections

In a subsequent step, climate data are then fed into GEM. Using historical data such as spatially disaggregated precipitation and temperature data obtained from the national weather office, past impacts of climate change on sectoral outcomes are identified and serve as the basis for estimating future impacts in the model. Future climate projections under RCP 4.5 are then incorporated into the model. For Ethiopia, the climate projection data developed by the Canadian Earth System Model (CanESM2-CMIP5) [2], are applied. In Burkina Faso meanwhile, the model ensemble climate projections from the Third National Communication [3] are used. As the impact of climate change is regional and not uniform within a country, a spatial disaggregation of the model is undertaken, as shown in Figure 2 and 3.

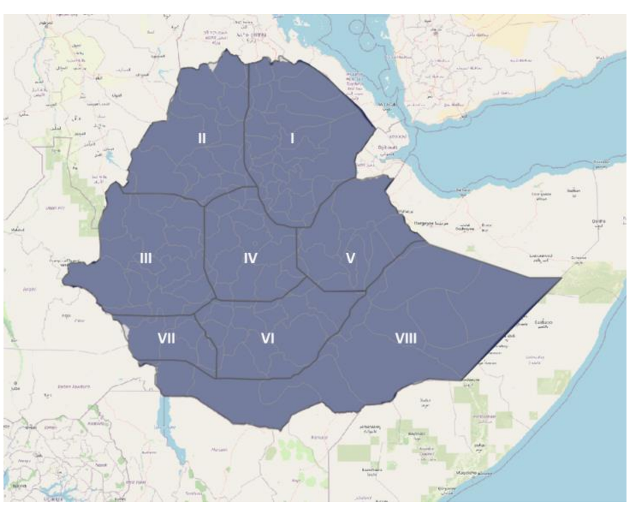

Figure 2 - Regionalisation of Ethiopia in GEM according to homogenous rainfall regions

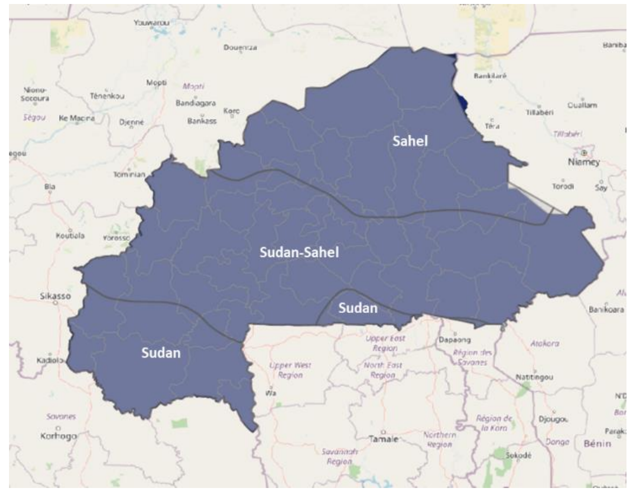

Figure 3 - Regionalisation of Burkina Faso in GEM according to agro-climatic zones

In Ethiopia, spatial disaggregation is carried out according to the homogeneous rainfall regions, as recommended by the Ethiopian National Meteorology Office. In Burkina Faso, the model is disaggregated according to the agro-climatic regions of the Sahel, Sudan and Sahel-Sudan. In all scenarios, climate change impacts are modelled only for the energy and agriculture sectors, as these sectors are given high priority by the government, and it is in these sectors that climate change will have the greatest impact. The exact approach to modelling climate change impacts in these sectors is discussed in more detail in sections 2.4.1 (Energy) and 2.4.2 (Agriculture).

It is important to note that the approach applied in the Ethiopian and Burkina Faso LT-LEDS is the first of their kind to fully integrate climate change impacts into long-term development scenarios. This is considered an important milestone as climate change adaptation is a critical component of national priorities in both countries, which are extremely vulnerable to the adverse effects of climate change. Both governments also intend to combine long-term climate change mitigation and adaptation strategies to better understand the strong synergies and leverage them in national planning processes.

2.4 Scenario development

Three scenarios are defined and presented in this paper:

- Reference (REF) – The REF scenario constitutes the baseline against which the performance of the BAU and the low-emission and climate resilient scenarios will be measured. The REF scenario represents a BAU development without any consideration of climate change impacts or additional mitigation and adaptation actions.

- Business-as-Usual (BAU) – The BAU scenario represents the development of emissions that would result if future development trends follow those of the past and no changes in policies take place. The BAU scenario considers climate impacts, but no additional mitigation or adaptation actions.
- Low-emission and climate-resilient scenario (LECR) – The LECR scenario represents a decarbonisation pathway in reaching net-zero emissions and climate resilience in 2050, where various sectoral mitigation and adaptation actions and targets are defined.

2.5 Climate impacts and climate adaptation actions

This chapter presents the approach of including climate impacts and climate adaptation measures in the energy and agriculture sectors. The mitigation measures that contribute to achieving net zero emissions are presented in the annex.

2.5.1 Energy

The impacts of climate change on the energy sector consider (i) the effects of water scarcity in hydropower plants as a result of fluctuating precipitation, and (ii) the effects of rising temperatures on the efficiency of thermal power plants and electricity distribution systems. Currently, in both countries, the lack of generation capacity at hydropower plants during periods of drought or lower precipitation is compensated by electricity from diesel generators, which increases overall emissions from the power sector during these periods. In the model, the elasticity of hydropower to the change in precipitation is assumed to be 1, based on findings in the literature that the reduction is in a one-to-one ratio with the reduction in precipitation (see, for example, [4] and [5]).

As for the reduction in efficiency of the thermal power plants, historical data shows an average annual reduction of 4% in the generation in the past periods for fossil fuel powered plants. For the future scenarios, the approach proposed by [6] is applied, where the optimum temperature for no impacts on fossil power plants is assumed to 15°C following ISO conditions and the efficiency drops by 0.06% per °C rise in ambient temperature.

Based on a discussion with the power sector working groups in both countries, composed of local experts and government officials, two key climate adaptation measures for the power sector, as listed in Table 1 and Table 2, were identified and modelled in GEM to assess their contribution to reducing the negative impacts of climate change in the power sector. The modelling of these measures represents the potential benefits of diversifying the energy mix and improving the energy efficiency and resilience of the power system.

Table 1 - Adaptation interventions and their respective targets for the energy sector in Ethiopia used in the LT-LEDS as set by the local stakeholders in the working group.

Adaptation intervention	Indicator	Baseline indicator	2030 Target	2050 Target
Increasing the share of PV, wind and biogas to replace the share of fossil fuel in electricity generation	% of renewable electricity generation excluding hydro power plants	9.0 %	80.0 %	100 %
Reduction of transmission losses in the electricity distribution system	% of transmission losses	19.6 %	12.5 %	10.0 %

Table 2 - Adaptation interventions and their respective targets for the energy sector in Burkina Faso used in the LT-LEDS as set by the local stakeholders in the working group.

Adaptation intervention	Indicator	Baseline indicator	2030 Target	2050 Target
Increasing the share of renewable energy share in electricity generation	% of renewable electricity generation	19.4 %	45.0 %	90.0 %
Reduction of transmission losses in the electricity distribution system	% of transmission losses	27.7 %	10.0 %	10.0 %

2.5.2 Agriculture

The agricultural sector in Ethiopia and Burkina Faso is highly vulnerable to climate change impacts, with droughts becoming more frequent and severe. This is also mainly due to its heavy dependence on rain-fed agriculture and relatively low adaptive capacity to climate impacts. The vulnerability is made even more severe by the fact that a large share of the population relies economically on the agriculture sector. For example, the agricultural and silvo-pastoral activities contribute to more than 30% of Burkina Faso's GDP and employs more than 80% of the population.

The modelling of the agricultural sector is differentiated by crop type and region, as shown in Figures 2 and 3. For Burkina Faso, crops are grouped into two categories, cash crops (cotton, sesame, soybeans, groundnuts) and food crops (millet, maize, rice, sorghum, potatoes, yams, cowpeas). Meanwhile in Ethiopia, crops are aggregated into seven categories, namely cereals, pulses, oilseeds, vegetables, root crops, fruits, and permanent crops. The guidelines for crop aggregation were provided by the agriculture working groups of both countries.

The analysis of climate change impacts in agriculture under the LT-LEDS considers the impacts of water scarcity on crop production that occur when precipitation is insufficient to meet crop water needs on non-irrigated cropland. A water scarcity threshold is applied to determine the negative impact, which is calibrated based on historical precipitation data provided by national meteorological agencies. Agricultural value loss is calculated by multiplying the lost crop production by the average profitability per crop (average producer price per tonne) obtained from FAOSTAT [7]. The impact of water scarcity on production of cereals and pulses for two selected regions is shown in Figure 4 and Figure 5.

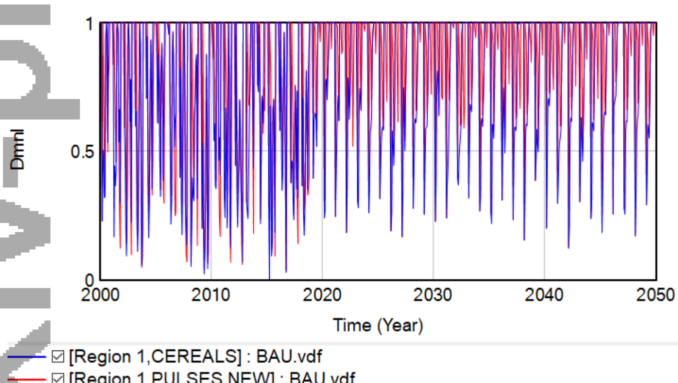

Figure 4 - Effect of water scarcity on cereals and pulses in the BAU scenario for region 1 in Ethiopia

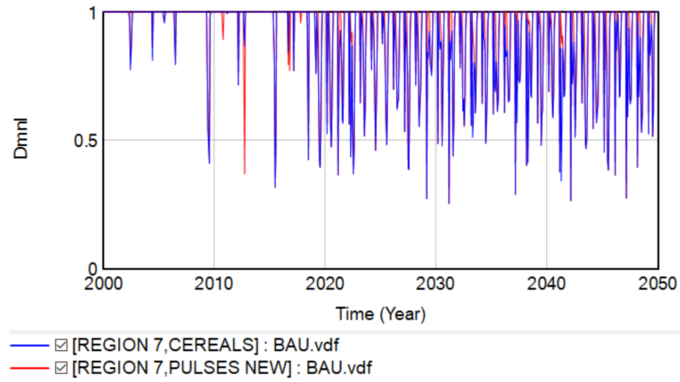

Figure 5 - Effect of water scarcity on cereals and pulses in the BAU scenario for region 7 in Ethiopia

The downward slopes show that the effects of water scarcity occur only in certain months. The figures also show two important observations: Water scarcity impacts different crops differently, and the impacts are not uniform across the country but vary by region. In addition to water scarcity, GEM also models the effects of flooding and erosion of topsoil as a result of rainfall variability. A flood indicator is determined from the precipitation peaks, which is then compared to a maximum threshold value that determines whether flooding is very likely. The threshold is also determined by the occurrence of past floods based on historical climate data. The impact of topsoil erosion is also affected by the occurrence of flooding and a distinction is made between conventional and organic agriculture. Figure 6 shows an example of the effect of topsoil erosion on crop productivity in all three regions in the BAU and LECR scenarios relative to a base year of 2000. It can also be seen that in the LECR scenarios, where additional climate adaptation measures are defined, topsoil erosion decreases, improving resilience and crop productivity.

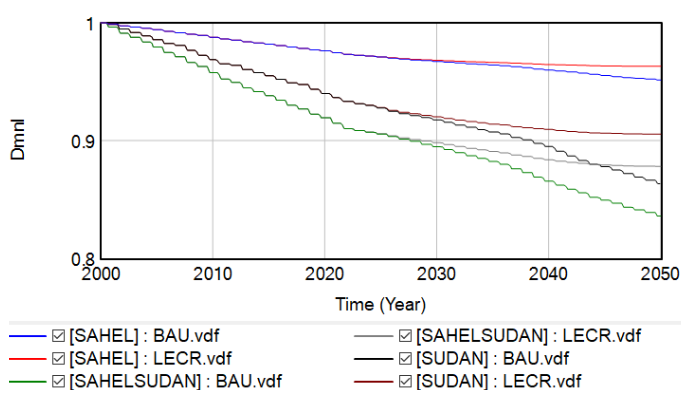

Figure 6 - Effect of topsoil erosion on agriculture productivity

As shown in Table 3 and Table 4, several climate adaptation actions are defined and modelled in the LECR scenarios of both countries to empirically analyse their role in minimizing the losses and to improve the resilience of the agriculture sector.

Table 3 - Adaptation interventions and their respective targets for the agriculture sector in Ethiopia used in the LT-LEDS as set by the local stakeholders in the adaptation working group.

Adaptation intervention	Indicator	Baseline indicator 2020	2030 Target	2050 Target
Reducing pre-harvest losses in crop production	% of losses in yield	25%	23%	10%
Increasing climate smart agriculture practices	Share of land that has CSA practices	0%	25%	80%
Increasing irrigation schemes	Area under irrigation schemes	0.49 mil. Ha	1.2 mil. Ha	3.6 mil. Ha
Utilizing climate smart technology based mechanical agriculture	Annual increase in mechanization rate in crop production	NA	1%/a	1%/a
Diversification of livestock using genetically improved breeds	% of improved dairy cattle	2.7%	17%	30%

Table 4 - Adaptation interventions and their respective targets for the energy sector in Burkina Faso used in the LT-LEDS as set by the local stakeholders in the working group.

Adaptation intervention	Indicator	Baseline indicator 2020	2030 Target	2050 Target
Reduction of fertilizer usage on sustainable agriculture land	% of reduction of fertilizer usage	25%	23%	10%
Share of land under sustainable agriculture practices	Share of land that has CSA practices	0%	33%	100%
Solar irrigation systems for crop	Fraction of agricultural land irrigated by solar	0%	50%	100%

3. RESULTS AND DISCUSSION

3.1 Wide-economy net-zero and climate resilient development pathway

As shown in Figure 7, in the Ethiopian BAU scenario, total country CO2e emissions are projected to increase from 299.42 Mt in 2020 to around 560.35 Mt by 2050. In the LECR scenario, total emissions reach net zero around the year 2035 and remain below zero afterwards thanks to the continued implementation of ambitions. The cumulative avoided CO2e emissions in the LECR scenario, compared to the BAU, total 11,667 Mt, equivalent to 388.8 Mt in avoided emissions per year for the period between 2020 and 2050.

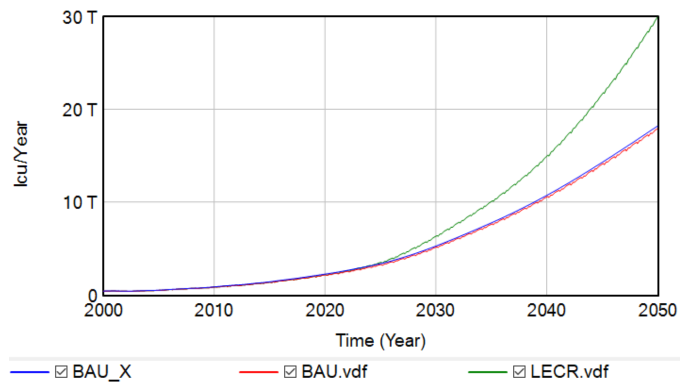

Figure 7 - Total annual GHG emissions of all scenarios in Ethiopia

In the BAU scenario of Burkina Faso, total country CO2e emissions are projected to increase from 67 Mt in 2020 to around 102.7 Mt by 2050. In the LECR scenario, total emissions reach net zero around the year 2045 and remain below zero afterwards thanks to the continued implementation of ambitions. By 2050, the continued implementation of reforestation ambitions has created a net sink of around 7 Mt per year. The cumulative avoided CO2e emissions in the LECR scenario total 1,819 Mt, equivalent to 64.96 Mt in avoided emissions per year for the period between 2022 and 2050.

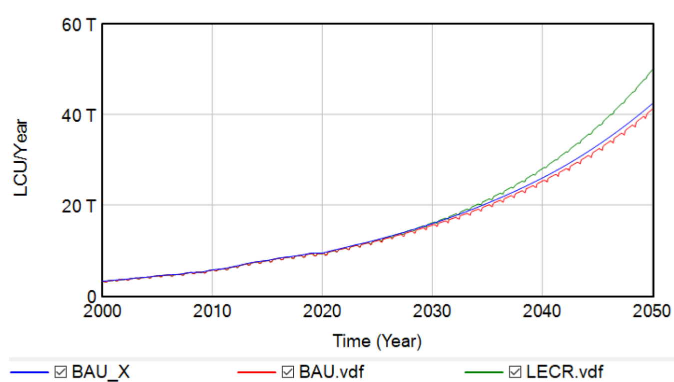

Figure 8 - Total annual GHG emissions of all scenarios in Burkina Faso

3.2 Climate resilience of the energy sector

Figure 9 shows the missing generation capacity due to climate change impacts as a difference in the load factor of hydropower plants in the scenarios with (BAU) and without climate impacts (BAU_X) in Ethiopia. The lack of generation capacity of hydropower plants during drought is compensated by electricity from diesel generators, which leads to an increase in total emissions. In Figure 9, the capacity gap is the space between the two lines of the scenarios. The projected decrease in hydroelectric generation is between 4% and 12% per year between 2020 and 2050.

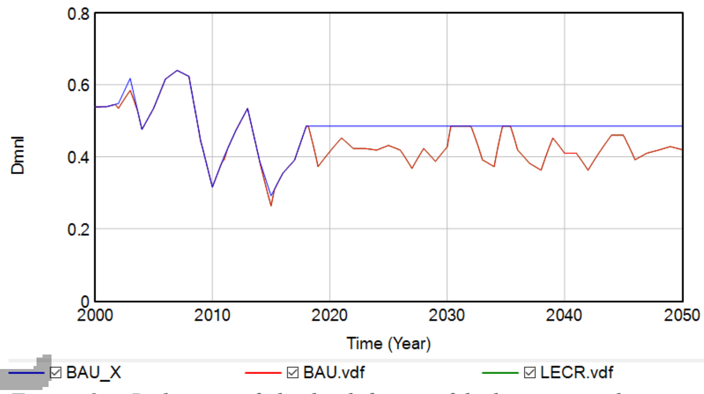

Figure 9 - Reduction of the load factor of hydro power plant in Ethiopia once climate impacts are included in the model

As for the reduction in efficiency of the thermal power plants, historical data shows an average annual reduction of 4% in the generation in the past periods for fossil fuel powered plants. Simulation results from GEM show that the annual reduction in generation of fossil fuel powered plants until 2050 varies around 4-12% annually.

In Ethiopia, the long-term strategy of a climate-resilient energy sector in Ethiopia has been previously discussed and defined in Ethiopia's Climate-Resilient Green Economy: Water and Energy. As a long-term strategy for LT-LEDS, the following priorities, in addition to the two interventions that were modelled, are identified, which aligns with the actions defined in the national Climate Resilient Green Economy strategy:

- Diversifying the energy mix in order to reduce the dependency of hydro power plants that is dependent on rainfall variability
- Improve energy efficiency to reduce overall demand for electricity
- Improve efficiency of biomass use to reduce the overall demand for biomass
- Accelerate non-grid energy access to improve electrification of rural area

In Burkina Faso, climate impacts on the power generation sector are relatively small at the system level, as the current generation capacity of hydropower plants represents less than 6% of the total generation capacity. In terms of reductions in thermal power plant efficiency, GEM's simulation results show that annual reductions in electricity generation at fossil fuel-fired power plants vary by an average of 3% per month through 2050. This can be seen in the reduction of the annual load factor of fossil fuel-fired power plants, as shown in Figure 10. In the BAU_X scenario, where no climate impacts are assumed, the model simulates a constant load factor of 0.236 for fossil-fuelled power plants, whereas when climate impacts are considered in the BAU scenario, the load factor decreases by 3.4% on average by 2050. In the LECR scenario, the share of renewable energy, mainly from biomass and photovoltaics, reaches 90% and reduces the dependence of the power system on precipitation and ambient temperature.

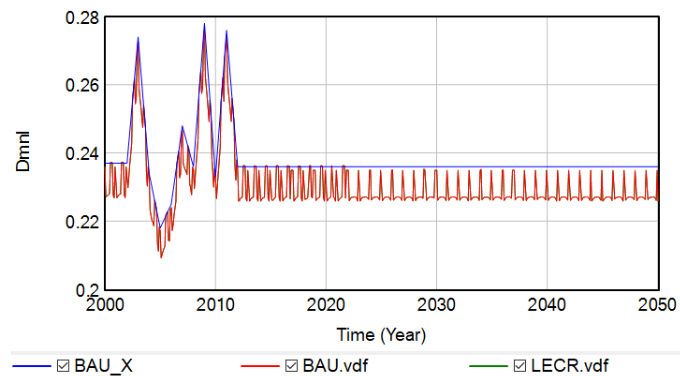

Figure 10 – Monthly variation and reduction of the load factor of fossil fuel power plants in Burkina Faso once climate impacts are included in the model

3.3 Climate resilience of the agriculture sector

As displayed in Figure 11, projected cumulative losses in Ethiopia in crop production due to climate change between 2020 and 2050 total 201.5 million tons (10.5% of maximum potential yield) in the BAU scenario. In the LECR scenario, total crop production between 2020 and 2050 is 3.6 and 211.8 million tons higher than in the BAU_X and BAU scenarios, respectively. The results imply that adaptation measures in the form of sustainable practices and expanded irrigation and their respective targets are capable of completely offsetting the negative impacts of climate change with respect to crop production in the agricultural sector.

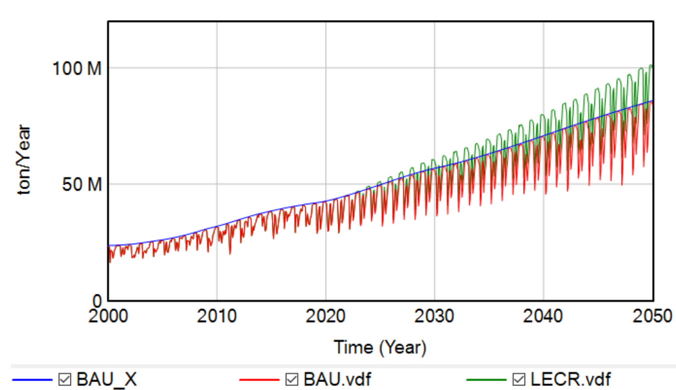

Figure 11 - Total agriculture production across all crop types and area in Ethiopia

In Burkina Faso, projected losses in crop production due to climate change between 2020 and 2050 are estimated at 59.6 million tons (13% of maximum potential yield) in the BAU scenario. The evolution of total crop production in Burkina Faso is shown in figure 11. It can be observed that climate adaptation measures, as modelled in the LECR scenario, reduce the negative impacts of climate change in the agricultural sector by bringing crop production closer to the maximum potential level in 2050. In the LECR scenario, projected losses in crop production are estimated to be much lower at 25.2 million tons (5% of maximum potential yield). Compared to the results from Ethiopia, there are two main takeaways here. Firstly, results indicate that the climate change impacts in terms of crop production losses are greater in the agriculture sector in Burkina Faso compared to Ethiopia. Secondly, the results also suggest that the national adaptation targets set by the government, while having a positive impact on addressing production losses, could be even more ambitious to fully offset the impacts of climate change. Considering that the sustainable cropping target is already set at 100% in 2050, other resilience measures, such as planting early varieties or drought-resistant crops, or less technical measures, such as improving farmers' access to high-quality mechanical equipment and climate finance, may still have room for improvement.

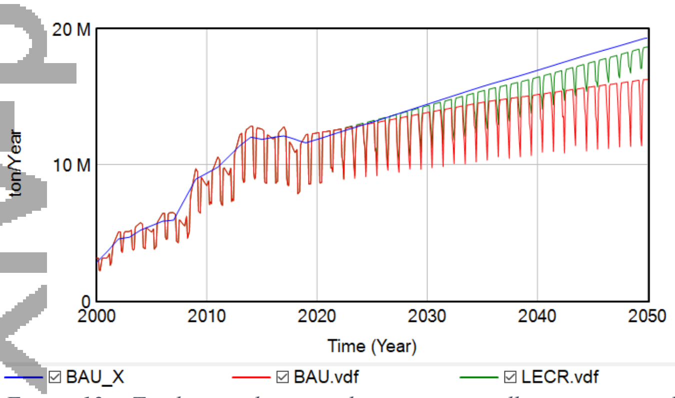

Figure 12 - Total agriculture production across all crop types and area in Burkina Faso

3.4 Socio-economic impact of climate impacts

3.4.1 Impact on Gross Domestic Product

In the BAU scenario, the total real GDP is expected to reach around USD 649 billion in 2050 with an average annual growth rate of around 7.3% between 2020 and 2050. In comparison, the BAU_X scenario estimates a GDP of USD 639 billion in 2050. This shows that impact of climate change resulting from the negative impacts in the energy and agriculture sector in Ethiopia reduces the GDP by 1.6%. In contrast, the LECR scenario projects an average real GDP growth rate of 9.07% per year between 2020 and 2050, with total real GDP reaching USD 1013 billion in 2050 (+67.1% vs BAU scenario). Between 2020 and 2050, the LECR scenario generates USD 4009 billion in cumulative additional real GDP, indicating that early action for decarbonization and climate resilience benefits overall economic growth. On average, the cumulative additional real GDP is equivalent to around USD 134 billion in added real GDP per year over 30 years.

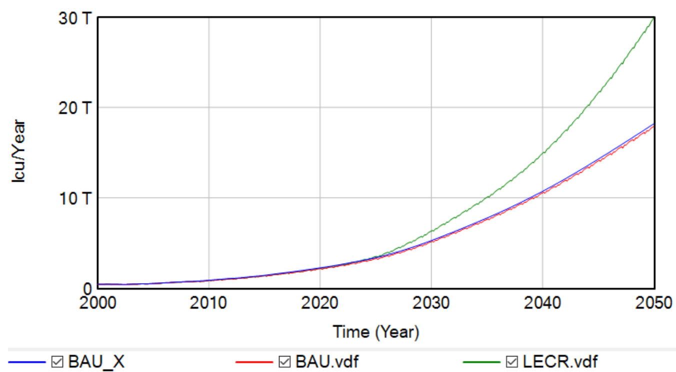

Figure 13 - Development of the total real GDP in Ethiopia for all simulated scenarios

As for Burkina Faso, the total real GDP in 2050 in the BAU scenario is expected to reach around CFA 41.22 trillion with an average annual growth rate of around 5% between 2020 and 2050. In the BAU_X scenario, the GDP in 2050 is slightly lower at CFA 40.1 trillion. As observed in the climate change impacts in the agriculture sector, the impact of climate change on the GDP of Burkina Faso is higher than in Ethiopia, with a reduction of 2.7 % in the GDP.

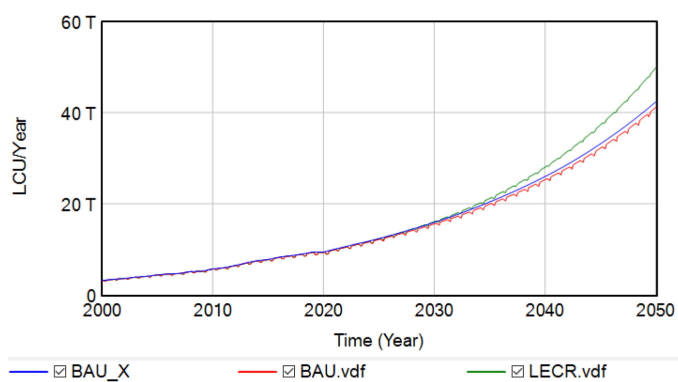

Figure 14 - Development of the total real GDP in Burkina Faso for all simulated scenarios

The LECR projects an average real GDP growth rate of 5.62% per year between 2020 and 2050, with total real GDP reaching CFA 49.93 trillion in 2050 (+21.1% vs BAU scenario). Between 2022 and 2050, the LECR scenario generates CFA 78.13 trillion in cumulative additional real GDP, indicating that the LECR scenario for decarbonization and climate resilience yields the highest benefits concerning economic growth. On average, the cumulative additional real GDP is equivalent to around CFA 2.79 trillion in added real GDP per year over 28 years.

3.4.2 Impact on total cost of low-carbon interventions

To achieve these goals, information on investment needs is essential so that governments can develop financing strategies to either increase domestic or international resource mobilization or develop innovative financing instruments. Based on the results in Ethiopia, the total cost of interventions is 8% higher in the BAU scenario compared to the BAU_X scenario. These higher costs in the BAU scenario are mainly caused by the additional fuel that needs to be used to compensate the hydropower plants during the drought. The total cost of all low-carbon measures and climate adaptation measures in the LECR scenario is 4.9 times higher than in the BAU scenario. Comparing the total cost with the share of GDP, the total cost of the measures in the LECR scenario is 7.0% of GDP, while it is 1.8% in the BAU scenario.

Table 5 - Total discounted cost (7.5% discount rate) in billion USD and share of investment as a share of GDP in Ethiopia in %

	Total cost of interventions	Additional real investment as a share of GDP
BAU_X	51.3	1.6
BAU	55.5	1.8
LECR	274.1	7.0

In Burkina Faso, the total cost of interventions is almost identical between the BAU and BAU_X scenarios. This is mainly due to the fact that in contrast to Ethiopia, the additional fossil fuel demand for electricity generation is lower in Burkina Faso, as there is less reliance on hydropower plants. In the LECR scenario, the total cost of interventions is eight times higher than in the BAU scenario. The share of investment in GDP is 1.7% in the BAU scenario, but 11.5% in the LECR scenario.

Table 6 - Total discounted cost (7.5% discount rate) in billion USD and share of investment as a share of GDP in Burkina Faso in %

	Total cost of interventions	Additional real investment as a share of GDP
BAU_X	1886.1	1.6
BAU	1897.9	1.7
LECR	15098.8	11.5

Although the additional low-emission and climate-resilient measures could account for a large share of GDP, it is important to note that there are additional benefits that are not captured by the model. For example, reducing emissions and improving air quality will improve the social well-being of the population and strengthen the economic resilience of the vulnerable share of populations. Such benefits cannot be modelled using the framework applied in this paper, but are definitely important, as discussed extensively in the literature (for example, see [8] and [9]). Another additional benefit of investing in climate-resilient measures is the creation of green jobs, which is discussed in the following section.

3.4.3 Impact on green jobs creation

The decarbonization and climate resilience targets are projected to increase the total number of green jobs in both economies and create additional green jobs compared to the BAU scenario. In Ethiopia, the LECR scenario creates 41 million green jobs between 2021 and 2050. This is 3.5 times the development in the BAU scenario. The difference between BAU and BAU_X is relatively small at 2.8%. In terms of green job creation in Burkina Faso, neglecting climate impacts (comparing BAU and BAU_X) underestimates the jobs created by only 0.05%. In the LECR scenario, over 5.8 million green jobs are created between 2021 and 2050, compared to only 3.3 million jobs in the BAU scenario.

4. CONCLUSIONS

In this paper, we explore the implications of integrating the climate dimension into a top-down macroeconomic model to assess the environmental and socioeconomic impacts of climate adaptation and mitigation policies, with a focus on the energy and agriculture sectors. For this purpose, we use the Green Economy Model (GEM) developed and applied as part of the development of the Long-term Low Emission Development Strategy (LT-LEDS) of Ethiopia and Burkina Faso.

Our results empirically demonstrate the importance of including climate impacts when modelling long-term development scenarios, assessing their GHG emissions and economic growth implications. For example, under a business-as-usual scenario, neglecting climate impacts overestimates GDP growth by between 1.6% and 2.7% in both countries. In terms of green job creation, depending on the extent of climate change impacts, there is a discrepancy of up to 2.8% in total green job creation when climate impacts are taken into account. In terms of sectoral outputs, Ethiopia's power sector is highly vulnerable to climate change due to its reliance on hydropower generation. According to climate projections, annual electricity generation is expected to decline by 4% to 12% between 2020 and 2050 due to fluctuating rainfall and droughts. As for the agricultural sector, crop production declines by 10.5% in Ethiopia and 13% in Burkina Faso, indicating that the negative impacts of climate change are somewhat more severe in Burkina Faso.

Although the impacts of climate change are apparent in both countries, the modelled climate adaptation actions and their targets can largely offset the negative impacts of climate change and improve resilience in both sectors. While the actions and ambitious targets set in the agriculture sector in Ethiopia seem to be adequate to overcome the negative impacts, there is still room for more ambitious climate adaptation target in Burkina Faso to completely counteract climate impacts. However, it is important to mention that all these improvements are achieved all while generating high economic growth and creating more green jobs. As further work, we propose an extended cost-benefit analysis of the scenarios to further justify the need to invest in long-term low-emission and climate-resilient development.

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