Climate-Resilient Landscapes for Sustainable Livelihoods in Northern Ghana

ANNEX 3

ECONOMIC FEASIBILITY ANALYSIS

APPENDIX B

UN environment

United Nations
Environment Programme

Contents

List of Figures *3*

List of Tables *3*

Glossary *4*

Executive Summary *6*

1 Introduction *8*

2 Sustainable Asset Valuation (SAVi) *10*

2.1 Importance of Systems Thinking **10**

2.2 Causal Loop Diagram **10**

2.3 Climate Data Analysis **13**

2.4 Spatially Explicit Analysis **16**

2.4.1 Methodology 16

2.4.2 Results 18

2.5 Integrated Cost-Benefit Analysis **19**

2.5.1 Methodology 19

2.5.2 Scenarios 20

2.5.3 Integrated CBA 20

3 Results *28*

3.1 Results by intervention scenario **28**

3.2 Results by climate scenario **29**

3.3 Results by area **30**

4 Conclusions *42*

5 References *44*

Appendix A. Estimation of climate indicators and extreme events *45*

List of Figures

Figure 1: Causal Loop Diagram of the dynamics identified for the Ghana assessment 12
Figure 2: Extreme dry percentile 13
Figure 3: Extreme wet percentile 14
Figure 4: Average monthly temperature 14
Figure 5: Average precipitation (2000-2020), SSP3 scenario 15
Figure 6: Average precipitation (2040-2060), SSP3 scenario 15
Figure 7: LULC Current (Jirapa Municipal, Lambussie Karni, Lawra Municipal, and Wa West districts).....16
Figure 8: LULC Current (Binduri, Garu, Mamprusi East, and Yunyoo-Nasaun districts)............................17
Figure 9: LULC Restored (Jirapa Municipal, Lambussie Karni, Lawra Municipal, and Wa West districts) ..17
Figure 10: LULC Restored (Binduri, Garu, Mamprusi East, and Yunyoo-Nasaun districts) 17

List of Tables

Table 1. Spatial analysis results 18
Table 2: Methodologies to quantify selected indicators – Example from the CBA of Lambussie 21
Table 3: CBA indicators used for four locations (Lambussie, Wa West, Lawra, and Jirapa) 27
Table 4: Results of the CBA, BCR (Discounted and Undiscounted) and IRR, by location and scenario. 33
Table 5: Cost-benefit statement (undiscounted) - Lambussie 34
Table 6: Cost-benefit statement (undiscounted) - Lawra..35
Table 7: Cost-benefit statement (undiscounted) - Jirapa 36
Table 8: Cost-benefit statement (undiscounted) – WA West 37
Table 9: Lambussie – Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario ...38
Table 10: Lawra – Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario 39
Table 11: Jirapa– Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario 40
Table 12: WA West – Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario ...41

Glossary

Deep uncertainty: "A situation in which analysts do not know or cannot agree on (1) models that relate key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the value of alternative outcomes" (Hallegatte et al., 2012)

Discounting: A finance process to determine the present value of a future cash value.

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Program [UNEP], 2014).

Internal Rate of Return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST): "A suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people" (Natural Capital Project, 2019)

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits: The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.

Net Present Value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Optimization: A stream of modelling that aims to identify the policy or set of policies that deliver the best possible outcome from a set of alternatives, given a set of criteria (i.e., parameters to optimize) and/or constraints (i.e., available budget) (UNEP, 2014) .

Robust decision: A decision that produces favorable outcomes under a range of possible scenarios (Hallegatte et al., 2012)

Scenarios: Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

Sustainable Internal Rate of Return (S-IRR): An indicator of the net benefit prospects of a potential investment. The S-IRR is the discount rate that makes the net present value of benefits from a particular project equal to zero.

Sustainable Net Present Value (S-NPV): The difference between the present value of benefits and avoided costs net of financing costs and the present value of cash outflows. It is used to analyze the net value of a projected investment or project.

Executive Summary

Northern Ghana faces escalating climate impacts, including shifting rainy seasons, river flooding induced by the Bagre hydropower dam, flash floods, and water scarcity. To mitigate these challenges and enhance resilience, we collaborated with UNEP and local stakeholders to analyze Nature-Based Infrastructure (NBI) and Hybrid Scenarios in the region. Our analysis, co-developed with UNEP and local government counterparts, utilized an Excel-based model and spatial tools. The model, validated through a Causal Loop Diagram, incorporated data from project partners to ensure a localized and comprehensive understanding of the region's vulnerabilities and opportunities. Furthermore, the model also provides the capability to analyze the effectiveness of interventions across different climate scenarios.

In order to analyze the impacts of interventions on increasing climate resilience in northern Ghana, scenario analysis is employed. The results show that, without intervention, the baseline scenario portrays escalating vulnerabilities, including increased infrastructure damage, higher emergency aid requirements, and exacerbation of water scarcity due to environmental degradation. The cumulative damages of extreme weather events, when considering the SSP3 climate scenario up to 2050, are estimated to be considerable, with WA West reaching a value of USD 215.9 million, followed by Lawra (USD 160.3 million), Lambussie (USD 155.4 million) and Jirapa (USD 148.6 million). In the NBI and Hybrid scenarios, the adoption of reforestation, climate-smart agriculture, and restoration measures (affecting a total of 12,000 hectares across the four districts) enhance resilience by maintaining income, reducing environmental encroachment, and combating food insecurity and malnutrition. For Lambussie, the climate impacts in the SSP3 scenario decline to USD 60.7 million (instead of 67.2 million by 2050, in both the NBI and Hybrid scenarios) in relation to flood damages to agriculture; USD 43.0 million (NBI scenario) and USD 13.4 million (Hybrid scenario) for drought damages (instead of USD 53.8 million in the Reference case). In addition to the reduction of damages, the NBI and Hybrid scenarios generate income from the implementation of the investment, specifically from tree planting and the adoption of new agriculture practices, (USD 0.27 million) and from agroforestry (USD 2 million). These avoided costs and additional benefits emerge as a result of a total investment and O&M cost of USD 11.2 million (NBI scenario) and USD 16.7 million (Hybrid scenario). Similar cost reductions, and added benefits emerge for other locations in the NBI and Hybrid scenarios. For instance, the NBI and Hybrid scenarios generate cumulative undiscounted net benefits in the range of USD 13.2 million and USD 46.3 million across climate scenarios in the case of Lawra. These values increase to USD 19.6 million and USD 55.3 million in the case of WA West.

The NPV of the project, considering all districts, reaches USD 22.4 million (SSP1), USD 18.4 million (SSP3) and USD 23.5 million (SSP5) in the NBI scenario; the Hybrid scenarios results instead in an NPV of USD 68.8 million (SSP1), USD 58.8 million (SSP3) and USD 68.5 million (SSP5).

The results of the analysis also show that the investments considered (both the NBI interventions and irrigation) are economically viable. The discounted Benefit to Cost Ratio (BCR) (using a 6.5% discount rate), estimated for the period 2024 – 2050 ranges between 1.55 and 2.36 for Lambussie, 1.63 and 2.59 for Lawra, 1.65 and 2.62 for Jirapa, 2.05 and 2.95 for WA West. The Internal Rate of Return (IRR) instead ranges overall, across all locations, between 17.4% and 37.9% (worth considering, the current central bank interest rate is 29%, and inflation is expected to decline to 6%-10% by 2030 [1]). Concerning the financial analysis, when only the avoided costs of floods (to buildings and agriculture) and droughts (to agriculture) are considered, together with the additional revenues from agroforestry, in the case of Lambussie and for the SSP3 climate scenario (the one resulting in the lowest returns across all climate scenarios and all locations) the BCR would decline from 1.55 to 1.31 in the NBI scenario, and the IRR would decline from 17.4% to 12.8%.This highlights the relevance of the indicators excluded in the financial analysis, namely the value of loss of life, cost of malnutrition, and value of carbon sequestration.

Concluding, these result indicate that the investments proposed are both economically and financially viable, and generate considerable societal benefits. The following key messages emerge from the analysis:

Prioritize Hybrid Solutions:

Given the higher Benefit-to-Cost Ratio (BCR) of the Hybrid Scenario, policymakers and investors should prioritize interventions that integrate both nature-based and technological solutions. This approach, especially focusing on improving water supply, demonstrates a strong potential for maximizing economic returns while fostering climate resilience.

Invest in Nature-Based Infrastructure:

Allocate resources towards Nature-Based Infrastructure (NBI) interventions, acknowledging their positive economic and financial performance. Reforestation, restoration, and climate-smart agriculture contribute not only to environmental sustainability but also to economic gains, showcasing a balanced approach that aligns with sustainable development goals.

Community-Based Adaptation:

Integrate community-based adaptation strategies into policy initiatives and project implementation. Empower local communities to actively participate in and benefit from nature-based interventions, ensuring that interventions align with their needs, and fostering a sense of ownership and sustainable practices.

Promote Adaptive Management:

Embed adaptive management principles into policy frameworks and project implementation. Recognize the dynamic nature of climate impacts and the evolving effectiveness of interventions, over time and across climate scenarios. Regularly monitor, evaluate, and adjust policies to align with emerging challenges and opportunities, ensuring a responsive and iterative approach.

[1] The IMF World Economic Outlook (October 2023) forecasts inflation at 42.2% in 2023, 23.16% in 2024, 11.5% in 2025, and 8% from 2026 onward. Accessed on April 24, 2024: https://www.imf.org/en/Publications/WEO

1 Introduction

Many of the four million residents in northern Ghana, where agriculture sustains 70% of the population, are struggling with increased impacts of climate change. Shifts of the rainy season have shortened farmers' windows to grow crops before river flooding. At the same time, prolonged dry seasons and droughts decrease agricultural production. As increased flooding and more intense rainfall pose challenges, stakeholders in Northern Ghana are exploring solutions to enhance the climate resilience of vulnerable smallholder farming communities, improve food security and bolster the agro-based rural economy.

The population in northern Ghana experience floods as a result of an overflowing hydropower dam, river floods caused by prolonged rainfall, and heavy rains that exceed the landscape's water retention capacity and lead to flash floods:

- The Bagre hydropower dam is located near Barge Village in Burkina Faso and manages the flow of the White Volta, a waterway that flows through Northern Ghana before emptying into Lake Volta. With increased upstream rainfall, dam spilling has made flooding along the White Volta "longer and more extreme compared to the 10 years before" (Lugt et al., 2023, p. 9). For example, in August 2020, Bagre Dam spilling induced floods that washed away the access road to the bridge over the White Volta River.
- Fluvial flooding, or overflow flooding along rivers due to heavy and prolonged rainfall, affects communities along the White Volta, Black Volta, and Oti rivers and their tributaries.
- The third type of flooding experienced is pluvial flooding, or flash floods caused by severe and heavy rainfall. In August 2021, the norther Ghana experienced severe pluvial flooding, damaging main roads and leaving multiple districts inaccessible from the rest of the country.

This has resulted in the destruction of crops and livestock, damaged roads and houses, and human casualties and drownings. Agricultural fields near the White Volta have been inundated during floods. Increased rainfall has also caused breaches in poorly constructed and maintained local dams and dugouts, cutting off roads and undermining efforts of One Village One Dam, a government initiative to construct ten dams in each constituency in the Northern Regions.

Without intervention, climate change scenarios indicate that all three types of flooding (Bagre spilling, fluvial and pluvial floods) will become more severe by 2050 and 2100 (Lugt et al., 2023, p. 36). To address these challenges, the Ghanian Environmental Protection Agency (EPA), the Ministry of Environment, Science, Technology and Innovation (MESTI), and the UN Capital Development Fund are submitting a proposal to the Green Climate Fund (GCF). The proposal aims to support smallholder agroecological systems in northern Ghana through landscape restoration, climate-resilient agriculture, and flood-based farming. This proposal focuses on eight out of Northern Ghana's 42 districts: Jirapa Municipal, Lambussie Karni, Lawra Municipal, Wa West, Binduri, Garu, Mamprusi East and Yunyoo-Nasaun.

The project will benefit 120,000 (56,400 men and 63,600 women) and is expected to strengthen 12,000 hectares of smallholder agroecosystems strengthened in response to climate change. Direct beneficiaries represent about 15% of the total population of the eight districts and approximately 3% of the people in northern Ghana. The rest of the population of these Districts, about 800,000 people will benefit indirectly through landscape-level ecosystem benefits.

In preparation for the GCF proposal, UNEP commissioned a report for adaptation measures. The report emphasizes non-structural measures, including the improvement of early warning systems through communication between authorities in Ghana, Burkina Faso, and affected communities. It also identifies the need for more accurate forecasting models and better early warning infrastructure. On the district level, potential adaption measures are in the form of grey infrastructure, including dredging along the White Volta which is "at best only temporal" due to Bagre Dam spills and sedimentation (Lugt et al., 2023, p. [Page 5])). Other grey infrastructure includes flood-proofing roads and bridges, culverts and road drains to direct water flows to agricultural fields, better flood zone management, and climate-smart crop varieties to prevent crop loss during the rainy season.

At the farm level, a variety of nature-based solutions or nature-based infrastructure can be implemented, including reforestation efforts through tree planting to reduce soil erosion and increase infiltration capacity and establishing riparian buffer zones along the riverside to reduce flood impacts (Lugt et al., 2023). Encouraging the adaptation of flood-based farming measures to store flood water to be used during dry spells and drain the land after rainfall or floods will preserve agricultural production.

This Sustainable Asset Valuation (SAVi) analyzes the economic, social and environmental outcomes of investing in the nature-based interventions for climate adaptation. The quantification and valuation of benefits can inform the funding proposal for the GCF and support scaling up NBI for climate resilience in northern Ghana. We assessed two adaptation scenarios, based on the analysis of solutions by Lugt et al. (2023) and priorities of project stakeholders:

- **Nature-based adaptation:** Implementation of riparian forests along the rivers as flood buffer zones, tree planting / agroforestry, and climate smart agriculture with measures such as halfmoons, improved tillage practices and soil management, and on-farm water retention.
- **Hybrid adaptation:** NBI + conventional water storage and irrigation
- All scenarios are relative to a **reference scenario** with flood damages, floodplain farming, and (increasing) river dredging. The baseline includes impacts of climate change.

2 Sustainable Asset Valuation (SAVi)

2.1 Importance of Systems Thinking

In analyzing the impacts of interventions and increasing climate resilience in northern Ghana, the approach of systems thinking is utilized. Systems thinking is a holistic approach that considers the interconnectedness of various factors within a system. By applying this methodology, the study examines how different indicators and variables within the system interact with one another.

Systems thinking allows for an analysis of the complex relationships and interdependencies between key indicators related to climate resilience in northern Ghana. It considers factors such as rainfall patterns, temperature changes, agricultural practices, water availability, infrastructure, and socio-economic aspects. By understanding these interconnections, we can develop a more comprehensive and nuanced understanding of the system.

Through systems thinking, we can identify the key drivers and dynamics that influence the climate resilience system in northern Ghana. Key drivers could include factors such as deforestation, population growth, urbanization, and policy frameworks. Dynamics refer to the interactions and feedback loops within the system that lead to certain behaviors or outcomes. By unraveling these key drivers and dynamics, the study gains insights into the underlying causes and mechanisms shaping the climate resilience system.

The application of systems thinking enhances the understanding of the climate resilience system in northern Ghana by capturing the complexity and interconnectedness of the various components. It offers a more holistic perspective, recognizing that changes in one aspect of the system can have cascading effects on other elements. This improved understanding allows for a more accurate assessment of the potential impacts of interventions and the overall effectiveness of climate resilience strategies.

By analyzing the system using systems thinking, the study can identify policy entry points. These are areas or aspects within the system where interventions or policies can have the greatest impact. Systemic understanding allows for a more strategic approach to policy formulation, as it unveils the leverage points and areas where interventions can be most effective in enhancing climate resilience. By identifying these entry points, policymakers can prioritize and target their efforts, maximizing the efficiency and effectiveness of policy interventions.

In summary, by employing systems thinking, the study gains a more comprehensive understanding of the climate resilience system in northern Ghana. This approach helps identify the interconnectedness of key indicators, uncover key drivers and dynamics, and ultimately identify the most impactful policy entry points to enhance climate resilience in the region.

2.2 Causal Loop Diagram

The development of a Causal Loop Diagram (CLD) played a pivotal role in strategically understanding the intricate dynamics of the northern Ghana context. This visual representation facilitated a comprehensive exploration of the causal relationships between key variables, providing a foundation for subsequent model development. It was developed in collaboration with UNEP and local stakeholders and served as a holistic tool, enabling the integration of diverse elements that contribute to climate resilience. By visualizing the complex interconnections, it enhanced our understanding of how various factors influence one another, guiding the subsequent development of a nuanced and context-specific model. The CLD resulting from this process is presented in Figure 1.

A significant aspect of the CLD was dedicated to water dynamics, encompassing variables like agriculture water availability, runoff, and the occurrence of floods. Understanding these intricacies was essential for comprehending the impact of climate pressures on water resources and, subsequently, on agricultural practices and overall resilience. For instance, reinforcing loops (R1) and (R2) depict the dynamics of continued soil erosion as a consequence of reduced water retention, caused by land conversion and sedimentation during flood events. Increased sedimentation, in turn, leads to higher water runoff and faster water flow, exacerbating the loss of water retention capacity, further driving soil loss and flooding. The runoff from the Bagre dam was explicitly included, as this is one factor that is not under Ghana's control but puts crop production as well as people living by the riverside at risk.

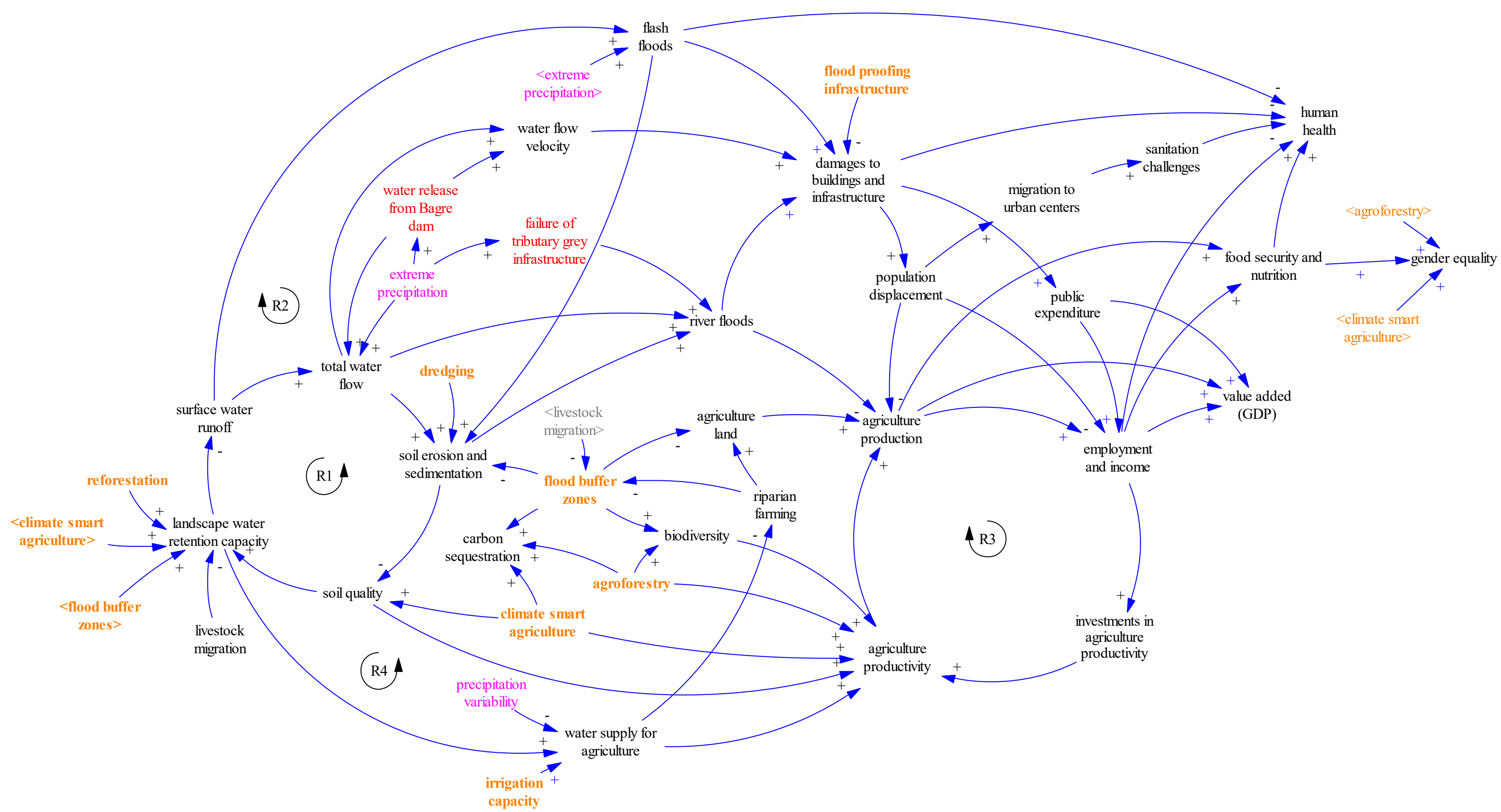
Reinforcing loop (R3), on the other hand, illustrates how crop production and income generated maintain the ability to invest in continued production. The CLD placed a spotlight on critical areas such as crop production, recognizing it as a cornerstone of the region's livelihood. Emphasis was given to variables encompassing cropland, total crop production, and their intricate relationships with land use and climate dynamics. This focus allowed for a nuanced exploration of the vulnerabilities and opportunities within the agricultural sector. By incorporating variables related to total crop production, the CLD provided a dynamic perspective on the agricultural output. It considered the interactions between climate dynamics, land use practices, and their collective impact on the overall crop yield.

Of particular interest to UNEP was reinforcing loop (R4), which captures the increased encroachment of riparian areas for farming because of inland water scarcity. Driven by lack of water, farmers move to the riverbank to establish farmland, increasing the vulnerability of riverbanks to erosion during flood events. The CLD delved also presents the complexities of agricultural water availability, recognizing its pivotal role in sustaining crop production. By examining the variables influencing water availability, the diagram shed light on how climate impacts and land use practices collectively shape the region's water dynamics. Therefore, the CLD captures land and climate dynamics influencing crop production. This comprehensive approach facilitated a nuanced exploration of how changes in climate patterns and land use practices interact to shape the region's agricultural landscape.

Variables related to runoff and floods were key components of the water dynamics focus. The CLD provided insights into how climate pressures exacerbate these phenomena, contributing to challenges such as flash floods and water scarcity during peak precipitation events. For this purpose, the CLD incorporated variables related to damages to infrastructure, recognizing the economic repercussions of climate-induced events. Understanding the relationships between climate impacts, water dynamics, and infrastructure damage was crucial for assessing the overall economic vulnerability of the region.

In addition to the above, we identified value added and household income as a critical economic indicator. By understanding the factors influencing income, including crop production and damages to infrastructure, the diagram provided a pathway to assess the economic resilience of communities in the face of climate impacts. The CLD encompassed variables related to value-added processes, providing insights into the economic contributions of agriculture and associated activities. This holistic approach allowed for a comprehensive examination of how economic value is generated and influenced by climate dynamics.

Figure 1: Causal Loop Diagram of the dynamics identified for the Ghana assessment



2.3 Climate Data Analysis

Climate data considered in this analysis are based on the Shared Socioeconomic Pathways (SSPs) scenarios. The SSPs defines different baselines that might occur based on various underlying factors like population, technological and economic growth, which may lead to different future GHGs emissions and warming outcomes (Carbon Brief, 2018). The SSPs are based on various narratives describing broad socio-economic trends that can shape future societies. Specifically, this study considers the following SSPs, as described by Meinshausen et al (2020):

- SSP1-2.6 or "2◦C scenario", corresponds to the RCP2.6 scenario, where global temperatures are expected to increase by 2◦C by 2100
- SSP3-7.0 is a medium-high reference scenario
- SSP5-8.5 correspond to a high reference scenario in a high-fossil fuel use world throughout the 21st century

Figure 2 shows the extreme dry percentile from 2000 to 2100 under different SSPs scenarios from 2000 to 2100. Climate data suggest that the extreme dry percentile will remain stable under all climate scenarios. At the same time, *Figure* 3 shows the extreme wet percentile from 2000 to 2100 under the same SSPs scenarios from 2000 to 2100. Here, the SSP5-8.5 scenario shows an increase in wet conditions. This result further suggests that under this climate scenario drier conditions will be less frequent, while wetter weather will be more common. Therefore, it is possible that the frequency and intensity of flood risk will increase in the study area.

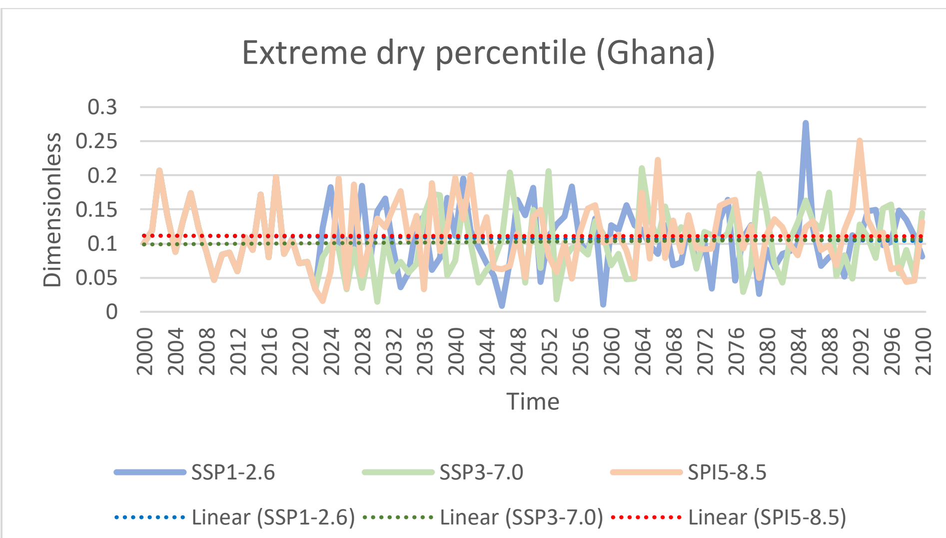


Figure 2: Extreme dry percentile

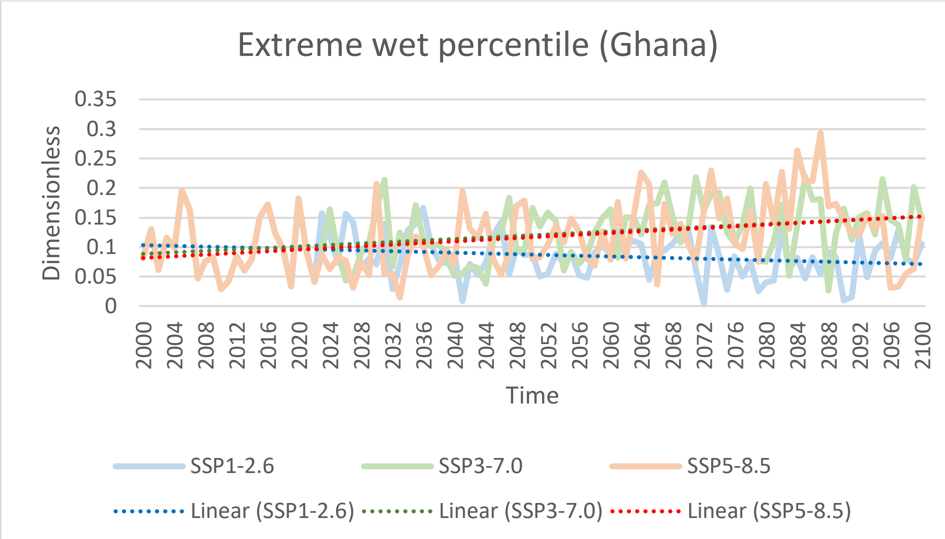


Figure 3: Extreme wet percentile

Figure 4 shows the average monthly temperature (°C) in the study area from 2000 to 2100 under the three different SSPs scenarios. The trends are similar under all three SSPs scenarios until 2050, after which they bifurcate. In the SSP1-2.6, monthly temperature remains relatively constant throughout the decades between 2050 and 2100. In the SSP3-7.0 and SSP5-8.5 scenarios, average monthly temperature increases by roughly 2°C compared to 2050, or 3°C compared to 2000. The increase in temperature after 2050 will cause a decline in crop yields, given that air temperatures will increase further above the optimal temperature range for many crops. It may also increase the frequency and intensity of heatwaves, threatening human health.

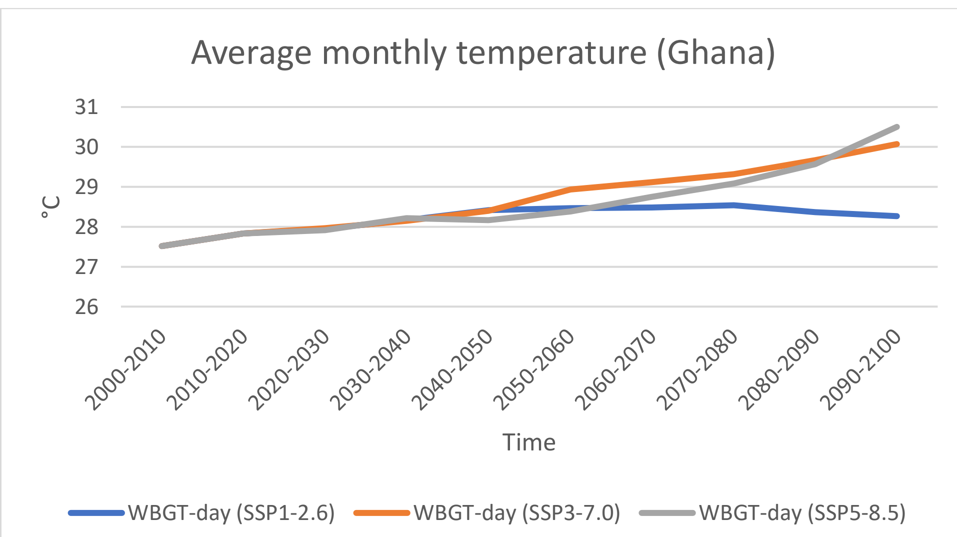


Figure 4: Average monthly temperature

Figure 5 shows in a box plot the average precipitation (mm/month) in the study area for the period 2000 to 2020 under the SSP5-3 scenario, while *Figure* 6 shows the same variables but for the period 2040-2060. The results suggest that the average precipitation estimated for the period 2040 to 2060 from January to

March will be lower, and that variability will increase in the central months of the year, where most of the precipitation will be concentrated. This means that precipitation patterns are expected to experience changes in the future, potentially leading to wetter conditions during certain months of the year, with a higher probability of extreme events.

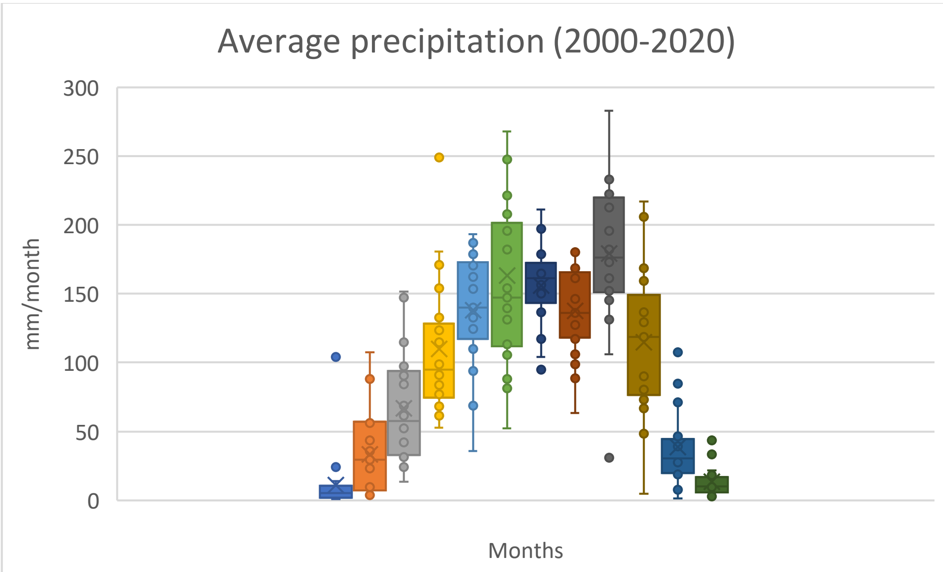


Figure 5: Average precipitation (2000-2020), SSP3 scenario

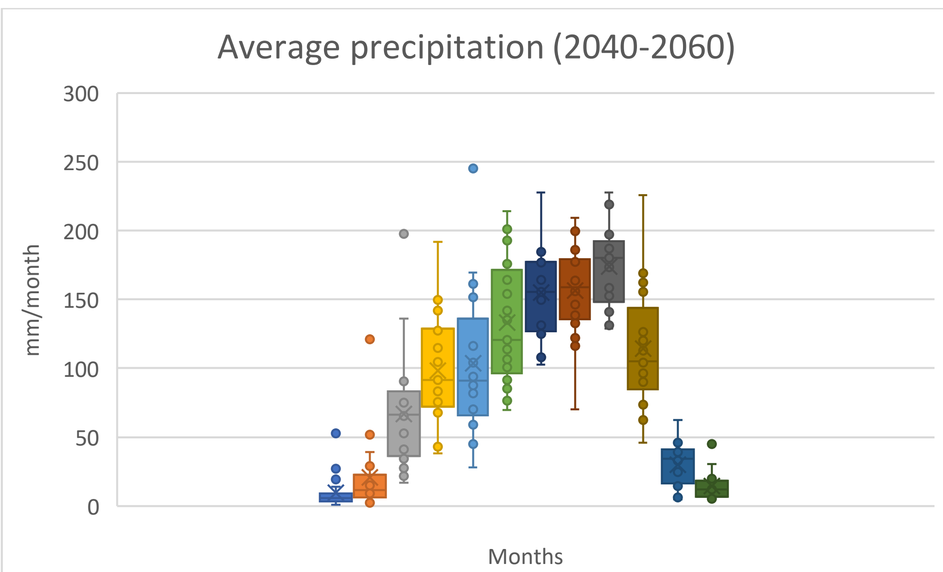


Figure 6: Average precipitation (2040-2060), SSP3 scenario

2.4 Spatially Explicit Analysis

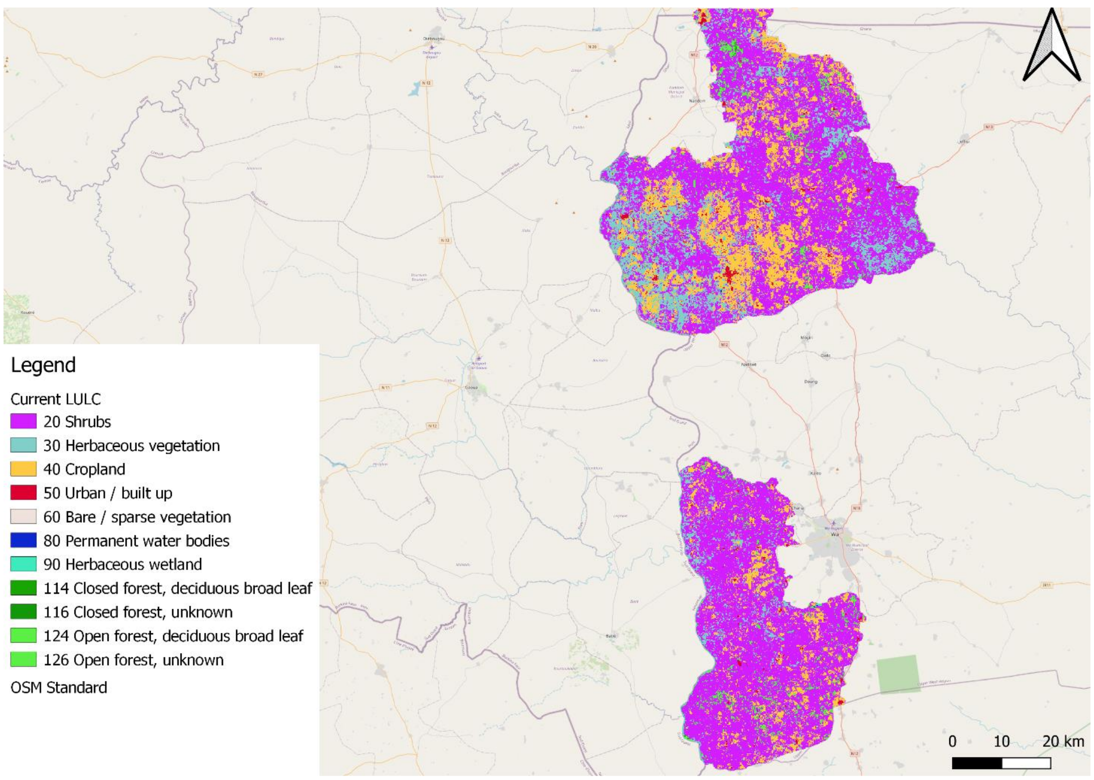
2.4.1 Methodology

The spatially explicit analysis performed for this assessment relies on the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) suite of models[2]. These models, developed by the Natural Capital Project, use land-use/land cover maps as input and quantify a wide range of ecosystem services.

For this assessment, we used the Moderate Dynamic Land Cover map created by the Copernicus Global Land Operations[3] with a resolution of 100m. The area of interest was extracted from this map and its resolution was increased to 1m in QGIS 3.8.0.

Figure 7 and Figure 8 show the Current LULC (Current). We then considered a second scenario (Restored Scenario, shown in Figure 9 and Figure 10) where the project is expected to strengthen 12,000 hectares of smallholder agroecosystems in response to climate change.

Figure 7: LULC Current (Jirapa Municipal, Lambussie Karni, Lawra Municipal, and Wa West districts)



[2] https://naturalcapitalproject.stanford.edu/software/invest
[3] https://land.copernicus.eu/global/sites/cgls.vito.be/files/products/CGLOPS1_PUM_LC100m-V3_I3.4.pdf)

Figure 8: LULC Current (Binduri, Garu, Mamprusi East, and Yunyoo-Nasaun districts)

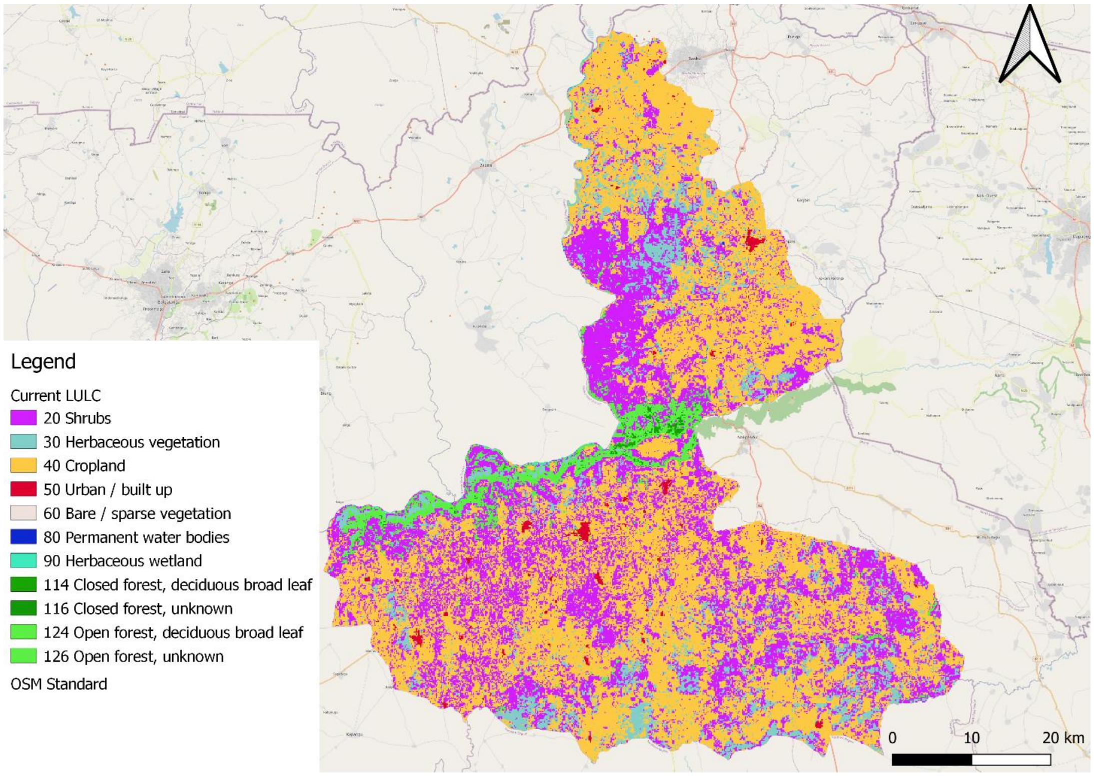


Figure 9: LULC Restored (Jirapa Municipal, Lambussie Karni, Lawra Municipal, and Wa West districts)

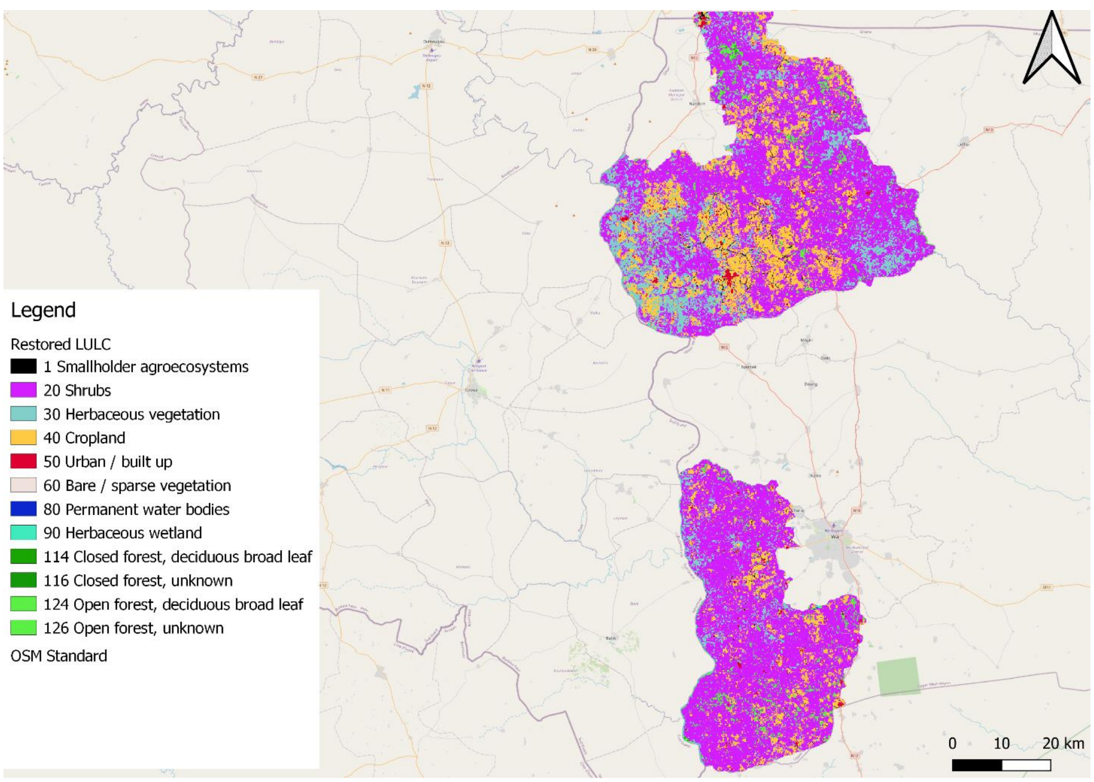
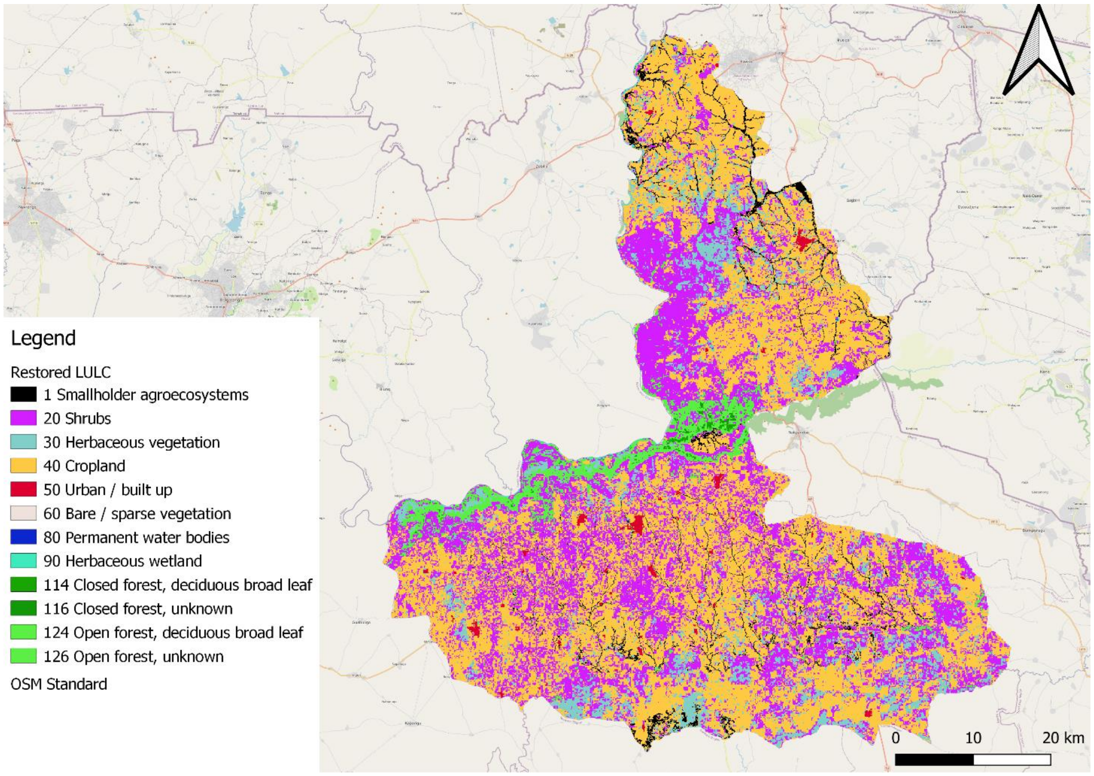


Figure 10: LULC Restored (Binduri, Garu, Mamprusi East, and Yunyoo-Nasaun districts)



2.4.2 Results

The results of six InVEST models are presented. First, the Carbon Storage model calculates the amount of carbon stored in the landscape. Second, the Water Yield model estimates the annual average quantity of water produced by one or more watersheds found in the study area. Third, the habitat quality model estimates changes in disturbances to habitat, defined using a unitless index that ranges from 0 to 1, where 0 represents no habitat, and 1 is the highest quality habitat. Next, the Urban Flood Risk mitigation calculates the runoff reduction, which is the amount of runoff retained per pixel compared to the storm volume, when land cover changes. Fifth, the Sediment Delivery Ratio (SDR) model quantifies the avoided erosion in the landscape. Lastly, the Cooling model calculates the change in temperature due to modifications in land use.

Table 1 shows the changes in of selected ecosystem services, when transitioning from the Current to the Restored LULC scenario.

Table 1. Spatial analysis results

LULC Scenario	Carbon Storage (ton)	Water Yield Volume (m3)	Habitat Quality (mean)	Runoff Retention (m3)	Sediment export (tons)	Temperature (degC)
Restored vs Current	171,630	(2,052,553)	0.00019	1,824,573	557	-0.00018

These results suggest that landscape restoration not only increases carbon storage, but it also reduces sediment export, impacting positively on agricultural production by reducing soil erosion. Further, land cover change increases runoff retention and reduced water yield (e.g. by 34% when converting agriculture or base land to forest or agroforestry), resulting in lower flood risk and flood damage to agriculture and infrastructure (Manashi, 2016). These are considerable impacts, especially for the livelihoods of small communities.

Additional impacts include improved habitat quality and temperature mitigation. On the other hand, these are relatively small when compared to the improvement in other ecosystem services. This is because habitat quality and temperature mitigation are estimated by the model using a larger area (i.e. the area of each district), rather than considering the hectares in which the project is implemented. As a result, the 12,000 ha impacted by the project represent a very small area when compared to the districts analyzed.

2.5 Integrated Cost-Benefit Analysis

2.5.1 Methodology

The study utilizes an Excel spreadsheet-based model and spatial modeling tools to analyze the current and future impacts of climate resilience interventions across different scenarios. The modelling analysis was performed for 4 districts, namely Lambussie, Wa West, Lawra, and Jirapa. The alternative scenarios, considering the implementation of NBI interventions, include reforestation (3,000 hectares in total, 750 hectares per district), restoration of riparian buffer zones (3,000 hectares in total, 750 hectares per district), agroforestry practices (2,000 hectares in total, 500 hectares per district), and the adoption of climate-smart agriculture techniques (4,000 hectares in total, 1,000 hectares per district), for a total of 12,000 hectares.

Excel allows for the integration and manipulation of data, facilitating the analysis and interpretation of complex systems. Spatial modeling tools help incorporate geographic data and visualize the spatial distribution of the impacts and outcomes.

The structure of the Excel model is based on and includes key indicators used in the CLD, which is developed and validated in collaboration with local project counterparts. The model's structure captures these interconnections to simulate the dynamics of the climate resilience system in northern Ghana.

To ensure that the modeling results are as close to the local reality as possible, the Excel model is developed using data provided by local stakeholders. These stakeholders may include farmers, community representatives, government agencies, and non-profit organizations with expertise in climate resilience and related fields. Collaborative data collection ensures that the model reflects the local context and accurately represents the specific challenges and opportunities in northern Ghana.

While the primary focus is on using local data, certain information may not be available at the local level. In such cases, the study obtains data from national statistics and conducts a comprehensive literature review. National statistics provide broader insights and macro-level data, while the literature review enables the incorporation of existing scientific research, best practices, and case studies from similar regions or contexts. This ensures a robust analysis that leverages both local and wider knowledge.

By utilizing an Excel model and spatial modeling tools and basing its structure on a CLD, we can analyze the impacts of interventions more holistically and assess the dynamics of the climate resilience system. Incorporating data from local stakeholders, national statistics, and literature review guarantees that the modeling results accurately represent the local reality in northern Ghana. This integrated approach enhances the reliability and applicability of the study's findings and supports evidence-based decision-making processes.

2.5.2 Scenarios

In order to analyze the impacts of interventions on increasing climate resilience in northern Ghana, scenario analysis is employed. This approach helps compare the outcomes of different interventions with the baseline situation. The study considers three scenarios to assess the potential impacts of interventions. These scenarios are the Reference scenario, the Nature-Based Infrastructure (NBI) scenario, and the Hybrid scenario.

The **Reference scenario** represents the baseline situation wherein no action is taken to address challenges related to extreme weather events. In this scenario, increased encroachment of riverbanks, higher occurrences of flash floods, significant loss of crops, and damage to infrastructure due to inadequate preparedness are expected.

The **NBI scenario** assumes interventions that focus on nature-based solutions for enhancing climate resilience, with targeted interventions in areas that would deliver the most benefit in relation to climate resilience. These interventions entail activities such as reforestation (3,000 hectares in total, 750 hectares per district), restoration of riparian buffer zones (3,000 hectares in total, 750 hectares per district), agroforestry practices (2,000 hectares in total, 500 hectares per district), and the adoption of climate-smart agriculture techniques (4,000 hectares in total, 1,000 hectares per district). The purpose of these interventions, affecting a total of 12,000 hectares is to restore natural ecosystems, improve land management practices, and enhance the resilience of agricultural systems to changing climatic conditions.

The **hybrid scenario (NBI + irrigation)** incorporates the interventions assumed in the NBI scenario while also adding additional measures. In addition to reforestation, restoration of riparian buffer zones, agroforestry, and climate-smart agriculture practices, this scenario includes the implementation of irrigation systems and conventional water storage systems. These supplementary interventions are aimed at addressing water scarcity during the dry season and improving water management for agricultural purposes.

By comparing the impacts of these different scenarios, the study aims to evaluate the effectiveness of the NBI approach and the potential added benefits of implementing the hybrid scenario. This analysis provides insights into the economic and financial viability of different strategies for increasing climate resilience in northern Ghana and inform decision-making processes regarding future investments.

2.5.3 Integrated CBA

The study utilizes an integrated cost benefit analysis (CBA) to assess the economic feasibility and provide insights into the benefit-to-cost ratio of the intervention scenarios. CBA is a method that systematically compares the costs and benefits associated with different interventions. In this case, it helps evaluate the economic viability of the interventions aimed at increasing climate resilience in northern Ghana.

The integrated CBA considers several factors, including the additional investment required for implementing the intervention scenarios, the avoided costs resulting from the interventions, and the additional benefits compared to the baseline (Reference) scenario. By accounting for these factors, the analysis provides a comprehensive picture of the potential economic outcomes of the intervention strategies.

The CBA quantifies a range of indicators to assess the economic benefits and costs associated with the intervention scenarios. These indicators are important for understanding the potential impacts and informing decision-making. The following indicators have been quantified, and the approach used to calculate them is presented in Table 2 (with values reflecting the case of Lambussie):

- **Avoided Flood Damage**: The CBA assesses the reduction in flood damage to agriculture, infrastructure, and buildings that can be achieved through the intervention scenarios. It quantifies the economic value of avoided damages, considering factors such as crop loss, damage to infrastructure, and repair costs.
- **Avoided Drought Damage**: The analysis quantifies the potential increase in agricultural production resulting from interventions that improve water availability. It evaluates the economic value of additional crop yields and market value.
- **Income from Job Creation**: The analysis considers the potential job creation resulting from the interventions. It quantifies the number of jobs created and evaluates the economic impact of employment generation.
- **Value of loss of life from flooding**: the CBA considers the Value of Statistical Life in USD per the average annual deaths from flooding, and estimates the avoided costs of life saved by the interventions.
- **Malnutrition:** Improved nutrition from increased agricultural production and enhanced food security is examined. The CBA quantifies the health benefits associated with improved nutrition.
- **Carbon Storage and Avoided Emission Costs**: The CBA assesses the carbon storage potential of interventions, such as reforestation and agroforestry, and estimates the avoided costs of offsetting/reducing emissions through other projects. It quantifies the economic value related to carbon sequestration and avoided emission costs.
- **Cost of Dredging**: For the Nature-Based Infrastructure (NBI) and Hybrid scenarios, the CBA evaluates the avoided cost of dredging. These scenarios assume interventions that address riverbank encroachment and reduce sedimentation, thereby reducing the need for regular dredging to maintain waterways assumed in the Reference scenario.
- **Revenues from Agroforestry**: The analysis quantifies the potential revenues from agroforestry from interventions that improve water availability. It evaluates the economic value of additional yields and market value.

By quantifying these indicators, the integrated CBA provides valuable insights regarding the economic feasibility, costs, and benefits of the intervention scenarios. This information assists decision-makers in evaluating the potential returns on investment and formulating policies and strategies to increase climate resilience in northern Ghana.

Table 2: Methodologies to quantify selected indicators – Example from the CBA of Lambussie

Indicator	Method and assumptions
Construction costs	• The construction costs of the NBI scenario are calculated as the sum of four different interventions (reforestation, revegetating riparian areas, climate smart agriculture, and agroforestry). Each of the four interventions is calculated as the multiplication of a fixed number of ha by a fixed construction unit cost. Specifically: - Reforestation: 750 ha * 1,500 USD/ha - Revegetating riparian areas: 750 ha * 750 USD/ha - Climate Smart Agriculture: 1,000 ha * 250 USD/ha - Agroforestry: 500 ha * 1,000 USD/ha • The construction costs of the NBI + Irrigation scenario are identical to the ones of the NBI scenario with the addition of the costs for irrigation, which have been calculated as follows: - Irrigation: 500 ha * 6,500 USD/ha • The construction costs of the Reference scenario are set to zero.
O&M Costs	• The O&M costs of the NBI scenario are calculated as the sum of four different interventions (reforestation, revegetating riparian areas, climate smart agriculture, and agroforestry). Each of the four interventions is calculated as the multiplication of a fixed number of ha by a fixed annual O&M unit cost. Specifically: - Reforestation: 750 ha * 150 USD/ha/year - Revegetating riparian areas: 750 ha * 150 USD/ha/year - Climate Smart Agriculture: 1,000 ha * 75 USD/ha/year - Agroforestry: 500 ha * 50 USD/ha/year • The O&M costs of the NBI + Irrigation scenario are identical to the ones of the NBI scenario with the addition of the O&M annual costs for irrigation, which have been calculated as follows: - Irrigation: 500 ha * 163 USD/ha/year • The O&M annual costs of the Reference scenario are set to zero.
Flood Damage to Buildings	• This indicator is identical for the NBI and NBI + Irrigation scenario, and it is calculated as follows: - First, the average annual number of floods was set to 10 (this value is for Lambussie only, and it was provided by UNEP). This value is impacted by the extreme wet index under the various SSPs scenarios, and changes over time. - Next, the increased water retention from the NBI was set to 10%, decreasing the frequency of flooding annual events. - Since the total number of buildings affected by 10 floods events was 285 (this value, indicated by UNEP, is for Lambussie only, please check Table 3 for other locations), we assumed an average number of buildings affected per flood to 28.5. - We multiplied the average number of buildings affected per flood by the forecasted annual flooding events, obtaining the number of buildings affected per year under specific climate scenarios, considering also the NBI effect in reducing the flood events.

	- The forecasted number of buildings damaged per specific year was then multiplied by 583 USD (this value was indicated by the country team of UNEP and is for Lambussie only, please check Table 3 for other locations), which is the average damage per building. • Under the Reference scenario, this indicator was calculated in the same way as for the other two scenarios, but without the mitigation impact of the NBI.
Flood damages to agriculture production	• This indicator is identical for the NBI and NBI + Irrigation scenario, and it is calculated as follows: - Total agricultural land is 154,264 ha, and assumed grow by 1% annually (the total agricultural land was indicated by the country team of UNEP, it refers to Lambussie only, please check Table 3 for other locations). - Since the agricultural land affected by flood in Lambussie was reported to amount to 1,700 ha (1.1% of 154,264), as reported by the country team of UNEP in Table 3, we assumed that 1.1% is the initial share of agricultural land affected by flood each year. This value changes over time, in accordance with the forecasted probability of extreme wet events, as presented in the following bullet points. - Next, the increased water retention from the NBI was set to 10%, reducing the frequency of flooding annual events. Specifically, we estimate that water retention is 26.154 m3 for agriculture and 35.117 m3 for smallholder agroecosystems. Thus the increase in retention increases by 34.27%, when using data from USDA (1989), which estimate runoff curve number computations based different land cover typologies. On the other hand, we assume that the increase in water retention in the area impacted by the project is not directly proportional to the reduction in flood risk. This is also due to the relatively small project area, when compared to the area at risk of flood. For this reason, we consider an average 10% reduction in flood risk in the study area when 12,000 ha of land are impacted by the project. - To calculate the actual share of cropland affected by flood, we considered the above-mentioned indicators including the impact on flood frequency of the extreme wet index under the various SSPs scenarios. - By multiplying the above-mentioned index by the annual number of ha of agricultural land, we calculated the number of ha of agriculture land affected by floods. - The average yield per ha was set to 4 Ton/ha/year (as indicated by the country team of UNEP and is for Lambussie only, please check Table 3 for other locations), while the average value per ton lost to floods was calculated by dividing the value of production lost due to floods (provided by UNEP) by the agriculture land affected by each flood (1,700 ha, provided by UNEP) multiplied by the average yield per ha. In this way, it was possible to calculate the annual flood damages to agriculture production in USD. • Under the Reference scenario, this indicator was calculated in the same way as for the other two scenarios, but without the mitigation impact of the NBI.
Drought damages to agriculture production	• Under the NBI scenario, this indicator was calculated as follows:

	- The share of agriculture land affected by drought was calculated by diving the number of ha of agriculture affected by drought by the total agriculture land (both data were provided). - Next, the share of agriculture land affected by drought was multiplied by the extreme dry index under the considered SSPs climate scenarios, and then multiplied by the annual number of ha of agricultural land (growing by 1% each year, as indicated by the country team of UNEP) to calculate the annual number of ha of agriculture affected by drought. In this share was also considered the positive impact of the change in water yield from NBI (1%) and the positive impact of reduction in water stress from it (20%) (values indicated by the country team of UNEP). - By multiplying the annual number of ha of agriculture affected by drought by 4, which is the average yield per ha (tons) in Lambussie (as reported by the country team of UNEP in Table 3), we obtained the annual agriculture production lost to droughts. - The annual agriculture production lost was then multiplied by 568 (USD/Ton) which is the average value per ton lost to drought in Lambussie, calculated from data provided by the country team of UNEP (Table 3) on the value of production lost to drought divided by the tons of production lost to droughts. In this way, we calculated the annual value in USD of drought damages to agricultural production. • Under the NBI + Irrigation scenario, this indicator was calculated as under the NBI scenario with the addition of the positive impact of irrigation, represented by the share of additional land irrigated (0.3%, calculated by dividing the area under irrigation – 500 ha - by the total agricultural land – 154,264 ha) • Under the Reference scenario, this indicator was calculated in the same way as for the other two scenarios, but without the mitigation impact of the NBI and Irrigation infrastructure.
Income	• Under the NBI and NBI + Irrigation scenarios, total income is calculated from the income for construction (occurring the 1st year) and income from O&M (occurring every year starting from the 2nd). - Income from construction is calculated from the total income from construction multiplied by 10%, which is the share of discretionary income. Total income from construction comes from the sum of construction of “revegetating riparian areas”, “climate smart agriculture”, “agroforestry”, and “reforestation”, which come from given data that multiply the number of workers hired by their average salary. - Income from O&M is calculated from the total income from O&M multiplied by 10%, which is the share of discretionary income. Total income from O&M comes from the sum of construction of “revegetating riparian areas”, “climate smart agriculture”, “agroforestry”, and “reforestation”, which come from given data that multiply the number of workers hired by their average salary. • This indicator was not calculated under the Reference scenario.
Value of loss of life from flooding	• Under the NBI and NBI + Irrigation scenarios, total population was assumed, as well as its annual grow rate. From these assumptions, we calculated the total annual population affected by floods, also considering the annual share of population that

	is impacted from given data (Total Population/Number of people affected by floods), as well as the flood risk reduction from increased water retention from the NBI and the extreme wet index under the various SSPs climate scenarios. Once we obtained the annual number of people affected by flood each year, we multiplied it by the average death rate (calculated from historical data on annual deaths from flooding compared to the total population), obtaining the annual deaths from flooding. Annual deaths from flooding were then multiplied with the value of statistical life (based on work carried out by WHO, for Africa[4]). • Under the Reference scenario, this indicator was calculated in the same way as for the other two scenarios, but without the mitigation impact of the NBI.
Cost of malnutrition	• Under the NBI scenario, cost of malnutrition was calculated by multiplying the population affected by malnutrition by the average annual cost of malnutrition. - Population affected by malnutrition is calculated by multiplying the following indicators: 1) Total production lost to floods and droughts (from the time series values of crop production losses of floods and droughts, depending on the SSPs scenarios on extreme wet and dry indices as well as the positive impact of increased water retention from the NBI and the reduction in water stress from CSA, divided by the initial recorded losses) 2) Annual population, assuming an annual linear growth of 1% 3) Share of population affected by malnutrition (from recorded data on the number of people affected by malnutrition divided by total population) - Average cost of malnutrition is calculated by multiplying data provided on the number of people affected by malnutrition by the average cost of it per person. • Under the NBI + Irrigation scenario, this indicator was calculated the same way as the NBI scenario, but also considering the positive impact of irrigation to contrast drought • Under the Reference scenario, this indicator was calculated in the same way as for the other two scenarios, but without the mitigation impact of the NBI and of irrigation.
Carbon Storage	• Under the NBI and NBI + Irrigation scenarios, carbon storage was calculated by multiplying given data on additional carbon stored (tons), by 3.67 (conversion C to CO2), and by the USD 12 per ton of CO2. This value was then spread equally over 20 years, which is the assumed time required for trees to reach their full size. • A higher value per ton of CO2 was considered in an alternative scenario (i.e. USD 89.925 per ton of CO2, in accordance with the updates of the High-Level Commission on Carbon Prices (2017) presented in the World Bank's State and Trends of Carbon Pricing 2023).

[4] https://gh.bmj.com/content/bmjgh/5/1/e001535/DC1/embed/inline-supplementary-material-1.pdf?download=true

	• The lower value (USD 12 per ton of CO_2) reflects the amount that may be realized as carbon payment; the higher value (USD 86.925 per ton of CO_2) is instead the amount that would be required to reach net zero globally. • Under the Reference scenario carbon storage was not calculated.
Additional revenues from agroforestry	• Under the NBI and NBI + Irrigation scenarios, these additional revenues have been calculated from given data on the ha of agroforestry (500 ha per district, for a total of 2,000 ha in the study area) multiplied by the average revenues per ha of agroforestry (USD 150/ha). This indicator was not calculated under the Reference scenario.

Table 3 summarizes the specific data and numerical assumptions used to parametrized the models for Lambussie, Wa West, Lawra, and Jirapa. This information was collected on the ground by the UNEP project team.

Table 3: CBA indicators used for four locations (Lambussie, Wa West, Lawra, and Jirapa)

Indicator	**Unit**	**Value**			
Number of floods		**LAMBUSSIE**	**LAWRA**	**JIRAPA**	**WA WEST**
Average number of floods per year	Floods/Year	10	12	7	11
Land affected by floods	Ha/Year	46,279.20	39,046.20	35,494.80	49,297.20
Population and land					
Population	Person	51,118	58433	91279	96957
Agriculture land	Hectare	154,264	118,316	130154	164,324
Flood damages to agriculture					
Agriculture land affected by floods	Ha/Year	1,700	980	900	1,600
Loss of production due to floods	Ton/Year	3,400	2,156	1980	3,680
Value of production lost	GSH/Year	23,800,000	15,092,000	13,860,000	25,760,000
Average productivity per hectare	Ton/Ha/Year	4	4.4	4.4	4.6
Flood damages to buildings					
Buildings affected by floods	Buildings/Year	285	295	179	298
Average flood damages per building	USD/Building	583	479	525	598
People displaced by floods per year	Person/Year	738	885	879	872
Drought impacts on agriculture					
Agriculture land affected by water scarcity	Ha/Year	825	859	978	932
Loss of production due to water scarcity	Ton/Year	3,300	3,780	4,303	4,287
Value of production lost	GSH/Year	23,100,000	26,457,200	30,122,400	30,010,400
Human health					
People killed or injured by floods	Person / year	4	7	5	9
People affected by malnutrition	person	128	321	139	420
Health impacts of malnutrition	USD/person	120	145	135	150

3 Results

The results of the analysis show that the investments considered (both the NBI interventions and irrigation) are economically viable. Table 4 indicates that the discounted Benefit to Cost Ratio (BCR) (using a 6.5% discount rate), estimated for the period 2024 – 2050 ranges between 1.55 and 2.36 for Lambussie, 1.63 and 2.59 for Lawra, 1.65 and 2.62 for Jirapa, 2.05 and 2.95 for WA West. The Internal Rate of Return (IRR) instead ranges overall, across all locations, between 17.4% and 37.9%.

The NPV of the project, considering all districts, reaches USD 22.4 million (SSP1), USD 18.4 million (SSP3) and USD 23.5 million (SSP5) in the NBI scenario; the Hybrid scenarios results instead in an NPV of USD 68.8 million (SSP1), USD 58.8 million (SSP3) and USD 68.5 million (SSP5). For the SSP3 scenario specifically, considering respectively the NBI and the Hybrid scenarios, the NPVs of each district are as follows: USD 3.5 million and USD 12.1 million (Lambussie), USD 4.0 million and USD 14.2 million (Lawra), USD 4.2 million and USD 14.5 million (Jirapa), USD 6.7 million and USD 18.1 million (WA West).

When shifting to the financial analysis, when only the avoided costs of floods (to buildings and agriculture) and droughts (to agriculture) are considered, together with the additional revenues from agroforestry, in the case of Lambussie and for the SSP3 climate scenario (the one resulting in the lowest returns across all climate scenarios and all locations) the BCR would decline from 1.55 to 1.31 in the NBI scenario, and the IRR would decline from 17.4% to 12.8%.

Further, if only climate smart agriculture practices and agroforestry are considered, without accounting for the climate resilience and other intangible co-benefits they bring (only the increased resilience of climate smart practices to drought are considered), the BCR reaches 3.78 (undiscounted) and 2.74 (discounted) and the IRR is estimated to be 37.5% in the SSP3 scenario. When implemented in isolation, agroforestry has an IRR of 10%, and climate smart practices range from 30% to an upper value of 100%, with improved resilience to drought in the range of 10% and 20% respectively.

An alternative scenario was created, considering a higher shadow price for carbon. Instead of USD 12 per ton of CO_2, USD 86.925 per ton of CO_2 was considered. In the case of Lambussie, in the SSP3 scenario, the value of carbon sequestration increases from USD 0.171 million to USD 1.24 million, a proportional increased caused by the higher shadow price. Further, the undiscounted BCR increases to 2.16 (from 2.07), the discounted BCR grows to 1.64 (from 1.55), the IRR reaches 19.7% (from 17.4%) and the NPV is estimated at USD 4.1 million (from USD 3.5 million). A similar proportional increase is expected for all other districts also.

These result indicate that the investments proposed are both economically and financially viable, and generate considerable societal benefits, under several scenarios.

3.1 Results by intervention scenario

The **Reference Scenario** (results are presented, by location, in Table 5 through Table 8) shows growing impacts of climate change over time. In the case of Lambussie, with reference to the SSP3 scenario, cumulative flood damages to agriculture total USD 67.2 million by 2050 (USD 42.6 million for Lawra, USD 39.1 million for Jirapa, USD 72.7 million for WA West); drought damages reach instead USD 53.8 million (USD 61.6 million for Lawra, USD 70.2 million for Jirapa, USD 69.9 million for WA West). Flood damages to buildings are estimated at USD 5.0 million (USD 4.3 million for Lawra, USD 2.8 million for Jirapa, USD 5.4 million for WA West) and value of loss of life from flooding and the cost of malnutrition are instead

USD 28.5 million and USD 0.79 million respectively (USD 49.9 and 1.9 million for Lawra, USD 35.7 and 0.76 million for Jirapa, USD 64.2 and 3.7 million for WA West). The cumulative impacts of climate change therefore add up to USD 155.4 million by 2050 (USD 160.3 million for Lawra, USD 148.6 million for Jirapa, USD 215.9 million for WA West).

These values change in the SSP1 and SSP5 climate scenarios, with both showing lower flood damage but higher drought damage, with the SSP5 showing the highest climate damage overall in all four districts.

On the other hand, climate damages also differ by location, with WA West reaching an estimated total cumulative damage to 2050 of USD 215.9 million, followed by Lawra (USD 160.3 million), Lambussie (USD 155.4 million) and Jirapa (USD 148.6 million).

The **NBI Scenario** and the **Hybrid Scenario** reduce the impact of climate change, both in relation to floods and droughts. In the NBI scenario, strategic land restoration measures and the adoption of climate-smart agriculture practices synergistically contribute to improved resilience against climate shocks (reducing climate damage while also increasing land productivity and revenues from crops and agroforestry). The addition of water storage and irrigation significantly increases water availability, reducing crop losses attributed to water scarcity, providing farmers with a more reliable water supply for agricultural activities.

Specifically, Table 5 through Table 8 show that the NBI and Hybrid scenarios reduce climate damages considerably. For Lambussie, the climate impacts in the SSP3 scenario decline to USD 60.7 million (instead of 67.2 million by 2050) in relation to flood damages to agriculture; USD 43.0 million (NBI scenario) and USD 13.4 million (Hybrid scenario) for drought damages (instead of USD 53.8 million in the Reference case). In addition to the reduction of damages, the NBI and Hybrid scenarios generate income from the implementation of the investment, specifically from tree planting and the adoption of new agriculture practices, (USD 0.27 million) and from agroforestry (USD 2 million). These avoided costs and additional benefits emerge as a result of a total investment and O&M cost of USD 11.2 million (NBI scenario) and USD 16.7 million (Hybrid scenario). Similar cost reductions, and added benefits emerge for other locations in the NBI and Hybrid scenarios.

Net impacts compared to the Reference scenarios are presented in Table 9 through Table 12. The NBI and Hybrid scenarios generate cumulative net benefits in the range of USD 13.2 million and USD 46.3 million across climate scenarios in the case of Lawra. These values increase to USD 19.6 million and USD 55.3 million in the case of WA West. For Lambussie the range is USD 11.9 million and USD 40.7 millions. In the case of Jirapa USD 13.6 million and USD 47.5 million.

The explain the results in more detail, the outcomes of the investments proposed are assessed across (i) climate scenarios and (ii) across locations in the next sections.

3.2 Results by climate scenario

The climate scenarios utilized in this assessment are SSP1, SSP3 and SSP5. Monthly forecasts were obtained from the EU Copernicus Climate Data Store. An additional analysis was performed to estimate the probability of extreme events, for floods and droughts, using the Standard Precipitation Index (SPI). The climate forecasts were downloaded for each location, using longitude and latitude.

The results presented for the absolute cost of extreme weather events (Table 5 through Table 8) and for the reduction emerging from the NBI and Hybrid scenarios (Table 9 through Table 12) provide useful insights to interpret results across climate scenarios.

First, taking the example of Lambussie, we notice that the impact of floods to agriculture in the Reference simulation (SSP1) is USD 52 million, while the impact of droughts is USD 62.1 million. It is important to note that droughts impacts are larger.

Second, the flood damage to agriculture increases by almost USD 10 million in the SSP3 scenario and USD 4 million in the SSP5. This indicates that flood events are more numerous in the SSP3 scenario, followed by the SSP5 and SSP1. The drought damage to agriculture decreases instead by approximately USD 8 million in the SSP3 scenario and increases by USD 5.5 million in the SSP5. This indicates that drought events are more numerous in the SSP5 scenario, followed by the SSP1 and SSP3.

Third, the impact of NBI and irrigation investments are not equally effective. Table 9 shows that, for Lambussie, the avoided flood damage ranges between USD 5.5 million (NBI scenario) and USD 44 million (Hybrid scenario) in the SSP1 climate scenario. The larger effectiveness of irrigation in reducing the cost of extreme weather events makes so that the BCR and IRR will be higher in scenarios and locations more exposed to droughts.

Fourth, the moment in time in which the extreme event emerges under the different climate scenarios also plays a role. If extreme events take place earlier in time in the SSP1 scenario, compared to the SSP5, the value of the economic damage will be higher in the CBA when considering discounted results. This is evident for Lambussie, where Table 4 shows that the undiscounted BCR for the SSP5 scenario (3.44) is higher than the undiscounted BCR of the SSP1 scenario (3.31). On the other hand, the discounted BCR of the SSP1 is larger than the SSP5 (2.36 and 2.34 respectively). This is due to the different temporal distribution of the forecast of extreme events across climate scenarios.

3.3 Results by area

Comparing the results across study areas shows that the largest amount of benefits emerges for WA West (Table 4). Lambussie, Lawra and Jirapa show smaller benefits than WA West, but similar across the three study areas. The differences across study areas can by explained by looking at Table 9 through Table 12, and especially at Table 3, with the values used to parametrize each model.

First, it is possible to note that the number of floods experience by each region differs. Lawra reports 12 flood events per year on average, followed by WA West (11), Lambussie (10) and Jirapa (7). Lambussie and WA West also show the largest amount of agriculture land impacted by floods (1,700 and 1,600 hectares respectively), followed by Lawra and Jirapa (980 and 900 hectares respectively). Land productivity, used to estimate the impacts to agriculture production, is highest in WA West (4.6 ton per hectare per year), followed by Jirapa and Lawra (4.4 ton per hectare per year) and Lambussie (4 ton per hectare per year). Concerning buildings, WA West, Lawra and Lambussie show similar values (close to 330 buildings impacted by floods), while Jirapa indicated 179 buildings.

Second, concerning droughts, Jirapa and WA West show the highest amount of hectares impacted (978 and 932 respectively), followed by Lawra (850 hectares) and Lambussie (825 hectares).

Third, WA West is the area with the highest mortality due to floods, as well as the highest number of people affected by malnutrition. This makes so that the avoided social costs for WA West are higher than the other study areas.

The combination of these initial conditions, and the assumption on the areas impacted by the investment (same number of hectares in each study area), makes so that the WA West, which is the most exposed to extreme weather events, is the area that shows the largest BCR and highest IRR.

Text Box 1: Changing ambition for stronger climate resilience

An alternative scenario was simulated, increasing the ambition for reforestation, from 750 hectares to 3,500 hectares, for Lambussie Karnie. This new scenario was created to assess the impact of a scale up for the investment, with the goal to further reduce the impact of floods on buildings, agriculture and human health.

Expanding the ambition to 3,500 hectares for reforestation results in a 46.7% reduction in flood risk, when considering a proportional impact of tree planting on water retention from the area (for comparison, water retention was assumed to increase by 10% with 750 ha of reforestation).

The investment required increases to USD 26.5 million cumulatively, compared to USD 11.2 million in the original NBI scenario. On the other hand, the BCR and IRR improve: 1.68 discounted BCR vs. 1.55, and 19.3% IRR vs. 17.4, in the SSP3 climate scenario.

This highlights that there is a positive return for a scaled-up investment, provided that reforestation efforts are concentrated in areas that contribute to further reducing flood risk, e.g. addressing upstream water flow.

Additional level of ambition, and the resulting required investments are presented in the table below.

% Flood risk reduction	10%	46.7%	80%
Hectares required	750 (3,000 for four districts)	3,500 (14,000 for four districts)	6,000 (24,000 for four districts)
Upfront cost (planting)	USD 1.125 million (USD 4.5 million for four districts)	USD 5.25 million (USD 21 million for four districts)	USD 9 million (USD 36 million for four districts)
Total cost (planting and O&M cost over 20 years)	USD 11.2 million (USD 44.8 million for four districts)	USD 26.5 million (USD 106 million for four districts)	USD 40.35 million (USD 161.4 million for four districts)

Table 4: Results of the CBA, BCR (Discounted and Undiscounted) and IRR, by location and scenario.

	SSP1-2.6		SSP3-7.0		SSP5-8.5	
	NBI vs Reference	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**
Lambussie						
BCR	2.09	3.31	2.07	3.17	2.25	3.44
BCR discounted	1.67	2.36	1.55	2.14	1.70	2.34
IRR	23.1 %	28.9 %	17.4 %	22.9 %	19.6 %	24.5 %
Lawra						
BCR	2.24	3.64	2.19	3.48	2.41	3.78
BCR discounted	1.78	2.59	1.63	2.35	1.83	2.58
IRR	25.8 %	32.4 %	18.7 %	25.4 %	21.8 %	27.4 %
Jirapa						
BCR	2.31	3.70	2.21	3.53	2.49	3.85
BCR discounted	1.85	2.62	1.65	2.37	1.92	2.63
IRR	27.8 %	32.7 %	19.2 %	25.5 %	23.9 %	28.5 %
WA West						
BCR	2.76	4.14	2.74	4.02	2.98	4.32
BCR discounted	2.20	2.95	2.05	2.71	2.24	2.93
IRR	35.7 %	37.9 %	26.5 %	30.3 %	28.2 %	31.7 %

Table 5: Cost-benefit statement (undiscounted) - Lambussie

		SSP1-2.6			SSP3-7.0			SSP5-8.5		
		NBI	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**
Lambussie										
Constructions costs	USD	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-
O&M	USD	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-
Flood damages to buildings	USD	(3,923,664)	(3,923,664)	(4,341,165)	(4,548,791)	(4,548,791)	(5,035,750)	(4,105,841)	(4,105,841)	(4,543,584)
Flood damages to agriculture production	USD	(51,973,979)	(51,973,979)	(57,534,219)	(60,681,597)	(60,681,597)	(67,209,350)	(55,570,016)	(55,570,016)	(61,529,815)
Drought damages to agriculture production	USD	(49,588,579)	(18,009,090)	(62,119,418)	(43,008,827)	(13,397,565)	(53,811,650)	(54,124,337)	(22,146,256)	(67,846,385)
Income	USD	273,642	273,642	-	273,642	273,642	-	273,642	273,642	-
Value of loss of life from flooding	USD	(22,061,210)	(22,061,210)	(24,421,345)	(25,757,302)	(25,757,302)	(28,528,114)	(23,587,607)	(23,587,607)	(26,117,342)
Cost of malnutrition	USD	(635,672)	(504,102)	(734,182)	(686,325)	(562,084)	(786,679)	(693,619)	(559,792)	(801,352)
Carbon storage	USD	171,082	171,082	-	171,082	171,082	-	171,082	171,082	-
Additional revenues from agroforestry	USD	2,025,000	2,025,000	-	2,025,000	2,025,000	-	2,025,000	2,025,000	-
Total	USD	(136,925,880)	(110,665,321)	(149,150,329)	(143,425,617)	(119,140,615)	(155,371,542)	(146,824,197)	(120,162,789)	(160,838,479)

Table 6: Cost-benefit statement (undiscounted) - Lawra

		SSP1-2.6			SSP3-7.0			SSP5-8.5		
		NBI	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**
Lawra										
Constructions costs	USD	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-
O&M	USD	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-
Flood damages to buildings	USD	(3,336,844)	(3,336,844)	(3,691,904)	(3,868,477)	(3,868,477)	(4,282,608)	(3,491,775)	(3,491,775)	(3,864,050)
Flood damages to agriculture production	USD	(32,957,617)	(32,957,617)	(36,483,464)	(38,479,271)	(38,479,271)	(42,618,635)	(35,237,928)	(35,237,928)	(39,017,142)
Drought damages to agriculture production	USD	(56,795,453)	(21,684,163)	(71,147,440)	(49,259,443)	(16,178,472)	(61,632,276)	(61,990,407)	(26,489,567)	(77,706,726)
Income	USD	273,642	273,642	-	273,642	273,642	-	273,642	273,642	-
Value of loss of life from flooding	USD	(38,607,118)	(38,607,118)	(42,737,355)	(45,075,278)	(45,075,278)	(49,924,199)	(41,278,313)	(41,278,313)	(45,705,349)
Cost of malnutrition	USD	(1,540,488)	(1,097,120)	(1,810,811)	(1,599,132)	(1,178,538)	(1,862,837)	(1,680,308)	(1,230,018)	(1,975,831)
Carbon storage	USD	171,082	171,082	-	171,082	171,082	-	171,082	171,082	-
Additional revenues from agroforestry	USD	2,025,000	2,025,000	-	2,025,000	2,025,000	-	2,025,000	2,025,000	-
Total	USD	(141,980,296)	(111,876,139)	(155,870,973)	(147,024,377)	(118,973,313)	(160,320,555)	(152,421,507)	(121,920,877)	(168,269,097)

Table 7: Cost-benefit statement (undiscounted) - Jirapa

		SSP1-2.6			SSP3-7.0			SSP5-8.5		
		NBI	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**
Jirapa										
Constructions costs	USD	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-
O&M	USD	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-
Flood damages to buildings	USD	(2,219,171)	(2,219,171)	(2,455,303)	(2,572,734)	(2,572,734)	(2,848,152)	(2,322,208)	(2,322,208)	(2,569,789)
Flood damages to agriculture production	USD	(30,267,199)	(30,267,199)	(33,505,222)	(35,338,106)	(35,338,106)	(39,139,563)	(32,361,362)	(32,361,362)	(35,832,069)
Drought damages to agriculture production	USD	(64,663,507)	(28,602,591)	(81,003,721)	(56,083,510)	(21,591,877)	(70,170,391)	(70,578,135)	(33,944,480)	(88,471,685)
Income	USD	273,642	273,642	-	273,642	273,642	-	273,642	273,642	-
Value of loss of life from flooding	USD	(27,576,513)	(27,576,513)	(30,526,682)	(32,196,627)	(32,196,627)	(35,660,142)	(29,484,509)	(29,484,509)	(32,646,678)
Cost of malnutrition	USD	(633,801)	(450,142)	(750,002)	(647,820)	(471,055)	(759,550)	(691,231)	(503,788)	(818,249)
Carbon storage	USD	759,839	171,082	-	759,839	171,082	-	759,839	171,082	-
Additional revenues from agroforestry	USD	2,025,000	2,025,000	-	2,025,000	2,025,000	-	2,025,000	2,025,000	-
Total	USD	(133,514,211)	(103,308,893)	(148,240,930)	(134,992,817)	(106,363,675)	(148,577,798)	(143,591,464)	(112,809,624)	(160,338,471)

Table 8: Cost-benefit statement (undiscounted) – WA West

		SSP1-2.6			SSP3-7.0			SSP5-8.5		
		NBI	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**	**NBI**	**Hybrid**	**Reference**
WA West										
Constructions costs	USD	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-	(2,437,500)	(5,687,500)	-
O&M	USD	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-	(8,775,000)	(10,975,500)	-
Flood damages to buildings	USD	(4,208,195)	(4,208,195)	(4,655,971)	(4,878,654)	(4,878,654)	(5,400,926)	(4,403,583)	(4,403,583)	(4,873,070)
Flood damages to agriculture production	USD	(56,254,189)	(56,254,189)	(62,272,331)	(65,678,905)	(65,678,905)	(72,744,237)	(60,146,370)	(60,146,370)	(66,596,977)
Drought damages to agriculture production	USD	(64,423,078)	(27,012,319)	(80,702,536)	(55,874,982)	(20,271,961)	(69,909,486)	(70,315,714)	(32,471,795)	(88,142,733)
Income	USD	273,642	273,642	-	273,642	273,642	-	273,642	273,642	-
Value of loss of life from flooding	USD	(49,637,723)	(49,637,723)	(54,948,027)	(57,953,929)	(57,953,929)	(64,188,256)	(53,072,116)	(53,072,116)	(58,764,020)
Cost of malnutrition	USD	(3,005,080)	(2,365,461)	(3,488,910)	(3,207,737)	(2,595,110)	(3,693,922)	(3,278,670)	(2,628,718)	(3,807,738)
Carbon storage	USD	134,886	171,082	-	134,886	171,082	-	134,886	171,082	-
Additional revenues from agroforestry	USD	2,025,000	2,025,000	-	2,025,000	2,025,000	-	2,025,000	2,025,000	-
Total	USD	(186,307,236)	(153,671,162)	(206,067,776)	(196,373,179)	(165,571,834)	(215,936,828)	(199,995,426)	(166,915,859)	(222,184,538)

Table 9: Lambussie – Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario

		SSP1-2.6		SSP3-7.0		SSP5-8.5	
		NBI vs Reference	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**
Lambussie							
Constructions costs	USD	2,437,500	5,687,500	2,437,500	5,687,500	2,437,500	5,687,500
O&M	USD	8,775,000	10,975,500	8,775,000	10,975,500	8,775,000	10,975,500
Flood damages to buildings	USD	(417,501)	(417,501)	(486,960)	(486,960)	(437,743)	(437,743)
Flood damages to agriculture production	USD	(5,560,240)	(5,560,240)	(6,527,753)	(6,527,753)	(5,959,800)	(5,959,800)
Drought damages to agriculture production	USD	(12,530,839)	(44,110,328)	(10,802,823)	(40,414,085)	(13,722,048)	(45,700,128)
Income	USD	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)
Value of loss of life from flooding	USD	(2,360,135)	(2,360,135)	(2,770,812)	(2,770,812)	(2,529,735)	(2,529,735)
Cost of malnutrition	USD	(98,510)	(230,080)	(100,354)	(224,594)	(107,733)	(241,560)
Carbon storage	USD	(171,082)	(171,082)	(171,082)	(171,082)	(171,082)	(171,082)
Additional revenues from agroforestry	USD	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)
Total	USD	(12,224,449)	(38,485,008)	(11,945,925)	(36,230,927)	(14,014,282)	(40,675,690)

Table 10: Lawra – Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario

		SSP1-2.6		SSP3-7.0		SSP5-8.5	
		NBI vs Reference	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**
Lawra							
Constructions costs	USD	2,437,500	5,687,500	2,437,500	5,687,500	2,437,500	5,687,500
O&M	USD	8,775,000	10,975,500	8,775,000	10,975,500	8,775,000	10,975,500
Flood damages to buildings	USD	(355,060)	(355,060)	(414,130)	(414,130)	(372,274)	(372,274)
Flood damages to agriculture production	USD	(3,525,846)	(3,525,846)	(4,139,363)	(4,139,363)	(3,779,214)	(3,779,214)
Drought damages to agriculture production	USD	(14,351,988)	(49,463,277)	(12,372,833)	(45,453,805)	(15,716,319)	(51,217,159)
Income	USD	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)
Value of loss of life from flooding	USD	(4,130,237)	(4,130,237)	(4,848,921)	(4,848,921)	(4,427,036)	(4,427,036)
Cost of malnutrition	USD	(270,323)	(713,691)	(263,706)	(684,299)	(295,523)	(745,813)
Carbon storage	USD	(171,082)	(171,082)	(171,082)	(171,082)	(171,082)	(171,082)
Additional revenues from agroforestry	USD	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)
Total	USD	(13,890,677)	(43,994,834)	(13,296,178)	(41,347,242)	(15,847,591)	(46,348,221)

Table 11: Jirapa– Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario

		SSP1-2.6		SSP3-7.0		SSP5-8.5	
		NBI vs Reference	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**
Jirana							
Constructions costs	USD	2,437,500	5,687,500	2,437,500	5,687,500	2,437,500	5,687,500
O&M	USD	8,775,000	10,975,500	8,775,000	10,975,500	8,775,000	10,975,500
Flood damages to buildings	USD	(236,133)	(236,133)	(275,418)	(275,418)	(247,581)	(247,581)
Flood damages to agriculture production	USD	(3,238,022)	(3,238,022)	(3,801,456)	(3,801,456)	(3,470,707)	(3,470,707)
Drought damages to agriculture production	USD	(16,340,214)	(52,401,130)	(14,086,881)	(48,578,515)	(17,893,551)	(54,527,205)
Income	USD	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)
Value of loss of life from flooding	USD	(2,950,169)	(2,950,169)	(3,463,515)	(3,463,515)	(3,162,169)	(3,162,169)
Cost of malnutrition	USD	(116,200)	(299,859)	(111,730)	(288,495)	(127,018)	(314,461)
Carbon storage	USD	(759,839)	(171,082)	(759,839)	(171,082)	(759,839)	(171,082)
Additional revenues from agroforestry	USD	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)
Total	USD	(14,726,719)	(44,932,037)	(13,584,981)	(42,214,123)	(16,747,006)	(47,528,847)

Table 12: WA West – Costs, Avoided Costs, and Added Benefits compared to the Reference Scenario

		SSP1-2.6		SSP3-7.0		SSP5-8.5	
		NBI vs Reference	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**	**NBI vs Reference**	**Hybrid vs Reference**
WA West							
Constructions costs	USD	2,437,500	5,687,500	2,437,500	5,687,500	2,437,500	5,687,500
O&M	USD	8,775,000	10,975,500	8,775,000	10,975,500	8,775,000	10,975,500
Flood damages to buildings	USD	(447,777)	(447,777)	(522,272)	(522,272)	(469,487)	(469,487)
Flood damages to agriculture production	USD	(6,018,142)	(6,018,142)	(7,065,333)	(7,065,333)	(6,450,607)	(6,450,607)
Drought damages to agriculture production	USD	(16,279,458)	(53,690,217)	(14,034,504)	(49,637,525)	(17,827,019)	(55,670,938)
Income	USD	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)	(273,642)
Value of loss of life from flooding	USD	(5,310,305)	(5,310,305)	(6,234,327)	(6,234,327)	(5,691,904)	(5,691,904)
Cost of malnutrition	USD	(483,830)	(1,123,449)	(486,185)	(1,098,812)	(529,068)	(1,179,020)
Carbon storage	USD	(134,886)	(171,082)	(134,886)	(171,082)	(134,886)	(171,082)
Additional revenues from agroforestry	USD	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)	(2,025,000)
Total	USD	(19,760,540)	(52,396,614)	(19,563,649)	(50,364,993)	(22,189,112)	(55,268,679)

4 Conclusions

The foundation of our analysis framework is rooted in a collaborative effort with the United Nations Environment Programme (UNEP) and local government counterparts actively engaged in regional planning. This partnership ensures that the analysis is aligned with international best practices while remaining contextually relevant to the specific needs and challenges faced by the local communities in northern Ghana. The co-development of the analysis framework reflects an inclusive planning process where diverse perspectives and expertise are integrated. By involving both international and local stakeholders, we ensure a comprehensive understanding of the region's intricacies and a more effective strategy for addressing climate impacts.

In conclusion, our analysis presents a robust framework for addressing the pressing climate challenges in northern Ghana, highlighting the efficacy of Nature-Based Infrastructure (NBI) and Hybrid Scenarios in fostering resilience. The nuanced integration of nature-based interventions, such as reforestation and sustainable agriculture, along with the strategic inclusion of water storage and irrigation in the Hybrid Scenario, emerges as a promising avenue for sustainable development.

The insights derived from this analysis provide a roadmap for stakeholders to collaboratively address climate impacts in northern Ghana. By strategically implementing nature-based and hybrid solutions, stakeholders can build a more resilient, economically vibrant, and ecologically sustainable future for the region. The integration of local knowledge, ongoing collaboration, and adaptive management will be pivotal in navigating the complex challenges posed by climate change. The following steps can be implemented, by stakeholder group.

1. **Local Communities:**
    a. *Adoption of Sustainable Practices*: Local communities can adopt and integrate sustainable practices, such as climate-smart agriculture and land restoration activities, to enhance their own resilience.
    b. *Active Participation*: Engaging in the maintenance of restored areas can create additional employment opportunities and strengthen community ties.
2. **Government Agencies:**
    a. *Policy Formulation*: Government agencies can utilize these results to formulate policies that promote and incentivize nature-based and hybrid interventions, aligning national development goals with climate resilience.
    b. *Resource Allocation*: Informed by the cost-benefit analysis, policymakers can allocate resources efficiently, prioritizing interventions that yield maximum societal and environmental benefits.
3. **International Organizations:**
    a. *Funding Allocation*: International organizations can channel funds towards initiatives that align with the identified scenarios, leveraging their support to maximize positive impacts.
    b. *Knowledge Exchange*: Facilitating knowledge exchange between regions facing similar challenges can enhance the global understanding of effective climate resilience strategies.
4. **Research and Academic Community:**

a. *Continuous Monitoring and Evaluation*: Researchers can contribute by implementing ongoing monitoring and evaluation mechanisms to track the long-term effectiveness of implemented interventions, ensuring adaptive management.

The next steps involve the drafting of concrete policy recommendations and the development of comprehensive implementation plans for the recommended Nature-Based Infrastructure (NBI) interventions. These plans should outline a strategic roadmap, delineating the specific actions, timelines, and responsibilities for each proposed intervention, including their physical location. The roadmap should clearly articulate the resource requirements, including financial, human, and technological resources, necessary for successful implementation. This ensures that stakeholders understand the investment needed to realize the proposed interventions.

Further, it is important to recognize the spatial variability of impacts resulting from NBI implementation. This study comprises a scoping study of potential benefits, given that the physical location of assets has yet to be determined. Follow up research should enhance the modeling framework to incorporate location-specific factors and the actual locations for NBI actions to consider variations in terrain and how these may impact cost. This spatial specificity ensures a more accurate representation of the diverse impacts across the region. Analysts should collaborate closely with local stakeholders, including communities, landowners, and regional authorities, to gather site-specific data and insights. Local knowledge is invaluable in refining impact models to reflect the intricacies of different locations within northern Ghana.

5 References

Carbon Brief. (2018). CLIMATE MODELLING 19 April 2018 12:58 Explainer: How ‘Shared Socioeconomic Pathways’ explore future climate change. Retrieved from https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change/.

Lugt, D., de Vries, L., Udo, J., & Kasei, R. (2023, April). *GCF climate change and flood risk assessment* (Flood Risk and Climate Change Assessment - Task 2). HKV.

Lugt, D., de Vries, L., Udo, J., Huthoff, F., Sambolino, F., & Kasei, R. (2023, May). *GCF climate change and flood risk assessment* (Flood adaptation measures – Task 3). HKV.

Manashi, P. (2016). Impacts of land use and climate changes on hydrological processes in South Dakota Watersheds. Retrieved from Open Prairie, Public research access Institutional repository and information exchange: https://openprairie.sdstate.edu/etd/1018/

Meinshausen, M., Nicholls, Z. R., Lewis, J., Gidden, M. J., Vogel, E., Freund, M., Wang, R. H. (2020). he shared socio-economic pathway (SSP) greenhouse gas concentrations and their extensions to 2500. Geoscientific Model Development, 13(8), 3571-3605.

USDA. (1989). Module 104: Runoff Curve Number Computations. Study Guide. . Washington, DC, USA: United States Department of Agriculture Hydrology Training Series. Natural Resources Conservation Service.

Appendix A. Estimation of climate indicators and extreme events

The climate dataset builds on the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), specifically, on the ISIMIP3a and ISIMIP3b protocols. See https://data.isimip.org/ for more information and GUI download of the gridded data. Gridded data is then averaged for a selected country or region, and climate statistics are computed based on the reference period 1981 – 2014.

IISD developed a python-based code THAT allows to download climate data based on the following available climate scenarios (noting that the obsclim gswp3-w5e5 experiment is the reference observational dataset):

- historical: historical simulation
- ssp126: strong mitigation scenario (unlikely to occur in reality as of today)
- ssp585: strong warming scenario (unlikely to occur in reality as of today)
- ssp370: middle of the road scenario

The available climate models to retrieve historical and forecasted climate data are the following:

- canesm5
- cnrm-cm6-1
- cnrm-esm2-1
- ec-earth3
- gfdl-esm4
- ipsl-cm6a-lr
- miroc6
- mpi-esm1-2-hr
- mri-esm2-0
- ukesm1-0-ll

The available variables that can be considered into the climate dataset are the following:

- tas: near-surface temperature (converted to degrees C)
- tasmax: max daily temperature (converted to degrees C)
- pr: precipitation (converted to mm / day)
- sfcwind: surface wind (m / s)
- hurs: relative humidity (%)
- rsds: surface solar downward radiation (W / m2)

Standardized precipitation index (SPI)

Precipitation is one of the key indicators required for estimating a range of climate impacts. Spatial precipitation data can be used to calculate the Standardized Precipitation Index (SPI). The SPI provides a measure of how current precipitation levels compare to the mean precipitation ranges from -3 to +3 in any given month. A month with a value of -3 indicates an extreme dry abnormality, which implies that, in light of usual rainfall, this month has extremely little precipitation. A value of +3 means an extreme wet abnormality, or in other words, in light of the mean precipitation for this month, the precipitation in that given month is extremely high. This makes the SPI a useful measure to analyze, in space, what the occurrence of climate abnormalities in any given month is. The SPI is subsequently subdivided into 10 deciles of 0.6 each, whereby the lowest decile (SPI_l00) can be regarded as indicator of drought events and the highest decile (SPI_l09) as indicator for flood events, given that these two deciles capture the outer ends of the extreme abnormalities estimated using the SPI. This implies that precipitation is used to as input to the parameters that are used to determine whether flood or drought events occur, by means of determining whether an abnormality occurs in any given month.

SPI is defined as spi-{m} where m is the number of months and can vary from 1 to 48.
This index is derived from pr (when m=1) and pr-{m}-months (when m>1). It is computed on every grid cell first, and then averaged across the country. The reference period used is 1981-2014. For computational reasons, instead of fitting a pearson3 distribution to the reference period, we compute empirical quantiles. The standardization is then done by attributing each value at any time to the precomputed historical quantiles (binning). Each quantile bin is mapped to a standardized value (Based on the normal distribution). For example, quantile 0.5 (the median) is mapped to zero, while quantile 0.87 (+1 standard deviation) is mapped to 1.

Climate statistics

The reference period for climate statistics is 1981-2014. The reason is:

- long-enough record (> 30 years)
- does not overlap with CMIP6 / ISIMIP projection period for the SSP scenarios (2015-)
- statistics are representative of our recent experience (the climate in the 1930s was likely significantly different)

The baseline climate percentiles are computed after fitting a distribution (e.g. dist_95th) or empirically (e.g. empirical_95th). The aim of using a fitted distribution is to "smooth" out the resulting percentiles due to undersampling. Note however that estimating tail percentiles (>95th or <5th) is inherently uncertain with our sample size of 33*12 and sensitive on the choice of the underlying distribution.

The following distributions are used to fit the baseline climate:

- tas, tasmax, twet, wbgt, wbgt-day, esi, esi-day: normal distribution
- pr and derivatives pr-{m}-months: pearson3 distribution (recommended in the literature referring to the SPI indices)
- sfcwind: chi distribution (suited for the square root of the sum of normally distributed squares -- here sfcwind = sqrt(u**2 + v**2))