Adapting Together, Thriving Tomorrow

An economic appraisal of financial and economic costs and benefits of prioritised adaptation options in Ghana

Contacts Information

No. 91 Starlet Street, Opp

Telephone: 050 6694760 /

050 6699466

P.O. Box M.326

info@epa.gov.gh

www.epa.gov.gh

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EXECUTIVE SUMMARY

Background and Purpose

Ghana faces escalating climate change risks, including rising temperatures, erratic rainfall, sea-level rise, and extreme weather events, which threaten key sectors such as biodiversity and ecosystems, agriculture, water, health, and cities. Under the auspices of the Ministry of Environment, Science, Technology, and Innovation (MESTI) and the Environmental Protection Agency (EPA), the Green Climate Fund (GCF) Readiness Project on National Adaptation Plans (NAPs) titled “Enhancing multi-sector planning and capacity for effective adaptation in Ghana” aims to build resilience through medium- to long-term adaptation planning, budgeting, and integration into national development processes. This report, prepared by the Regional Centre for Energy and Environmental Sustainability (RCEES) at the University of Energy and Natural Resources (UENR), provides a comprehensive economic appraisal of prioritized adaptation options across six focal sectors: biodiversity and ecosystems, agriculture, water, health, and cities. The appraisal quantifies financial and economic costs and benefits, emphasizing the complementary nature of adaptation actions to inform sustainable financing, policy integration, and implementation. Drawing on prior sectoral vulnerability assessments, the analysis evaluates adaptation investments’ potential to avert climate-induced losses, using a framework that links stressors, impacts, and economic outcomes (e.g., mangrove restoration to mitigate coastal erosion).

The primary objective is to identify viable adaptation strategies, compute cost-benefit streams, and prioritize options based on efficiency metrics such as Benefit-Cost Ratio (BCR), Net Present Value (NPV), and Internal Rate of Return (IRR). The report highlights the exponential reduction in economic losses from climate effects through targeted investments, while acknowledging residual risks. Gender, youth, and indigenous knowledge are cross-cutting themes, ensuring inclusive and equitable adaptation.

Methodology

The appraisal uses a hybrid approach combining system dynamics modeling (Stella Architect) with Cost-Benefit Analysis (CBA). The analysis integrates validated historical data (2015–2025), scenario simulations to 2040, and a base discount rate of 5% for present values. Proxy pricing was applied to non-market benefits (e.g., carbon sequestration) where practicable and qualitative discussions in the absence of practical proxies. Sensitivity analysis considered climate severity and discounting assumptions.

The Bundled Adaptation Action Approach

There were a total of 373 adaptation actions across the various Sectors and Sub-sectors. To enhance the practicality and effectiveness of this appraisal, adaptation options were evaluated not as standalone measures but as complementary “bundles” of interconnected actions. This approach not only makes it practical, but it also recognizes that climate vulnerabilities in Ghana are multifaceted and interlinked—rarely addressed by a single intervention. For instance, in agriculture, improving crop yields under drought conditions might require bundling drought-resistant seed varieties with efficient irrigation systems, farmer training, and weather advisory services.

This bundled method departs from traditional appraisals that treat options as competitive alternatives, which can overlook real-world complementarities and lead to fragmented implementation. Instead, by modeling bundles in system dynamics, we capture feedback loops (e.g., restored ecosystems improving water availability for agriculture) and non-linear impacts, leading to more accurate cost-benefit projections. For readers unfamiliar with this, consider it akin to building a resilient house: walls (one action) provide structure, but adding a roof, foundation, and insulation (bundled actions) creates a complete, durable shelter. This ensures the analysis aligns with Ghana's NAP goals of integrated, multi-sectoral planning, while highlighting policy needs like coordinated funding mechanisms to support bundle or programmatic rollout instead of siloed projects.

Key Findings by Sector

The analysis projects costs and revenues from 2015–2040 under baseline and high-emission (SSP8.5) scenarios, revealing positive economic returns for bundled adaptations. Total adaptation investments reduce losses exponentially, with BCRs generally >1, positive NPVs, and IRRs exceeding discount rates.

a) Biodiversity & Ecosystems

Across forestry, marine, aquatic and wetlands, revenues generally exceed costs under Baseline; however, under SSP8.5 costs catch up or overtake revenues in marine and aquatic systems. Net benefits are strongest in forestry and marine under Baseline, while aquatic turns negative under SSP scenarios. Priority actions include reforestation, mangrove/wetland restoration, and riparian rehabilitation, with portfolio financing and environmental-economic accounting to capture non-market value.

b) Agriculture

Crops, fisheries and livestock bundles were evaluated. Fisheries consistently yield the highest BCRs across scenarios, while livestock becomes sub-optimal under SSP8.5 (BCR<1). Policy emphasis should retain crops as the adaptation cornerstone, scale high-return fisheries/aquaculture, and transform livestock systems (feed, animal health, diversification).

c) Water

At the subsector level, groundwater management exhibits very strong efficiency (Baseline discounted BCR of 8.9), whereas surface water investments fall below unity under SSP4.5 (0.52) and SSP8.5 (0.27). Aggregated at sector level, BCRs are 2.9 (Baseline), 1.8 (SSP4.5), and 1.0 (SSP8.5)—highlighting the need to prioritise lower-cost, high-impact groundwater and watershed measures as climate stress intensifies.

d) **Health**

Three subsectors—Workforce, Facilities, Monitoring and Response—were assessed. Discounted (5%) efficiency metrics indicate:

i. Facilities: BCR 4.34 (Baseline), 1.88 (SSP4.5), 1.16 (SSP8.5); IRR declines under SSP8.5.

ii. Monitoring: BCR 3.60 (Baseline), 2.25 (SSP4.5), 1.76 (SSP8.5).

iii. Workforce: BCR 2.00 (Baseline), 1.25 (SSP4.5), 0.98 (SSP8.5).

These results prioritise resilient facilities and disease/climate surveillance as cost-effective "no-regrets" investments, while workforce scaling may require phasing and targeted productivity reforms under SSP8.5.

e) **Cities (Urban)**

Roads and Buildings show strong returns under Baseline—e.g., Buildings discounted BCR 3.41—moderating under SSP4.5 and deteriorating under SSP8.5. By 2040, overall urban BCR falls to 1.18 (SSP4.5) and 0.77 (SSP8.5), with roads turning negative. This highlights the need for phased standards, nature-based drainage, and innovative financing to keep capital-intensive investments viable under severe climate stress.

Cross-Sector Priorities for a National Portfolio

a) Double-down on high-BCR prevention systems. Scale climate-health monitoring/response, hydro-meteorological early warning, and groundwater/watershed management; these consistently return BCR>2 under most scenarios.
b) Protect and restore the natural capital base. Reforestation and coastal/wetland restoration underpin agriculture, fisheries, flood control and carbon outcomes; adopt portfolio financing that values non-market benefits.
c) Make cities investable under SSP8.5. Pair hard infrastructure with green/blue-grey systems, stricter zoning, staged retrofits, and concessional/blended finance to keep roads/buildings above BCR≥1.
d) Target agriculture's winners and transform laggards. Maintain crops as the backbone; scale fisheries; de-risk livestock under high warming via feed/health innovation and diversification.

Financing and Value for Money

Given fiscal constraints and rising costs under SSP8.5, Ghana should prioritise: (i) blended finance/PPPs for urban and coastal packages; (ii) environmental-economic accounting and PES to monetise ecosystem services; and (iii) innovative climate-health finance to sustain monitoring/response programs.

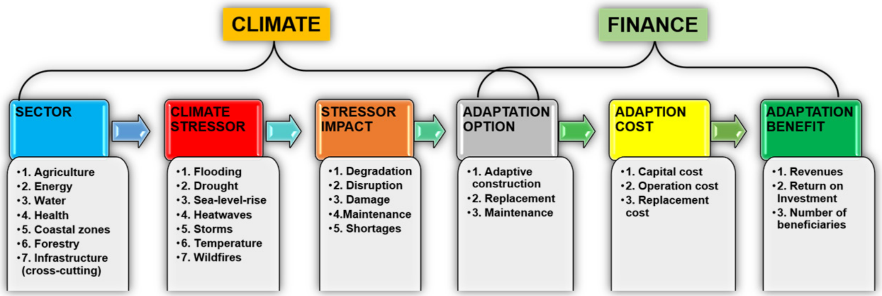
Conclusion

The economic case for adaptation in Ghana is strong—particularly for prevention-focused and nature-based packages—even as climate severity erodes returns for capital-intensive infrastructure. A national portfolio that front-loads high-BCR systems, secures the natural capital base, and de-risks urban investments can maintain positive NPVs across plausible futures while delivering co-benefits for equity, health, and livelihoods. The appraisal and indicators presented here provide a ready blueprint for sequencing, financing, and tracking results within the NAP. One of the limitations of this work is the scale (National Level) at which it was done. Adaptation planning must be tailored to regional and ecological differences (e.g., northern savannah vs. southern forest zones). This ensures interventions are context-specific, addressing distinct groundwater recharge rates, surface water availability, and community demand patterns. We therefore recommend that this sub-national analysis be carried out for a more targeted plan.

1. INTRODUCTION

The Ghana Environmental Protection Agency, under the auspices of the Ministry of Environment, Science, Technology, and Innovation (MESTI), is implementing a three-year Green Climate Fund (GCF) Readiness Project on National Adaptation Plans (NAPs) to build capacity for adaptation planning in Ghana. The NAP project, "Enhancing multi-sector planning and capacity for effective adaptation in Ghana," aims to facilitate multi-sectoral, medium- to long-term adaptation planning and budgeting in Ghana while promoting the incorporation of climate change adaptation considerations into development planning processes and policies. It aims to enhance systems for developing and disseminating climate risk and vulnerability information and establish sustainable financial channels for climate change adaptation efforts. Some adaptation options were proposed, and the cost of adaptation investments and the resulting impact or risk aversion were analysed. Below (see Figure 1) illustrates our conceptualisation of climate adaptation options as inputs for economic appraisal regarding cost and benefits.

Figure 1: Schematic overview of the link between adaptation impact and finance



This framework outlines the proposed adaptation options to address the stressors and avert adverse impacts, as well as the linkage between the output from these adaptation options and the inputs for the economic appraisal.

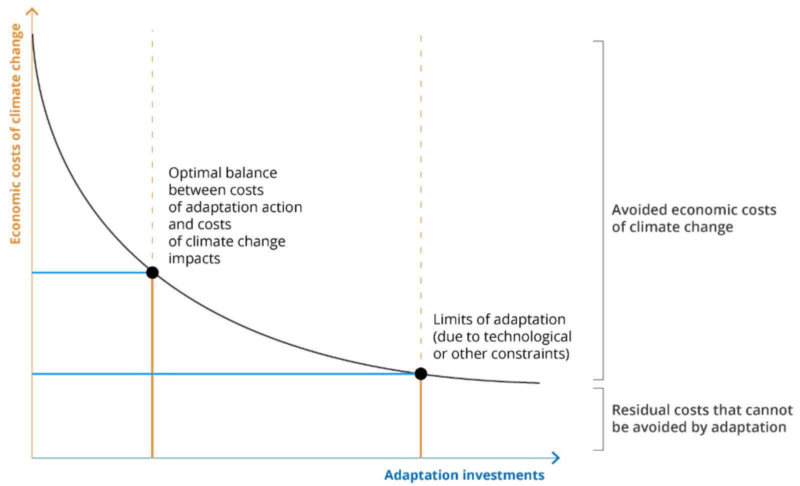
For example, coastal ecosystems, as a sector, are vulnerable to sea-level rise —a climate stressor that can lead to shoreline erosion and other impacts. The adaptation option could be mangrove restoration. The size of the coastalline requiring restoration and the restoration cost per square kilometre help compute the adaptation cost. The benefits would include the length of the protected shoreline and the livelihoods and assets within the protected area.

2. OBJECTIVE OF THE REPORT

The report aims to provide an economic appraisal of financial and economic costs and benefits of prioritised adaptation options for six sectors at the national level. The sectors in focus include biodiversity and ecosystems, agriculture, water, disaster risk reduction, health, cities, and water, sanitation and hygiene.

It aimed to identify options and conduct an economic appraisal of the cost and benefit streams associated with different adaptation strategies. The benefits and cost adaptation strategy framework proposed demonstrates a relationship between (monetised) climate change impacts and adaptation costs or adaptation investments, as illustrated in Figure 2.

Figure 2: Adaptation investments and the economic costs of climate change



Source: Dasgupta, P. (2016)[1].

Adaptation investments reduce (economic) losses from climate effects exponentially, with larger investments resulting in lower losses. Still, there will always be costs from residual climate change consequences that adaptation cannot mitigate.

1 Dasgupta, S., Sobhan, I., & Wheeler, D. (2016). Impact of Climate Change and Aquatic Salinization on Mangrove Species and Poor Communities in the Bangladesh Sundarbans. Policy Research Working Paper No. 7736. World Bank Group, Washington, DC.

3. GENERAL METHODOLOGY

3.1. Overview of Approach

The methodology for the economic appraisal of adaptation actions under Ghana's National Adaptation Plan (NAP) integrates system dynamics modeling with Cost-benefit analysis (CBA). CBA quantifies each cost and benefit, determining a course of action as favourable when benefits surpass expenses. If the benefit-cost ratio exceeds 1, the alternative is deemed economically viable. Various strategies for the same objective can be evaluated, and the option with the optimal benefit-cost ratio can be chosen. Acquiring precise data for all costs and benefits associated with non-marketed goods, services, and advantages was challenging. Proxy prices were used in place of market prices where applicable.

A system dynamics model was developed using Stella Architect to compute the climate impact on various sectors, assess the potential benefits of adapting to climate change, and evaluate the economic implications of adaptation actions. System Dynamics modelling, developed by Jay Forrester at the Massachusetts Institute of Technology in the late 1950s, encompasses causal relationships, feedback loops, delays, and non-linearities, making it particularly effective for depicting and understanding complex real-world systems. It is utilised in the absence of market prices.

The processes for developing a system dynamics model closely correspond to the stages of the United Nations (UN) integrated policymaking cycle. The development of a system dynamics model entails a five-step iterative process:

1. problem identification,
2. dynamic hypotheses formulation,
3. formal model construction,
4. validation, and
5. simulation of different scenarios.

Insights from the Sectorial adaptation plans, which were developed through a comprehensive stakeholder participation approach, were translated into stock and flow diagrams in Stella Architect, simulating scenarios from 2015 to 2040, and validated with historical data (2015–2025). The methodology draws on Fiji's NAP costing approach for rapid cost estimation, the "Aggregated Cost Approach" was employed for this assignment[2]. This hybrid approach ensures scientific rigor and practical

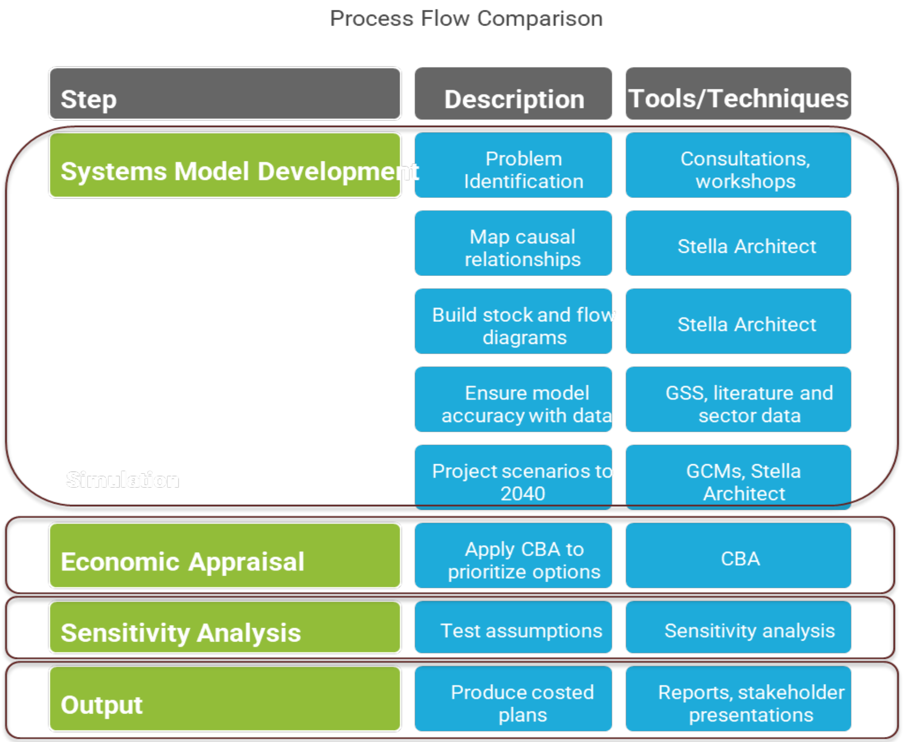
2 Government of Fiji, Ministry of Economy, Climate Change and International Cooperation Division. (2020). *Costing Methodology for Fiji's National Adaptation Plan*. Suva: Government of Fiji. napgn-en-2020-costing-methodology-for-Fiji-NAP.pdf

applicability, addressing four national sectors—agriculture, health, biodiversity, and urban/cities—plus resilient infrastructure, with gender and youth as a cross-cutting theme.

3.2. Process Flow

The economic appraisal follows a five-step iterative process, aligned with system dynamics principles and the UN integrated policymaking cycle[3], tailored to appraise pre-identified adaptation options from prior risk and vulnerability assessments conducted by the Government of Ghana.

Figure 3: Summary of Methodology for Costing Adaptation Options



3 Forrester, J. W. (1961). Industrial Dynamics. Cambridge, MA: MIT Press.

3.2.1. Systems Model Development

1. Problem Identification: Engage stakeholders, including the CSPG, MESTI, and women's groups, to validate adaptation options from sector action plans, ensuring gender considerations and alignment with national priorities.

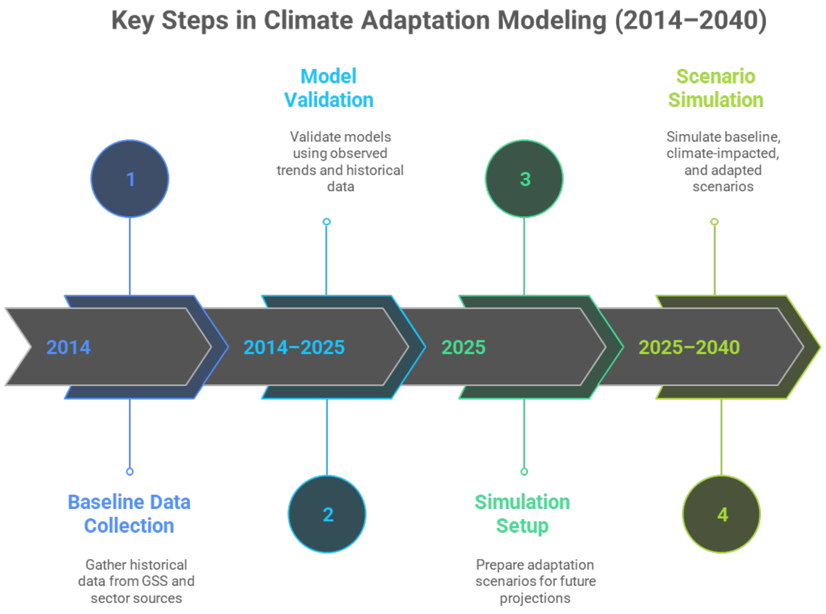
2. Dynamic Hypotheses Formulation: Develop CLDs to map causal relationships (e.g., climate impacts on crop yields, economic feedback loops from NTFP income), guiding model development. For example, a CLD for ecosystems might show how forest cover affects carbon sequestration and local livelihoods.

3. Formal Model Construction: Build stock and flow diagrams in Stella Architect, defining stocks (e.g., forest cover, urban infrastructure), flows (e.g., restoration rate, flood damage), and drivers (e.g., population growth, climate change).

4. Validation: Validate models using historical data (2015–2025) from GSS and sector-specific sources, ensuring alignment with observed trends (e.g., historical crop yields or flood damage).

5. Simulation of Scenarios: Simulate adaptation scenarios to 2040, including baseline (no climate change), climate-impacted, and adapted scenarios, using GCM projections (SSP4.5 for low risk and SSP8.5 for high risk for this work).

Figure 4: A Schematic of the Systems Dynamics Modelling Process



3.2.2. Economic Appraisal

Calculate benefit-cost ratios, incorporating proxy prices for non-market benefits (e.g., carbon sequestration valued at $40 per ton of CO2 equivalent). For example, reforestation costs are weighed against benefits like carbon storage and NTFP income. The discount rate of 5% was selected as the base rate for computing the Discounted Benefit-Cost Ratio (BCR) in this economic appraisal. This rate was referenced from similar studies[45] and directly relates to Ghana's climate adaptation context. Climate adaptation projects often involve intergenerational benefits (e.g., ecosystem restoration, reduced flood risks, or improved agricultural yields), which are sensitive to discounting. A lower rate like 5%, despite the prevailing economic conditions, avoids overly penalizing future benefits, reflecting ethical considerations for sustainability and equity in climate economics. The IPCC AR5 WGII Chapter 17 on Economics of Adaptation recommends low rates (e.g., those used in the Stern Review, around 1.4%) for climate adaptation, especially in vulnerable regions like Africa, to account for future generations

4 Dasgupta, S., Sobhan, I., & Wheeler, D. (2016). Impact of Climate Change and Aquatic Salinization on Mangrove Species and Poor Communities in the Bangladesh Sundarbans. Policy Research Working Paper No. 7736. World Bank Group, Washington, DC.
5 World Bank. (2010). Economics of Adaptation to Climate Change: Ghana Country Study. Washington, D.C.: World Bank. Available at World Bank Open Knowledge Repository.

and uncertainty. It critiques high rates for underestimating long-term benefits. However, 5% is a practical compromise in development contexts like Ghana's NAP. To assess the economic viability of the bundled adaptation actions for each sub-sector, three standard efficiency metrics were applied:

- **Benefit–Cost Ratio (BCR):** The BCR was computed as the ratio of the present value of total benefits to the present value of total costs. A BCR greater than 1 indicates that the benefits outweigh the costs, suggesting the action is economically viable. Both undiscounted and discounted BCRs were calculated, with discounting performed at a real rate of 5% to reflect the time value of money.
- Net Present Value (NPV): NPV represents the difference between the present value of benefits and the present value of costs over the 2015–2040 period. A positive NPV indicates that an adaptation action generates a net economic gain when future cash flows are discounted.
- Internal Rate of Return (IRR): The IRR was estimated as the discount rate at which the NPV of an adaptation action equals zero. It represents the implicit rate of return of the investment in the adaptation action. In cases where multiple sign changes occurred in the net benefit stream, the IRR could be undefined or yield multiple roots. Such instances were flagged accordingly, with results interpreted cautiously and supplemented by BCR and NPV values.

3.2.3. Sensitivity Analysis

In Sensitivity analyses, assumptions are tested (e.g., discount rates of 5% vs. 10%, climate scenarios like SSP4.5 vs. SSP8.5, proxy prices for ecosystem services) to ensure robustness, following methods from the EACC study[6]. For example, varying the discount rate assesses impacts on long-term cost estimates, while testing climate scenarios evaluates cost increases under higher warming.

3.2.4. Stakeholder Validation

The costed adaptation plans for agriculture, health, ecosystems/forestry, urban/cities, and resilient infrastructure, are validated by stakeholders and made ready for implementation. The plans include detailed cost estimates, benefit-cost ratios, and prioritized options, presented to the CSPG for national adoption and to district stakeholders for local integration.

Table 1. Summary of Methodological Steps and Tools

Step	Description	Tools/Techniques
Problem Identification	Validate pre-identified adaptation options with stakeholders	Consultations, workshops
Dynamic Hypotheses	Map causal relationships using CLDs	Stella Architect

6 World Bank. (2010). Economics of Adaptation to Climate Change: Ghana Country Study. Washington, D.C.: World Bank. Available at World Bank Open Knowledge Repository.

Formal Model Construction	Build stock and flow diagrams	Stella Architect
Validation	Use historical data (2015–2025) to ensure model accuracy	GSS, literature and sector data
Simulation	Project scenarios to 2040 under climate change and adaptation	GCMs, Stella Architect
Economic Appraisal	Apply CBA to prioritize options	CBA
Sensitivity Analysis	Test assumptions (e.g., discount rates, climate scenarios)	Sensitivity analysis
Deliverables	Produce costed plans for four sectors and ten districts	Reports, stakeholder presentations

Table 2. Example Cost and Benefit Streams for Bundled Adaptation Actions

Sector	Adaptation Option	Cost Streams	Benefit Streams
Agriculture	Climate-smart agriculture	Capital: Irrigation equipment	Private: Increased crop yields
		Operating: Farmer training	Public: Food security, job creation
Ecosystems/ Forestry	Reforestation	Capital: Seedlings, equipment	Public: Carbon sequestration, biodiversity
		Operating: Ranger salaries	Private: NTFP income
Health	Malaria prevention	Capital: Hospital buildings, Mosquito nets	Public: Reduced healthcare costs
		Operating: Distribution programs	Private: Improved workforce productivity
Urban/Cities	Flood defenses	Capital: Dikes, drainage systems	Public: Reduced property damage
		Operating: Maintenance	Private: Business continuity
Resilient Infrastructure	Road retrofitting	Capital: Construction materials	Public: Economic stability
		Operating: Maintenance	Private: Reduced transport disruptions

This methodology ensures a transparent, inclusive, and scientifically grounded appraisal, tailored to Ghana's NAP objectives and stakeholder needs, leveraging lessons from global and regional adaptation costing methodologies. It builds on prior risk and vulnerability assessments to focus solely on costing and appraising adaptation options, ensuring alignment with Ghana's national development priorities.

3.3. Understanding the Complementary Nature of Adaptation Options and Implications for Economic Appraisal and Costing

Some adaptation options across sectors often exhibit a complementary rather than competitive character. This means that individual actions are not mutually exclusive or alternatives vying for selection; instead, they work together to reinforce resilience outcomes. For instance, climate-resilient agriculture practices such as improved irrigation, agroforestry, and climate information services are more effective when implemented as an integrated package. Similarly, actions that improve health systems' capacity to manage climate-sensitive diseases are stronger when combined with water and sanitation infrastructure improvements and early warning systems.

This complementary nature reflects the complex and interlinked vulnerabilities that communities and ecosystems face due to climate change. It also aligns with systems-based and nature-based adaptation approaches that require integrated responses to yield sustained outcomes. Traditionally, economic appraisal methods such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and multi-criteria analysis (MCA) are used to compare and prioritize options based on economic efficiency or multi-dimensional value. However, in situations where adaptation options are complementary, prioritization shifts from ranking options to sequencing and packaging interventions.

The goal is not to select the 'best' single option, but to identify coherent bundles of actions that collectively address multiple risks and deliver synergies. Costing is done at the package level, recognizing interactions, economies of scale, and cumulative benefits. For example, in the agriculture sector, bundling soil conservation, drought-resistant seeds, and extension services may yield greater resilience per dollar spent than assessing each option in isolation.

3.4. Framework for Costs and Benefits

The framework for costs and benefits is designed to comprehensively capture the financial and socio-economic impacts of adaptation actions, including non-market and gender-specific dimensions.

3.4.1. Cost Streams

Costs are categorized as follows:

- Capital Costs: Investments in infrastructure, equipment, and technology, such as climate-resilient irrigation systems or coastal defenses[7].

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7 World Bank. (2010). Economics of Adaptation to Climate Change: Ghana Country Study. Washington, D.C.: World Bank. Available at World Bank Open Knowledge Repository.

- Operating Costs: Ongoing expenses for maintenance, personnel, and operations, including training programs and monitoring systems.
- Shared Costs: Resources used across multiple sectors or measures, such as policy development or cross-sectoral research.

3.4.2. Benefit Streams

Benefits are divided into private and public goods. Private Goods are direct economic benefits, such as increased crop yields from climate-smart agriculture or income from non-timber forest products (NTFPs) like shea nuts. Public Goods include indirect benefits such as:

i) Ecosystem Services:
  - *Provisioning Services*: Timber, water, and NTFPs.
  - *Regulating Services*: Soil protection, water regulation, and climate regulation (e.g., carbon sequestration).
  - *Cultural Services*: Spiritual, recreational, and aesthetic values, such as sacred groves.
  - *Supporting Services*: Nutrient cycling and seed dispersal.

ii) Multiplier Effects: Secondary economic impacts, including job creation, increased labor demand, and livelihood opportunities from adaptation actions (e.g., agroforestry enterprises).

3.4.3. Non-Market Benefits

Most non-market benefits, critical in Ghana's context, such as ecosystem services (e.g., soil protection, water regulation, cultural values) and social benefits (e.g.,community resilience, gender equity), were not quantified due to the complexity of assigning monetary values and limited data availability. Instead, these benefits were qualitatively discussed to highlight their importance in adaptation planning. Where feasible, select non-market benefits, such as carbon sequestration, were quantified using proxy prices like willingness to pay (WTP) or willingness to accept (WTA) compensation, derived from literature (e.g., international carbon prices at $40 per ton of CO2 equivalent). This approach addresses the challenge of monetizing ecosystem services, ensuring their inclusion in CBA.

3.4.4. Gender Considerations

Gender is a cross-cutting theme, with specific attention to women's roles and vulnerabilities. Women often lead in NTFP harvesting and face disproportionate climate impacts, such as increased time spent on water collection due to droughts. The framework identifies gender-specific benefits and costs, ensuring equitable appraisal. Stakeholder consultations with women's groups can validate these impacts, aligning with Ghana's gender-responsive adaptation goals.

3.5. Data Sources and Gaps

The methodology leverages diverse data sources to ensure representative cost and benefit estimates while acknowledging and addressing data limitations, drawing on lessons from global adaptation cost estimation practices[8].

3.5.1. Data Sources

i) Climate Data: Climate stressors such as temperature and precipitation impact the different sectors to various degrees. The model uses historical and projected climate datasets (from CHMIS)[9] to compute the effect of changes in the stressors on the sectors.

ii) Socio-Economic Data: National and household survey data from the Ghana Statistical Service (GSS), the World Bank and the International Food Policy Research Institute (IFPRI).

iii) Sector-Specific Data:

- Agriculture: Crop yields, soil parameters, and irrigation data from regional studies studies.
- Health: Disease prevalence (e.g., malaria) and healthcare cost data from the Ministry of Health, used to assess adaptation costs like mosquito net distribution.
- Ecosystems/Forestry: Forest cover (Land Cover), NTFP yields, and biodiversity data from the Forestry Commission of Ghana, supporting reforestation and monitoring cost estimates.
- Urban/Cities: Urban flood risk and infrastructure data from municipal authorities, used to cost flood defenses.
- Resilient Infrastructure: Retrofitting costs and adaptation strategies from World Bank studies, focusing on roads and coastal defenses.

iv) Ecosystem Services: Valuation studies, both local (e.g., Ghana-specific wetland assessments) and international (e.g., TEEB database), supplemented by community engagement.

v) Stakeholder Input: Consultations with the Ministry of Environment, Science, Technology, and Innovation (MESTI), Cross-Sectoral Policy Group (CSPG), and local communities, validating pre-identified adaptation options from prior risk and vulnerability assessments and benefits from ecosystems services.

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8 Chapagain, D., Baarsch, F., Schaeffer, M., & D'Haen, S. (2020). Climate change adaptation costs in developing countries: Insights from existing estimates. Climate and Development, 12(10), 934–942. DOI: 10.1080/17565529.2020.1711698.

9 Climate Hazard Management Information System https://climatedataguide.ucar.edu/climate-data/indices

3.5.2. Data Gaps

- District-Level Data: Limited granular data at the district level, particularly for smaller districts, requires extrapolation from national datasets or reliance on stakeholder input. For example, detailed cost data for mangrove restoration in Keta is unavailable.
- Cultural and Gender-Specific Data: Sparse data on cultural services (e.g., spiritual values of sacred groves) and gender impacts (e.g., women's time use under climate stress) necessitates qualitative assessments through community surveys.
- Ecosystem Services Valuation: Regulating and cultural services lack comprehensive local valuation, requiring proxy indicators from regional studies or international benchmarks.

These gaps can be addressed through participatory workshops and expert consultations, ensuring data quality and local relevance. The methodology's flexibility, inspired by similar studies such as Fiji's approach, allows for iterative refinement as new data emerges.

3.6. Challenges and limitations

Quantitative evaluation of climate change impacts in Ghana is difficult, mainly due to a lack of data. The absence of comprehensive data, particularly in sectors with inadequate infrastructure, hinders the proper evaluation of climate impacts and the formulation of policy decisions. Moreover, uncertainties in climate forecasts stemming from variations in data quality and measurement methodologies impede accurate quantification. Climate adaptation solutions include legislative and institutional frameworks that are challenging to quantify monetarily. To address data gaps, proxy data is used in some cases for this assessment.

4. BIODIVERSITY AND ECOSYSTEM SECTOR

4.1. Background

Ghana's biodiversity and ecosystem sector, encompassing its forests, wetlands, marine environments, and aquatic systems, is vital for its ecological resilience, economic vitality, and societal well-being. These ecosystems deliver essential services, including carbon sequestration, water purification, and resources that sustain livelihoods through fisheries, agriculture, and timber production. Yet, they are increasingly threatened by climate change, with rising temperatures, erratic rainfall patterns, sea level rise, and extreme weather events threatening their integrity. These climate-induced pressures are compounded by human activities such as deforestation, illegal mining (galamsey), overfishing, and pollution, which further degrade these vital systems and the communities that rely on them.

Recognising these challenges, the "Climate Change Adaptation Action Plan for the Biodiversity and Ecosystems Sector in Ghana," developed under the National Adaptation Plan (NAP) framework, proposes a suite of adaptation strategies to enhance ecological resilience, preserve biodiversity, and secure livelihoods. The action plan outlines interventions such as reforestation, wetland restoration, marine protected areas, and riparian rehabilitation, each designed to address the specific vulnerabilities of Ghana's ecosystems while contributing to sustainable development.

Implementing these adaptation measures, however, requires significant financial investment. A thorough economic appraisal is essential to ensure feasibility and optimise resource allocation. This document introduces the economic appraisal of adaptation options for Ghana's biodiversity and ecosystem sector, with the primary aim of developing a methodology to cost these climate adaptation strategies and evaluate their associated costs and benefits. By quantifying these interventions' financial inputs and socioeconomic returns, this appraisal seeks to integrate climate change adaptation into national development planning and budgeting processes while establishing sustainable financial channels to support long-term resilience efforts.

The appraisal examines a range of adaptation options detailed in the "Climate Change Adaptation Action Plan for the Biodiversity and Ecosystems Sector in Ghana." For example, reforestation efforts in areas like the Ankasa Conservation Area not only protect biodiversity, such as the forest elephant (Loxodonta africana cyclotis) but also enhance carbon storage, offering dual benefits for adaptation and mitigation[10]. Similarly, mangrove restoration in the Keta Lagoon Complex supports fish breeding grounds and reduces coastal erosion, bolstering local fisheries and community resilience[11]. These benefits, however, come with costs—such as expenses for land reclamation, community training, and enforcement—that must be carefully assessed against their long-term ecological and economic gains.

This economic appraisal outlines a methodology to estimate both direct costs (e.g., implementation and maintenance) and indirect costs (e.g., opportunity costs of land use) alongside the monetary and non-monetary benefits, including enhanced ecosystem services, improved livelihoods, and reduced climate vulnerability. To conduct

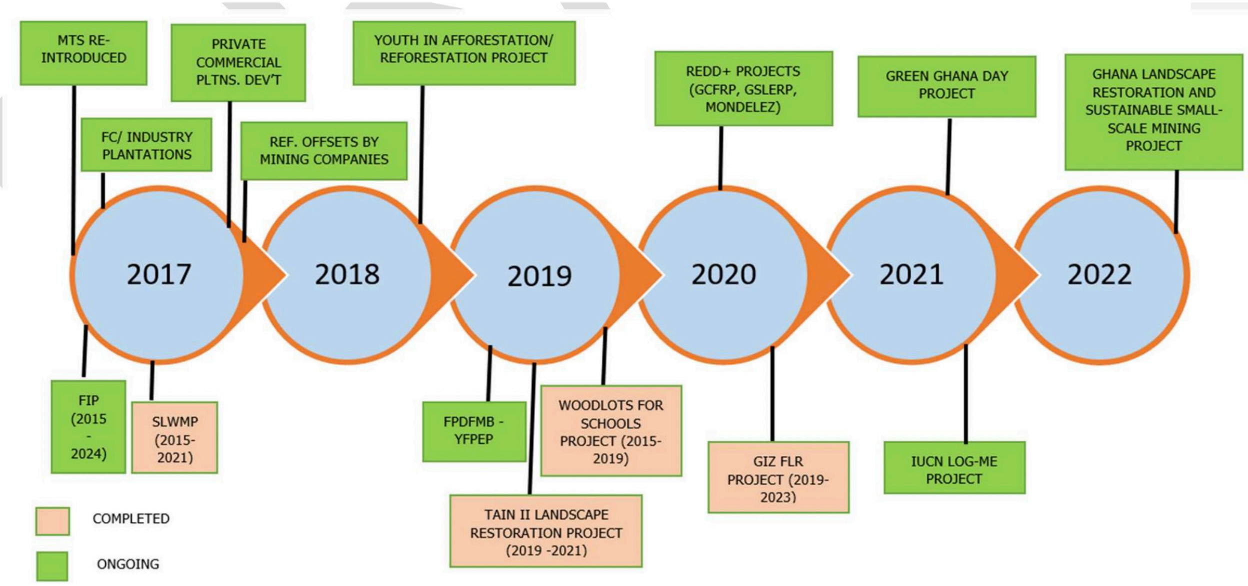
10 Forestry Commission. (2023). Reviewed Ghana Forest Plantation Strategy (Draft). Forestry Commission of Ghana. Retrieved from https://fcghana.org/wp-content/uploads/2024/10/Reviewed_Ghana-Forest-Plantation-Strategy_DRAFT.pdf

11 United Nations Framework Convention on Climate Change (UNFCCC). (2020). Ghana's Fourth National Communication to the UNFCCC. Environmental Protection Agency, Ghana. Retrieved from https://unfccc.int/documents/258141

this analysis, the appraisal employs a hybrid approach combining cost-benefit analysis (CBA) and system dynamics modelling, as detailed in the methodology. These insights will guide the prioritisation of adaptation options, ensuring limited resources are directed toward interventions with the greatest potential impact.

Aligned with the NAP project's objectives, this appraisal aims to facilitate multi-sectoral, medium- to long-term adaptation planning in Ghana. By embedding climate risk considerations into financial frameworks, it seeks to secure sustainable funding mechanisms—such as ecotourism revenues from Kakum National Park[12] or international climate finance—while fostering resilience across the biodiversity and ecosystem sector.

Figure 5: Major ongoing and completed forest restoration projects in Ghana (2017-2022)



Source: Ghana Forestry Commission 2023[13].

12 Forestry Commission. (2022). Ghana Forest Plantation Strategy – Annual Report 2021. Forestry Commission of Ghana. Retrieved from https://fcghana.org/ghana-forest-plantation-strategy-annual-report-2021/

13 Forestry Commission. (2023). Reviewed Ghana Forest Plantation Strategy (Draft). Forestry Commission of Ghana. Retrieved from https://fcghana.org/wp-content/uploads/2024/10/Reviewed_Ghana-Forest-Plantation-Strategy_DRAFT.pdf

The next sections will elaborate on the costing methodology, present the economic analysis of selected adaptation options, and offer recommendations to support Ghana's efforts to adapt to a changing climate.

4.2. Biodiversity & Ecosystem Sector Model Description

The biodiversity and ecosystems sector methodology builds on the general system dynamics and cost–benefit analysis framework (see GENERAL METHODOLOGY). The focus is on assessing adaptation options that enhance ecosystem resilience, protect biodiversity hotspots, and sustain ecosystem services under climate change. The modelling integrates both terrestrial and coastal ecosystems, including forest restoration, mangrove rehabilitation, wetland protection, and green infrastructure. Stock-and-flow diagrams (Figure 6-9) illustrate the causal pathways between adaptation investments, ecosystem condition, and long-term ecological and socio-economic outcomes.

4.2.1. Systems Dynamics Model Structure

The system dynamics model conceptualizes biodiversity as a stock of natural capital that changes over time depending on flows of restoration, degradation, and management interventions. Key flows include reforestation rates, mangrove restoration activities, and wetland protection measures. Adaptation actions are parameterized as policy levers affecting these flows. The model also links ecosystem condition to ecosystem services such as carbon sequestration, coastal protection, and habitat provision. Economic valuation is incorporated by associating improved ecosystem services with avoided damages and non-market benefits, informed by national and global valuation studies (TEEB, 2010; IPBES, 2019).

Figure 6. Forestry Sub-sector (Biodiversity and Ecosystems Sector) Stock-and-Flow Structure

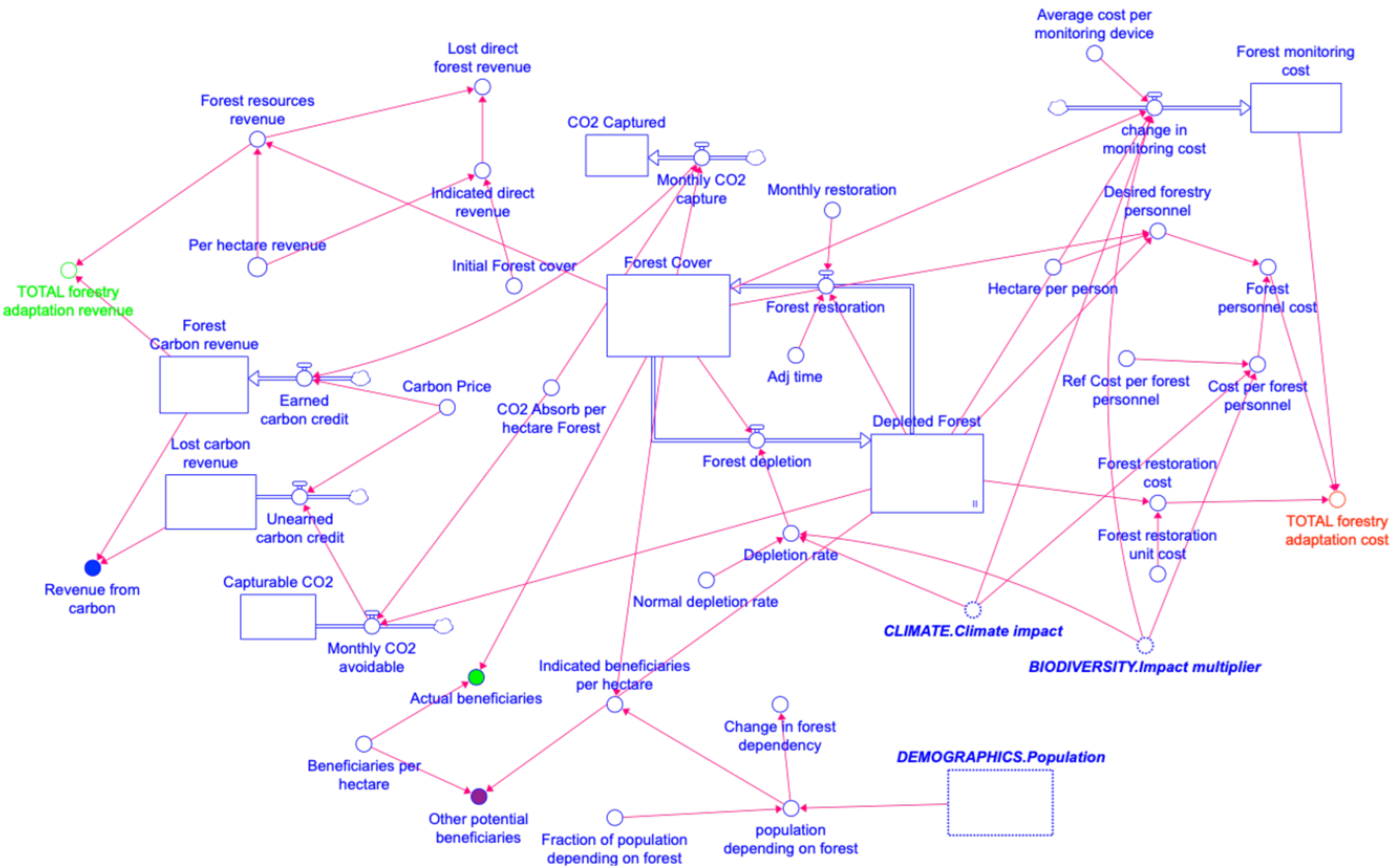


Figure 7. Marine Sub-sector Stock-and-Flow Structure (Biodiversity and Ecosystems Sector).

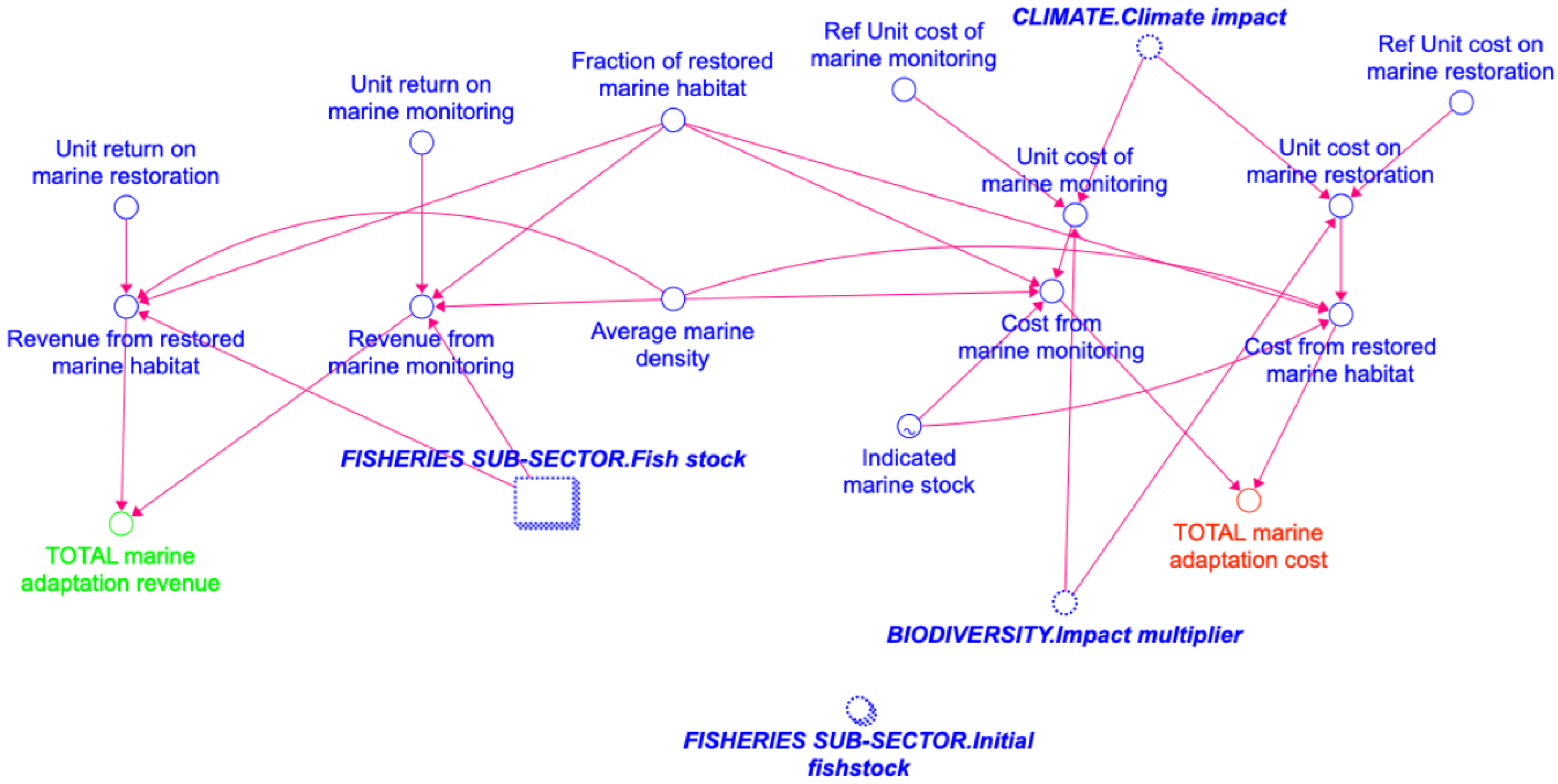


Figure 8. Wetlands Sub-sector Stock-and-Flow Structure (Biodiversity and Ecosystems Sector).

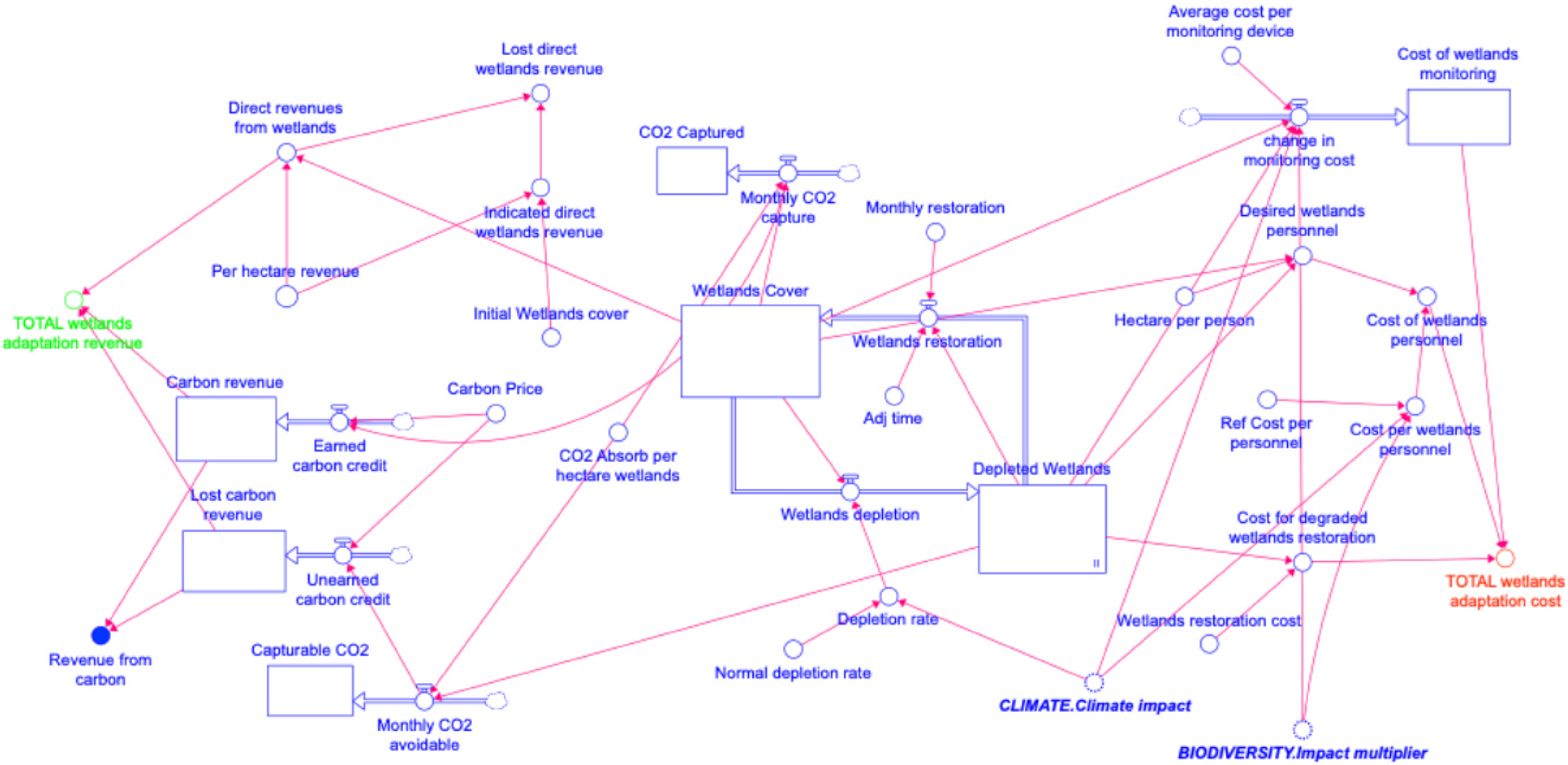
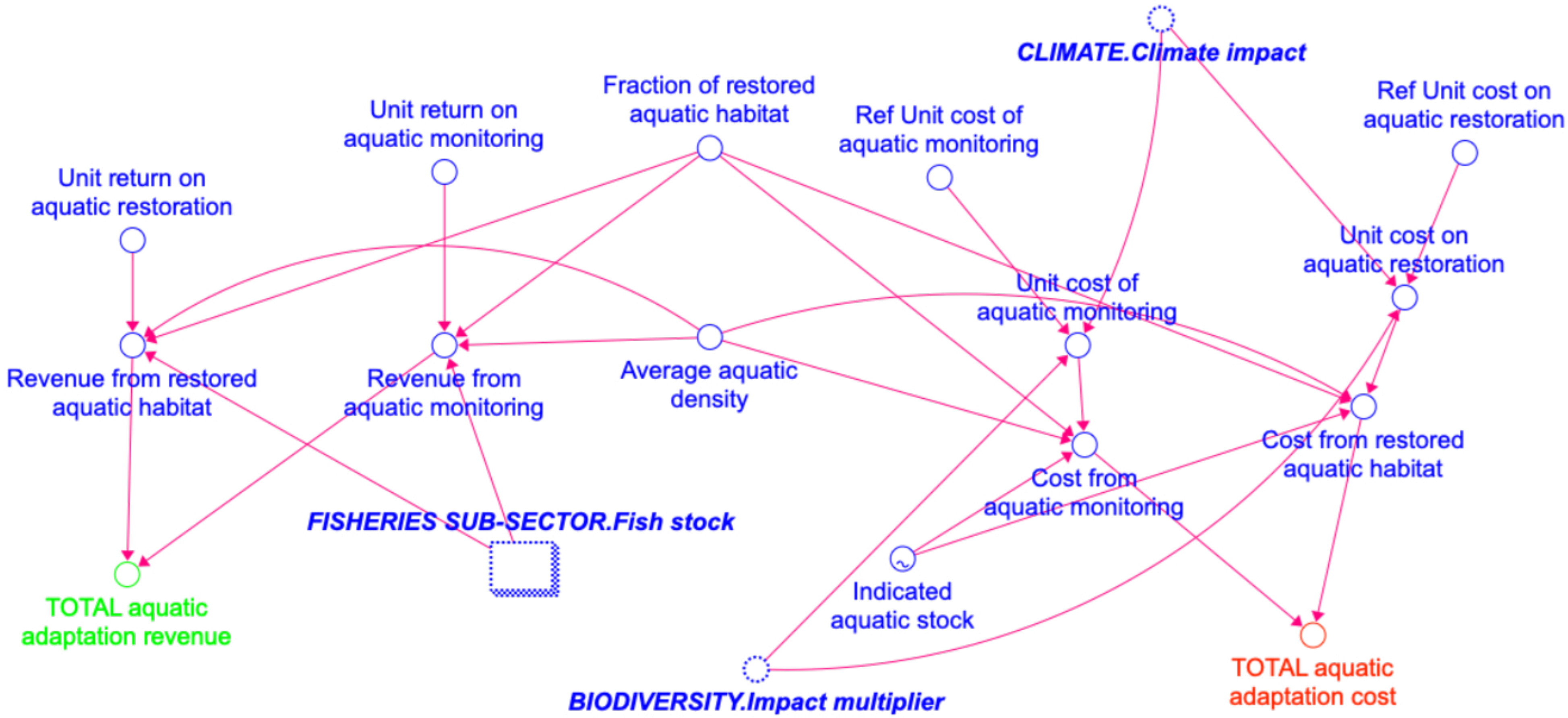


Figure 9. Aquatic Sub-sector Stock-and-Flow Structure (Biodiversity and Ecosystems Sector).



4.2.2. Data and Parameters

The sectoral model draws on national inventories (Forestry Commission, 2021; EPA, 2022) for forest and mangrove cover, wetland extent, and biodiversity indices. Biophysical parameters for carbon sequestration, erosion control, and habitat connectivity were sourced from IPCC (2019) and peer-reviewed literature. Cost data are drawn from recent adaptation costing exercises in Ghana and comparable West African contexts. Indicator matrices from the Monitoring and Reporting (M&R) Plan of the NAP Framework provide a baseline and target values for monitoring. The majority of biodiversity indicators were either partially or fully catered for by model variables. For example, "forest area restored (ha)" directly matched model variables, while "species diversity index" only partially matched via habitat indices (see Table 3).

Table 3. Biodiversity & Ecosystems Sector – Indicator to Model Alignment

Indicator (M&R)	Model Variable	Alignment Status	Notes
Number of drought- and pest-resistant crop varieties promoted	crop_variety_index	Partial	Proxy: model tracks crop productivity, not specific variety counts.
Area under irrigation (ha)	irrigated_area	Match	Directly aligned.
Crop yield (tons/ha)	yield_per_hectare	Match	Directly aligned, central variable in model.
Adoption of efficient irrigation systems	irrigation_efficiency	Match	Directly aligned.
Number of farmers trained in CSA practices	*No direct variable*	Unmatched	Governance/awareness indicator, not modelled quantitatively.

The following assumptions underlie the modelling of biodiversity actions:

1. Indicator alignment: Where direct alignment existed (e.g., hectares restored), model outputs were treated as equivalent to M&R indicators. Where only partial alignment existed (e.g., habitat index as a proxy for biodiversity richness), proxies were applied.

2. Proxy use: For indicators not explicitly modelled but closely related, proxy variables were assumed valid substitutes. For instance, "ecosystem services index" was used to approximate "wetland ecological integrity."

3. Unmatched indicators: Governance, awareness, and gender-related biodiversity indicators were not represented in the model and are recommended for qualitative assessment.

4. Restoration dynamics: Restoration rates were assumed to follow linear or logistic growth functions depending on intervention scale.

5. Degradation drivers: Land use change and coastal erosion were assumed constant in the baseline but moderated under adaptation scenarios.

6. Economic valuation: Carbon sequestration values are based on median estimates from tropical forest studies (Pan et al., 2011). Non-market ecosystem benefits were proxied through benefit transfer from regional studies where Ghana-specific data was unavailable.

7. Cost coverage: Implementation costs included direct investment, maintenance, and opportunity costs of land, but excluded broader macroeconomic feedbacks.

4.2.3. Analytical Approach

The analysis simulates adaptation scenarios for biodiversity up to 2040, comparing baseline degradation with intervention pathways. Net present value (NPV), benefit–cost ratio (BCR), and internal rate of return (IRR) are calculated for each intervention bundle using a 5% discount rate.

Results should be interpreted with higher confidence for indicators that directly aligned with model variables (e.g., hectares restored, mangrove length). Outputs for partially aligned indicators (e.g., biodiversity richness approximated by habitat index) are indicative and should be treated cautiously. Governance (including gender mainstreaming) and awareness indicators remain outside the model scope and are to be assessed qualitatively. These limitations highlight areas where further model development or complementary assessment methods would be beneficial.

4.3. Proposed Adaptation Options for the Biodiversity and Ecosystems Sector

The Action Plan for the sector sets out a package of mutually reinforcing actions across four ecological subsectors: forest, wetland, marine, and freshwater systems. These actions are summarised in Table 3. They are the results of national consultations, stakeholder workshops, and literature reviews.

Table 4: Summary of Adaptation Options for the Biodiversity and Ecosystems Sector

Subsector	Key Adaptation Actions
Forest Ecosystems	- Reforest using native and climate-resilient species - Establish Forest restoration corridors - Promote sustainable non-timber forest product (NTFP) harvesting - Strengthen monitoring and enforcement against illegal logging/mining - Encourage agroforestry in forest-fringe communities
Wetland Ecosystems	- Restore degraded mangroves and swamp forests - Develop alternative livelihoods (e.g., aquaculture) - Support community-led wetland monitoring and conservation - Establish buffer zones to prevent encroachment - Promote ecotourism in Ramsar sites - Introduce wetland-compatible agriculture - Apply floodplain zoning to protect habitats
Marine Ecosystems	- Establish marine protected areas (MPAs) - Enforce seasonal fishing bans - Reduce marine pollution via coastal waste management - Support sustainable artisanal fishing practices - Build capacity for biodiversity monitoring and research - Replant mangroves along coastal zones - Develop coastal green infrastructure (e.g., dunes, sea walls)

Aquatic Ecosystems	- Rehabilitate riparian zones (e.g., Volta and Pra Rivers) - Remove invasive species like water hyacinths - Implement watershed management programs - Create biodiversity-rich artificial reservoirs - Promote integrated water resource management (IWRM) - Establish fish sanctuaries in key river habitats - Encourage ecotourism linked to biodiversity conserva-tion

4.3.1. Costed Adaptation Bundle

As outlined in the general methodology, adaptation options are complementary when they work together to enhance each other's effectiveness, address multiple vulnerabilities simultaneously, and create co-benefits across ecological, social, and economic dimensions. In the biodiversity sector, the proposed actions—such as reforestation, enhanced monitoring, sustainable NTFP harvesting, mangrove restoration, and marine protected areas (MPAs)—demonstrate clear synergies that amplify their impact.

Consider the adaptation actions across different ecosystems:

a. Reforestation and Forest Restoration Corridors (Forest Ecosystems): Reforestation with climate-resilient species like *Milicia excelsa* not only restores forest cover but also supports the establishment of forest restoration corridors. These corridors reconnect fragmented ecosystems, allowing species migration and gene flow, which enhances biodiversity resilience. For example, reforested areas can serve as starting points for corridors, creating a network of habitats that benefit wildlife and improve ecosystem stability.

b. Mangrove Restoration and Coastal Green Infrastructure (Wetland and Marine Ecosystems): Restoring degraded mangroves in areas like Keta Lagoon protects coastal zones from storm surges, a benefit that complements the development of coastal green infrastructure such as artificial dunes. Mangroves act as natural barriers, reducing wave energy, while artificial structures provide additional defence. Together, they safeguard marine nurseries, ensuring fish stock regeneration—an objective of marine ecosystem actions like MPAs and seasonal fishing bans.

c. Sustainable NTFP Harvesting and Agroforestry (Forest Ecosystems): Sustainable harvesting of NTFPs, such as shea nuts, can be integrated with agroforestry practices in forest-fringe communities. Agroforestry systems, which incorporate trees into farmland, can provide shade and resources for NTFP species, enhancing their productivity while improving soil health and agricultural yields. This dual approach supports livelihoods and reduces pressure on natural forests, creating a reinforcing cycle of sustainability.

The adaptation costing is done to restore lost forest cover, train needed personnel, and acquire technology for monitoring forest activities. Table 4 summarises the bundled adaptation options and the costing approach used. See Annex A for the detailed information on the cost estimates and source of data.

Table 5: Bundled adaptation options in the biodiversity sector

No	Adaptation Actions	Economic appraisal
1	Reforestation to enhances biodiversity, improves carbon sequestration, and supports local livelihoods	Costed using afforestation
2	Enhanced monitoring and enforcement to combat illegal logging and mining and protects critical ecosystems from degradation, maintains biodiversity, and supports local economies.	Costed using personnel and technology
3	Sustainable harvesting of non-timber forest products (NTFPs) such as shea nuts and medicinal plants	Costed using personnel
4	Establishment of forest restoration corridors to reconnect fragmented ecosystems	Not costed but policy can enhance the practice
5	Promotion of agroforestry practices in forest-fringe communities	Not costed directly but trained personnel can provide services

4.4. Results and Discussion

The biodiversity sector was assessed across four ecological sub-sectors: Forestry, Marine, Aquatic, and Wetlands; under three climate scenarios: Baseline (business-as-usual with adaptation), SSP4.5, and SSP8.5. Results are presented in monetary terms (USD, billions) over the period 2015–2040. Table 5 presents a summary of key results from economic analysis of the adaptation actions. The detailed results are provided in the APPENDIX.

Table 6. Biodiversity Sector Results Summary: Revenues, Costs, Net Benefits, and Benefit-Cost Ratios (BCR) by Sector, Scenario, and Year (2015–2040)

Sector	Scenario	Year	Revenue (Million USD)	Cost (Million USD)	Net Benefit (Million USD)	BCR	Cost per $ Revenue
Aquatic	Baseline	2015	101	55	47	1.85	0.54
Aquatic	Baseline	2030	412	222	190	1.86	0.54
Aquatic	Baseline	2040	1,050	565	485	1.86	0.54
Aquatic	SSP4.5	2015	101	65	36	1.54	0.65
Aquatic	SSP4.5	2030	277	274	3	1.01	0.99
Aquatic	SSP4.5	2040	528	706	- 178	0.75	1.34
Aquatic	SSP8.5	2015	101	65	36	1.54	0.65
Aquatic	SSP8.5	2030	175	277	- 102	0.63	1.58
Aquatic	SSP8.5	2040	243	713	- 470	0.34	2.93
Forestry	Baseline	2015	2,090	143	1,947	14.62	0.07
Forestry	Baseline	2030	2,300	832	1,468	2.76	0.36
Forestry	Baseline	2040	2,450	1,220	1,230	2.01	0.50
Forestry	SSP4.5	2015	2,090	172	1,918	12.15	0.08
Forestry	SSP4.5	2030	2,120	1,040	1,080	2.04	0.49
Forestry	SSP4.5	2040	2,190	1,510	680	1.45	0.69
Forestry	SSP8.5	2015	2,090	172	1,918	12.15	0.08
Forestry	SSP8.5	2030	2,110	1,060	1,050	1.99	0.50
Forestry	SSP8.5	2040	2,170	1,530	640	1.42	0.71
Marine	Baseline	2015	1,230	950	280	1.29	0.77
Marine	Baseline	2030	2,040	950	1,090	2.15	0.47
Marine	Baseline	2040	2,850	950	1,900	3.00	0.33
Marine	SSP4.5	2015	1,230	1,140	90	1.08	0.93
Marine	SSP4.5	2030	1,450	1,170	280	1.24	0.81
Marine	SSP4.5	2040	1,590	1,190	400	1.34	0.75
Marine	SSP8.5	2015	1,230	1,140	90	1.08	0.93

Marine	SSP8.5	2030	984	1,190	- 206	0.83	1.21
Marine	SSP8.5	2040	825	1,200	- 375	0.69	1.45
Wetlands	Baseline	2015	188	10	178	19.46	0.05
Wetlands	Baseline	2030	185	63	122	2.94	0.34
Wetlands	Baseline	2040	197	91	106	2.16	0.46
Wetlands	SSP4.5	2015	188	12	176	16.21	0.06
Wetlands	SSP4.5	2030	171	78	93	2.20	0.45
Wetlands	SSP4.5	2040	180	111	69	1.62	0.62
Wetlands	SSP8.5	2015	188	12	176	16.21	0.06
Wetlands	SSP8.5	2030	170	79	91	2.16	0.46
Wetlands	SSP8.5	2040	179	113	66	1.58	0.63

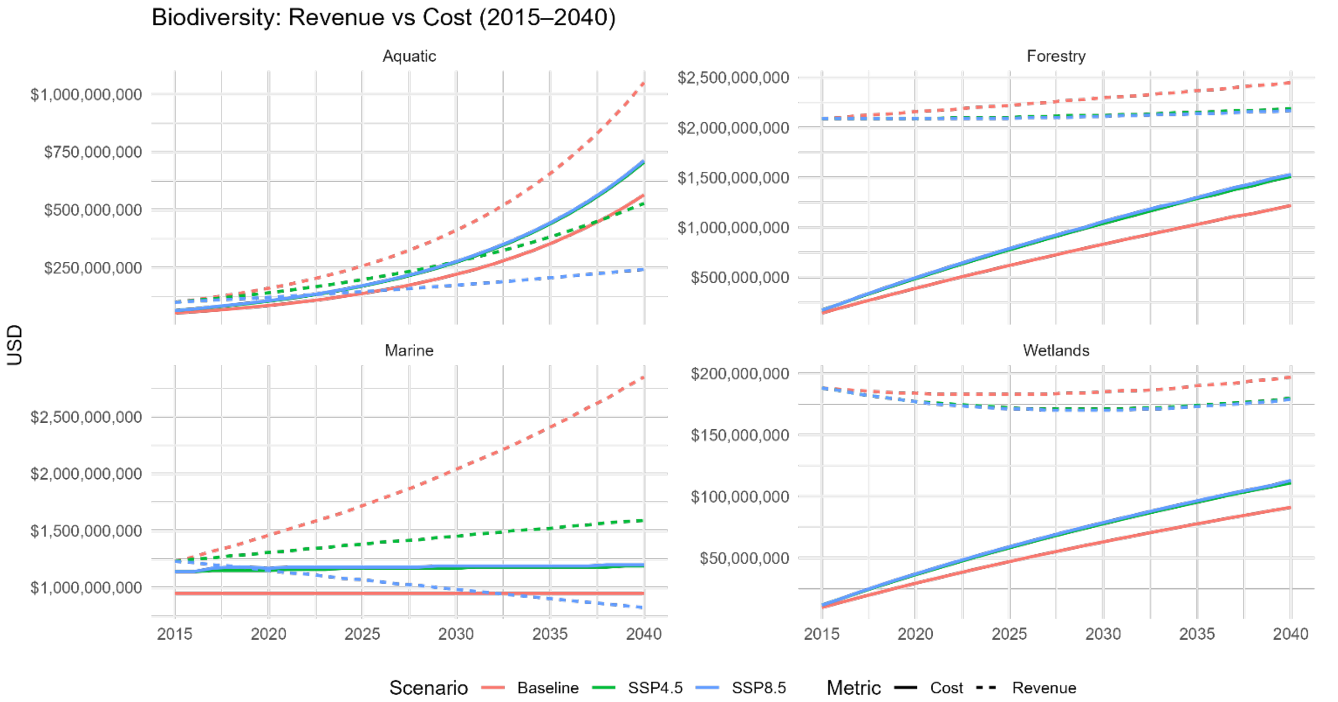
4.4.1. Revenue and Cost Trends

Figure 8 illustrates the projected trajectories of total biodiversity adaptation revenues and costs for the period 2015–2040 across the three climate scenarios.

A consistent pattern emerges: revenues remain substantial across all sub-sectors, particularly in forestry and marine ecosystems, where ecosystem services (timber, carbon sequestration, habitat restoration) account for the largest share.

Forestry revenues remain above USD 2 billion annually under all scenarios, while marine ecosystem services generate between USD 1.2–2.8 billion annually depending on the climate pathway.

Figure 10. Revenue vs. Cost Trends (2015–2040) for Aquatic, Forestry, Marine, and Wetlands under Baseline, SSP4.5, and SSP8.5 scenarios. Revenues (dashed lines) and costs (solid lines) diverge strongly in Forestry, while Marine and Aquatic show costs catching up with or overtaking revenues under SSP8.5.



Costs, while lower in magnitude than revenues, increase steadily over time. These include expenses for restoration, monitoring, and personnel across the four sub-sectors. For example, forestry adaptation costs rise from USD 143 million in 2015 to above USD 1.2 billion by 2040 under Baseline and even higher under SSP8.5. Similarly, marine adaptation costs remain high, reaching nearly USD 1.2 billion per year by 2040 under SSP8.5.

The net revenue–cost gap varies substantially by scenario. Under Baseline, adaptation revenues consistently outpace costs, resulting in strong surpluses. **However, under SSP8.5, while revenues are maintained in forestry, marine and aquatic revenues begin to plateau or decline after 2030, while costs accelerate—leading to progressively tighter margins.**

Table 5 provides a consolidated summary of annual and cumulative revenues and costs across all sub-sectors. The table confirms that, **at aggregate level, biodiversity adaptation remains a net revenue-generating investment under all scenarios, but the efficiency margins narrow under SSP8.5 due to escalating costs and climate stressors.**

Rising costs, particularly in monitoring and personnel, indicate the need for careful budgetary planning and efficiency improvements in delivery mechanisms. Forestry demonstrates increasing long-term returns from carbon revenues, highlighting the need for synergies and co-benefits with mitigation programs and the value of prioritizing and strengthening Ghana's carbon markets and REDD+ frameworks. Meanwhile, the Marine and Aquatic subsectors highlight a dependency on habitat restoration, implying the necessity for sustained government and donor funding in the early years to support these efforts.

4.4.2. Net Benefits in 2040

The net benefits of biodiversity adaptation in 2040 across the four sub-sectors and three climate scenarios are illustrated in Figure 9. Forestry emerges as the strongest contributor under all scenarios, with net benefits exceeding USD 1 billion annually by 2040. This is driven by sustained revenues from timber resources and rapidly growing carbon markets, which more than offset rising restoration and monitoring costs.

Marine ecosystems show high potential under the Baseline and SSP4.5 scenarios, with net benefits in the order of USD 0.7–1.3 billion by 2040. However, under SSP8.5, marine revenues decline sharply after 2030 due to degradation of habitats and reduced productivity, while costs remain relatively fixed, resulting in near-zero or even negative net benefits by 2040.

Aquatic systems (inland waters and reservoirs) demonstrate consistent but moderate growth. Net benefits rise from less than USD 50 million in 2015 to over USD 400 million by 2040 under Baseline and SSP4.5. Under SSP8.5, however, growth is subdued, with net benefits capped below USD 200 million.

Wetlands, though critical for ecosystem services, remain the smallest contributor in monetary terms. Net benefits are limited to USD 50–100 million annually by 2040 under Baseline and SSP4.5. Under SSP8.5, rising costs combined with stagnating revenues reduce the sector's net benefit to negligible levels.

Figure 11. Net Benefit in 2040 by Biodiversity Subsector and Scenario. Forestry and Marine provide the highest net benefits under the Baseline, while Aquatic shows negative net benefits under SSP4.5 and SSP8.5, indicating higher costs than revenues.

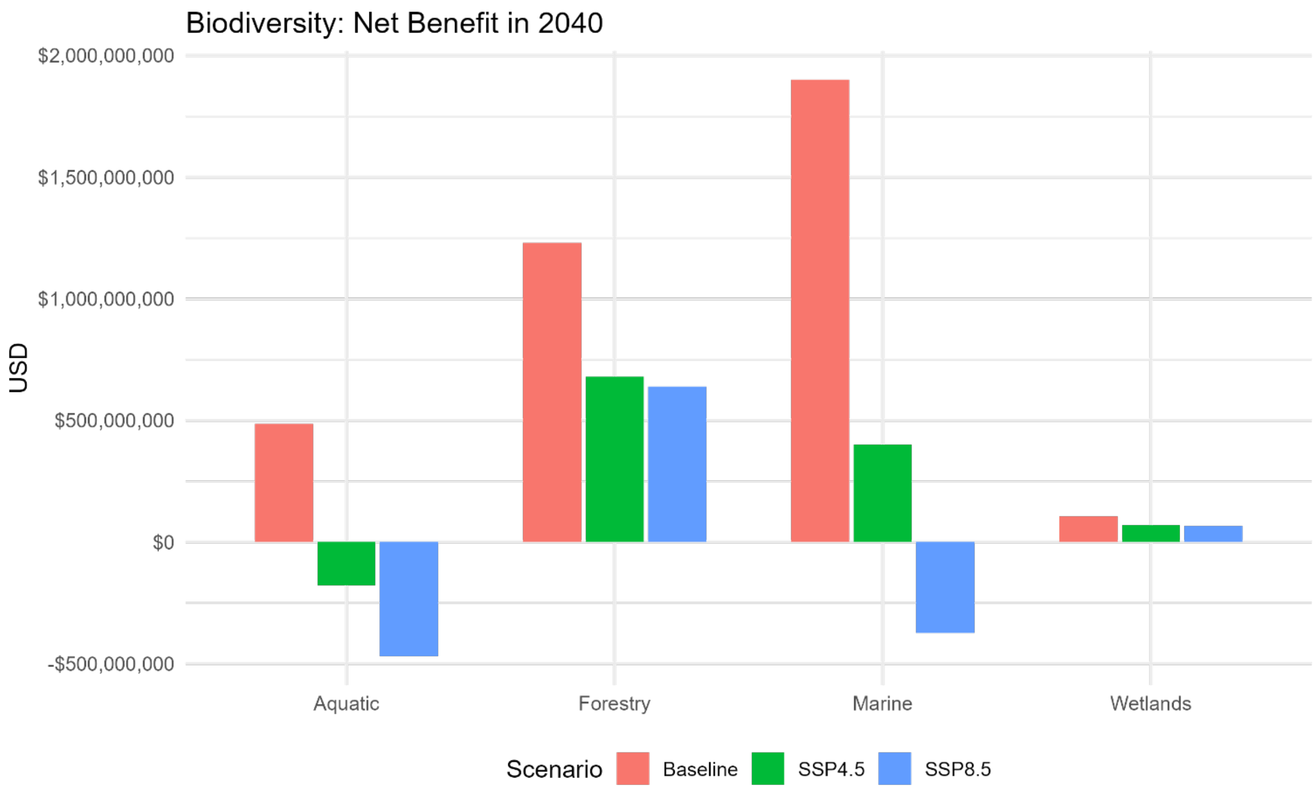


Table 5 further substantiates these findings, showing that while aggregate biodiversity adaptation is profitable, the distribution of gains is uneven. The forestry and marine adaptation sub-sectors dominate overall benefits, while aquatic and wetlands provide smaller but important complementary contributions. These results highlight that resource allocation should follow a portfolio approach, prioritizing high-return subsectors like Forestry and Marine, but maintaining Wetlands as a low-cost, high-value risk buffer for broader resilience.

4.4.3. Cost Composition

Forestry costs are dominated by personnel expenditures, which account for nearly 50% of total costs across all scenarios. Restoration and monitoring costs expand steadily over time, reaching USD 500–650 million annually by 2040, but are outweighed by the growing revenues from carbon markets. The heavy personnel component reflects the labor-intensive nature of forestry management and monitoring systems.

Marine ecosystems show a different profile, habitat restoration costs (USD 0.9–1.0 billion annually) represent the bulk of expenditures, followed by monitoring costs (approximately USD 200–240 million). This structure holds constant across scenarios, suggesting that large-scale investments in marine habitat rehabilitation are unavoidable. Under SSP8.5, however, revenues decline while these costs remain fixed, eroding net benefits.

Aquatic systems incur relatively balanced costs between restoration (approximately USD 500–600 million by 2040) and monitoring (approximately USD 100 million). Growth in monitoring costs under SSP8.5 is particularly pronounced, reflecting the need for more intensive observation as stress on aquatic systems rises.

Wetlands remain the least cost-intensive, with total costs below USD 120 million by 2040. Monitoring expenditures form a rising share, climbing steadily with climate stress, while personnel costs remain constant. Despite their small financial footprint, wetlands provide essential non-market ecosystem services (e.g., flood regulation, water purification, biodiversity habitat), which are not fully captured in the monetary cost-benefit framework.

Overall, forestry and marine ecosystems absorb the largest adaptation costs, but also deliver the greatest revenues. By contrast, aquatic and wetland systems require smaller financial outlays but remain critical for resilience. The persistent high monitoring and personnel costs highlight the need for capacity-building, technology-enabled monitoring such as drones and satellites, and improved human resource planning. For Marine and Aquatic subsectors, restoration dominates costs, suggesting the value of public-private partnerships to mobilize upfront investment. Wetlands, with their low-cost burden, indicate that scaling interventions in this area could deliver cost-effective resilience at a national scale.

4.4.4. Efficiency Metrics

The efficiency of biodiversity adaptation investments was evaluated using Benefit–Cost Ratios (BCRs) and Internal Rates of Return (IRRs) at a 5% discount rate (see Table 6).

Table 7. Benefit-Cost Ratio (Undiscounted & 5% Discounted) and Internal Rate of Return (IRR) by Sector and Scenario for the Biodiversity Sector (2015–2040).

Sector	Scenario	Undiscounted Benefits (Million USD)	Undiscounted Costs (Million USD)	BCR (Undis-counted)	PV Benefits (Million USD)	PV Costs (Million USD)	BCR	IRR (%)*
Aquatic	Baseline	10,717	5,771	1.86	4,867.88	2,621.75	1.86	-
Aquatic	SSP4.5	6,839	7,145	0.96	3,325.82	3,235.32	1.03	3.13
Aquatic	SSP8.5	4,282	7,222	0.59	2,261.62	3,271.87	0.69	18.67
Forestry	Baseline	58,830	18,480	3.18	33,580.79	8,988.10	3.74	-
Forestry	SSP4.5	55,180	23,053	2.39	31,879.99	11,210.76	2.84	-
Forestry	SSP8.5	54,930	23,385	2.35	31,767.49	11,373.69	2.79	-
Marine	Baseline	50,260	24,700	2.03	26,638.09	14,339.25	1.86	-
Marine	SSP4.5	36,810	30,370	1.21	20,785.72	17,555.66	1.18	-
Marine	SSP8.5	26,700	30,730	0.87	16,165.70	17,772.17	0.91	23.40
Wetlands	Baseline	4,854	1,391	3.49	2,805.40	675.41	4.15	-
Wetlands	SSP4.5	4,567	1,711	2.67	2,666.36	831.77	3.21	-
Wetlands	SSP8.5	4,548	1,733	2.62	2,657.18	842.80	3.15	-

** Note: NA values in the IRR column indicate cases where no real Internal Rate of Return could be calculated, typically due to all cash flows being of the same sign or zero, rendering IRR undefined.*

Results highlight varying levels of economic performance across sub-sectors and climate scenarios. Forestry emerges as the strongest performer. Under the Baseline scenario, the BCR exceeds 3.0, with an IRR comfortably above 20%, demonstrating that revenues from both timber and carbon markets substantially outweigh the growing adaptation costs. Even under SSP8.5, the forestry BCR remains above 2.0, signalling resilience to climate stress.

Marine ecosystems show more modest returns. While the Baseline and SSP4.5 scenarios yield BCRs slightly above 1.0, indicating marginal economic viability, the SSP8.5 pathway results in BCRs below unity. This suggests that under severe climate stress, costs of marine habitat restoration and monitoring outweigh the revenues, making investments less efficient.

Aquatic systems present mixed results. In the Baseline and SSP4.5 scenarios, BCRs range between 1.3 and 1.6, with IRRs of 8–12%, pointing to moderate but positive efficiency. Under SSP8.5, however, the BCR drops close to 1.0, implying that costs almost cancel out the benefits by 2040.

Wetlands consistently show BCRs above 2.0 under all scenarios, though the absolute scale of revenues and costs is smaller compared to other sub-sectors. The high BCR reflects the relatively low cost of wetlands management relative to the sustained stream of benefits. However, much of the true value of wetlands lies in non-market ecosystem services such as flood mitigation and biodiversity support, which are not fully accounted for in the monetary analysis.

Taken together, these results indicate that biodiversity adaptation investments are generally efficient under the Baseline and SSP4.5 scenarios, with forestry and wetlands leading the performance. Under SSP8.5, efficiency weakens considerably in the marine and aquatic sub-sectors, raising concerns about the economic viability of large-scale adaptation measures if global climate action falters.

4.4.5. Non-Market Benefits

Non-market benefits, including carbon sequestration, flood control, and habitat services, significantly exceed the financial metrics presented. Therefore, Ghana's policies should internalize ecosystem service values. This can be done by strengthening environmental-economic accounting (SEEA), exploring payments for ecosystem services (PES), and integrating biodiversity values into development planning.

4.5. Conclusion

The biodiversity sector analysis demonstrates that adaptation investments across Forestry, Marine, Aquatic, and Wetlands subsectors deliver positive returns, with benefit-cost ratios (BCRs) exceeding unity under most scenarios and substantial net present values (NPVs) at a 5% discount rate. Notably, Forestry subsector actions, particularly restoration and carbon revenue streams, emerged as the most efficient, while Marine and Aquatic actions showed consistent long-term benefits despite higher upfront costs. Wetlands interventions, though relatively modest in scale, exhibited strong cost-effectiveness given their comparatively low investment needs.

A key insight from the efficiency analysis is the variation in cost drivers across subsectors. In Forestry, personnel and monitoring costs form a persistent burden, whereas restoration expenditures scale more gradually, yielding higher returns over time. For Marine and Aquatic systems, restored habitat costs dominate, but these are balanced by rapidly growing revenue streams from habitat recovery. Wetlands show the opposite profile: low costs dominated by personnel and monitoring, but with steady, if smaller, benefit flows. This diversity highlights the importance of tailoring adaptation portfolios to sector-specific dynamics rather than applying uniform benchmarks.

Beyond the quantified results, non-market benefits significantly enhance the case for biodiversity investments. **Forest restoration and protection generate ecosystem services such as carbon sequestration, water regulation, and pollination support that sustain agricultural productivity[14][15]. Marine and aquatic interventions safeguard fish nursery grounds and water quality, directly underpinning food security and coastal resilience. Wetlands, meanwhile, provide flood mitigation, groundwater recharge, and biodiversity refuges, critical functions that reduce disaster risks and sustain livelihoods even when not captured in direct revenue streams. These non-market contributions imply that the true value of biodiversity adaptation is underestimated by financial metrics alone.** These findings underpin the following policy recommendations:

1. Prioritize Forestry and Marine subsectors for investment, while scaling up Wetlands as a cost-effective resilience buffer.
2. Strengthen carbon finance mechanisms (e.g., REDD+, voluntary carbon markets) to capture forestry's growing carbon revenue potential.
3. Improve monitoring efficiency through technology and partnerships to reduce persistent cost burdens in Forestry.
4. Mobilize blended finance and PPPs for Marine and Aquatic restoration to spread upfront costs.
5. Integrate non-market benefits into policy through environmental-economic accounting, PES, and ecosystem-based management.
6. Adopt a portfolio approach to funding, balancing high-return subsectors with smaller-scale, low-cost interventions (e.g., wetlands) for resilience diversification.

In summary, the biodiversity sector's adaptation portfolio shows robust economic efficiency and significant co-benefits, confirming its role as a cornerstone of Ghana's climate resilience strategy. Investments in biodiversity adaptation not only deliver measurable financial returns but also secure the ecological foundations of agriculture, fisheries, and human well-being.

14 https://www.teebweb.org/publication/mainstreaming-the-economics-of-nature-a-synthesis-of-the-approach-conclusions-and-recommendations-of-teeb/
15 https://ipbes.net/global-assessment

5. AGRICULTURE SECTOR

5.1. Background

The agriculture sector in Ghana is integral to the nation's economy, contributing significantly to gross domestic product (GDP), employment, and food security. Agriculture remains a primary livelihood source, particularly accounting for approximately 20% of GDP and employing about 34% of the workforce[16]. The sector encompasses diverse activities, including crop production, livestock rearing, fisheries, and agroforestry, with key crops such as cocoa, maize, rice, yam, and cassava driving domestic consumption and export revenues. Cocoa, in particular, is a major foreign exchange earner, positioning Ghana as one of the world's leading producers.

Ghana's agriculture is predominantly rain-fed, making it highly sensitive to the impact of climate change. The country's agroecological zones—ranging from the humid forest zones of the south to the savannah regions of the north—support varied farming systems but face distinct climate-related challenges. Rising temperatures, erratic rainfall patterns, prolonged droughts, and extreme weather events like floods increasingly disrupt agricultural productivity. Northern regions like the Upper East and Northern experience severe dry spells that reduce yields of staples like millet and sorghum, while southern areas contend with flooding that damages crops like maize and vegetables[17].

Beyond climate risks, the sector grapples with anthropogenic pressures, including land degradation, deforestation for farmland expansion, and unsustainable farming practices. Soil fertility decline, driven by continuous cropping and inadequate fertilizer use, affects productivity, particularly in the savannah and transition zones. Additionally, post-harvest losses, limited access to modern technology, and inadequate irrigation infrastructure exacerbate vulnerabilities, especially for smallholder farmers who constitute the majority of the sector, producing about 80% of the output from the Sector[18].

The fisheries sub-sector, both inland and marine, is equally critical, providing protein for millions and supporting coastal and lakeside communities. Lake Volta and Ghana's Exclusive Economic Zone are key fishing grounds, but overfishing, pollution, and rising sea temperatures threaten fish stocks, impacting livelihoods in areas like Keta and Tema. Livestock production, concentrated in the northern savannahs, faces challenges from heat stress and reduced pasture availability due to climate-induced droughts[19].

Despite these challenges, Ghana's agriculture sector holds immense potential for resilience and growth. Government initiatives, such as the Planting for Food and Jobs program and the Ghana Climate-Smart Agriculture Action Plan, promote sustainable practices, improved seed varieties, and irrigation development[20]. However, addressing the sector's vulnerabilities requires targeted adaptation strategies to mitigate climate risks, enhance productivity, and secure livelihoods. The "Climate

16
17 Environmental Protection Agency (EPA). (2021). Ghana Wetland Conservation Report. Accra: EPA Ghana.
18 AGRICULTURE IN GHANA (Facts & Figures) 2021.pdf
19 Ghana's National Adaptation Plan Framework - NAP Global Network
20 AGRICULTURE IN GHANA (Facts & Figures) 2021.pdf

Change Adaptation Action Plan for the Agriculture Sector in Ghana", developed under the National Adaptation Plan (NAP) framework, aims to integrate climate resilience into agricultural planning, aligning with the broader NAP project, "Enhancing multi-sector planning and capacity for effective adaptation in Ghana," led by the Ghana Environmental Protection Agency under the Ministry of Environment, Science, Technology, and Innovation (MESTI) with Green Climate Fund (GCF) support.

This background underscores the vital role of agriculture in Ghana's economy and its susceptibility to climate and non-climate stressors. It sets the stage for assessing adaptation options that can safeguard food security, boost economic stability, and ensure sustainable development in the face of a changing climate.

5.2. Agriculture Sector Model Description

The agriculture sector methodology extends the general system dynamics and cost–benefit framework (see GENERAL METHODOLOGY). It focuses on adaptation options that improve crop productivity, enhance resilience of smallholder farming systems, and secure food supply under climate change. The model includes both rainfed and irrigated agriculture, with specific modules for crop yields, livestock productivity, and aquaculture development. Stock-and-flow diagrams (Figure 12-14) depict the relationships between investments in climate-smart agriculture, irrigation expansion, and productivity gains.

5.2.1. Systems Dynamics Model Structure

The agriculture sub-model is built around stocks of cultivated land and productive capacity, with flows representing crop yields, adoption of improved technologies, and losses from climate-related stresses. Adaptation measures, such as expansion of solar-powered irrigation, drought-resistant varieties, and efficient water use, are introduced as policy levers influencing these flows.

5.2.2. Data and Parameters

The agricultural model draws on national datasets[21][22] for crop production, irrigation coverage, and livestock/aquaculture baselines. Biophysical parameters (e.g., crop yield response factors) are based on FAO AquaCrop and regional adaptation studies. Cost data were compiled from national agricultural adaptation costings and international benchmarks for irrigation technologies.

Indicator baselines and targets from the Monitoring and Reporting (M&R) Plan of the NAP Framework were used to guide parameterization. For example, irrigation area expansion targets informed the capacity expansion scenarios, while productivity improvements were benchmarked against CSA adoption goals. As shown in Table 8, indicators such as area under irrigation (ha) and crop yield (tons/ha) directly align with model variables (irrigated_area, yield_per_hectare), while others, such as number of drought- and pest-resistant varieties promoted, are only partially aligned through proxy variables (e.g., crop_variety_index). Governance-related indicators such as number of farmers trained in CSA practices are not captured within the model boundary and are assessed qualitatively.

21 Ghana's National Adaptation Plan Framework - NAP Global Network
22 AGRICULTURE IN GHANA (Facts & Figures) 2021.pdf

Figure 12. Crop sub-sector Sector Stock-and-Flow Structure (Agriculture Sector)

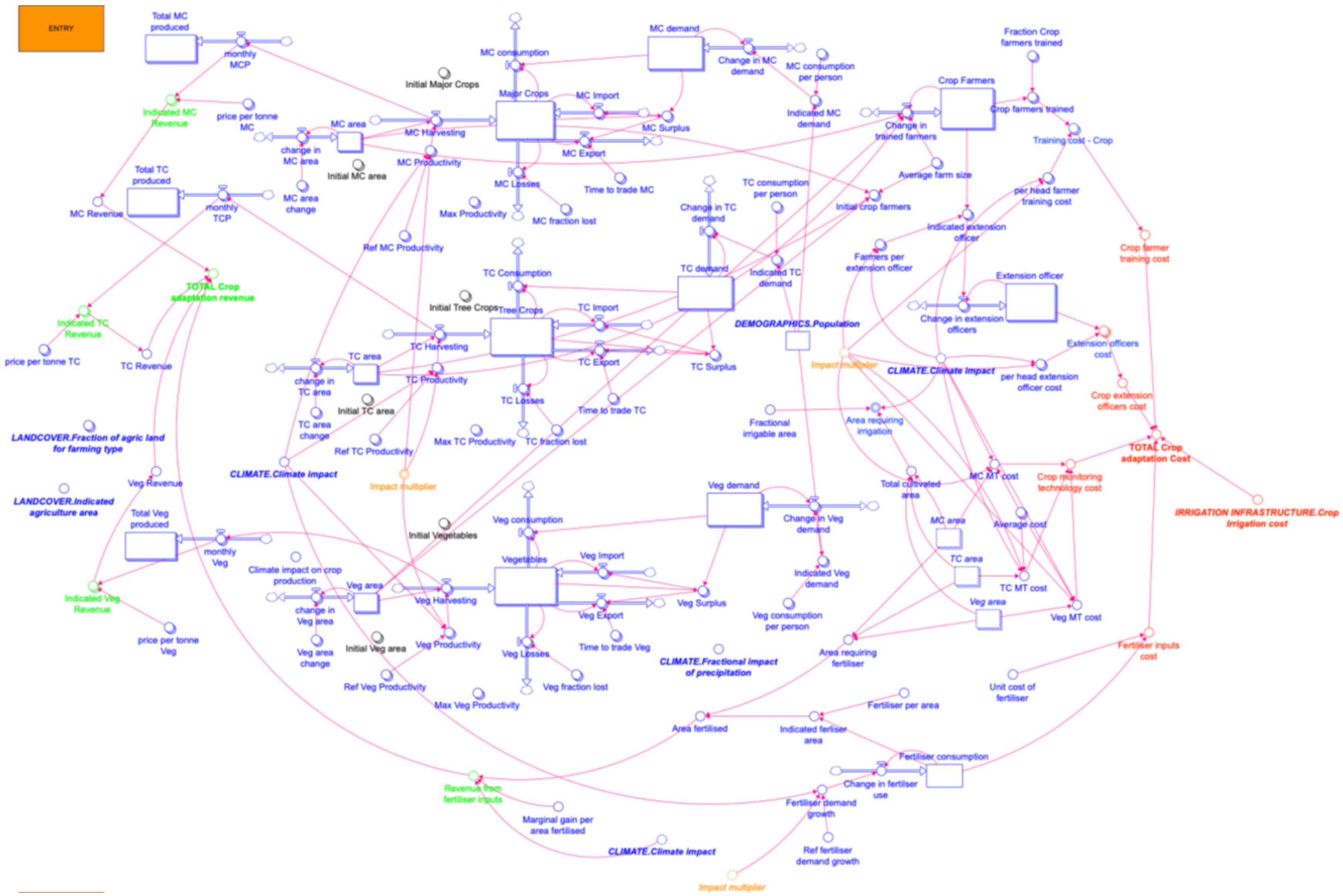


Figure 13. Livestock sub-sector Sector Stock-and-Flow Structure (Agriculture Sector)

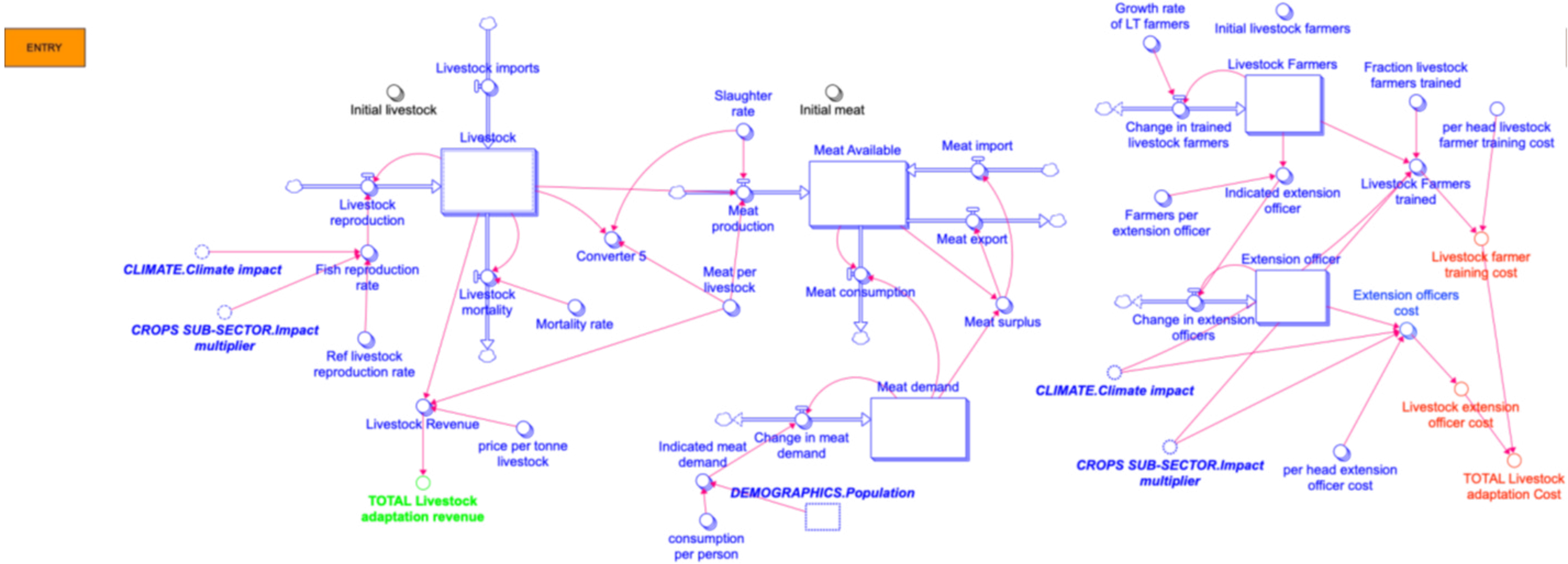
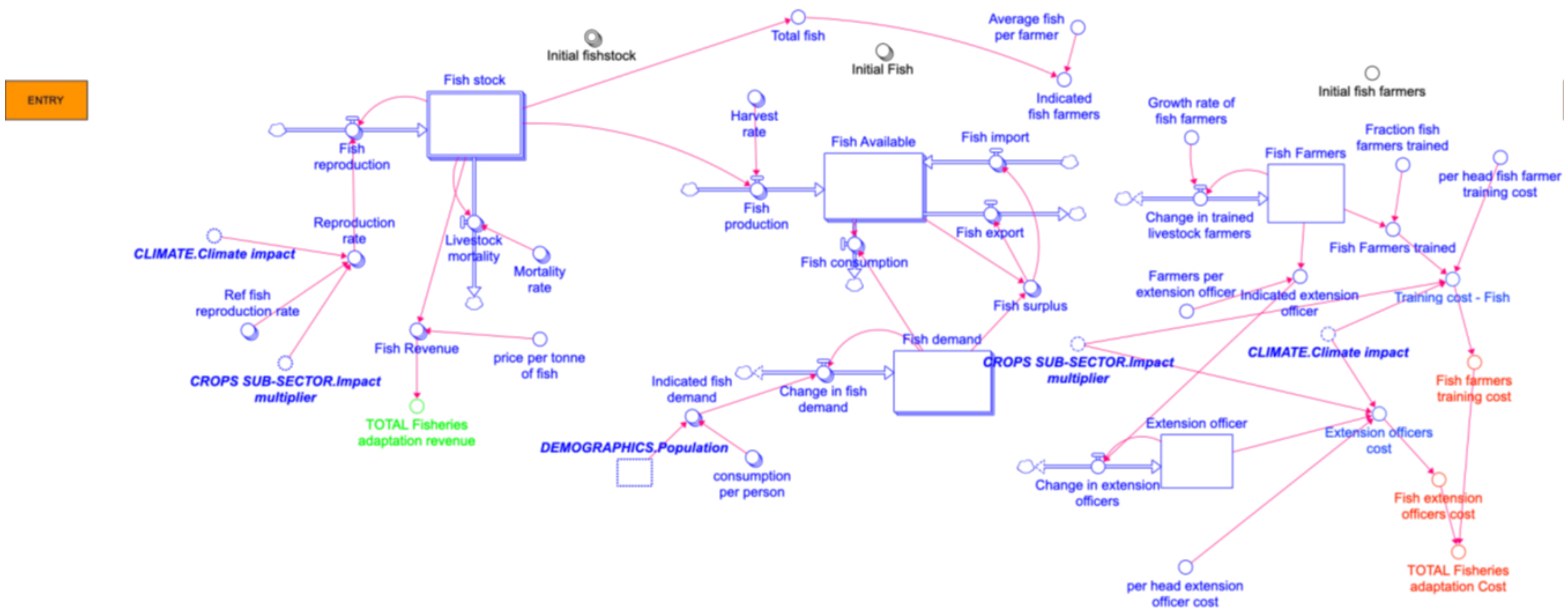


Figure 14. Fisheries sub-sector Sector Stock-and-Flow Structure (Agriculture Sector)



The agriculture sub-model incorporates three sub-components: (i) crops (Figure 12), (ii) livestock (Figure 13), and (iii) aquaculture/fisheries (Figure 14). Each is represented as a distinct stock-and-flow system, with core stocks such as cultivated area, herd size, aquaculture capacity, and flows including yields, mortality, feed use, and irrigation adoption. Adaptation levers, such as climate-smart agriculture practices, solar-powered irrigation, and improved breeds, modify these flows, driving resilience across sub-sectors.

Table 8. Agriculture Sector – Indicator to Model Alignment

Indicator (M&R)	Closest Model Variable	Alignment Status	Notes
Number of drought- and pest-resistant crop varieties promoted	crop_variety_index	Partial	Proxy: model tracks crop productivity, not specific variety counts.
Area under irrigation (ha)	irrigated_area	Match	Directly aligned.
Crop yield (tons/ha)	yield_per_hectare	Match	Directly aligned, central variable in model.
Adoption of efficient irrigation systems	irrigation_efficiency	Match	Directly aligned.
Number of farmers trained in CSA practices	*No direct variable*	Unmatched	Governance/awareness indicator, not modelled quantitatively.

Key assumptions for the agriculture module include:

1. Indicator alignment: Directly matched indicators (e.g., irrigated area, crop yields) are reported as-is. Partially matched indicators are proxied (e.g., crop_variety_index as a stand-in for varietal promotion).
2. Proxy use: Farmer training and awareness indicators are assumed to influence adoption indirectly but are not modelled quantitatively.
3. Climate response functions: Yield response to water and temperature stress is based on empirical elasticities derived from regional studies (e.g., Climate-Smart Agriculture Sourcebook[23]).
4. Technology adoption: Uptake of efficient irrigation systems follows a logistic growth function, assuming increasing adoption rates under policy support.
5. Cost coverage: Investment costs include capital and O&M of irrigation infrastructure and seeds, but exclude transaction costs and broader macroeconomic spillovers.

5.2.3. Analytical Approach

Simulations extend to 2040 under baseline and adaptation scenarios. Economic appraisal metrics—NPV, BCR, and IRR—were calculated for bundles of agricultural adaptation measures using a 5% discount rate. Scenario outputs are presented through time-series plots of irrigated area, yields, and food security indices. Sensitivity analyses tested reliability under different adoption rates and climate stress intensities. Interpretation of results should distinguish between:

- High-confidence indicators: e.g., irrigated area and crop yield, which directly match the model.

23 Food and Agriculture Organization (FAO). (2017). *Climate-Smart Agriculture Sourcebook.* http://www.fao.org/climate-smart-agriculture-sourcebook

- Indicative indicators: e.g., varietal promotion, which are proxied through adoption indices.
- Non-modelled indicators: e.g., farmer training numbers, which are outside the quantitative scope.

5.3. Adaptation Options for the Agriculture Sector.

The Agriculture Sector Adaptation Action Plan proposes sixty adaptation actions for the Agriculture sector, spanning the Crop, Livestock, and Fisheries sub-sectors. To balance simplicity and thoroughness, not all actions were selected for costing. As described in the general methodology, adaptation options are complementary, working synergistically to enhance effectiveness, address multiple vulnerabilities, and deliver ecological, social, and economic co-benefits. Similar to the approach for the biodiversity sector, Table 5 summarizes the bundled adaptation options costed for the Agriculture sector.

Table 9. Bundled adaptation options in the agriculture sector

Sub-Sector	Adaptation Action
Crop	Climate-Smart Extension Services for Women
	Gender Integration in Planning & Budgeting
	Employ rainwater harvesting systems for irrigation during dry periods
	Adoption of Efficient Irrigation Systems
Livestock	Gender-Sensitive Training & Capacity Building
	Rotational Grazing Strategies
	Localized Disease-Resistant Breeding Programs
	Weather Forecasting & Advisory Access
Fisheries	Promote Aquaculture and Diversify Fish Species
	Climate-Adaptive Fish Breeding Programs
	Marine Ecosystem Restoration
	Create Climate-Resilient Aquaculture Technologies

5.4. Results and Discussion

The analysis covers the period 2015–2040 and provides results expressed in monetary terms (USD, billions). Specifically, the study presents both annual trajectories of revenues and costs (see Figure 12) and summary efficiency metrics, including:

- Benefit–Cost Ratios (BCRs),
- Net Present Values (NPVs), and
- Internal Rates of Return (IRRs).

These metrics allow for a comparative evaluation of adaptation actions across subsectors and scenarios, highlighting which investments are robust, which are marginal, and where policy interventions may be required to sustain economic viability under climate stress.

The findings presented in subsequent sections provide the basis for identifying priority adaptation actions in agriculture, and for situating them within Ghana's broader National Adaptation Plan (NAP) framework[24]. The sector analysis is also aligned with global best practices for adaptation economics, which recommend combining financial metrics with broader sustainability and resilience considerations[25,26]. Table 8 provides a summary of the results of the economic analysis (For the detailed results, see the APPENDIX).

Table 10. Agriculture Sector Results Summary – Revenues, Costs, Net Benefits, and Benefit-Cost Ratios (BCR) by Sub-sector, Scenario, and Year (2015–2040).

Sub-sector	Scenario	Year	Revenue (Million USD)	Cost (Million USD)	Net Benefit (Million USD)	BCR	Cost per $ Revenue	Rev CAGR (2015-2040)	Cost CAGR (2015-2040)
Crops	Baseline	2015	6,030	1,510	4,520	3.99	0.25	0.027	0.039
Crops	Baseline	2030	8,410	2,660	5,750	3.16	0.32	0.027	0.039
Crops	Baseline	2040	11,600	3,910	7,690	2.97	0.34	0.027	0.039
Crops	SSP4.5	2015	4,820	1,810	3,010	2.66	0.38	0.027	0.043
Crops	SSP4.5	2030	6,480	3,310	3,170	1.96	0.51	0.027	0.043
Crops	SSP4.5	2040	9,270	5,190	4,080	1.79	0.56	0.027	0.043

24 https://napglobalnetwork.org/resource/ghana-nap-framework/
25 https://unfccc.int/documents/273711
26 https://www.ipcc.ch/report/ar6/wg2/

Crops	SSP8.5	2015	3,620	1,950	1,670	1.86	0.54	0.032	0.052
Crops	SSP8.5	2030	4,370	3,780	590	1.16	0.86	0.032	0.052
Crops	SSP8.5	2040	7,890	6,940	950	1.14	0.88	0.032	0.052
Livestock	Baseline	2015	2,655	703	1,952	3.78	0.26	0.035	0.040
Livestock	Baseline	2030	4,481	1,298	3,182	3.45	0.29	0.035	0.040
Livestock	Baseline	2040	6,231	1,860	4,371	3.35	0.30	0.035	0.040
Livestock	SSP4.5	2015	2,655	843	1,811	3.15	0.32	0.011	0.041
Livestock	SSP4.5	2030	3,084	1,604	1,480	1.92	0.52	0.011	0.041
Livestock	SSP4.5	2040	3,497	2,325	1,173	1.50	0.66	0.011	0.041
Livestock	SSP8.5	2015	2,655	1,687	968	1.57	0.64	-0.003	0.042
Livestock	SSP8.5	2030	2,353	3,242	- 890	0.73	1.38	-0.003	0.042
Livestock	SSP8.5	2040	2,489	4,695	- 2,206	0.53	1.89	-0.003	0.042
Fisheries	Baseline	2015	887	41	846	21.85	0.05	0.057	0.092
Fisheries	Baseline	2030	1,950	168	1,782	11.61	0.09	0.057	0.092
Fisheries	Baseline	2040	3,580	366	3,214	9.78	0.10	0.057	0.092

Fisheries	SSP4.5	2015	887	49	838	18.21	0.05	0.031	0.094
Fisheries	SSP4.5	2030	1,360	207	1,153	6.57	0.15	0.031	0.094
Fisheries	SSP4.5	2040	1,900	457	1,443	4.16	0.24	0.031	0.094
Fisheries	SSP8.5	2015	887	97	790	9.11	0.11	0.002	0.094
Fisheries	SSP8.5	2030	897	419	478	2.14	0.47	0.002	0.094
Fisheries	SSP8.5	2040	930	923	7	1.01	0.99	0.002	0.094

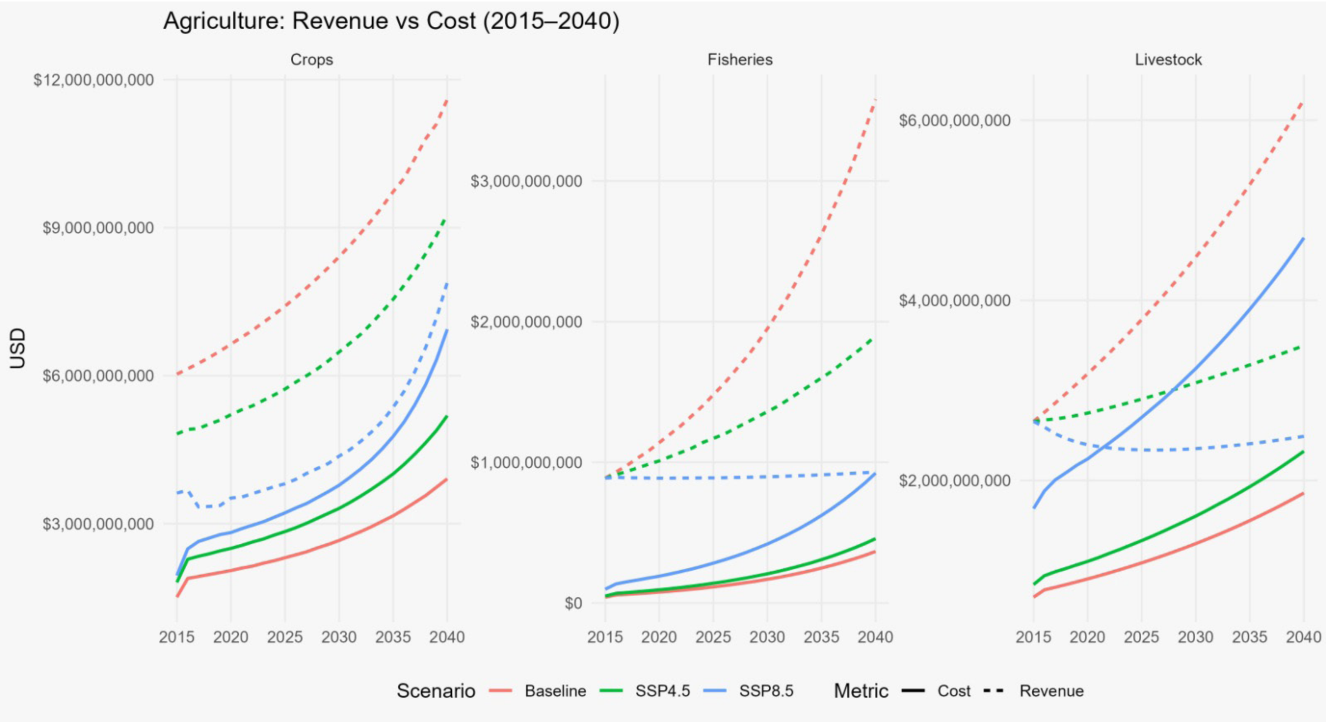
5.4.1. Revenue and Cost Trends

Figure 10 presents the trajectories of adaptation revenues and costs for Crops, Livestock, and Fisheries across the three climate scenarios. Overall, both revenues and costs increase steadily over the assessment period (2015–2040), reflecting the scaling of adaptation interventions and the rising demand for resilience in the face of climate change.

For the Crops subsector, revenues are consistently the highest in magnitude, driven by widespread interventions in irrigation, improved seed varieties, and fertilizer application. Costs, though significant, are more than offset by the economic returns in both the Baseline and SSP4.5 scenarios. However, under SSP8.5, costs rise sharply, narrowing the revenue–cost gap. This suggests that while crop adaptation remains beneficial, climate stress under high-emissions futures erodes profitability.

The Livestock subsector shows a more delicate balance. In the Baseline and SSP4.5 scenarios, revenues grow steadily and exceed costs, supporting a positive adaptation case. Under SSP8.5, however, costs escalate faster than revenues—driven largely by increased feed requirements, veterinary services, and climate-related disease management. By the late 2030s, adaptation costs outstrip revenues, producing negative net benefits (see Section 5.4.2). This highlights livestock as a highly vulnerable subsector, requiring careful policy design and potentially transformative adaptation pathways.

Figure 15. Agriculture Revenue vs Cost (2015–2040) for Crops, Fisheries, and Livestock under Baseline, SSP4.5, and SSP8.5 scenarios. Revenues (dashed lines) grow faster than costs (solid lines) in most subsectors under the baseline, while SSP8.5 shows rising cost catching up with or surpassing revenues in livestock.



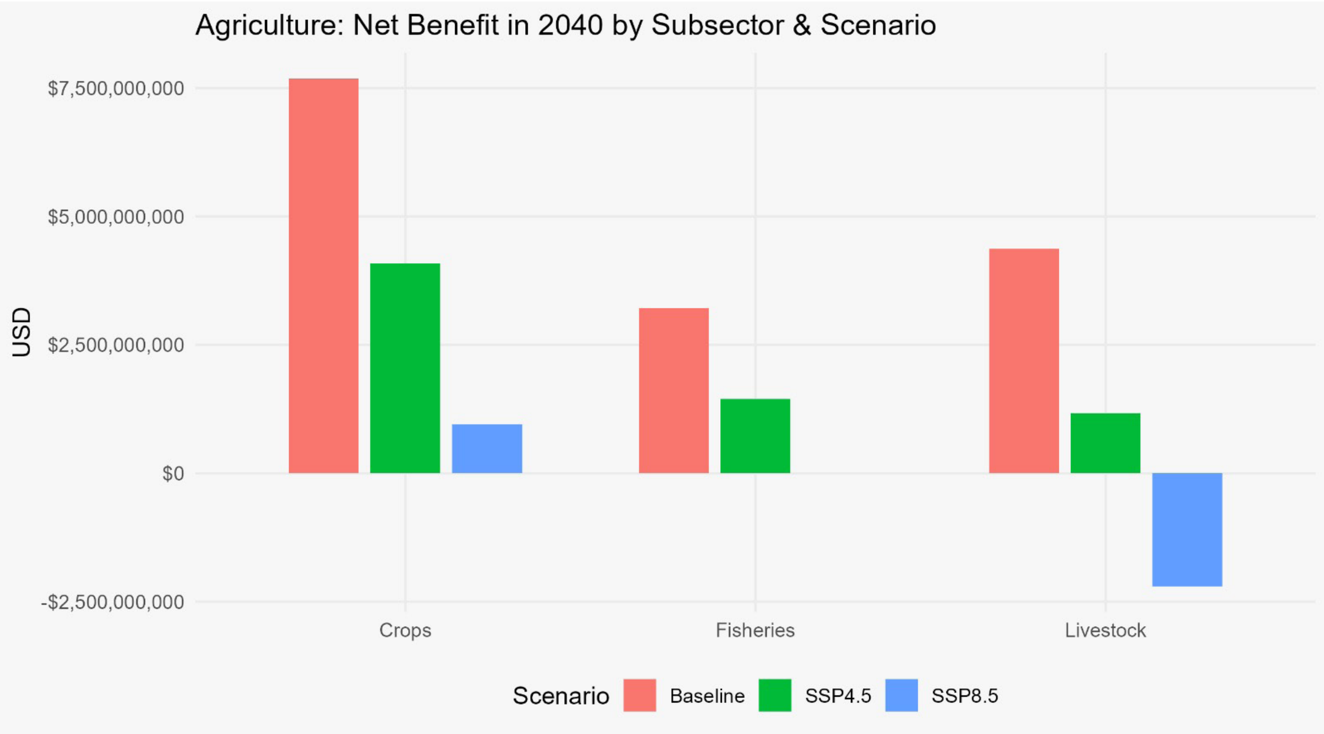
In the Fisheries subsector, adaptation investments are relatively smaller in absolute terms compared to crops and livestock, but revenues significantly exceed costs across all scenarios. Interventions such as aquaculture expansion, inland fisheries management, and ecosystem restoration deliver consistently high returns, even under SSP8.5. This robustness suggests fisheries adaptation could serve as a strategic buffer for national food and nutrition security.

The evidence points to a differentiated sub-sectoral outlook. Crops and fisheries adaptation are resilient economic opportunities, while livestock adaptation faces growing risks under harsher climate futures. These trends reinforce the need for subsector-specific strategies within the agriculture adaptation portfolio.

5.4.2. Net Benefits in 2040

The distribution of net benefits in the year 2040 across subsectors and scenarios is presented in Figure 11, while detailed efficiency metrics are summarized in Table 9. The analysis reveals notable differences in how adaptation actions perform under varying climate futures.

Figure 16. Net Benefit in Agriculture by Subsector and Scenario in 2040. Crops and livestock generate the highest net benefits under the baseline, while SSP8.5 shows declining or negative returns, especially in livestock.



For the Crops subsector, net benefits remain substantial across all scenarios. In the Baseline and SSP4.5 scenarios, benefits significantly outweigh costs, resulting in high Benefit–Cost Ratios (BCRs) of approximately 3.2 and 2.0, respectively. Even under the high-emissions SSP8.5 scenario, net benefits persist, albeit at a reduced level, with a BCR of 1.2. This demonstrates that while climate stress erodes profitability, crop adaptation remains a viable investment case even in adverse futures.

The Fisheries subsector consistently yields the most favorable outcomes. Net benefits are positive under all scenarios, with BCRs of 12.0 (Baseline), 7.4 (SSP4.5), and 2.7 (SSP8.5). These results underscore the resilience of fisheries-based adaptation, where aquaculture and sustainable inland fisheries management continue to deliver significant economic returns despite increasing climate pressures.

In contrast, the Livestock subsector reveals greater vulnerability. While the Baseline (BCR 3.5) and SSP4.5 (BCR 2.1) scenarios indicate clear net economic gains, the SSP8.5 scenario results in a BCR below unity (0.9), meaning costs exceed benefits. The Internal Rate of Return (IRR) in this case is approximately 12%, reflecting volatile cashflows where early costs are not consistently offset by later benefits. This suggests that livestock adaptation under harsher climate futures will require additional support, transformative practices, or complementary adaptation measures to remain viable.

The efficiency metrics confirm that fisheries and crops are robust investment options, while livestock faces serious adaptation risks under high emissions. Strategic prioritization and differentiated support will be necessary to maximize returns from agriculture adaptation and safeguard national food security.

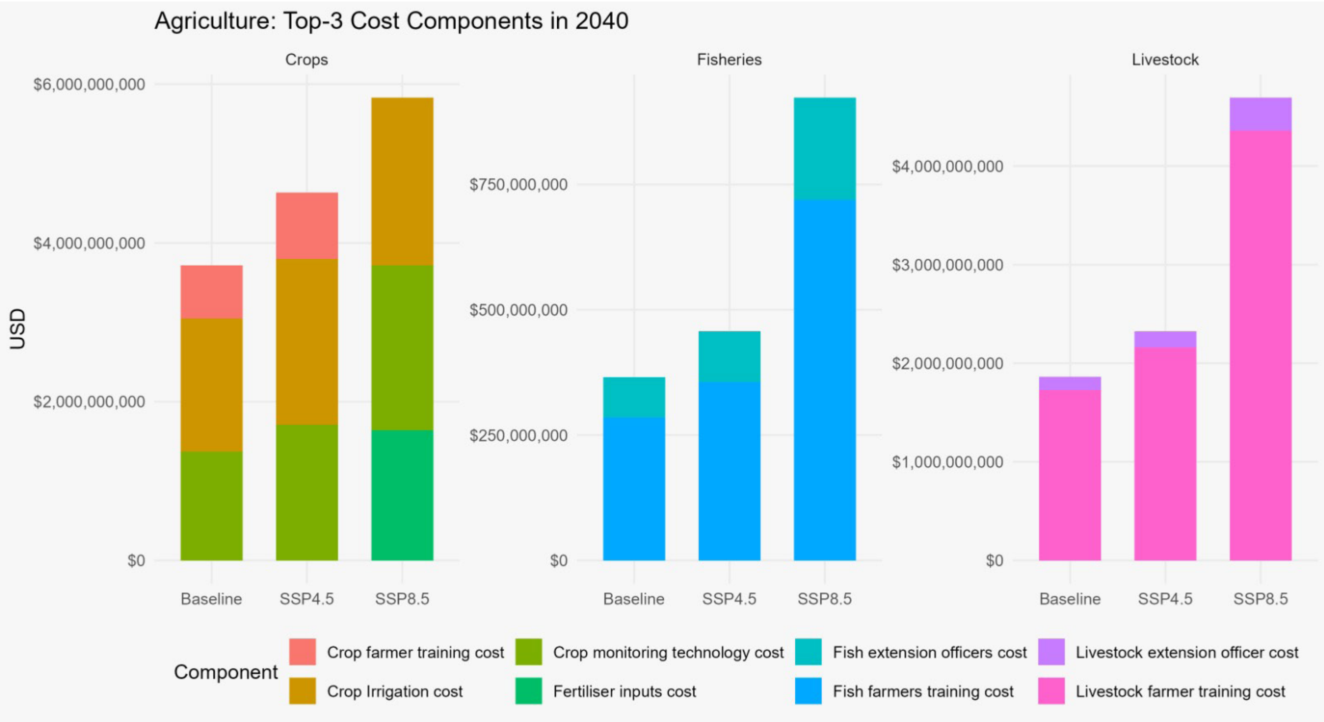
5.4.3. Cost Composition in 2040

The distribution of adaptation costs by component in 2040 is illustrated in Figure 12. The analysis highlights the dominant cost drivers in each subsector and how they shape the overall adaptation investment profile.

In the Crops subsector, costs are concentrated in three major areas: fertilizer subsidies, irrigation investments, and farmer training and extension services. Together, these account for the bulk of adaptation spending across all scenarios. Under the SSP8.5 scenario, the share of irrigation rises significantly, reflecting the growing need to address water stress in a hotter and more variable climate.

For the Livestock subsector, the largest shares of costs are associated with feed provision and supplementation, veterinary services, and extension support. These interventions become increasingly expensive under SSP8.5, as climate change amplifies disease risks and feed shortages. This escalation of costs helps explain why livestock adaptation becomes less economically viable under high-emissions futures (see Section 4.1.3). In the livestock subsector, training costs are particularly high because of the need for intensive capacity building in animal health, feed management, and disease surveillance. These trainings are recurrent and require continuous investment to equip farmers with the skills to manage climate-driven risks such as emerging zoonotic diseases and pasture shortages.

Figure 17. Top-3 Agriculture Cost Components in 2040 across Crops, Fisheries, and Livestock under Baseline, SSP4.5, and SSP8.5 scenarios. Crops are driven by irrigation, monitoring technology, and fertilizer inputs; fisheries by training and extension officer costs; and livestock by farmer training and extension services.



In the Fisheries subsector, expenditures are dominated by aquaculture development, fisheries resource management, and ecosystem restoration activities. Notably, while these interventions represent a smaller absolute cost base compared to crops and livestock, their returns are disproportionately high (see Table 8). This highlights fisheries as a high-value, cost-efficient adaptation opportunity for Ghana.

The cost structure indicates that adaptation in agriculture is heavily driven by technology and capacity investments. Efficiency gains could be achieved by:

a). promoting integrated soil fertility management to reduce reliance on fertilizer subsidies,

b). scaling climate-smart irrigation technologies, and c). strengthening preventive livestock health systems.

This underlines the importance of targeting resources not only to maximize net benefits, but also to address the systemic vulnerabilities (e.g., water stress, feed scarcity, and disease burdens) that drive costs upward under harsher climate futures.

5.4.4. Efficiency Metrics

The efficiency of agricultural adaptation actions was further assessed using Benefit–Cost Ratios (BCRs), Net Present Values (NPVs), and Internal Rates of Return (IRRs), as summarized in Table 9. These indicators provide insight into the economic attractiveness and resilience of investments across subsectors and climate scenarios.

For the Crops subsector, efficiency metrics demonstrate robust viability. In the Baseline scenario, the discounted BCR at 5 percent is approximately 3.2, confirming that every dollar invested yields over three dollars in benefits. Under SSP4.5, the BCR declines to 2.0, but still indicates strong returns. Even in SSP8.5, where climate impacts intensify, the BCR remains marginally positive at 1.2. Although no IRR is defined, because benefits consistently outweigh costs, these BCR values affirm crops as a strategic priority for adaptation investment.

Table 11. Benefit-Cost Ratio (Undiscounted & 5% Discounted) and Internal Rate of Return (IRR) by Sub-sector and Scenario for the Agriculture Sector (2015–2040).

The table compares benefits, costs, and returns for Crops, Fisheries, and Livestock under the Baseline, SSP4.5, and SSP8.5 scenarios. Both undiscounted and discounted (5%) values are shown, alongside BCRs and IRRs. Results highlight that fisheries consistently deliver the highest BCRs, while livestock under SSP8.5 yields sub-optimal returns (BCR < 1).

Sub-sector	Scenario	Undiscounted Benefits (Million USD)	Undiscounted Costs (Million USD)	BCR (Undis-counted)	PV Benefits (Million USD)	PV Costs (Million USD)	BCR (Discounted)	IRR (%)*
Crops	Baseline	213,050	67,590	3.15	115,335	36,069	3.2	-
Crops	SSP4.5	166,270	84,700	1.96	90,089.1	44,789.6	2.01	-
Crops	SSP8.5	117,760	99,530	1.18	62,929	51,795	1.21	-
Fisheries	Baseline	48,975	4,225.3	11.59	24,429.1	1,987	12.29	-
Fisheries	SSP4.5	33,969	5,225.1	6.5	18,156	2,449	7.41	-
Fisheries	SSP8.5	23,376	10,565.4	2.21	13,513	4,954	2.73	-
Livestock	Baseline	110,141	31,929.3	3.45	58,319.9	16,787	3.47	-

Livestock	SSP4.5	78,482	39,385	1.99	44,183.3	20,624	2.14	-
Livestock	SSP8.5	62,725	79,668	0.79	36,588	41,738.4	0.88	12

** Note: NA values in the IRR column indicate cases where no real Internal Rate of Return could be calculated, typically due to all cash flows being of the same sign or zero, rendering IRR undefined.*

The Fisheries subsector outperforms other subsectors on all metrics. Discounted BCRs reach 12.0 in Baseline, 7.4 under SSP4.5, and 2.7 under SSP8.5, far exceeding the standard investment threshold. The consistently high NPVs confirm fisheries as a resilient and cost-effective adaptation pathway, even under severe climate change.

In contrast, the Livestock subsector displays mixed efficiency. Baseline (BCR 3.5) and SSP4.5 (BCR 2.1) scenarios suggest strong returns. However, under SSP8.5, the BCR falls to 0.9, indicating costs surpass benefits. The calculated IRR of approximately 12% for SSP8.5 underscores the volatility of livestock adaptation, where net benefits are not guaranteed and depend heavily on the timing and magnitude of costs versus revenues.

The efficiency analysis reinforces a differentiated strategy for agricultural adaptation. Crops and fisheries present robust investment opportunities, while livestock adaptation faces significant risks under high-emissions futures. Policymakers must consider complementary measures such as technology innovation, institutional support, and risk-sharing mechanisms to sustain livestock adaptation outcomes.

5.4.5. Conclusion

The results of the agricultural sector assessment provide a number of important insights for Ghana's adaptation planning. First, the sector as a whole generates substantial economic benefits from adaptation investments, but the distribution of these benefits is highly uneven across subsectors and climate scenarios. Crops and fisheries demonstrate strong and resilient economic returns across scenarios, while livestock adaptation becomes increasingly challenged under high-emissions futures.

From a policy perspective, these findings underline the importance of a differentiated sub-sectoral approach:

- Crops should remain the cornerstone of national agricultural adaptation, supported by investments in irrigation, improved seed systems, and farmer training.
- Fisheries present a particularly high-value and resilient opportunity, where relatively modest investments yield disproportionately high benefits. Scaling up aquaculture and strengthening inland fisheries management could help Ghana build climate-resilient food and nutrition security.
- Livestock, while profitable under lower-stress scenarios, is vulnerable under SSP8.5. This calls for transformative interventions, including climate-resilient feed systems, improved disease management, and possibly diversification of protein sources to buffer against climate shocks.

- Ensure gender-sensitive adaptation by mandating female representation in farmer training, extension services, and local adaptation committees through policy interventions.

Beyond monetary measures, adaptation in agriculture generates significant non-market co-benefits that strengthen the overall investment case:

- Food security and nutrition: Adaptation actions help stabilize national food supplies, reduce hunger risks, and improve dietary diversity.
- Poverty reduction and rural livelihoods: Increased resilience in agriculture directly benefits smallholder farmers, pastoralists, and fishing communities, who are among the most vulnerable to climate change27
- Gender empowerment: Women play key roles in crop processing, fisheries, and livestock care. Adaptation programs that improve access to resources and training can contribute to women's empowerment and social inclusion28.
- Ecosystem health: Fisheries and crop interventions that promote sustainable practices contribute to biodiversity conservation, soil fertility, and water resource management[29].

These non-market benefits are not fully captured in the BCR and IRR values, but they significantly enhance the overall justification for agricultural adaptation. When combined with the economic metrics, they make a compelling case for sustained and scaled investment in agricultural adaptation as a pillar of Ghana's National Adaptation Plan.

27 https://openknowledge.worldbank.org/entities/publication/abb56867-65c5-5957-bba3-af55e8baf23c#:~:text=The%20Agriculture%20Sector%20Policy%20Note,modernization%20of%20its%20agriculture%20sector.
28 AGRICULTURE IN GHANA (Facts & Figures) 2021.pdf
29 https://www.ipcc.ch/report/ar6/wg2/

6. WATER SECTOR

6.1. Background

Ghana's water sector is essential to the nation's ecological stability, economic growth, and social well-being, providing vital services for household use, agriculture, energy production, and ecosystem health. However, this sector faces mounting pressures from climate change, including shifting rainfall patterns, prolonged droughts, rising temperatures, and frequent flooding, which threaten water availability, quality, and security[30]. These climate-induced challenges are compounded by anthropogenic factors such as watershed degradation, overexploitation, and pollution, particularly in mining-affected areas and urban centers, placing vulnerable rural and low-income communities—especially women and girls tasked with water collection—at heightened risk[31].

To address these vulnerabilities, the "Climate Change Adaptation Action Plan for the Water Sector in Ghana," developed under the National Adaptation Plan (NAP) framework, proposes a suite of adaptation strategies to enhance resilience and ensure sustainable water resource management. This action plan is integral to the broader NAP project, "Enhancing multi-sector planning and capacity for effective adaptation in Ghana," led by the Ghana Environmental Protection Agency under the Ministry of Environment, Science, Technology, and Innovation (MESTI), with support from the Green Climate Fund (GCF). Proposed interventions, such as sustainable watershed management, resilient infrastructure development, and community-based water supply schemes, aim to mitigate climate risks while fostering equitable access and supporting livelihoods.

Implementing these adaptation measures demands significant financial investment, necessitating a comprehensive economic appraisal to assess their viability and guide resource allocation. This section introduces the economic appraisal of adaptation options for Ghana's water sector, with the primary goal of developing a methodology to evaluate the costs and benefits of these strategies. The appraisal seeks to integrate climate change adaptation into national water management policies and budgeting processes, while identifying sustainable financing mechanisms to bolster long-term resilience.

The appraisal builds on the adaptation options outlined in the "Climate Change Adaptation Action Plan for the Water Sector in Ghana." For example, afforestation along the Volta River Basin enhances groundwater recharge and reduces erosion, supporting downstream communities[32], while modernizing reservoirs like Lake Volta improves water storage to buffer against droughts. These interventions involve costs—such as infrastructure development, monitoring systems, and community engagement—that must be weighed against their economic and social returns.

30 Environmental Protection Agency. (2021). Climate change effects on water resources and adaptation strategies in Ghana.
31 Ministry of Water Resources, Works and Housing. (2007). Ghana national water policy. Accra, Ghana.2025-PBB-MWHWR.pdf
32 Water Resources Commission. (2012). Tano River Basin - Integrated Water Resources Management Plan.

Drawing on existing research on water stress[33] and on water quality[34], this appraisal employs a robust analytical approach to quantify costs and benefits, assess trade-offs, and explore future scenarios. The methodology, detailed in the following section, leverages economic tools and dynamic modeling to provide decision-makers with evidence-based insights for prioritizing adaptation options. These insights ensure that limited resources target interventions with the greatest potential impact, aligning with the NAP project's objectives of multi-sectoral, medium- to long-term planning.

Beyond costing, the appraisal aims to secure sustainable funding sources—such as resource usage fees or public-private partnerships35—to enhance water sector resilience. The subsequent sections will outline the methodology, present the economic analysis of selected adaptation options, and offer recommendations to guide Ghana's efforts to adapt to a changing climate.

6.2. Model Description

The water sector methodology builds on the overarching system dynamics and cost–benefit analysis framework (see General Methodology). It addresses adaptation actions to improve water supply, enhance water quality, manage surface and groundwater resources, and strengthen drainage systems in urban areas. The model integrates hydrological processes (surface runoff, reservoir storage, groundwater abstraction) with service delivery metrics (water quality, access indices). Stock-and-flow diagrams (Figure 18) show how investments in infrastructure and management affect water availability, quality, and access over time.

6.2.1. Systems Dynamics Model Structure

The water sub-model conceptualizes water resources as interacting stocks: reservoir storage, groundwater storage, and urban drainage capacity. Flows include inflows from precipitation, withdrawals for irrigation and domestic supply, recharge, and drainage expansion. Adaptation measures—such as improved treatment systems, expansion of boreholes, and stormwater drainage—are parameterized as interventions altering these flows.

As summarized in Table 12, several national M&R (the Monitoring and Reporting Plan of the NAP Framework) indicators align directly with model variables, including Water Quality Index (WQI) (water_quality_index), reservoir capacity (m^3) (reservoir_storage), and groundwater abstraction (m^3) (groundwater_withdrawal). Other indicators show only partial alignment, such as length of urban drainage constructed (km) (proxied by drainage_km) and percentage of population with access to safe water supply (represented by water_access_index).

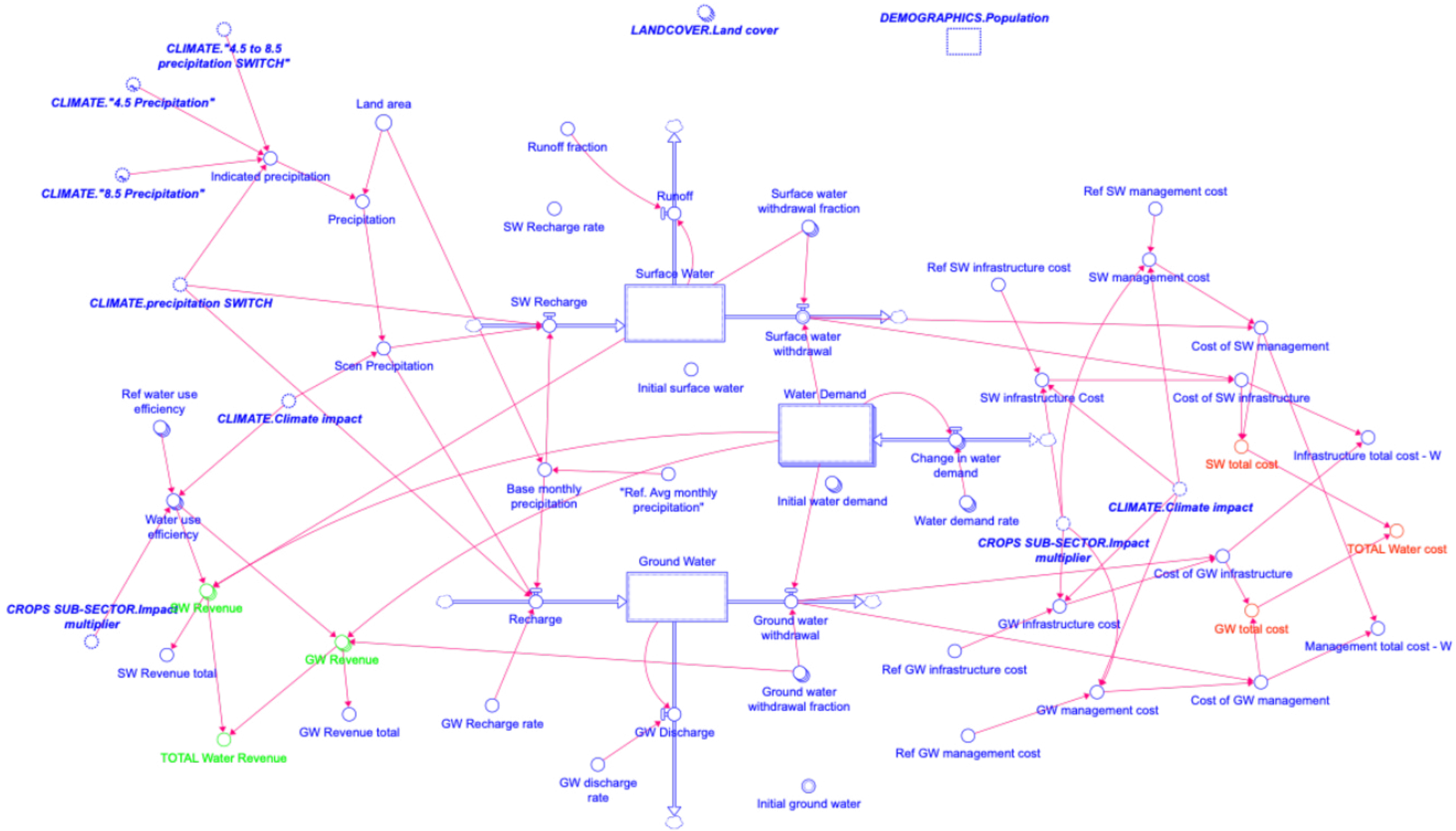
33 Obuobie, E., Kankam-Yeboah, B., Amisigo, Y., Opoku-Ankomah, Y., & Ofori, D. (2012a). Assessment of water stress in river basins in Ghana. Journal of Water and Climate Change, 3(4), 276–286. https://doi.org/10.2166/wcc.2012.030

34 Yeleliere, E., Cobbina, S. J., & Duwiejuah, A. B. (2018). Review of Ghana's water resources: The quality and management with focus on freshwater resources. Applied Water Science, 8(3), 93. https://doi.org/10.1007/s13201-018-0736-4

35 Ministry of Water Resources, Works and Housing. (2007). Ghana national water policy. Accra, Ghana.2025-PBB-MWHWR.pdf

The water sector model captures both surface water (reservoir storage, river flows) and groundwater systems, alongside urban drainage infrastructure. Flows include recharge, withdrawals, inflows, and drainage expansion. Adaptation actions—such as borehole development, water treatment upgrades, and drainage expansion—improve water availability, quality, and flood resilience.

Figure 18. Water Sector Stock-and-Flow Structure



6.2.2. Data and Parameters

Baseline data for water resources were obtained from the Ghana Water Company Ltd., WRC, and EPA. Reservoir and groundwater parameters are consistent with hydrological datasets and FAO AQUASTAT values. WQI benchmarks were taken from national water quality monitoring reports. Cost data were derived from recent adaptation costings of water infrastructure projects in Ghana and peer-reviewed global benchmarks.

National targets from the M&R matrices (see Table A3) provided calibration points for reservoir capacity expansion, groundwater development, drainage length, and WQI improvement goals.

Table 12. Water Sector – Indicator to Model Alignment

Indicator (M&R)	Closest Model Variable	Alignment Status	Notes
Water Quality Index (WQI)	water_quality_index	Match	Directly aligned.
Reservoir capacity (m^3)	reservoir_storage	Match	Directly aligned.
Groundwater abstraction (m^3)	groundwater_withdrawal	Match	Directly aligned.
Length of urban drainage constructed (km)	drainage_km	Partial	Proxy: model tracks drainage coverage, not length.
% population with access to safe water supply	water_access_index	Partial	Proxy via coverage index, not % households directly.

The following assumptions underpin the water sector model:

1. Indicator alignment: Directly matched indicators (WQI, storage, abstraction) are reported quantitatively; partial matches are approximated using proxy indices.
2. Water quality: WQI improvements are modelled as a function of investment in treatment systems, with baseline values held constant under no adaptation.
3. Drainage infrastructure: Modelled as an aggregate coverage index rather than exact kilometers; scaling assumptions were used to interpret this against national targets.
4. Water access: Represented by a composite index capturing service coverage; interpreted as a proxy for the percentage of households with safe supply.

5. Economic appraisal: Costs include capital and O&M for reservoirs, boreholes, and drainage, but exclude secondary economic impacts such as changes in energy costs.

6.2.3. Analytical Approach

Future scenarios were simulated to 2040, comparing baseline water stress against intervention pathways. Outputs included time-series projections of reservoir capacity, groundwater withdrawals, WQI scores, and drainage coverage. Economic appraisal indicators (NPV, BCR, IRR) were computed at a 5% discount rate for adaptation bundles. Sensitivity analysis explored variation in water demand growth and alternative water quality improvement costs. Results should be interpreted with confidence for directly aligned indicators (e.g., WQI, reservoir capacity). Outputs for partially aligned indicators—such as drainage length and water access—should be considered indicative, as they rely on proxy indices. Governance and institutional measures in the M&R framework (e.g., PPP arrangements for water services) remain outside the model's quantitative scope.

6.3. Adaptation Options and Costed Adaptation Bundle for the Water Sector

Ghana's Water Sector Adaptation Action Plan prioritizes a suite of complementary actions focused on Groundwater (GW) and Surface Water (SW) systems, with cross-cutting measures for integrated management. The actions emphasize nature-based solutions (NbS), resilient infrastructure, monitoring, and community engagement to enhance water security, reduce losses, and support equitable access, particularly for women and vulnerable groups. The list of adaptation options is provided in Table 10.

Table 13. Summary of Adaptation Options for the Water Sector

Adaptation Action
Restoration and conservation of wetlands and watersheds
Restoration of buffer zones
Watershed management
Promotion of Indigenous knowledge and practices in water conservation
Strengthen research on water resource management including groundwater resources
Management plans for River basins
Real-time monitoring and forecasting of the flows
Climate-smart River Management System
Provide climate-resilient infrastructure in critical areas of disaster risk reduction
Strengthen capacity in designing and developing climate-resilient infrastructure

Monitoring of extreme rainfall events that could cause flood
Comprehensive Disaster Management (DM) Plans
Improved drought and flood forecasting, preparedness and response system
Enhance awareness of communities on water-related hazards
Harvesting rainwater for domestic use
Adoption of Green roofing in cities
Ensuring proper monitoring, planning and supply of drinking water
Strengthen drinking water quality monitoring and surveillance
Strengthen database on drinking water supply schemes
Improve planning, designing and implementation of climate-resilient irrigation infrastructures and systems
Integrate watershed management in hydropower planning

These actions are designed to be mutually reinforcing, addressing interconnected challenges like water scarcity, pollution, and extreme events while generating co-benefits such as improved health outcomes (e.g., reduced waterborne diseases) and economic gains (e.g., sustained agricultural productivity).

6.3.1. Costed Adaptation Bundle

Adaptation options in the water sector are highly complementary, as they collectively enhance system resilience, optimize resource use, and create synergies across ecosystems and users. For instance:

a). **Watershed Restoration and Research/Monitoring (GW & SW Management):** Restoring wetlands and buffer zones (e.g., along the Volta River) improves natural recharge and filtration, complementing strengthened research on groundwater and real-time monitoring systems. Together, these reduce contamination risks and enable data-driven decisions, such as early warnings for floods or droughts.

b). **Resilient Infrastructure and Disaster Planning (Cross-Cutting):** Climate-resilient irrigation and hydropower integration (e.g., solar-powered micro-irrigation) pairs with comprehensive disaster plans and forecasting to minimize infrastructure damage from extremes.

c). **Awareness and Water Supply Efficiency (SW Ecosystems):** Community awareness campaigns on hazards reinforce quality monitoring, ensuring safe drinking water supply. These align with indigenous knowledge promotion, fostering sustainable practices that support alternative livelihoods and gender equity in water access.

Therefore, the costing bundles these actions into two thematic groups; Water Management and Infrastructure Adaptation Strategy focused on two primary subsectors, Groundwater (GW) and Surface Water (SW) systems, with cross-cutting measures for integrated management.

6.4. Results and Discussion

The water sector was analyzed across two subsectors, **Groundwater** and **Surface Water,** under three climate scenarios: **Baseline (business-as-usual with adaptation), SSP4.5**, and **SSP8.5.** Results are expressed in monetary terms (USD, billions) over the period **2015–2040**, with both annual trajectories and efficiency metrics examined. The efficiency metrics include **Benefit–Cost Ratios (BCRs), Net Present Values (NPVs),** and **Internal Rates of Return (IRRs),** which provide a comprehensive view of the financial and economic viability of adaptation investments in the sector. Table 11 provides a summary of the water sector results.

Table 14. Master summary table for the water sector showing revenues, costs, net benefits, benefit–cost ratios (BCRs), cost per dollar of revenue, and compound annual growth rates (CAGR) for selected years (2015, 2030, 2040).

Subsector	Scenario	Year	Revenue (Million USD)	Cost (Million USD)	Net Benefit (Million USD)	BCR	Cost per USD Revenue	Cost CAGR (2015-2040)	Rev CAGR (2015-2040)
Groundwater	Baseline	2015	821.00	92.29	728.71	8.90	$0	7.50%	7.50%
Groundwater	Baseline	2030	2,420.00	271.60	2,148.40	8.91	$0	7.50%	7.50%
Groundwater	Baseline	2040	4,960.00	557.40	4,402.60	8.90	$0	7.50%	7.50%
Groundwater	SSP4.5	2015	657.00	110.23	546.77	5.96	$0	7.60%	7.20%
Groundwater	SSP4.5	2030	1,850.00	334.90	1,515.10	5.52	$0	7.60%	7.20%
Groundwater	SSP4.5	2040	3,720.00	696.00	3,024.00	5.34	$0	7.60%	7.20%
Groundwater	SSP8.5	2015	493.00	128.80	364.20	3.83	$0	7.80%	6.50%
Groundwater	SSP8.5	2030	1,210.00	406.90	803.10	2.97	$0	7.80%	6.50%
Groundwater	SSP8.5	2040	2,360.00	848.80	1,511.20	2.78	$0	7.80%	6.50%
SurfaceWater	Baseline	2015	230.00	267.30	–$37.3	0.86	$1	7.50%	7.50%
SurfaceWater	Baseline	2030	676.00	787.70	–$111.7	0.86	$1	7.50%	7.50%

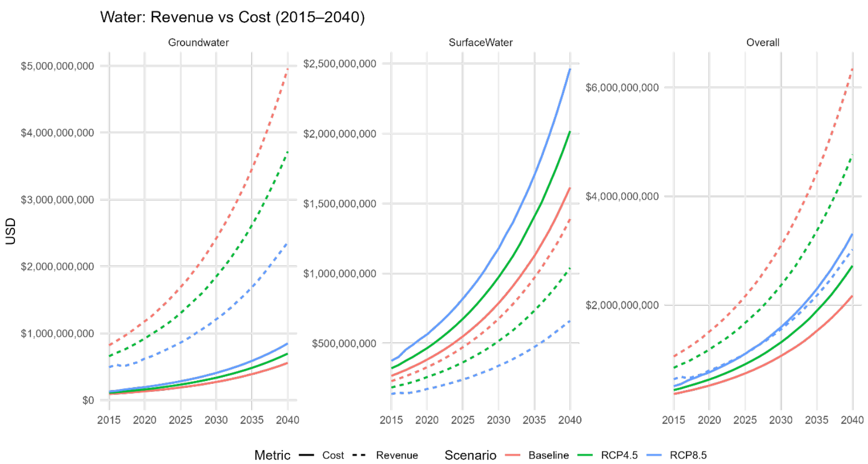
SurfaceWater	Baseline	2040	1,390.00	1,615.00	–$225	0.86	$1	7.50%	7.50%
SurfaceWater	SSP4.5	2015	184.00	321.80	–$137.8	0.57	$2	7.60%	7.20%
SurfaceWater	SSP4.5	2030	517.00	973.10	–$456.1	0.53	$2	7.60%	7.20%
SurfaceWater	SSP4.5	2040	1,040.00	2,018.00	–$978	0.52	$2	7.60%	7.20%
SurfaceWater	SSP8.5	2015	138.00	375.20	–$237.2	0.37	$3	7.80%	6.50%
SurfaceWater	SSP8.5	2030	340.00	1,178.30	–$838.3	0.29	$3	7.80%	6.50%
SurfaceWater	SSP8.5	2040	661.00	2,465.00	–$1,804	0.27	$4	7.80%	6.50%

Beyond financial metrics, water sector adaptation generates significant non-market benefits, including improved public health, strengthened water security, and enhanced resilience of communities and ecosystems. These co-benefits further strengthen the case for prioritizing water investments in Ghana's National Adaptation Plan (NAP).

6.4.1. Revenue and Cost Trends

Revenues and costs in the water sector increase steadily over the period 2015–2040, but the balance between them differs significantly across subsectors and scenarios (Figure 11).

Figure 19. Revenue and cost trends in the water sector (2015–2040), disaggregated by subsector (Groundwater and Surface Water) and climate scenario (Baseline, SSP4.5, SSP8.5).



Groundwater shows the strongest financial performance. Revenues rise from approximately **USD 0.8 billion in 2015** to nearly **USD 5.0 billion by 2040** under the Baseline scenario, outpacing costs across all scenarios. This trend reflects the relatively low operating and infrastructure costs of groundwater supply, coupled with strong demand from municipal and industrial users.

By contrast, **surface water systems** remain cost-intensive. Although revenues grow over time, the costs of infrastructure construction, maintenance, and management consistently exceed revenues. This imbalance is accentuated under climate-stress scenarios, where higher variability in river flows and increased investment requirements for storage and treatment inflate costs disproportionately.

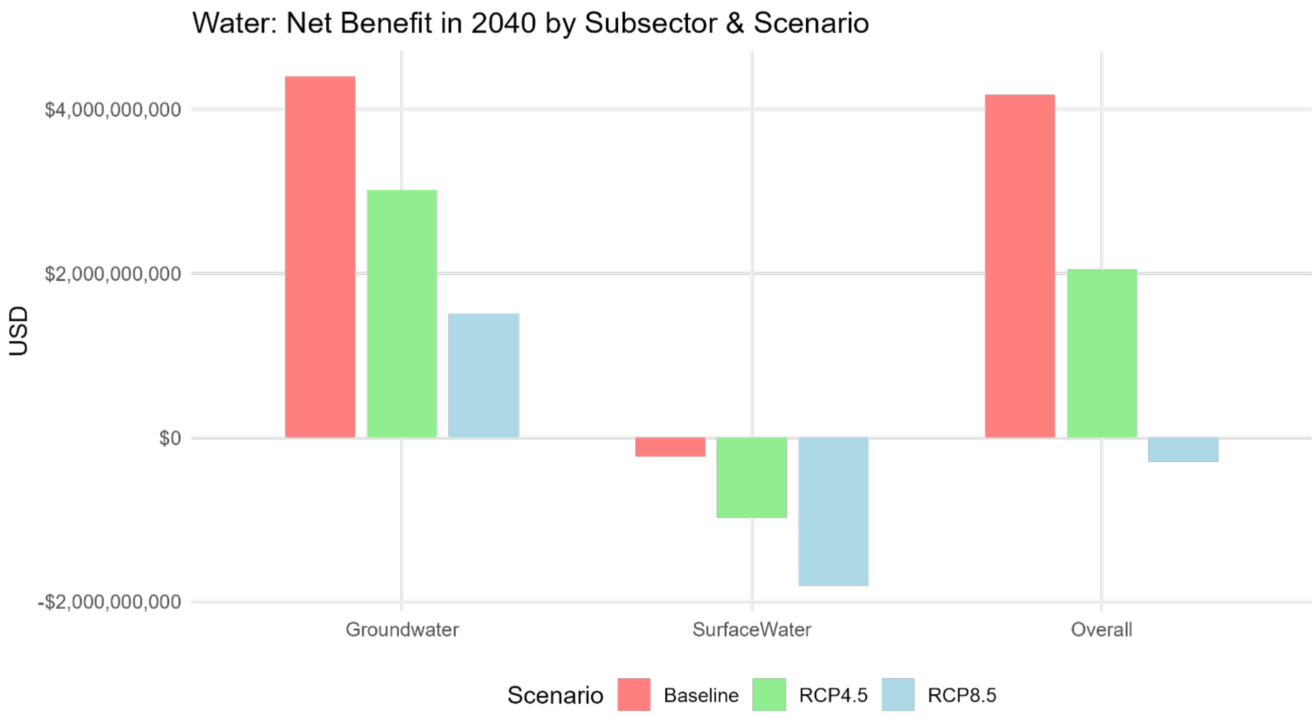
At the **sector-wide level**, the Baseline scenario delivers the most favorable revenue–cost balance, with total sector BCRs above **2.9** (see Table 11). Under **SSP4.5**, costs rise faster than revenues, moderating sector performance to a BCR of around **1.8**. Under **SSP8.5**, revenues stagnate while costs continue to escalate, pushing the overall sector BCR close to **1.0** by 2040.

The results suggest that climate stress disproportionately increases costs in surface water systems, eroding sector-wide returns. Prioritizing groundwater development and improving the efficiency of surface water investments are therefore critical for sustaining long-term water security.

6.4.2. Net Benefits in 2040

By 2040, the distribution of net benefits diverges sharply across subsectors and climate scenarios (Figure 12). **Groundwater** emerges as the most resilient subsector. Net benefits remain positive across all scenarios, reaching approximately **USD 4.1 billion under the Baseline, USD 2.8 billion under SSP4.5**, and still maintaining a modest surplus under **SSP8.5**. This underscores the strong financial viability of groundwater adaptation measures, even in the face of severe climate change impacts.

Figure 20. Net benefits in 2040 for water subsectors under Baseline, SSP4.5, and SSP8.5 scenarios.



Surface water, however, presents a more complex picture. Under the Baseline scenario, net benefits are marginally negative, largely due to the high capital and operational requirements of dams, reservoirs, and treatment systems. Under SSP4.5, these systems become significantly less viable from a financial perspective, with adaptation costs outweighing revenues by close to USD 0.9 billion. The fiscal challenge intensifies under SSP8.5, where net losses exceed USD 1.5 billion, underscoring the vulnerability of surface water infrastructure to climate stress and its potential fiscal unsustainability without substantial efficiency gains or targeted subsidies.

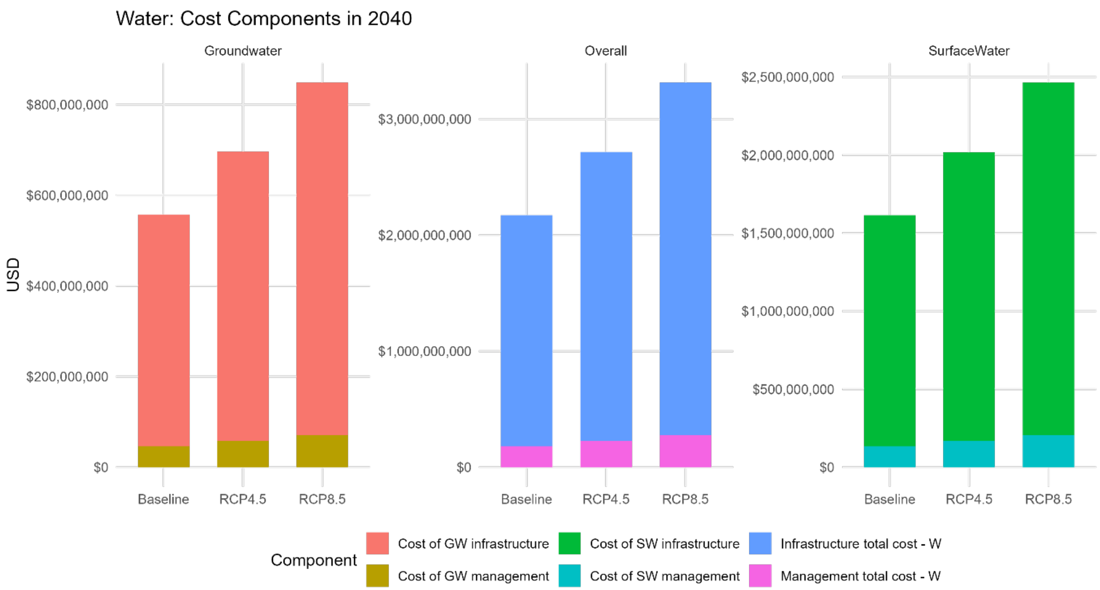
Yet, it is important to recognize that surface water systems provide substantial non-market benefits that extend beyond their immediate financial balance sheets. Investments in dams and reservoirs underpin water security for cities and industries, reduce vulnerability to seasonal variability, and enhance resilience against floods and droughts. Treatment systems safeguard public health by ensuring the quality of drinking water, reducing the incidence of waterborne diseases, and supporting broader socio-economic stability.

At the aggregate sector level, total net benefits remain positive under the Baseline (USD 5.6 billion) and SSP4.5 (USD 1.9 billion) scenarios, though they turn negative under SSP8.5, driven primarily by the high costs associated with surface water adaptation. Groundwater adaptation continues to represent a robust investment case across all climate futures. The challenge, therefore, lies in balancing financial sustainability with the essential public goods provided by surface water systems. A dual strategy is required, sustainably expanding groundwater supply while reorienting surface water investments toward efficiency improvements, ecosystem-based approaches, and climate-resilient infrastructure that maximizes both economic returns and non-market societal benefits.

6.4.3. Cost Composition in 2040

The composition of costs in the water sector varies substantially between subsectors, with clear implications for financial planning and efficiency strategies (Figure 13). For **groundwater systems**, costs are divided almost evenly between **infrastructure development** (e.g., boreholes, pumping stations, and distribution networks) and **management expenses** (operation, monitoring, and regulatory oversight).

Figure 21. Composition of adaptation costs in 2040, showing the distribution of expenditures across key cost components within the water sector.



In 2040, infrastructure accounts for approximately **52–55% of total groundwater costs**, while management makes up the remainder. This relatively balanced profile reflects the steady but manageable cost structure of groundwater systems, making them financially sustainable under most climate scenarios.

In contrast, surface water systems are dominated by infrastructure expenditures. By 2040, over 70% of total costs are attributable to large-scale construction and maintenance of dams, reservoirs, treatment plants, and distribution canals. Management costs, including water allocation, monitoring, and maintenance, comprise the remaining share but are overshadowed by the capital intensity of infrastructure. Under climate-stressed scenarios, these infrastructure costs escalate further, driven by the need for larger storage capacity, advanced treatment systems, and flood protection investments. At the sector-wide level, infrastructure costs dominate the adaptation profile, especially under SSP4.5 and SSP8.5, where efficiency losses compound capital requirements.

The heavy reliance on infrastructure investment, particularly for surface water, suggests significant opportunities for improving efficiency through climate-smart technologies, **decentralized systems, and demand management approaches**. Strengthening the role of management and regulatory frameworks could also optimize resource use and reduce long-term costs.

6.4.4. Efficiency Metrics

A detailed economic appraisal of water sector adaptation provides further insight into its long-term viability (Table 12). Efficiency metrics, including **Benefit-Cost Ratios (BCRs), Net Benefits,** Net Present Values (NPVs), and Internal Rates of Return (IRRs), were computed for the period 2015–2040.

Groundwater demonstrates consistently strong performance. Under the Baseline scenario, the BCR exceeds 3.0, with cumulative net benefits of over USD 4 billion, reflecting steady growth in revenues relative to manageable costs. Even under SSP4.5 and SSP8.5, groundwater maintains BCRs above 1.5, signaling continued financial viability. The IRR estimates were undefined due to all cash flows having the same positive sign. The BCR and CAGR (See Table 11) are used in such cases.

Table 15. Efficiency analysis of health sector adaptation, showing undiscounted and discounted (5%) BCRs, present values, and internal rates of return (IRR) by subsector and scenario.

Subsector	Scenario	Undisc. Benefits (Million USD)	Undisc. Costs (Million USD)	BCR (Undisc.)	PV Benefits @5% (Million USD)	PV Costs @5% (Million USD)	BCR (5% Disc.)	IRR (%)*
Groundwater	Baseline	60,482.00	6,792.97	8.9	28,962.95	3,252.93	8.9	-
Groundwater	SSP4.5	46,155.00	8,397.14	5.5	22,229.06	4,005.52	5.55	-
Groundwater	SSP8.5	30,181.00	10,191.40	2.96	14,675.67	4,854.78	3.02	-
SurfaceWater	Baseline	16,917.00	19,694.20	0.86	8,100.54	9,432.68	0.86	-

SurfaceWater	SSP4.5	12,913.00	24,372.30	0.53	6,219.77	11,629.22	0.53	-
SurfaceWater	SSP8.5	8,452.00	29,580.60	0.29	4,109.38	14,091.67	0.29	-
Overall	Baseline	77,380.00	26,484.00	2.92	37,050.94	12,684.75	2.92	-
Overall	SSP4.5	59,071.00	32,788.00	1.8	28,449.51	15,642.92	1.82	-
Overall	SSP8.5	38,656.00	39,767.00	0.97	18,794.25	18,946.72	0.99	6.8

Note: NA values in the IRR column indicate cases where no real Internal Rate of Return could be calculated, typically due to all cash flows being of the same sign or the occurrence of multiple sign changes, rendering IRR undefined.

Surface water, however, performs poorly across climate scenarios. While the Baseline scenario yields marginally positive returns with a BCR near **1.2**, both SSP4.5 and SSP8.5 show BCRs below unity, indicating that costs outweigh benefits. The IRRs for surface water under climate stress are undefined due to all cash flows having the same negative.

At the **aggregate sector level**, overall BCRs remain favorable under Baseline (**2.9**) and SSP4.5 (**approximately 1.8**) but decline to nearly **1.0** under SSP8.5. This indicates that while water sector adaptation is viable in the short-to-medium term, high-emissions futures could erode economic returns, particularly due to cost-intensive surface water projects.

Groundwater adaptation is a sound and resilient investment across all scenarios, while surface water adaptation will require **targeted subsidies, efficiency innovations, or alternative approaches** to remain viable under harsher climate futures. These findings emphasize the importance of diversifying water sector strategies and prioritizing interventions that maximize both financial and social returns.

6.5. Conclusion

The water sector analysis highlights both the economic and broader societal implications of adaptation investments. From an economic perspective, groundwater consistently outperforms surface water across all climate scenarios. Its strong BCRs, positive net benefits, and CAGR underscore its role as a low-cost, high-return adaptation pathway. Surface water, however, is increasingly challenged by escalating infrastructure and management costs, particularly under high-emission scenarios (SSP8.5). Without substantial innovation, efficiency gains, or financial support, large-scale surface water investments risk becoming fiscally unsustainable. From a policy perspective, these findings suggest that:

a. National adaptation planning should prioritize groundwater development and protection, while carefully re-evaluating the scale and design of surface water projects.

b. Scaling up recharge systems and groundwater quality monitoring should be prioritised to ensure a reliable supply under climate stress.

c. Sustainable groundwater abstraction practices should be enforced using regulations.

d. Integrated strategies that promote water-use efficiency, demand-side management, and ecosystem-based solutions will be essential in reducing the fiscal burden of surface water systems.

Beyond market metrics, water sector adaptation generates critical non-market benefits. These include:

a. Public health gains, through improved access to safe drinking water and reduced incidence of waterborne diseases.

b. Resilience of livelihoods, particularly for urban populations and industries reliant on secure water supply.

c. Gender equity, as reduced time spent by women and girls in water collection enhances educational and economic opportunities.

d. Ecosystem services, including aquifer recharge, watershed protection, and enhanced biodiversity associated with well-managed water resources.

e. Disaster risk reduction, as investments in resilient infrastructure and groundwater buffering mitigate drought and flood impacts.

These non-market co-benefits strengthen the case for water sector adaptation, even where financial returns appear modest (e.g., surface water under SSP8.5).

For national adaptation planning, the water sector must be seen not only as a cost–benefit calculation but as a strategic enabler of human development, public health, and climate resilience. Balancing investment between groundwater expansion, surface water efficiency improvements, and ecosystem-based measures will ensure long-term sustainability.

7. HEALTH SECTOR

7.1. Background

Ghana's health sector is fundamental to the nation's human development, economic productivity, and social equity, delivering essential services that protect public health, manage disease outbreaks, and support vulnerable populations. However, this sector is increasingly strained by climate change, which exacerbates direct and indirect health impacts through rising temperatures, erratic rainfall, and extreme weather events, leading to increased burdens of vector-borne diseases like malaria, waterborne illnesses such as diarrhea, and respiratory conditions[36][37]. These climate-induced risks are amplified by factors such as inadequate surveillance systems, limited institutional coordination, and vulnerabilities among women, children, and rural communities, who bear a disproportionate share of the health consequences[38].

To mitigate these challenges, the "Health National Adaptation Plan (HNAP) for Climate Change in Ghana," developed under the National Adaptation Plan (NAP) framework, outlines strategies to build climate-resilient health systems and address gaps in adaptive capacity. This HNAP is a core element of the broader NAP project, "Enhancing multi-sector planning and capacity for effective adaptation in Ghana," led by the Ghana Environmental Protection Agency under the Ministry of Environment, Science, Technology, and Innovation (MESTI), with support from the Green Climate Fund (GCF). Key interventions focus on leadership and governance, integrated surveillance, capacity building, and resilient infrastructure to safeguard health outcomes amid climate variability.

Implementing these adaptation measures requires considerable financial resources, making a rigorous economic appraisal essential to evaluate their viability and optimize resource allocation. This document introduces the economic appraisal of adaptation options for Ghana's health sector, aiming to develop a methodology for assessing the costs and benefits of these strategies. The appraisal seeks to integrate climate-resilient health planning into national policies and budgeting processes, while establishing sustainable financing mechanisms to enhance long-term resilience.

The appraisal draws on the adaptation options detailed in the "Health National Adaptation Plan (HNAP) for Climate Change in Ghana." For instance, establishing multi-sectoral steering committees improves coordination on climate-sensitive health outcomes (CSHOs), while revising the Public Health Act (Act 851, 2012) incorporates climate risks to strengthen disease surveillance and response[39]. These interventions involve costs—such as capacity building, monitoring systems, and policy revisions—that must be weighed against their benefits, including reduced disease burdens and improved health equity.

36 Adaptation to climate change in Africa: Plan of action for the health sector 2012-2016
37 Intergovernmental Panel on Climate Change. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fifth Assessment Report. Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-FrontMatterA_FINAL.pdf
38 United Nations Framework Convention on Climate Change. (2015). Paris Agreement. parisagreement_publication.pdf
39 Adaptation to climate change in Africa: Plan of action for the health sector 2012-2016

Leveraging existing research, such as WHO estimates on climate-related deaths[40] and Ghana's vulnerability assessments[41], this appraisal employs a reliable analytical approach to quantify costs and benefits, assess trade-offs, and explore future scenarios. The methodology, detailed in the following section, combines economic tools and dynamic modeling to provide decision-makers with evidence-based insights for prioritizing adaptation options. These insights ensure that limited resources target interventions with the greatest potential impact, aligning with the NAP project's objectives of multi-sectoral, medium- to long-term planning.The subsequent sections will outline the methodology, present the economic analysis of selected adaptation options, and offer recommendations to guide Ghana's efforts to adapt to a changing climate.

7.2. Model Description

The health sector methodology applies the general system dynamics and cost–benefit framework (see GENERAL METHODOLOGY) to analyze adaptation options that protect public health under climate change. The focus is on climate-sensitive diseases, health surveillance, and mortality/morbidity associated with extreme weather events. The model links environmental exposures (temperature, flooding, water quality) to health outcomes (vector-borne diseases, heat-related mortality, waterborne illnesses). The stock-and-flow diagram (Figure 22) illustrates the progression from climate drivers to health risks and the mitigating effects of adaptation actions.

7.2.1. Systems Dynamics Model Structure

The health sub-model consists of stocks representing population exposure, health system capacity, and disease incidence. Flows include new infections, mortality, treatment, and the expansion of surveillance coverage. Adaptation interventions—such as strengthening disease surveillance, public health campaigns, and infrastructure upgrades—are parameterized to reduce exposure or improve response capacity.

7.2.2. Data and Parameters

Baseline health data were drawn from the Ghana Health Service[42] , WHO databases, and EPA[43]. Climate-health exposure-response parameters were taken from peer-reviewed epidemiological studies in West Africa. Cost parameters reflect national budgets for disease surveillance and international cost estimates for climate-health interventions.

As summarized in Table 16, several M&R indicators are directly aligned with model variables, including number of functional disease surveillance sites (surveillance_sites), incidence of malaria (malaria_incidence_rate), and heat-related mortality (heat_mortality). Others, such as cholera incidence in flood-prone

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40 World Health Organization. (2015). Operational framework for building climate resilient health systems. https://www.who.int/publications/i/item/9789241565073

41 Environmental Protection Agency. (2008). National climate change vulnerability and adaptation assessment.

42 Ghana Health Service. (2020). *Annual Health Sector Performance Report.*

43 Environmental Protection Agency (EPA). (2022). *Ghana's National Adaptation Plan Framework.* napgn-en-2018-ghana-nap-framework.pdf

areas, are partially aligned via broader proxies (waterborne_disease_index), while governance-oriented indicators (e.g., awareness campaigns) remain outside the model boundary.

Table 16. Health Sector – Indicator to Model Alignment

Indicator (M&R)	Closest Model Variable	Alignment Status	Notes
Number of functional disease surveillance sites	surveillance_sites	Match	Directly aligned.
Incidence of malaria	malaria_incidence_rate	Match	Directly aligned.
Heat-related mortality	heat_mortality	Match	Directly aligned.
Cholera incidence in flood-prone areas	cholera_incidence	Partial	Proxy variable, combined into waterborne_disease_index.
Number of awareness campaigns on climate-health risks	*No direct variable*	Unmatched	Awareness/governance indicator.

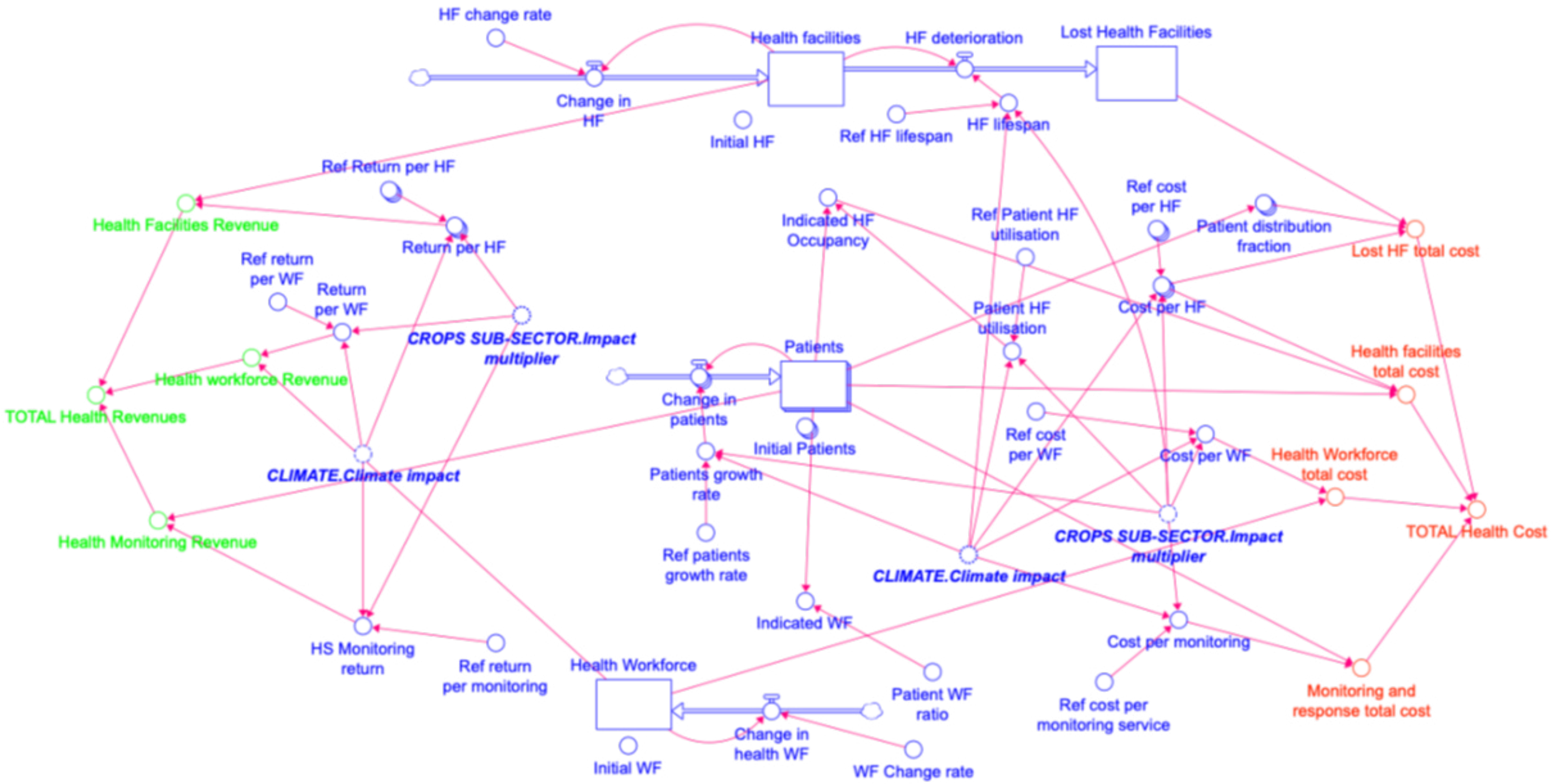
M&R targets guided calibration of surveillance expansion and reductions in malaria incidence, while heat mortality projections were benchmarked against climate scenarios.

The following assumptions underpin the health sector analysis:

1. Indicator alignment: Direct matches (malaria incidence, heat mortality, surveillance sites) are used directly; partial matches (cholera incidence) rely on proxy indices.
2. Proxy use: The waterborne_disease_index is assumed to reasonably approximate incidence of diarrheal and cholera outbreaks in flood-prone areas.
3. Population growth: Baseline health risks scale with population projections to 2040, unless mitigated by interventions.
4. Climate-health linkages: Heat mortality is modelled as a linear function of extreme temperature days; malaria incidence responds to rainfall/temperature thresholds consistent with WHO studies[44].
5. Costs: Include surveillance system investment, health infrastructure, and campaign expenditures; broader health system spillovers are excluded.

44 World Health Organization (WHO). (2016). *Climate Change and Human Health.* https://www.who.int/globalchange/publications

Figure 22. Health Sector Stock-and-Flow Structure



The health sub-model focuses on climate-sensitive diseases and extreme heat impacts. Stocks include disease incidence pools, surveillance system capacity, and population exposure. Flows represent infection rates, mortality, recovery, and expansion of surveillance coverage. Adaptation actions—strengthening surveillance, health campaigns, and resilient infrastructure—modify these flows to reduce vulnerability.

7.2.3. Analytical Approach

The model simulates health outcomes under baseline and adaptation scenarios to 2040. Outputs include incidence curves for malaria and cholera, heat mortality rates, and number of functional surveillance sites. Cost–benefit appraisal of adaptation bundles was conducted using NPV, BCR, and IRR at a 5% discount rate.

Sensitivity analysis tested variations in climate exposure intensity and health system response effectiveness. Results should be interpreted with high confidence for indicators directly aligned with model variables (malaria incidence, surveillance sites, heat mortality). Proxies such as cholera incidence should be viewed as indicative, not exact. Governance and awareness indicators remain outside the quantitative scope and should be evaluated through complementary qualitative assessment.

7.3. Proposed and Costed Adaptation Bundle for the Health Sector

The Health National Adaptation Action Plan framework is structured across 10 thematic areas covering leadership and governance, workforce development, financing, infrastructure, vulnerability assessment, management of health outcomes, risk monitoring, emergency preparedness, environmental health, and monitoring progress. Within these areas, a total of 182 adaptation actions have been identified. As highlighted in the General Introduction and Methodology, the appraisal adopts a bundled adaptation approach rather than assessing individual actions in isolation as discussed in the following section.

7.3.1. Costed Adaptation Bundle

As outlined in the Methodology, adaptation options are bundled to leverage synergies, address multiple vulnerabilities, and maximize co-benefits across health, social, and economic dimensions. In the health sector, adaptation measures were organised into three coherent bundles: Health Facilities, Health Workforce, and Monitoring and Response Systems. These bundles capture both hard and soft measures, ranging from infrastructure retrofitting and renewable energy integration to workforce training, institutional strengthening, and digital monitoring systems. The design of these bundles reflects a systems-based approach to building a climate-resilient health system, where infrastructure, human capacity, and information systems reinforce one another. These synergies are evident in the following examples:

a. **Upgrading Health Facilities and Workforce Training (Health Facilities and Workforce):** Retrofitting health facilities to withstand floods and heatwaves ensures operational continuity during climate events, while training health workers on climate-health risks enhances their ability to deliver care in these resilient facilities. For instance, solar-powered systems in facilities ensure reliable power for vaccine storage, complementing workforce training on managing heat-sensitive diseases like cholera.

b. **Climate-Health Database and M&E Framework (Monitoring and Response Systems):** Developing an operational climate-health database supports the mainstreaming of HNAP indicators into DHIMS2, enabling real-time tracking of climate-related health trends (e.g., malaria outbreaks during floods). This data informs evidence-based responses, amplifying the effectiveness of workforce training and facility upgrades by ensuring resources are targeted to high-risk areas.

c. **Reporting Structures and Digital Tools (Monitoring and Response Systems):** Establishing clear reporting structures at sectoral, national, and international levels (e.g., for UNFCCC compliance) works synergistically with digital tools for M&E. Real-time monitoring systems, such as mobile apps for disease surveillance, enhance the timeliness and accuracy of reports, which in turn guide adaptive healthcare policies and interventions.

Table 17. Summary of Adaptation Options for the Health Sector

Subsector	Key Adaptation Actions
Health Facilities	• Upgrade health facilities to climate-resilient standards (e.g., flood-proofing, heat-resistant designs) • Integrate climate risk assessments into facility planning and maintenance • Enhance energy reliability through solar-powered systems for critical operations • Retrofit existing facilities to withstand extreme weather events
Health Workforce	• Conduct gender-sensitive training on climate-health risks (e.g., heat stress, vector-borne diseases) • Build capacity for emergency response to climate-induced health crises • Increase recruitment and deployment of health workers in climate-vulnerable areas • Develop training modules on climate-adaptive healthcare delivery
Monitoring and Response Systems	• Develop a comprehensive HNAP M&E framework with climate-health indicators • Mainstream HNAP indicators into DHIMS2 and health M&E systems • Create and maintain an operational climate-health database • Establish reporting structures for sectoral, national, and international levels • Adopt digital tools for real-time monitoring of climate-health risks - Strengthen institutional capacity for M&E through training

7.4. Results and Discussion

The health sector was assessed across three areas: **Facilities, Workforce, and Monitoring**, under three climate scenarios: **Baseline (business-as-usual with adaptation), SSP4.5**, and **SSP8.5.** Results are expressed in monetary terms (USD, billions) for the period **2015–2040**, covering both annual trajectories and economic efficiency indicators, namely **Benefit-Cost Ratios (BCRs), Net Present Values (NPVs), and Internal Rates of Return (IRR)** (Table 14).

The analysis demonstrates that investment in the health sector generates substantial economic and social value, with particularly high returns from facilities expansion and health monitoring systems. However, workforce-related adaptation becomes increasingly vulnerable under high-emission scenarios, where costs begin to outpace benefits. This reflects broader global findings that climate change significantly compounds health system burdens, including infrastructure damage, higher treatment costs, and increased demand for services due to climate-sensitive diseases[45][46]. Table 14 provides a snapshot of the economic appraisal across the adaptation bundles and climate scenarios for some key years (2015, 2030 and 2040). The sections that follow give a detailed description of the results and provide recommendations based on the same.

Table 18. Health Sector Results Summary – Revenues, Costs, Net Benefits, and Benefit-Cost Ratios (BCR) by Sub-sector, Scenario, and Year (2015–2040)

Subsector	Scenario	Year	Revenue (Million USD)	Cost (Million USD)	Net Benefit (Million USD)	BCR	Cost per USD Revenue	Cost CAGR (2015-2040)	Rev CAGR (2015-2040)
Facilities	Baseline	2015	2,100.00	579.00	1,521.00	3.63	$0	3.70%	5.20%
Facilities	Baseline	2030	4,500.00	993.00	3,507.00	4.53	$0	3.70%	5.20%
Facilities	Baseline	2040	7,460.00	1,420.00	6,040.00	5.25	$0	3.70%	5.20%
Facilities	SSP4.5	2015	1,680.00	791.00	889.00	2.12	$0	4.90%	3.90%
Facilities	SSP4.5	2030	2,970.00	1,620.00	1,350.00	1.83	$1	4.90%	3.90%
Facilities	SSP4.5	2040	4,350.00	2,600.00	1,750.00	1.67	$1	4.90%	3.90%
Facilities	SSP8.5	2015	1,520.00	900.00	620.00	1.69	$1	5.60%	2.80%
Facilities	SSP8.5	2030	2,270.00	2,080.00	190.00	1.09	$1	5.60%	2.80%

45 WHO, UNFCCC, partners. *Guidance to Protect Health from Climate Change Through Health Adaptation Planning (HealthNAP).* https://climateandhealthalliance.org/wp-content/uploads/2018/02/1529-Health-National-Adaptation-Process-121113.pdf

46 Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2022: Impacts, Adaptation and Vulnerability—Summary for Policymakers.* https://www.ipcc.ch/report/ar6/wg2/chapter/summary-for-policymakers

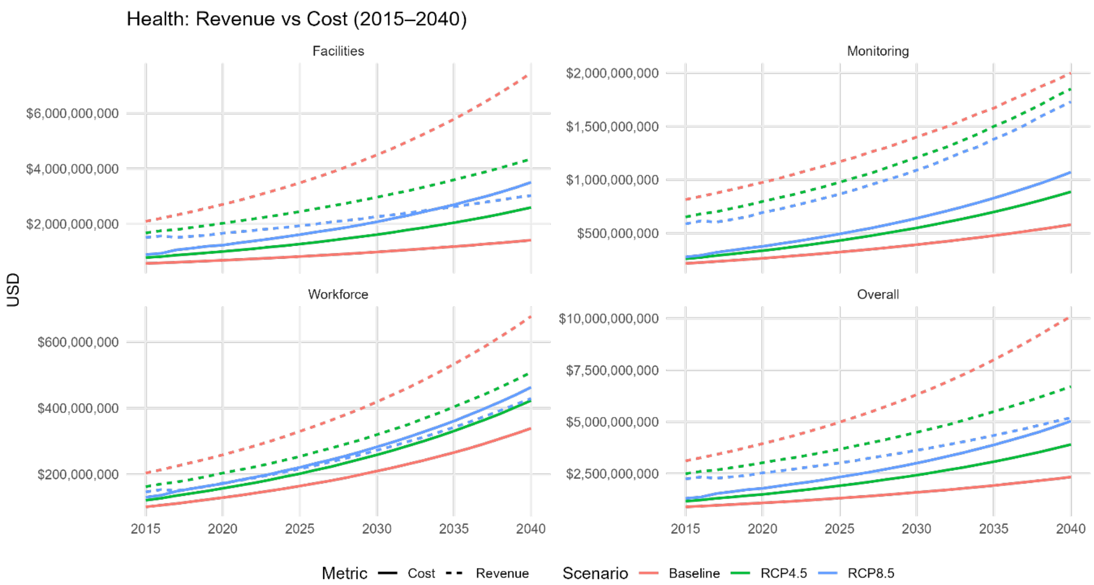
Facilities	SSP8.5	2040	3,030.00	3,510.00	–$480.00	0.86	$1	5.60%	2.80%
Monitoring	Baseline	2015	815.00	217.00	598.00	3.76	$0	4.00%	3.70%
Monitoring	Baseline	2030	1,400.00	393.00	1,007.00	3.56	$0	4.00%	3.70%
Monitoring	Baseline	2040	2,000.00	579.80	1,420.20	3.45	$0	4.00%	3.70%
Monitoring	SSP4.5	2015	652.00	261.00	391.00	2.50	$0	5.00%	4.30%
Monitoring	SSP4.5	2030	1,210.00	549.50	660.50	2.20	$0	5.00%	4.30%
Monitoring	SSP4.5	2040	1,850.00	887.30	962.70	2.08	$0	5.00%	4.30%
Monitoring	SSP8.5	2015	587.00	278.00	309.00	2.11	$0	5.50%	4.40%
Monitoring	SSP8.5	2030	1,090.00	639.60	450.40	1.70	$1	5.50%	4.40%
Monitoring	SSP8.5	2040	1,730.00	1,071.10	658.90	1.62	$1	5.50%	4.40%
Workforce	Baseline	2015	204.00	102.00	102.00	2.00	$0	4.90%	4.90%
Workforce	Baseline	2030	419.00	210.00	209.00	2.00	$1	4.90%	4.90%
Workforce	Baseline	2040	677.00	339.00	338.00	2.00	$1	4.90%	4.90%
Workforce	SSP4.5	2015	163.00	122.00	41.00	1.34	$1	5.10%	4.70%
Workforce	SSP4.5	2030	320.00	259.00	61.00	1.24	$1	5.10%	4.70%
Workforce	SSP4.5	2040	508.00	423.00	85.00	1.20	$1	5.10%	4.70%
Workforce	SSP8.5	2015	147.00	131.00	16.00	1.12	$1	5.20%	4.40%
Workforce	SSP8.5	2030	273.00	283.00	–$10.00	0.96	$1	5.20%	4.40%
Workforce	SSP8.5	2040	429.00	463.00	–$34.00	0.93	$1	5.20%	4.40%
Overall	Baseline	2015	3,120.00	898.00	2,222.00	3.47	$0	3.90%	4.80%
Overall	Baseline	2030	6,320.00	1,600.00	4,720.00	3.95	$0	3.90%	4.80%
Overall	Baseline	2040	10,100.00	2,340.00	7,760.00	4.32	$0	3.90%	4.80%
Overall	SSP4.5	2015	2,500.00	1,170.00	1,330.00	2.14	$0	4.90%	4.00%
Overall	SSP4.5	2030	4,500.00	2,430.00	2,070.00	1.85	$1	4.90%	4.00%
Overall	SSP4.5	2040	6,710.00	3,910.00	2,800.00	1.72	$1	4.90%	4.00%
Overall	SSP8.5	2015	2,250.00	1,310.00	940.00	1.72	$1	5.50%	3.40%
Overall	SSP8.5	2030	3,630.00	3,010.00	620.00	1.21	$1	5.50%	3.40%

Overall	SSP8.5	2040	5,200.00	5,040.00	160.00	1.03	$1	5.50%	3.40%

7.4.1. Revenue and Cost Trends

Adaptation revenues and costs in the health sector grow steadily between 2015 and 2040, though the balance between the two varies across subsectors and scenarios (Figure 14). Facilities emerge as a key driver, with revenues, reflecting avoided service disruption and sustained care delivery, rising more rapidly than costs under the Baseline and SSP4.5 scenarios. However, under SSP8.5, the sharp escalation of capital and operational expenditures significantly reduces the margin between revenues and costs, underscoring the vulnerability of physical infrastructure to severe climate impacts. Monitoring and response systems, which include investments in disease surveillance, outbreak management, and early warning mechanisms, demonstrate consistently positive returns across all scenarios, as costs remain modest relative to benefits.

Figure 23. Revenue and cost trends in the health sector (2015–2040), disaggregated by subsector (Facilities, Workforce, Monitoring and Response, and Overall) under Baseline, SSP4.5, and SSP8.5 scenarios.

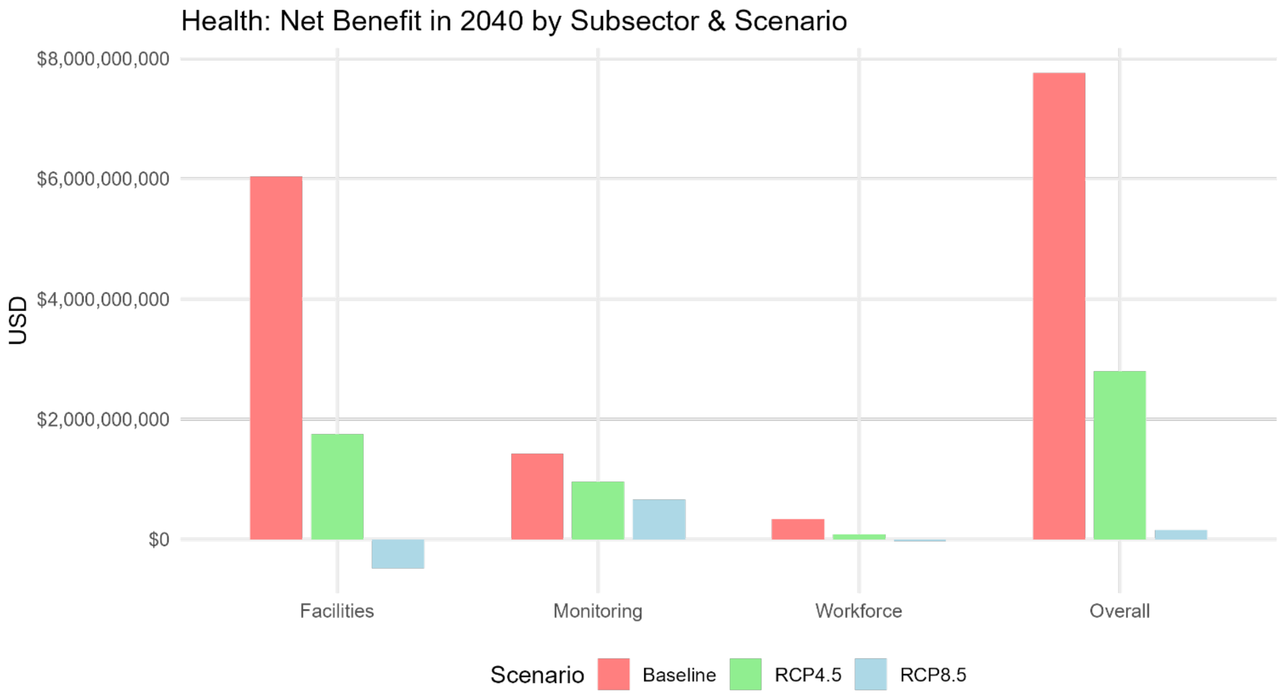


In contrast, workforce-related adaptation, while generating growing revenues through improved service delivery and reduced productivity losses, experiences a narrowing revenue, cost gap under SSP8.5, as training, deployment, and surge-capacity costs rise sharply. When viewed in aggregate, the sector shows its strongest balance of revenues and costs under the Baseline scenario, followed by moderate margins under SSP4.5 and increasingly tight viability under SSP8.5. These dynamics highlight the dual challenge for the health sector: securing adequate adaptation investments while managing the mounting costs imposed by climate change, thereby emphasizing the need for cost-efficient strategies such as preventive health measures, integrated service delivery, and climate-resilient infrastructure design.

7.4.2. Net Benefits in 2040

The distribution of net benefits in 2040 highlights the varying resilience of health subsectors under different climate scenarios (Figure 15). Facilities generate substantial positive net benefits under both the Baseline and SSP4.5 scenarios, confirming the strong economic case for investing in resilient health infrastructure.

Figure 24. Net benefits in 2040 across health subsectors and climate scenarios (Baseline, SSP4.5, SSP8.5).



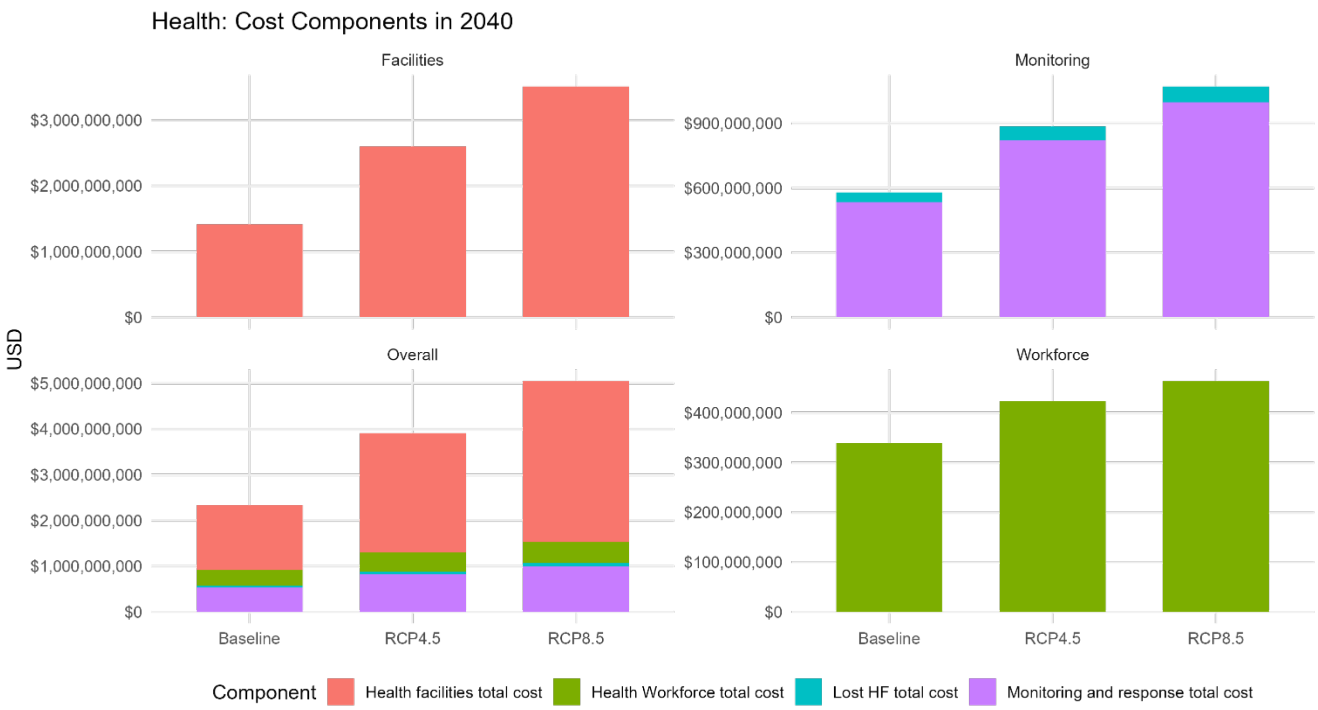
However, under SSP8.5, the sharp rise in costs relative to revenues significantly reduces net benefits, indicating that infrastructure adaptation becomes less viable in more severe climate futures unless complemented by efficiency-enhancing innovations.

Monitoring and response systems, in contrast, consistently deliver positive net benefits across all scenarios, demonstrating their robustness even under high-emission pathways. This underscores the value of preventive and surveillance-based measures, which provide cost-effective protection against climate-sensitive diseases and health emergencies. Workforce adaptation presents a more mixed picture: while net benefits are positive under the Baseline and SSP4.5 scenarios, they diminish under SSP8.5 as personnel-related costs outpace revenues. At the sectoral level, the analysis suggests that while facilities and monitoring remain the strongest pillars of adaptation in 2040, workforce investments will require complementary policies, such as technology-assisted service delivery and targeted subsidies, to sustain their economic viability under severe climate stress.

7.4.3. Cost Composition in 2040

The composition of adaptation costs in 2040 reveals the specific expenditure drivers within the health sector (Figure 16). For facilities, the bulk of costs are concentrated in capital investments for climate-resilient infrastructure, including the upgrading of hospitals and clinics to withstand extreme weather events and ensure continuity of service delivery. Workforce-related costs are dominated by training, recruitment, and deployment of health personnel, reflecting the need to expand service capacity in response to growing climate-sensitive health burdens. Monitoring and response systems account for a smaller but strategically vital share of total costs, with expenditures directed toward disease surveillance networks, outbreak management systems, and public health preparedness. When viewed across scenarios, Baseline and SSP4.5 maintain a relatively balanced cost structure, while under SSP8.5 the disproportionate escalation of facility and workforce costs significantly increases the overall burden, narrowing the space for efficient allocation of resources.

Figure 25. Composition of adaptation costs in 2040, showing expenditure distribution across facilities, workforce, and monitoring and response systems.



These patterns suggest that cost pressures in the health sector are heavily shaped by infrastructure and human resource needs, pointing to the importance of adopting innovative financing strategies, integrated health planning, and technology-enabled service models to optimize adaptation expenditure.

7.4.4. Efficiency Metrics

The economic appraisal of health sector adaptation, summarized in Table 14 and the BCR–IRR analysis (Table 15), provides deeper insight into the viability of investments across subsectors and scenarios. Overall, the sector demonstrates strong efficiency under the Baseline and SSP4.5 scenarios, with benefit–cost ratios (BCRs) comfortably above unity. Facilities consistently achieve favorable BCRs, reflecting the high economic and social value of resilient infrastructure that safeguards health service delivery and reduces long-term treatment costs. Monitoring and response systems exhibit exceptionally strong returns, with BCRs far exceeding those of other subsectors across all scenarios, highlighting the cost-effectiveness of preventive health interventions and early-warning systems. The workforce subsector, however, presents more mixed results. While it remains economically viable under Baseline and SSP4.5 with positive BCRs, its efficiency declines sharply in SSP8.5, where escalating training and personnel costs outpace projected revenues.

Table 19. Efficiency analysis of health sector adaptation, showing undiscounted and discounted (5%) BCRs, present values, and internal rates of return (IRR) by subsector and scenario.

Subsector	Scenario	Undisc. Benefits (Million USD)	Undisc. Costs (Million USD)	BCR (Undisc.)	PV Benefits @5% (Million USD)	PV Costs @5% (Million USD)	BCR (5% Disc.)	IRR (%)*
Facilities	Baseline	110,610.00	24,471.00	4.52	55,987.78	12,886.39	4.34	NA
Facilities	SSP4.5	73,130.00	39,844.00	1.84	38,284.50	20,348.15	1.88	NA
Facilities	SSP8.5	55,990.00	51,293.00	1.09	30,017.59	25,846.74	1.16	–8.4
Monitoring	Baseline	34,472.00	9,661.28	3.57	18,151.64	5,042.82	3.6	NA
Monitoring	SSP4.5	29,779.00	13,477.45	2.21	15,425.01	6,857.65	2.25	NA
Monitoring	SSP8.5	26,955.00	15,673.72	1.72	13,847.18	7,887.89	1.76	NA
Workforce	Baseline	10,301.00	5,153.00	2	5,251.18	2,626.90	2	NA
Workforce	SSP4.5	7,884.00	6,358.00	1.24	4,044.03	3,228.18	1.25	NA
Workforce	SSP8.5	6,717.00	6,944.00	0.97	3,455.22	3,524.25	0.98	12
Overall	Baseline	155,340.00	39,292.00	3.95	79,376.16	20,560.44	3.86	NA
Overall	SSP4.5	110,780.00	59,700.00	1.86	57,745.71	30,446.36	1.9	NA
Overall	SSP8.5	89,680.00	73,920.00	1.21	47,332.33	37,265.45	1.27	NA

Note: NA values in the IRR column indicate cases where no real Internal Rate of Return could be calculated, typically due to all cash flows being of the same sign or the occurrence of multiple sign changes, rendering IRR undefined.

The discounted efficiency metrics at a 5% rate reaffirm these patterns, showing that while net present benefits remain strongly positive for facilities and monitoring, workforce adaptation becomes marginal under severe climate futures. This suggests that targeted strategies, such as leveraging digital health technologies, optimizing staff deployment, and integrating task-shifting approaches, will be crucial to maintain workforce sustainability. At the aggregate level, the analysis demonstrates that health adaptation is a sound investment, but its efficiency is uneven across subsectors and is highly sensitive to the intensity of climate change impacts.

7.5. Conclusion

The analysis of the health sector confirms that climate adaptation generates significant economic and social value, though the scale and distribution of benefits vary across subsectors and scenarios. Facilities and monitoring systems emerge as the most resilient investment areas, delivering consistent net benefits and strong efficiency metrics even under high-emission pathways. Workforce adaptation, while critical for sustaining service delivery, is more vulnerable to rising costs under severe climate futures and will require targeted policy support to remain viable.

Beyond market-based outcomes, the health sector delivers extensive non-market benefits that reinforce its central role in national adaptation planning. These include improved population health outcomes, reduced morbidity and mortality from climate-sensitive diseases, strengthened community resilience to disasters, and enhanced public trust in the health system. Investments in facilities contribute to broader social stability by ensuring continuous access to essential care, even during crises. Workforce development provides indirect benefits in the form of employment, capacity building, and gender equity in the health labor force. Monitoring and response systems reduce the societal costs of disease outbreaks and support evidence-based policymaking for public health. Drawing on the above analysis, the following policy recommendations are proposed:

a. Investments in climate-resilient hospitals and clinics yield high returns by safeguarding service delivery and reducing disease burden. Policy should accelerate facility retrofitting and climate-proof design.

b. Surveillance and early warning provide consistently high BCRs, making them a priority for cost-effective adaptation.

c. While vulnerable under high emissions, workforce investments remain key. Policy should leverage digital health, training innovations, and task-shifting to reduce costs.

d. Mainstream health into national adaptation planning. Position the health sector as a cross-cutting enabler of resilience across agriculture, water, and ecosystems.

The health sector's role as an enabler of resilience in other sectors must not be overlooked. For national adaptation planning, health must be positioned as a cross-cutting priority, with policy interventions that not only secure direct economic returns but also safeguard human well-being and social stability in the face of a changing climate.

8. CITIES

8.1. Background

Ghana's cities and disaster risk reduction (DRR) sector are vital to the nation's economic growth, social stability, and urban development, serving as hubs for population growth, commerce, and infrastructure. However, these urban areas face escalating threats from climate change, including rising sea levels, intense rainfall leading to flooding, extreme heat, and drought, which disproportionately affect vulnerable communities in slums and informal settlements[47][48]. These climate risks are compounded by rapid urbanization, inadequate drainage systems, and poor sanitation, exacerbating public health challenges and disrupting livelihoods, particularly for women, youth, and marginalized groups[49].

To address these vulnerabilities, the "Climate Change Adaptation Action Plan for the Cities and Disaster Risk Reduction Sector in Ghana," developed under the National Adaptation Plan (NAP) framework, proposes a range of adaptation strategies to enhance urban resilience and disaster preparedness. This action plan is a key component of the broader NAP project, "Enhancing multi-sector planning and capacity for effective adaptation in Ghana," led by the Ghana Environmental Protection Agency under the Ministry of Environment, Science, Technology, and Innovation (MESTI), with support from the Green Climate Fund (GCF) and UN Environment. Proposed interventions, such as flood risk management, climate-resilient housing, and ecosystem-based adaptation, aim to mitigate climate impacts while fostering inclusive urban development.

Implementing these adaptation measures requires substantial financial investment, necessitating a thorough economic appraisal to evaluate their feasibility and guide resource allocation. This section introduces the economic appraisal of adaptation options for Ghana's cities and DRR sector, with the primary goal of developing a methodology to assess the costs and benefits of these strategies. The appraisal seeks to integrate climate adaptation and disaster risk reduction into urban planning and policy frameworks, while identifying sustainable financing mechanisms to support long-term resilience.

The appraisal builds on the adaptation options outlined in the "Climate Change Adaptation Action Plan for the Cities and Disaster Risk Reduction Sector in Ghana." For example, upgrading drainage systems in Accra reduces flood damage and protects vital infrastructure[50] while resilient housing in coastal cities like Keta mitigates

47 Appeaning Addo, K., Walkden, M., & Mills, J. P. (2018). Detection, measurement, and prediction of shoreline recession in Accra, Ghana. Ocean & Coastal Management, 152, 101–109. https://ui.adsabs.harvard.edu/link_gateway/2008JPRS...63..543A/doi:10.1016/j.isprsjprs.2008.04.001

48 Damte, E., Manteaw, B. O., & Wrigley-Asante, C. (2023). Urbanization, climate change and health vulnerabilities in slum communities in Ghana. The Journal of Climate Change and Health, 10, 100189. https://doi.org/10.1016/j.joclim.2022.100189

49 Wemegah, C. S., Yamba, E. I., Aryee, J. N., Sam, F., & Amekudzi, L. K. (2020). Assessment of urban heat island warming in the greater Accra region. Scientific African, 8, e00426. https://doi.org/10.1016/j.sciaf.2020.e00426

50 Karley, N. K. (2009). Flooding and physical planning in urban areas in West Africa: Situational analysis of Accra, Ghana. Theoretical and Empirical Researches in Urban Management, 4(13), 25–41.

sea level rise impacts[51]. These interventions involve costs—such as infrastructure upgrades, community training, and early warning systems—that must be balanced against their economic and social returns.

Drawing on existing research on urban health vulnerabilities[52] and on coastal flooding[53], this appraisal employs a strong analytical approach to quantify costs and benefits, assess trade-offs, and explore future scenarios. The methodology, detailed in the following section, leverages economic tools and dynamic modeling to provide decision-makers with evidence-based insights for prioritizing adaptation options. These insights ensure that limited resources target interventions with the greatest potential impact, aligning with the NAP project's objectives of multi-sectoral, medium- to long-term planning. The subsequent sections will outline the methodology, present the economic analysis of selected adaptation options, and offer recommendations to guide Ghana's efforts to build climate-resilient cities and communities.

8.2. Model Description

The cities sector methodology extends the general system dynamics and cost–benefit framework (see GENERAL METHODOLOGY) to urban adaptation. The focus is on infrastructure resilience, housing quality, mobility, drainage, and green infrastructure. Urban systems are particularly vulnerable to flooding, heat, and service disruptions under climate change. The modelling framework captures how investments in resilient housing, transport systems, and drainage influence urban resilience and quality of life. The stock-and-flow diagram (Figure 26) illustrates the causal links between adaptation measures, infrastructure capacity, and reduced vulnerability of urban households.

8.2.1. Systems Dynamics Model Structure

The Cities sub-model conceptualizes urban resilience through stocks of infrastructure (housing, drainage, transport) and urban ecosystem services (green infrastructure). Flows represent expansion or degradation of these stocks, influenced by adaptation interventions such as drainage construction, housing upgrades, and establishment of urban green spaces.

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51 Roy, P., Pal, S. C., Chakrabortty, R., Chowdhuri, I., Saha, A., & Shit, M. (2023). Effects of climate change and sea-level rise on coastal habitat: Vulnerability assessment, adaptation strategies and policy recommendations. Journal of Environmental Management, 330, 117187. https://doi.org/10.1016/j.jenvman.2022.117187

52 Damte, E., Manteaw, B. O., & Wrigley-Asante, C. (2023). Urbanization, climate change and health vulnerabilities in slum communities in Ghana. The Journal of Climate Change and Health, 10, 100189. https://doi.org/10.1016/j.joclim.2022.100189

53 Appeaning Addo, K., Walkden, M., & Mills, J. P. (2018). Detection, measurement, and prediction of shoreline recession in Accra, Ghana. Ocean & Coastal Management, 152, 101–109.

8.2.2. Data and Parameters

Baseline data were sourced from the Ministry of Works and Housing, Ghana Statistical Service, and EPA. Urban population, housing stock, and transport statistics informed initial conditions. Cost parameters for drainage and housing upgrades were derived from national infrastructure investment reports and World Bank benchmarks. M&R targets informed calibration for drainage expansion, green infrastructure coverage, and improvements in housing quality indices. As shown in Table 20, some indicators align directly with model variables, such as kilometers of urban drainage constructed (drainage_km) and urban green infrastructure established (urban_green_index). Others, including proportion of households with improved housing and public transport coverage, are partially aligned via proxy indices (housing_quality_index, transport_infra_index). Social indicators such as households relocated from flood-prone areas remain outside the model boundary.

Table 20. Cities Sector – Indicator to Model Alignment

Indicator (M&R)	Closest Model Variable	Alignment Status	Notes
Kilometers of urban drainage constructed	drainage_km	Match	Directly aligned.
Proportion of households with improved housing	housing_quality_index	Partial	Proxy via infrastructure quality score.
Public transport coverage (km of routes)	transport_infra_index	Partial	Proxy variable, aggregate measure of urban transport.
Number of flood-prone households relocated	*No direct variable*	Unmatched	Social relocation not modelled quantitatively.
Urban green infrastructure established (parks, corridors)	urban_green_index	Match	Directly aligned.

Key assumptions for the Cities module include:

1. Indicator alignment: Directly matched infrastructure indicators (drainage length, green infrastructure) are reported quantitatively. Partially aligned indicators (housing quality, transport coverage) are proxied via composite indices.

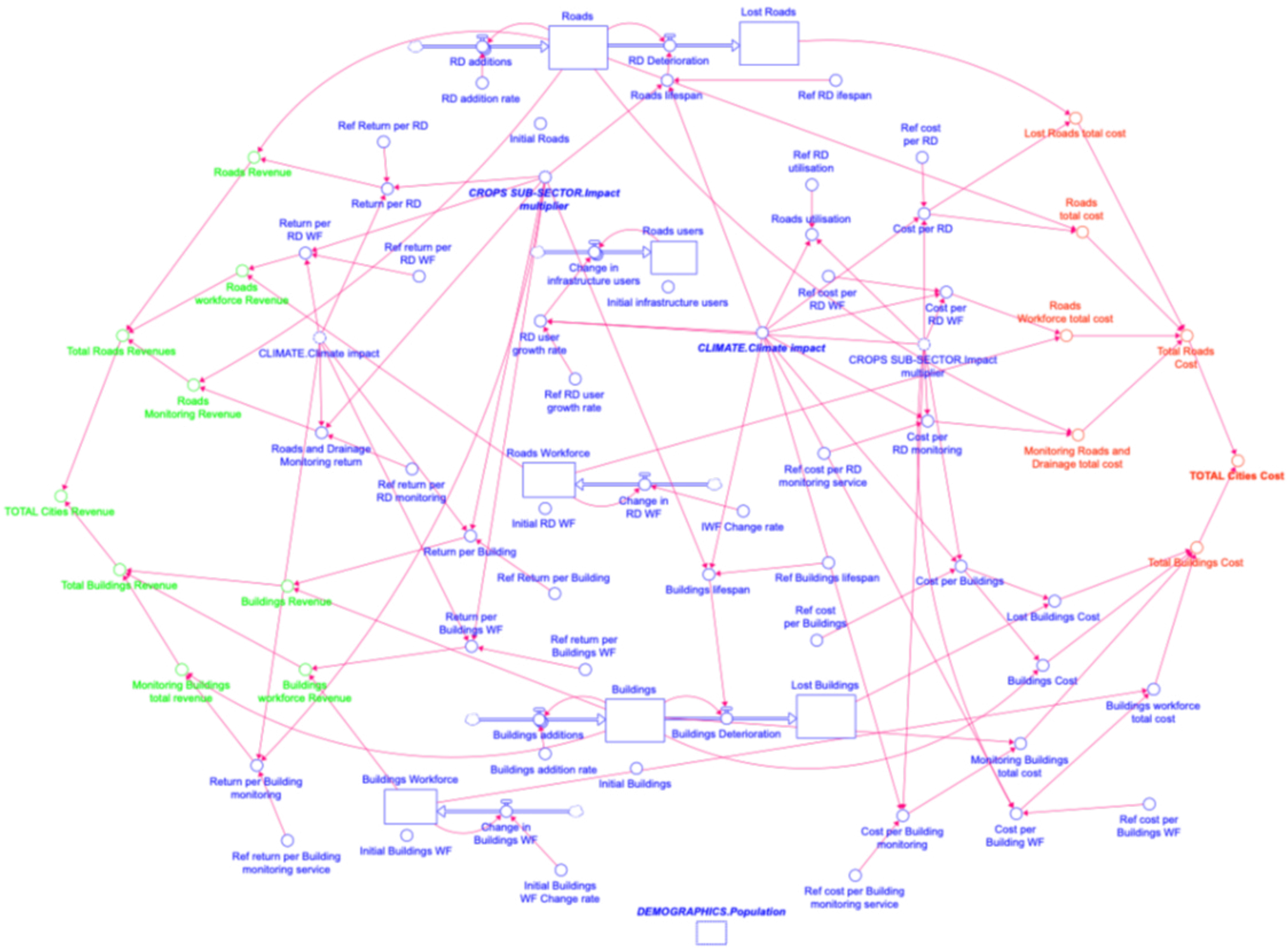
2. Proxy use: Housing quality improvements are assumed to scale with infrastructure investment; transport coverage is captured as an aggregated accessibility index.

3. Unmatched indicators: Relocation of households is not modelled quantitatively, as it requires socio-political and governance data beyond the system dynamics boundary.

4. Drainage function: Drainage expansion is assumed to reduce flood risk proportionally to coverage.

5. Costs: Include construction, maintenance, and upgrading of infrastructure, but exclude broader socio-economic costs of displacement or resettlement.

Figure 26. Cities Sector Stock-and-Flow Structure



The cities model includes two interlinked sub-systems: (i) housing and infrastructure (housing quality, transport infrastructure) and (ii) urban environmental systems (drainage capacity, green infrastructure). Flows include infrastructure degradation, new construction, and greening initiatives. Adaptation measures—such as resilient housing upgrades, public transport improvements, and urban green corridors—enhance urban resilience to floods, heat, and other climate risks.

8.2.3. Analytical Approach

Simulations extended to 2040 under baseline and adaptation pathways. Outputs included trajectories of drainage coverage, housing quality indices, transport infrastructure indices, and urban green space provision. Economic appraisal (NPV, BCR, IRR) was applied at a 5% discount rate. Sensitivity analysis assessed robustness under varying urban population growth and climate hazard intensities (e.g., flood frequency, heat stress). Results are most grounded for directly matched indicators (drainage length, green infrastructure). Outputs for partially aligned indicators (housing quality, transport coverage) should be interpreted as indicative approximations. Social and governance measures (e.g., relocation of households) remain outside the quantitative model and require complementary qualitative assessment. Cross-sectoral synergies are noted, especially with water (stormwater drainage) and biodiversity (urban green infrastructure).

8.3. Adaptation Options for the Cities Sector

The Cities Action Plan for the National Adaptation Plan Framework proposes a comprehensive suite of actions for the Cities sector, spanning multiple thematic areas such as flood risk management, water supply and sanitation, disaster preparedness, resilient housing and infrastructure, sustainable transport, urban food security, ecosystem-based adaptation, and coastal resilience. Altogether, 58 adaptation actions are identified for cities and urban systems organized under 8 Sub-sectors.

As described in the general methodology, the costing analysis adopts a bundled approach. This means actions are grouped into coherent packages that are complementary, reinforcing one another to address interconnected vulnerabilities while maximizing economic, ecological, and social co-benefits. For example, flood risk management measures (e.g., drainage upgrades and early warning systems) are inherently linked to housing and transport resilience, while ecosystem restoration supports both water supply reliability and coastal protection.

Table 21. Summary of Adaptation Options for the Cities Sector

Sub-sector	Adaptation Actions
Urban and Rural Flood Risk Management & Resilience	• Community-based flood risk mapping • Hydrological model development • Flood risk management committees • Zoning regulation enforcement • Drainage system upgrades • Retention basins & green infrastructure • Early warning systems for floods • Community evacuation training & drills

Improving Water Supply & Sanitation in Communities	• Water resource vulnerability assessments • Urban water distribution upgrades • Enforcement against galamsey (illegal mining) • Community-led water source protection • Watershed rehabilitation • Public awareness on sanitation & illegal mining • Housing law enforcement (toilets) • Emergency water storage systems • PPPs for sustainable infrastructure
Strengthened Disaster Preparedness & Emergency Response	• Inclusive vulnerability assessments • Hazard and risk profiles for all districts • Resilient shelters construction • GNFS fire tenders & hydrants • Ambulance services expansion • DRR funds & local committees • Coastal protection & monitoring systems
Climate-Resilient Housing & Infrastructure	• Housing/infrastructure vulnerability assessments • Enforcement of resilient building codes • Retrofitting public buildings • Disaster-resilient housing reconstruction • Zoning enforcement (removal of illegal structures in waterways)
Sustainable Transport Systems for Urban & Rural Mobility	• Transport network vulnerability assessments • Elevated roads & bridges • Road reconstruction with resilient materials • Expanded urban/rural mobility systems • Public transport expansion (bus/train) • Road drainage maintenance • Energy-efficient transport (electric buses)
Drought-Resilient Agricultural Practices & Urban Food Security	• Irrigation, improved seeds, & storage facilities • Drought vulnerability maps & early warning • Small-scale irrigation & reservoirs • Agroforestry & drought-resistant crops • Drought contingency funds • Urban food banks & cold storage hubs • Soil conservation & farmer training
Ecosystem-Based Adaptation (EbA) for Urban & Rural Communities	• Ecosystem vulnerability mapping • Awareness campaigns on EbA • Restoration of degraded ecosystems • Community-led conservation & incentives

Coastal Resilience Against Sea-Level Rise & Erosion	• Coastal protection (sea walls, mangroves, buffer zones) • Resilient coastal building standards • Relocation of vulnerable communities • Coastal defenses construction/maintenance • Research into nature-based solutions • Community awareness & engagement

8.3.1. Costed Adaptation Bundle

For costing purposes, the wide set of urban adaptation actions were consolidated into two primary subsector bundles: Roads (Transport & Mobility) and Buildings (Housing & Infrastructure). This bundling reflects the central role of transport networks and urban infrastructure in driving both the direct and indirect economic costs and benefits of adaptation in Ghana's cities.

Table 22. Costed Adaptation Bundles for the Cities Sector

Sub-sector	Adaptation Actions
Buildings (Housing & Infrastructure)	• Assess vulnerability of existing housing and infrastructure to climate hazards. • Enforce building codes for climate-resilient construction. • Retrofit critical public buildings (schools, hospitals, administrative offices). • Rebuild disaster-affected housing with resilient designs. • Enforce zoning regulations to prevent construction in waterways and flood-prone zones.
Roads (Transport & Mobility)	• Assess vulnerability of transport networks (roads, bridges, drainage) to climate hazards. • Build elevated roads and bridges in flood-prone areas. • Reconstruct damaged roads with climate-resilient materials. • Expand and enhance public transport systems (buses, trains) for resilience and emission reduction. • Maintain and upgrade roadside drainage to reduce flooding. • Introduce energy-efficient and low-emission transport options (e.g., electric buses, charging infrastructure).

The prioritized bundles reflect both their prominence in the national context and the significant role of roads and buildings as "lifeline" systems underpinning urban resilience[54]. Roads are particularly vulnerable to flooding, landslides, and heat extremes, with damages disrupting national connectivity, trade, and emergency response[55]. Buildings, meanwhile, require retrofitting and resilient standards to protect lives and ensure continuity of essential services such as schools and hospitals. Together, these subsectors represent the largest cost drivers for cities, with high potential for compounding benefits across the economy.

54 Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report.* Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

55 United Nations Office for Project Services (UNOPS). (2022). *Ghana: Roadmap for Resilient Infrastructure in a Changing Climate.* Global Center on Adaptation, World Bank, & Government of Ghana. https://gca.org/reports/ghana-roadmap-for-resilient-infrastructure-in-a-changing-climate/

The remaining six subsectors have strong interlinkages with the other sectoral bundles. For example, flood risk management and sanitation are covered by the Water sector through watershed restoration, resilient water supply, and forecasting systems[56]. Disaster preparedness and emergency response is partly internalized under the Health sector's workforce and monitoring bundles, complemented by resilient transport for evacuation. Urban food security links directly to Agriculture bundles such as irrigation, storage, and drought-resistant crops. Finally, EbA and coastal resilience are embedded in the Biodiversity bundles through mangrove restoration, wetland rehabilitation, and coastal green infrastructure, which directly benefit urban and peri-urban communities.

8.4. Results and Discussion

The Cities sector was assessed across two subsectors, Roads and Buildings, under three climate scenarios: Baseline (business-as-usual with adaptation), SSP4.5, and SSP8.5. Results are presented in monetary terms (USD, billions), covering the period 2015–2040. Both annual trajectories and summary efficiency metrics, including Benefit-Cost Ratios (BCRs), Net Present Values (NPVs), and Internal Rates of Return (IRRs) were examined (Table 18).

Table 23. Cities Sector Results Summary – Revenues, Costs, Net Benefits, and Benefit-Cost Ratios (BCR) by Sub-sector, Scenario, and Key Years (2015–2040)

Subsector	Scenario	Year	Revenue (Million USD)	Cost (Million USD)	Net Benefit (Million USD)	BCR	Cost per USD Revenue	Cost CAGR (2015-2040)	Rev CAGR (2015-2040)
Buildings	Baseline	2015	6,760.00	1,710.00	5,050.00	3.95	0	6.30%	5.30%
Buildings	Baseline	2030	14,700.00	4,450.00	10,250.00	3.30	0	6.30%	5.30%
Buildings	Baseline	2040	24,700.00	7,910.00	16,790.00	3.12	0	6.30%	5.30%
Buildings	SSP4.5	2015	5,400.00	2,050.00	3,350.00	2.63	0	6.20%	4.40%
Buildings	SSP4.5	2030	10,300.00	5,340.00	4,960.00	1.93	1	6.20%	4.40%
Buildings	SSP4.5	2040	16,000.00	9,230.00	6,770.00	1.73	1	6.20%	4.40%
Buildings	SSP8.5	2015	4,730.00	2,220.00	2,510.00	2.13	0	6.10%	3.50%
Buildings	SSP8.5	2030	7,790.00	5,780.00	2,010.00	1.35	1	6.10%	3.50%
Buildings	SSP8.5	2040	11,200.00	9,660.00	1,540.00	1.16	1	6.10%	3.50%
Roads	Baseline	2015	8,990.00	3,640.00	5,350.00	2.47	0	4.70%	2.70%
Roads	Baseline	2030	13,500.00	7,630.00	5,870.00	1.77	1	4.70%	2.70%
Roads	Baseline	2040	17,700.00	11,400.00	6,300.00	1.55	1	4.70%	2.70%

56 Intergovernmental Panel on Climate Change (IPCC). (2022b). *Chapter 6: Cities, Settlements and Key Infrastructure.* In *WGII AR6 Report.* https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-6/

Roads	SSP4.5	2015	7,190.00	4,360.00	2,830.00	1.65	1	4.50%	1.50%
Roads	SSP4.5	2030	8,960.00	9,080.00	–120.00	0.99	1	4.50%	1.50%
Roads	SSP4.5	2040	10,400.00	13,000.00	–2,600.00	0.80	1	4.50%	1.50%
Roads	SSP8.5	2015	6,290.00	4,730.00	1,560.00	1.33	1	4.30%	0.20%
Roads	SSP8.5	2030	6,400.00	9,750.00	–3,350.00	0.66	2	4.30%	0.20%
Roads	SSP8.5	2040	6,680.00	13,400.00	–6,720.00	0.50	2	4.30%	0.20%
Overall	Baseline	2015	15,700.00	5,340.00	10,360.00	2.94	0	5.30%	4.10%
Overall	Baseline	2030	28,200.00	12,100.00	16,100.00	2.33	0	5.30%	4.10%
Overall	Baseline	2040	42,400.00	19,300.00	23,100.00	2.20	0	5.30%	4.10%
Overall	SSP4.5	2015	12,600.00	6,410.00	6,190.00	1.97	1	5.10%	3.00%
Overall	SSP4.5	2030	19,300.00	14,400.00	4,900.00	1.34	1	5.10%	3.00%
Overall	SSP4.5	2040	26,400.00	22,300.00	4,100.00	1.18	1	5.10%	3.00%
Overall	SSP8.5	2015	11,000.00	6,950.00	4,050.00	1.58	1	4.90%	2.00%
Overall	SSP8.5	2030	14,200.00	15,500.00	–1,300.00	0.92	1	4.90%	2.00%
Overall	SSP8.5	2040	17,900.00	23,100.00	–5,200.00	0.77	1	4.90%	2.00%

The analysis highlights the centrality of urban infrastructure in Ghana's climate adaptation agenda. Roads are critical to national connectivity, trade, and access to services, while resilient buildings underpin economic activity, public service delivery, and household safety. With Ghana's urban population projected to surpass 65 percent by 2050[57], adaptation investments in cities are pivotal for sustaining economic growth and mitigating climate-related risks such as flooding, heat stress, and infrastructure damage[58].

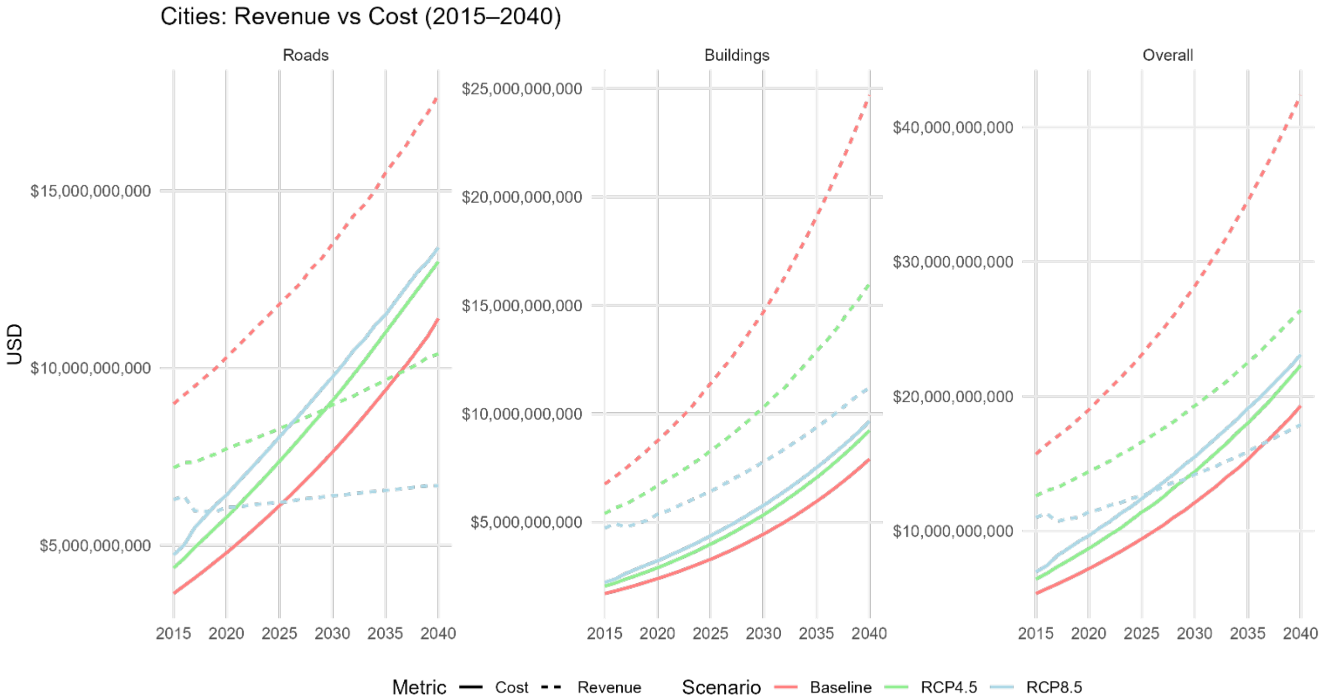
Overall, adaptation in the Cities sector shows increasing revenue and cost trajectories over the analysis period, with significant differences across scenarios. The Baseline scenario demonstrates strong positive net benefits and favorable efficiency metrics, while returns diminish under SSP4.5 and decline further under SSP8.5. These results highlight the sensitivity of urban adaptation outcomes to climate severity and emphasize the need for cost-efficient and innovative strategies in Ghana's urban resilience planning.

57 World Bank. (2022). *Ghana Urbanization Review: Leveraging Urbanization for Economic Growth and Poverty Reduction.* Washington, DC. Open Knowledge Repository
58 Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report.* Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

8.4.1. Revenue and Cost Trends

Figure 17 presents the revenue and cost trajectories for the Cities sector (2015–2040), disaggregated by subsectors (Roads and Buildings) and climate scenarios (Baseline, SSP4.5, and SSP8.5). Both revenues and costs increased steadily over the period, but the magnitude and balance differ by subsector and scenario. Roads dominate the sector, reflecting the extensive investment needs for transport infrastructure, while Buildings exhibit lower but steadily growing adaptation costs and revenues.

Figure 27. Revenue and Cost Trends in the Cities Sector (2015–2040).



In the Baseline scenario, revenues generally outpace costs, indicating strong returns to adaptation in both Roads and Buildings. For SSP4.5, revenues remain positive but are increasingly offset by higher costs, especially in Roads, narrowing the revenue–cost gap until there are deficits by the end of 2040. Similar but more pronounced than the SSP4.5, costs rise sharply in the SSP8.5 scenario, particularly for Roads, outstripping revenues by 2040. For Buildings, revenues plateau while costs escalate, driving net balances into negative territory.

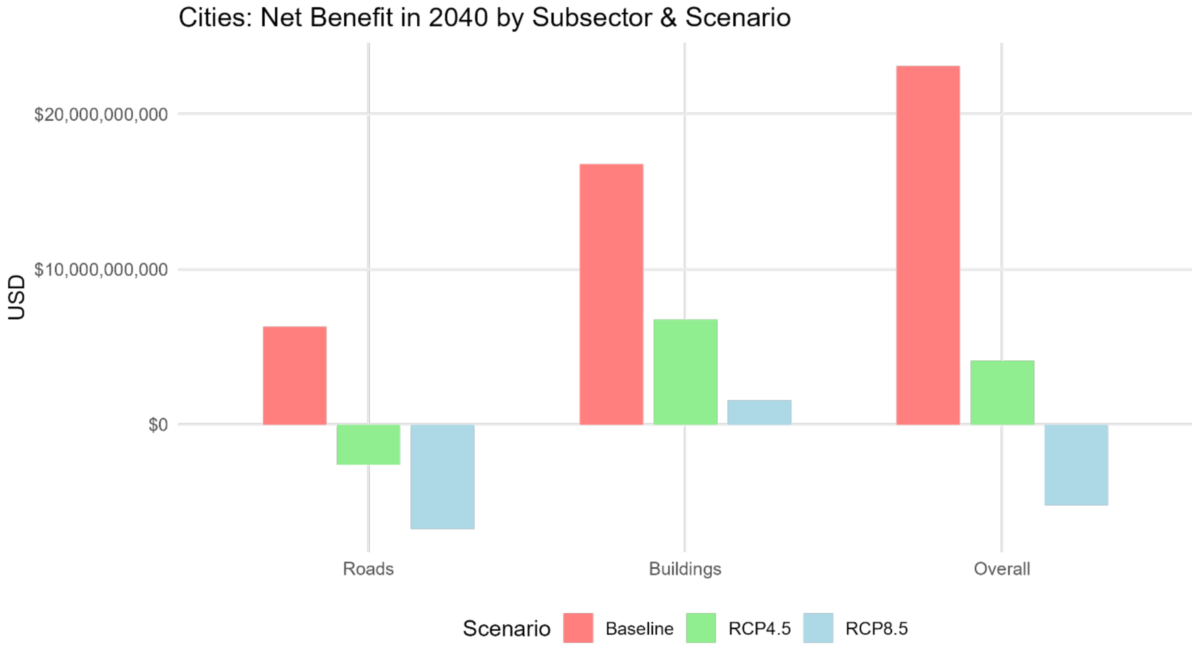
These findings mirror trends observed in the Water and Agriculture sectors: higher-emission scenarios (SSP8.5) amplify costs disproportionately relative to revenues, eroding economic viability[59]. The Baseline scenario, by contrast, maintains a favorable revenue–cost balance, suggesting that proactive adaptation planning under less severe climate trajectories is fiscally sustainable.

Roads, as the largest cost center, are especially vulnerable to escalating adaptation costs under severe climate change. Without significant efficiency improvements, innovative financing, or subsidies, adaptation investments in Roads—and to a lesser extent, Buildings—may become fiscally unsustainable under SSP8.5.

8.4.2. Net Benefits in 2040

Figure 18 summarizes the net benefits of adaptation in the Cities sector in 2040 across subsectors and scenarios (Baseline, SSP4.5, and SSP8.5).

Figure 28. Net Benefits in 2040 by Subsector and Scenario.



59 Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report.* Cam bridge University Press. https://www.ipcc.ch/report/ar6/wg2/

Net benefits remain positive under Baseline and SSP4.5, reflecting good returns from investments in climate-resilient transport infrastructure. However, under SSP8.5, rapidly escalating costs outweigh revenues, resulting in a negative net balance for roads. Adaptation in Buildings generates positive net benefits under Baseline, but these fall to marginal levels under SSP4.5 and become negative in SSP8.5. Rising costs for retrofitting and climate-proofing buildings exceed projected revenues under severe climate stress. Aggregating both subsectors, the Cities sector shows strong positive net benefits under Baseline, moderate surpluses under SSP4.5, and negative net outcomes under SSP8.5.

These results reinforce findings from other sectors, where higher-emission scenarios erode economic viability by driving costs higher than revenues (IPCC, 2022). The Cities sector is particularly sensitive to climate extremes because of the high capital intensity of roads and building infrastructure, which amplifies cost escalations.

8.4.3. Efficiency Metrics

Table 19 and the complementary Table 18 presents the efficiency metrics for the Cities sector, covering revenues, costs, benefits, Benefit-Cost Ratios (BCRs), cost per dollar of revenue, Compound Annual Growth Rates (CAGR) across the key years (2015, 2030, and 2040) and the BCR and Internal Rate of Return (IRR) analysis.

For the Roads subsector, BCRs remain above one under both the Baseline and SSP4.5 scenarios, confirming the strong economic viability of climate-resilient investments in transport infrastructure. However, under SSP8.5, the BCR declines below one, indicating that costs exceed revenues by 2040. In this severe climate scenario, IRRs also deteriorate, reflecting a reduced profitability of investments, even though IRRs remain undefined under the Baseline and SSP4.5 because annual cashflows are consistently positive. The CAGR values for Roads indicate robust growth in both revenues and costs, though costs grow faster than revenues under SSP8.5.

Table 24. Efficiency analysis of health sector adaptation, showing undiscounted and discounted (5%) BCRs, present values, and internal rates of return (IRR) by subsector and scenario.

Subsector	Scenario	Undisc. Benefits (Million USD)	Undisc. Costs (Million USD)	BCR (Undisc.)	PV Benefits @5% (Million USD)	PV Costs @5% (Million USD	BCR (5% Disc.)	IRR (%)*
Buildings	Baseline	362,250.00	108,750.00	3.33	182,737.02	53,627.56	3.41	NA
Buildings	SSP4.5	253,870.00	129,680.00	1.96	130,944.02	64,198.67	2.04	NA
Buildings	SSP8.5	191,860.00	139,580.00	1.37	100,902.06	69,538.78	1.45	NA

Overall	Baseline	696,700.00	292,910.00	2.38	363,113.31	148,324.80	2.45	NA
Overall	SSP4.5	479,800.00	347,640.00	1.38	256,944.76	176,912.99	1.45	NA
Overall	SSP8.5	356,100.00	372,770.00	0.96	195,238.52	191,104.42	1.02	3.4
Roads	Baseline	334,870.00	184,080.00	1.82	180,649.35	94,678.97	1.91	NA
Roads	SSP4.5	225,720.00	218,080.00	1.04	125,858.02	112,776.75	1.12	–2.4
Roads	SSP8.5	164,660.00	233,340.00	0.71	94,586.40	121,659.13	0.78	23

The Baseline scenario produces positive BCRs and net benefits for the Buildings subsector, though the scale of returns is smaller compared to Roads. Under SSP4.5, efficiency narrows considerably, with BCRs approaching unity, suggesting that revenues and costs are nearly balanced. By SSP8.5, costs outweigh revenues, leading to BCRs falling below one and net benefits turning negative. IRR results similarly highlight the volatility of building investments under harsher climate scenarios, where high adaptation costs erode economic returns. At the aggregate level, the Cities sector remains economically viable under the Baseline scenario, maintains moderate positive returns under SSP4.5, but shifts into negative territory under SSP8.5. Discounted BCRs confirm that fiscal efficiency declines significantly as climate severity increases, mirroring the patterns observed in the Agriculture and Water sectors where high-emission scenarios lead to disproportionate increases in costs relative to revenues[60]. **The policy implication is clear, while Roads present a relatively stronger investment case compared to Buildings, neither subsector sustains economic viability under SSP8.5 without substantial efficiency improvements, targeted subsidies, or the integration of non-market benefits such as avoided disaster losses, improved public safety, and enhanced equity outcomes.**

8.4.4. Conclusion

The analysis of the Cities sector demonstrates that adaptation investments in Roads and Buildings yield significant benefits under the Baseline and moderate climate scenarios, but their economic viability deteriorates sharply under SSP8.5. Roads consistently emerge as the economic backbone of urban adaptation, delivering larger revenues and net benefits relative to Buildings, though both subsectors face escalating costs as climate pressures intensify. This pattern reflects the capital-intensive nature of urban infrastructure, where climate extremes accelerate degradation, increase maintenance requirements, and raise reconstruction costs.

Beyond the financial metrics, the Cities sector delivers a range of non-market benefits that substantially enhance its overall value proposition. Investments in resilient roads reduce disaster-related disruptions, support emergency evacuation and relief operations, and safeguard national connectivity for trade and services. Similarly, resilient buildings ensure continuity of essential services such as schools, hospitals, and administrative centers, protect households from

60 Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report.* Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/

climate shocks, and contribute to public safety and welfare. These non-market benefits generate social and equity gains that are not fully captured in the cost–benefit ratios or IRRs, but which are critical to national adaptation objectives.

It is worthy to note that the Cities sector's outcomes are deeply interlinked with other sectors. For example, ecosystem-based adaptation measures such as mangrove restoration and coastal green infrastructure, costed under the Biodiversity sector, provide natural buffers that reduce urban flood and coastal risks in cities like Accra and Takoradi. Similarly, investments in watershed management and resilient water supply in the Water sector directly contribute to improved urban sanitation and flood risk reduction. In the Health sector, strengthened disaster preparedness and emergency response capacities amplify the effectiveness of resilient transport and housing investments by ensuring continuity of healthcare services during climate extremes. These synergies highlight that while the Cities costing focused on Roads and Buildings, broader resilience outcomes depend on the composite effect of interventions across multiple sectors.

In summary, the Cities sector remains a strategic national priority for adaptation planning. Even where financial metrics weaken under harsher climate scenarios, the wider co-benefits—reduced disaster losses, improved health and education outcomes, enhanced social equity, and greater resilience of urban systems—justify sustained and innovative investment in Roads and Buildings as cornerstones of Ghana's climate-resilient development pathway. The following recommendations are proposed for policy considerations based on the foregoing analysis:

1. Prioritize investment in resilient Roads and Buildings, as these are the important subsectors for sustaining economic activity, public services, and national connectivity.
2. Strengthen cost efficiency in road infrastructure through improved design standards, proactive maintenance, and integration of nature-based solutions (e.g., urban green infrastructure) to reduce long-term expenditure.
3. Enforce and update building codes to incorporate climate resilience, coupled with stronger zoning regulations to prevent construction in flood-prone and high-risk areas.
4. Scale up retrofitting of critical public facilities (schools, hospitals, administrative buildings) to safeguard essential services during climate extremes.
5. Enhance transport system resilience by investing in elevated roads, resilient bridges, and expanded low-emission public transport systems (e.g., electric buses).
6. Integrate Cities adaptation into cross-sectoral planning, recognizing that Water, Agriculture, Health, and Biodiversity actions already deliver significant co-benefits for urban resilience (e.g., watershed management for sanitation, mangrove restoration for coastal protection).

7. Promote innovative financing mechanisms (e.g., public–private partnerships, climate funds, concessional loans) to bridge adaptation financing gaps, especially under high-cost scenarios.

8. Leverage non-market benefits—such as reduced disaster losses, improved health and education outcomes, and social equity gains—to justify sustained investment even where direct financial returns weaken.

9. Institutionalize monitoring and evaluation systems for Roads and Buildings adaptation to track cost efficiency, ensure accountability, and guide adaptive policy responses.

9. GENERAL CONCLUSIONS

9.1. Cross-Cutting Insights

a. High-Return Adaptation Areas

Across all five sectors, certain adaptation investments consistently demonstrated superior economic performance and resilience across climate scenarios. Forestry, groundwater management, crop agriculture, wetlands, and health monitoring/response systems recorded the highest Benefit–Cost Ratios (BCRs) and Net Present Values (NPVs). These interventions are characterized by relatively low capital requirements, strong co-benefits, and rapid return on investment. They also provide foundational resilience benefits, such as ensuring water security, stabilizing agricultural production, and reducing disease burdens. Prioritizing these high-return areas provides Ghana with a clear pathway to maximize adaptation impact per unit of investment.

b. Importance of Non-Market Benefits

While the financial flows of adaptation actions were quantified, the analysis recognizes that non-market benefits are equally critical to national resilience and sustainable development. For example, wetlands provide flood regulation and biodiversity protection; forests contribute carbon sequestration, air purification, and cultural services; and health system resilience reduces mortality, morbidity, and productivity losses beyond measurable economic gains. These non-market benefits, though partially captured through proxy pricing, strengthen the case for adaptation and underscore the importance of embedding environmental-economic accounting into national planning and financing frameworks.

c. Climate Stress and Efficiency Margins

The results consistently show that severe climate scenarios (SSP8.5) erode efficiency margins, as adaptation costs rise faster than revenues or benefits. Marine ecosystems, surface water systems, and urban infrastructure are especially vulnerable under high-warming futures, with some investments turning unviable (BCR < 1). Conversely, preventive and nature-based measures (e.g., groundwater recharge, ecosystem restoration, and health surveillance systems) retain positive returns even under high climate stress. This suggests that Ghana's adaptation portfolio must be dynamic and stress-tested against worst-case scenarios, with deliberate phasing of investments and diversification across subsectors to reduce exposure to systemic risks.

d. **Gender and Social Inclusion Dimensions**

Adaptation outcomes are strongly influenced by social inclusion. Women, youth, and marginalized communities remain disproportionately vulnerable to climate risks, particularly in agriculture, water access, and urban livelihoods. Gender-sensitive adaptation—including mandatory female representation in farmer training programs, equitable access to groundwater and irrigation infrastructure, and targeted support for women-led enterprises—emerges as both a social and economic imperative. Ensuring that women and marginalized groups are central to adaptation design and implementation enhances community ownership, improves adoption rates, and strengthens long-term resilience. This is why Ghana's NAP implementation institutionalizes social inclusion benchmarks as part of monitoring and reporting systems.

9.2. Economic Case for Adaptation

The analysis confirms that climate adaptation is an economically sound investment for Ghana. Most adaptation actions deliver positive Benefit–Cost Ratios (BCRs) and Net Present Values (NPVs) under the Baseline and SSP4.5 scenarios, and several maintain viability even under SSP8.5. High-return measures such as forestry, groundwater management, crop agriculture, wetlands, and health surveillance systems stand out as cost-effective investments that also provide significant non-market co-benefits. While efficiency margins narrow in severe climate futures, a diversified portfolio of preventive and nature-based measures safeguards resilience and supports long-term development goals.

9.3. Priority Investment Sequencing (2025–2040)

A phased investment approach will maximize efficiency and resilience. This sequencing ensures that immediate needs are addressed while building the foundation for larger, more resource-intensive projects in later years:

i. **Phase 1 (2025–2030):** Implement quick-win, high-benefit-cost ratio interventions like groundwater recharge, wetlands restoration, crop intensification, fisheries management, and health monitoring and response.

ii. **Phase 2 (2030–2035):** Expand necessary investments that are capital-intensive, such as climate-proofing rural and district health facilities, upgrading urban drainage systems, and retrofitting housing to be more resilient.

iii. **Phase 3 (2035–2040):** Strengthen systemic resilience through advanced urban green infrastructure, large-scale reforestation efforts, and climate-safe hospitals that incorporate renewable energy, water efficiency, and waste management.

9.4. Financing and Partnerships

Sustained financing is important to delivering the adaptation agenda. Ghana will need to mobilize a blend of domestic resources, international climate finance, and private sector investment. Specific strategies include:

i. Leveraging Green Climate Fund (GCF), Adaptation Fund, and bilateral donor resources.

ii. Establishing Payment for Ecosystem Services (PES) schemes to capture biodiversity and watershed benefits.

iii. Expanding public–private partnerships (PPPs) for urban and health infrastructure.

iv. Mainstreaming adaptation costs into the national budget to ensure fiscal sustainability.

v. Encouraging regional partnerships to harmonize adaptation strategies and share knowledge across ecological zones.

APPENDIX

A1. Biodiversity Sector

All values are in USD (B = billion, M = million)

Table A1.1: Forestry Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL forestry adaptation revenue	TOTAL forestry adaptation cost	Forest resources revenue	Forest Carbon revenue	Forest restoration cost
2015	2.09B	143M	2.09B	53M	29.2M
2016	2.1B	195M	2.05B	53M	29.2M
2017	2.12B	245M	2.01B	105M	57.2M
2018	2.13B	294M	1.97B	156M	84.4M
2019	2.14B	343M	1.94B	206M	111M
2020	2.16B	391M	1.9B	255M	136M
2021	2.17B	438M	1.87B	303M	161M
2022	2.18B	485M	1.83B	351M	185M
2023	2.2B	530M	1.8B	397M	209M
2024	2.21B	575M	1.77B	443M	231M
2025	2.22B	620M	1.74B	488M	253M
2026	2.24B	663M	1.71B	532M	275M
2027	2.25B	706M	1.68B	575M	295M
2028	2.27B	749M	1.65B	618M	316M
2029	2.28B	791M	1.62B	660M	335M
2030	2.3B	832M	1.59B	701M	354M
2031	2.31B	873M	1.57B	741M	372M
2032	2.32B	913M	1.54B	781M	390M
2033	2.34B	952M	1.52B	820M	408M
2034	2.35B	992M	1.5B	859M	424M
2035	2.37B	1.03B	1.47B	897M	441M
2036	2.38B	1.07B	1.45B	934M	457M

2037	2.4B	1.11B	1.43B	971M	472M
2038	2.42B	1.14B	1.41B	1.01B	487M
2039	2.43B	1.18B	1.39B	1.04B	501M
2040	2.45B	1.22B	1.37B	1.08B	515M

Table A1.2: Forestry Subsector Revenues and Costs (SSP4.5 Scenario)

Year	TOTAL forestry adaptation revenue	TOTAL forestry adaptation cost	Forest resources revenue	Forest Carbon revenue	Forest restoration cost	Forest monitoring cost	Forest personnel cost
2015	2.09B	172M	2.09B	52.9M	37.9M	26.8M	172M
2016	2.09B	236M	2.04B	52.9M	37.9M	26.8M	172M
2017	2.09B	303M	1.99B	104M	75.1M	54.1M	173M
2018	2.09B	366M	1.94B	155M	111M	81.3M	174M
2019	2.09B	428M	1.89B	204M	145M	109M	174M
2020	2.09B	488M	1.84B	251M	178M	136M	174M
2021	2.09B	548M	1.8B	298M	210M	163M	174M
2022	2.1B	607M	1.75B	343M	241M	190M	175M
2023	2.1B	664M	1.71B	388M	271M	218M	175M
2024	2.1B	721M	1.67B	431M	300M	245M	175M
2025	2.1B	776M	1.63B	473M	328M	272M	176M
2026	2.11B	831M	1.59B	515M	355M	300M	176M
2027	2.11B	885M	1.56B	555M	381M	327M	176M
2028	2.12B	938M	1.52B	594M	406M	355M	177M
2029	2.12B	990M	1.49B	633M	431M	383M	177M
2030	2.12B	1.04B	1.45B	670M	454M	410M	177M
2031	2.13B	1.09B	1.42B	707M	477M	438M	177M
2032	2.13B	1.14B	1.39B	743M	499M	465M	177M
2033	2.14B	1.19B	1.36B	779M	520M	493M	177M
2034	2.15B	1.24B	1.33B	813M	540M	521M	178M

2035	2.15B	1.29B	1.31B	847M	560M	549M	178M
2036	2.16B	1.33B	1.28B	880M	579M	576M	178M
2037	2.17B	1.38B	1.25B	912M	597M	604M	178M
2038	2.17B	1.42B	1.23B	944M	614M	632M	178M
2039	2.18B	1.47B	1.2B	975M	632M	660M	179M
2040	2.19B	1.51B	1.18B	1.01B	648M	688M	179M

Table A1.3: Forestry Subsector Revenues and Costs (SSP8.5 Scenario)

Year	TOTAL forestry adaptation revenue	TOTAL forestry adaptation cost	Forest resources revenue	Forest Carbon revenue	Forest restoration cost	Forest monitoring cost	Forest personnel cost
2015	2.09B	172M	2.09B	52.9M	37.9M	26.8M	172M
2016	2.09B	236M	2.04B	52.9M	37.9M	26.8M	172M
2017	2.09B	307M	1.99B	104M	76M	54.6M	176M
2018	2.09B	372M	1.93B	155M	113M	82.3M	177M
2019	2.09B	436M	1.88B	203M	148M	110M	178M
2020	2.09B	497M	1.84B	251M	182M	138M	177M
2021	2.09B	557M	1.79B	298M	215M	166M	177M
2022	2.09B	617M	1.75B	343M	246M	193M	177M
2023	2.09B	675M	1.7B	387M	277M	221M	178M
2024	2.09B	733M	1.66B	430M	306M	249M	178M
2025	2.09B	789M	1.62B	472M	334M	277M	178M
2026	2.1B	844M	1.58B	513M	361M	304M	178M
2027	2.1B	898M	1.55B	553M	388M	332M	178M
2028	2.1B	952M	1.51B	592M	413M	360M	178M
2029	2.11B	1B	1.48B	631M	438M	388M	179M
2030	2.11B	1.06B	1.44B	668M	461M	416M	179M
2031	2.12B	1.11B	1.41B	705M	484M	444M	179M
2032	2.12B	1.16B	1.38B	740M	506M	472M	179M

2033	2.13B	1.21B	1.35B	775M	527M	500M	179M
2034	2.13B	1.25B	1.32B	810M	548M	528M	179M
2035	2.14B	1.3B	1.29B	843M	567M	556M	180M
2036	2.14B	1.35B	1.27B	876M	586M	584M	180M
2037	2.15B	1.4B	1.24B	908M	605M	612M	180M
2038	2.16B	1.44B	1.22B	940M	622M	640M	180M
2039	2.16B	1.49B	1.19B	970M	639M	668M	180M
2040	2.17B	1.53B	1.17B	1B	656M	696M	181M

Table A1.4: Marine Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL marine adaptation revenue	TOTAL marine adaptation cost	Revenue from restored marine habitat	Revenue from marine monitoring	Cost from restored marine habitat	Cost from marine monitoring
2015	1.23B	950M	1.09B	137M	760M	190M
2016	1.27B	950M	1.13B	141M	760M	190M
2017	1.32B	950M	1.17B	146M	760M	190M
2018	1.36B	950M	1.21B	151M	760M	190M
2019	1.41B	950M	1.25B	156M	760M	190M
2020	1.46B	950M	1.29B	162M	760M	190M
2021	1.51B	950M	1.34B	167M	760M	190M
2022	1.56B	950M	1.38B	173M	760M	190M
2023	1.61B	950M	1.43B	179M	760M	190M
2024	1.66B	950M	1.48B	185M	760M	190M
2025	1.72B	950M	1.53B	191M	760M	190M
2026	1.78B	950M	1.58B	198M	760M	190M
2027	1.84B	950M	1.64B	205M	760M	190M
2028	1.9B	950M	1.69B	212M	760M	190M

2029	1.97B	950M	1.75B	219M	760M	190M
2030	2.04B	950M	1.81B	226M	760M	190M
2031	2.11B	950M	1.87B	234M	760M	190M
2032	2.18B	950M	1.94B	242M	760M	190M
2033	2.25B	950M	2B	250M	760M	190M
2034	2.33B	950M	2.07B	259M	760M	190M
2035	2.41B	950M	2.14B	268M	760M	190M
2036	2.49B	950M	2.21B	277M	760M	190M
2037	2.58B	950M	2.29B	286M	760M	190M
2038	2.66B	950M	2.37B	296M	760M	190M
2039	2.76B	950M	2.45B	306M	760M	190M
2040	2.85B	950M	2.53B	317M	760M	190M

Table A1.5: Marine Subsector Revenues and Costs (SSP4.5 Scenario)

Year	TOTAL marine adaptation revenue	TOTAL marine adaptation cost	Revenue from restored marine habitat	Revenue from marine monitoring	Cost from restored marine habitat	Cost from marine monitoring
2015	1.23B	1.14B	1.09B	137M	912M	228M
2016	1.25B	1.14B	1.11B	139M	912M	228M
2017	1.26B	1.15B	1.12B	140M	921M	230M
2018	1.28B	1.15B	1.13B	142M	922M	230M
2019	1.29B	1.15B	1.15B	143M	924M	231M
2020	1.31B	1.15B	1.16B	145M	923M	231M
2021	1.32B	1.16B	1.17B	147M	925M	231M
2022	1.34B	1.16B	1.19B	148M	929M	232M
2023	1.35B	1.16B	1.2B	150M	930M	232M
2024	1.37B	1.17B	1.21B	152M	932M	233M

2025	1.38B	1.17B	1.23B	153M	933M	233M
2026	1.4B	1.17B	1.24B	155M	934M	234M
2027	1.41B	1.17B	1.25B	157M	936M	234M
2028	1.42B	1.17B	1.27B	158M	938M	234M
2029	1.44B	1.17B	1.28B	160M	939M	235M
2030	1.45B	1.17B	1.29B	161M	939M	235M
2031	1.47B	1.18B	1.3B	163M	940M	235M
2032	1.48B	1.18B	1.32B	165M	943M	236M
2033	1.5B	1.18B	1.33B	166M	943M	236M
2034	1.51B	1.18B	1.34B	168M	943M	236M
2035	1.52B	1.18B	1.35B	169M	944M	236M
2036	1.54B	1.18B	1.37B	171M	945M	236M
2037	1.55B	1.18B	1.38B	172M	947M	237M
2038	1.57B	1.18B	1.39B	174M	948M	237M
2039	1.58B	1.19B	1.4B	175M	949M	237M
2040	1.59B	1.19B	1.42B	177M	950M	237M

Table A1.6: Marine Subsector Revenues and Costs (SSP8.5 Scenario)

Year	TOTAL marine adaptation revenue	TOTAL marine adaptation cost	Revenue from restored marine habitat	Revenue from marine monitoring	Cost from restored marine habitat	Cost from marine monitoring
2015	1.23B	1.14B	1.09B	137M	912M	228M
2016	1.22B	1.14B	1.09B	136M	912M	228M
2017	1.2B	1.17B	1.07B	134M	937M	234M
2018	1.19B	1.18B	1.05B	132M	940M	235M
2019	1.17B	1.18B	1.04B	130M	943M	236M
2020	1.15B	1.17B	1.02B	128M	939M	235M
2021	1.13B	1.18B	1.01B	126M	942M	236M

2022	1.12B	1.18B	993M	124M	942M	236M
2023	1.1B	1.18B	978M	122M	943M	236M
2024	1.08B	1.18B	963M	120M	945M	236M
2025	1.07B	1.18B	948M	119M	946M	237M
2026	1.05B	1.18B	933M	117M	947M	237M
2027	1.03B	1.18B	918M	115M	947M	237M
2028	1.02B	1.18B	904M	113M	948M	237M
2029	1B	1.19B	889M	111M	949M	237M
2030	984M	1.19B	875M	109M	949M	237M
2031	968M	1.19B	860M	108M	951M	238M
2032	952M	1.19B	846M	106M	951M	238M
2033	935M	1.19B	831M	104M	952M	238M
2034	919M	1.19B	817M	102M	953M	238M
2035	903M	1.19B	803M	100M	954M	238M
2036	887M	1.19B	789M	98.6M	955M	239M
2037	871M	1.19B	775M	96.8M	956M	239M
2038	856M	1.2B	761M	95.1M	956M	239M
2039	840M	1.2B	747M	93.3M	957M	239M
2040	825M	1.2B	733M	91.6M	959M	240M

Table A1.7: Aquatic Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL aquatic adaptation revenue	TOTAL aquatic adaptation cost	Revenue from restored aquatic habitat	Revenue from aquatic monitoring	Cost from restored aquatic habitat	Cost from aquatic monitoring
2015	101M	54.5M	81.8M	19.5M	46.7M	7.79M
2016	111M	59.9M	89.8M	21.4M	51.3M	8.55M

2017	122M	65.7M	98.6M	23.5M	56.4M	9.39M
2018	134M	72.2M	108M	25.8M	61.9M	10.3M
2019	147M	79.3M	119M	28.3M	67.9M	11.3M
2020	162M	87M	131M	31.1M	74.6M	12.4M
2021	177M	95.6M	143M	34.1M	81.9M	13.7M
2022	195M	105M	157M	37.5M	89.9M	15M
2023	214M	115M	173M	41.1M	98.8M	16.5M
2024	235M	127M	190M	45.2M	108M	18.1M
2025	258M	139M	208M	49.6M	119M	19.8M
2026	283M	153M	229M	54.5M	131M	21.8M
2027	311M	167M	251M	59.8M	144M	23.9M
2028	342M	184M	276M	65.7M	158M	26.3M
2029	375M	202M	303M	72.1M	173M	28.8M
2030	412M	222M	333M	79.2M	190M	31.7M
2031	452M	243M	365M	86.9M	209M	34.8M
2032	496M	267M	401M	95.5M	229M	38.2M
2033	545M	294M	440M	105M	252M	41.9M
2034	599M	322M	483M	115M	276M	46M
2035	657M	354M	531M	126M	303M	50.6M
2036	722M	389M	583M	139M	333M	55.5M
2037	792M	427M	640M	152M	366M	60.9M
2038	870M	468M	703M	167M	402M	66.9M
2039	955M	514M	772M	184M	441M	73.5M
2040	1.05B	565M	847M	202M	484M	80.7M

Table A1.8: Aquatic Subsector Revenues and Costs (SSP4.5 Scenario)

Year	TOTAL aquatic adaptation revenue	TOTAL aquatic adaptation cost	Revenue from restored aquatic habitat	Revenue from aquatic monitoring	Cost from restored aquatic habitat	Cost from aquatic monitoring
2015	101M	65.4M	81.8M	19.5M	56.1M	9.35M
2016	109M	71.9M	87.7M	20.9M	61.6M	10.3M
2017	116M	79.7M	93.8M	22.3M	68.3M	11.4M
2018	124M	87.6M	100M	23.9M	75.1M	12.5M
2019	133M	96.4M	107M	25.6M	82.6M	13.8M
2020	142M	106M	115M	27.4M	90.6M	15.1M
2021	152M	116M	123M	29.3M	99.7M	16.6M
2022	163M	128M	131M	31.3M	110M	18.3M
2023	174M	141M	141M	33.5M	121M	20.1M
2024	186M	155M	150M	35.8M	133M	22.2M
2025	199M	171M	161M	38.2M	146M	24.4M
2026	213M	188M	172M	40.9M	161M	26.8M
2027	227M	206M	183M	43.7M	177M	29.5M
2028	242M	227M	196M	46.6M	195M	32.4M
2029	259M	249M	209M	49.8M	214M	35.6M
2030	277M	274M	223M	53.2M	235M	39.1M
2031	295M	301M	238M	56.8M	258M	43M
2032	315M	332M	255M	60.6M	284M	47.4M
2033	336M	364M	272M	64.7M	312M	52M
2034	359M	400M	290M	69M	343M	57.2M
2035	383M	440M	309M	73.6M	377M	62.8M
2036	409M	483M	330M	78.6M	414M	69M
2037	436M	531M	352M	83.8M	456M	75.9M
2038	465M	584M	375M	89.4M	501M	83.5M

2039	496M	642M	400M	95.3M	550M	91.7M
2040	528M	706M	427M	102M	605M	101M

Table A1.9: Aquatic Subsector Revenues and Costs (SSP8.5 Scenario)

Year	TOTAL aquatic adaptation revenue	TOTAL aquatic adaptation cost	Revenue from restored aquatic habitat	Revenue from aquatic monitoring	Cost from restored aquatic habitat	Cost from aquatic monitoring
2015	101M	65.4M	81.8M	19.5M	56.1M	9.35M
2016	106M	71.9M	85.7M	20.4M	61.6M	10.3M
2017	110M	81.1M	88.8M	21.1M	69.5M	11.6M
2018	114M	89.3M	92.1M	21.9M	76.6M	12.8M
2019	118M	98.4M	95.4M	22.7M	84.3M	14.1M
2020	122M	108M	98.9M	23.6M	92.2M	15.4M
2021	127M	118M	103M	24.4M	102M	16.9M
2022	132M	130M	106M	25.3M	112M	18.6M
2023	137M	143M	110M	26.3M	123M	20.4M
2024	142M	157M	114M	27.2M	135M	22.5M
2025	147M	173M	119M	28.2M	148M	24.7M
2026	152M	190M	123M	29.2M	163M	27.2M
2027	157M	209M	127M	30.3M	179M	29.8M
2028	163M	229M	132M	31.4M	197M	32.8M
2029	169M	252M	136M	32.5M	216M	36M
2030	175M	277M	141M	33.6M	237M	39.6M
2031	181M	305M	146M	34.8M	261M	43.5M
2032	187M	335M	151M	36M	287M	47.8M
2033	193M	368M	156M	37.2M	315M	52.5M
2034	200M	404M	162M	38.5M	346M	57.7M

2035	207M	444M	167M	39.8M	381M	63.5M
2036	214M	488M	173M	41.1M	418M	69.7M
2037	221M	536M	178M	42.5M	460M	76.6M
2038	228M	589M	184M	43.9M	505M	84.2M
2039	236M	648M	190M	45.3M	555M	92.5M
2040	243M	713M	196M	46.8M	611M	102M

Table A1.10: Wetlands Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL wetlands adaptation revenue	TOTAL wetlands adaptation cost	Cost of wetlands monitoring	Cost of wetlands personnel
2015	188M	9.66M	1.51M	9.66M
2016	187M	13.8M	1.51M	9.66M
2017	186M	17.8M	3.01M	9.66M
2018	185M	21.7M	4.52M	9.66M
2019	184M	25.6M	6.02M	9.66M
2020	184M	29.4M	7.53M	9.66M
2021	183M	33M	9.04M	9.66M
2022	183M	36.6M	10.5M	9.66M
2023	183M	40.2M	12M	9.66M
2024	183M	43.6M	13.6M	9.66M
2025	183M	47M	15.1M	9.66M
2026	183M	50.4M	16.6M	9.66M
2027	183M	53.6M	18.1M	9.66M
2028	183M	56.8M	19.6M	9.66M
2029	184M	60M	21.1M	9.66M
2030	185M	63M	22.6M	9.66M
2031	186M	66.1M	24.1M	9.66M
2032	186M	69M	25.6M	9.66M
2033	187M	72M	27.1M	9.66M
2034	188M	74.8M	28.6M	9.66M

2035	190M	77.7M	30.1M	9.66M
2036	191M	80.4M	31.6M	9.66M
2037	192M	83.2M	33.1M	9.66M
2038	194M	85.8M	34.6M	9.66M
2039	195M	88.5M	36.1M	9.66M
2040	197M	91.1M	37.7M	9.66M

Table A1.10: Wetlands Subsector Revenues and Costs (SSP8.5 Scenario)

Year	TOTAL wetlands adaptation revenue	TOTAL wetlands adaptation cost	Cost of wetlands monitoring	Cost of wetlands personnel
2015	188M	11.6M	1.81M	11.6M
2016	186M	16.7M	1.81M	11.6M
2017	183M	21.9M	3.65M	11.7M
2018	181M	26.9M	5.49M	11.7M
2019	179M	31.7M	7.33M	11.7M
2020	177M	36.4M	9.16M	11.7M
2021	176M	40.9M	11M	11.8M
2022	175M	45.4M	12.8M	11.8M
2023	174M	49.8M	14.7M	11.8M
2024	173M	54.1M	16.5M	11.8M
2025	172M	58.2M	18.4M	11.9M
2026	171M	62.3M	20.2M	11.9M
2027	171M	66.3M	22.1M	11.9M
2028	171M	70.2M	24M	11.9M
2029	171M	74M	25.8M	11.9M
2030	171M	77.7M	27.7M	11.9M
2031	171M	81.4M	29.5M	11.9M

2032	172M	85M	31.4M	12M
2033	172M	88.5M	33.3M	12M
2034	173M	91.9M	35.2M	12M
2035	174M	95.3M	37M	12M
2036	175M	98.6M	38.9M	12M
2037	176M	102M	40.8M	12M
2038	177M	105M	42.7M	12M
2039	178M	108M	44.5M	12.1M
2040	180M	111M	46.4M	12.1M

Table A1.11: Wetlands Subsector Revenues and Costs (SSP8.5 Scenario)

Year	TOTAL wetlands adaptation revenue	TOTAL wetlands adaptation cost	Cost of wetlands monitoring	Cost of wetlands personnel
2015	188M	11.6M	0	11.6M
2016	186M	16.7M	1.81M	11.6M
2017	183M	22.2M	3.68M	11.9M
2018	181M	27.3M	5.56M	11.9M
2019	179M	32.3M	7.43M	12M
2020	177M	37M	9.3M	11.9M
2021	175M	41.6M	11.2M	12M
2022	174M	46.2M	13M	12M
2023	173M	50.6M	14.9M	12M
2024	172M	54.9M	16.8M	12M
2025	171M	59.1M	18.7M	12M
2026	171M	63.2M	20.5M	12M
2027	170M	67.2M	22.4M	12M
2028	170M	71.2M	24.3M	12M

2029	170M	75M	26.2M	12.1M
2030	170M	78.7M	28.1M	12.1M
2031	170M	82.4M	30M	12.1M
2032	171M	86M	31.8M	12.1M
2033	171M	89.6M	33.7M	12.1M
2034	172M	93M	35.6M	12.1M
2035	173M	96.4M	37.5M	12.1M
2036	174M	99.8M	39.4M	12.1M
2037	175M	103M	41.3M	12.1M
2038	176M	106M	43.2M	12.1M
2039	177M	109M	45.1M	12.2M
2040	179M	113M	47M	12.2M

B1. Agriculture Sector

All values are in USD (B = billion, M = million)

Table B1.1: Crops Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL Crop adaptation revenue	TOTAL Crop adaptation Cost	MC Revenue	TC Revenue	Veg Revenue	Revenue from fertiliser inputs	Crop farmer training cost	Crop monitoring technology cost	Fertiliser inputs cost	Crop Irrigation cost
2015	6.03B	1.51B	3B	2.6B	419M	2.4M	342M	672M	2M	835M
2016	6.14B	1.89B	3.08B	2.63B	423M	2.87M	342M	685M	2.39M	850M
2017	6.25B	1.93B	3.16B	2.66B	428M	3.44M	349M	698M	2.86M	866M
2018	6.37B	1.97B	3.25B	2.69B	432M	4.11M	355M	712M	3.43M	883M
2019	6.5B	2.01B	3.34B	2.72B	437M	4.92M	362M	727M	4.1M	900M
2020	6.64B	2.05B	3.43B	2.76B	442M	5.89M	369M	743M	4.91M	919M
2021	6.78B	2.1B	3.53B	2.79B	447M	7.05M	377M	759M	5.88M	939M

2022	6.92B	2.14B	3.63B	2.83B	452M	8.44M	385M	777M	7.03M	960M
2023	7.08B	2.2B	3.74B	2.87B	457M	10.1M	394M	795M	8.42M	982M
2024	7.24B	2.25B	3.86B	2.91B	462M	12.1M	403M	815M	10.1M	1.01B
2025	7.41B	2.31B	3.98B	2.95B	468M	14.5M	413M	836M	12.1M	1.03B
2026	7.59B	2.37B	4.1B	3B	473M	17.3M	423M	858M	14.4M	1.06B
2027	7.78B	2.43B	4.24B	3.04B	478M	20.7M	434M	881M	17.3M	1.09B
2028	7.98B	2.51B	4.37B	3.09B	484M	24.8M	446M	906M	20.7M	1.12B
2029	8.19B	2.58B	4.52B	3.15B	489M	29.7M	458M	932M	24.7M	1.15B
2030	8.41B	2.66B	4.67B	3.2B	495M	35.5M	472M	960M	29.6M	1.18B
2031	8.64B	2.75B	4.83B	3.26B	501M	42.5M	486M	990M	35.4M	1.22B
2032	8.89B	2.84B	5B	3.33B	507M	50.9M	501M	1.02B	42.4M	1.25B
2033	9.15B	2.94B	5.18B	3.4B	513M	60.9M	517M	1.06B	50.8M	1.3B
2034	9.43B	3.05B	5.37B	3.48B	519M	72.9M	534M	1.09B	60.7M	1.34B
2035	9.73B	3.16B	5.56B	3.56B	525M	87.2M	553M	1.13B	72.7M	1.39B
2036	10B	3.29B	5.77B	3.65B	531M	104M	572M	1.17B	87M	1.44B
2037	10.4B	3.43B	5.98B	3.74B	538M	125M	594M	1.21B	104M	1.49B
2038	10.8B	3.57B	6.21B	3.85B	544M	150M	617M	1.26B	125M	1.55B
2039	11.1B	3.74B	6.45B	3.96B	551M	179M	641M	1.31B	149M	1.61B
2040	11.6B	3.91B	6.7B	4.09B	558M	214M	668M	1.37B	179M	1.68B

Table B1.2: Crops Subsector Revenues and Costs (RCP4.5 Scenario)

Year	TOTAL Crop adaptation revenue	TOTAL Crop adaptation Cost	MC Revenue	TC Revenue	Veg Revenue	Revenue from fertiliser inputs	Crop farmer training cost	Crop monitoring technology cost	Fertiliser inputs cost	Crop Irrigation cost
2015	4.82B	1.81B	2.4B	2.08B	335M	2.88M	411M	807M	2M	1B
2016	4.91B	2.28B	2.46B	2.11B	338M	3.57M	411M	822M	2.48M	1.02B
2017	4.93B	2.34B	2.49B	2.1B	337M	4.5M	423M	846M	3.09M	1.05B
2018	5.02B	2.39B	2.55B	2.12B	340M	5.6M	431M	864M	3.85M	1.07B
2019	5.1B	2.45B	2.62B	2.14B	343M	6.99M	440M	884M	4.79M	1.09B

2020	5.21B	2.5B	2.69B	2.17B	347M	8.69M	449M	902M	5.96M	1.12B
2021	5.31B	2.56B	2.76B	2.19B	350M	10.8M	459M	924M	7.42M	1.14B
2022	5.39B	2.63B	2.82B	2.2B	351M	13.6M	471M	950M	9.25M	1.17B
2023	5.5B	2.69B	2.9B	2.23B	355M	16.9M	482M	973M	11.5M	1.2B
2024	5.61B	2.77B	2.98B	2.25B	358M	21.1M	494M	999M	14.4M	1.23B
2025	5.73B	2.84B	3.07B	2.28B	361M	26.4M	507M	1.03B	17.9M	1.27B
2026	5.87B	2.92B	3.16B	2.31B	364M	33M	520M	1.05B	22.3M	1.3B
2027	6B	3.01B	3.25B	2.34B	367M	41.2M	535M	1.09B	27.9M	1.34B
2028	6.14B	3.11B	3.35B	2.37B	370M	51.5M	550M	1.12B	34.8M	1.38B
2029	6.3B	3.21B	3.46B	2.41B	374M	64.4M	566M	1.15B	43.4M	1.42B
2030	6.48B	3.31B	3.57B	2.45B	379M	80.4M	582M	1.19B	54.3M	1.46B
2031	6.66B	3.43B	3.69B	2.49B	382M	101M	601M	1.22B	67.8M	1.51B
2032	6.84B	3.56B	3.8B	2.53B	385M	126M	621M	1.27B	84.7M	1.56B
2033	7.06B	3.7B	3.93B	2.58B	390M	157M	641M	1.31B	106M	1.61B
2034	7.3B	3.85B	4.07B	2.64B	394M	197M	663M	1.35B	132M	1.66B
2035	7.55B	4.01B	4.21B	2.7B	398M	246M	687M	1.4B	165M	1.72B
2036	7.83B	4.2B	4.36B	2.76B	402M	308M	712M	1.46B	207M	1.79B
2037	8.13B	4.41B	4.51B	2.82B	406M	386M	740M	1.51B	258M	1.86B
2038	8.47B	4.64B	4.68B	2.9B	410M	484M	769M	1.57B	323M	1.93B
2039	8.84B	4.89B	4.85B	2.98B	414M	606M	801M	1.64B	405M	2.01B
2040	9.27B	5.19B	5.03B	3.07B	418M	759M	835M	1.71B	506M	2.09B

Table B1.3: Crops Subsector Revenues and Costs (RCP8.5 Scenario)

Year	TOTAL Crop adaptation revenue	TOTAL Crop adaptation Cost	MC Revenue	TC Revenue	Veg Revenue	Revenue from fertiliser inputs	Crop farmer training cost	Crop monitoring technology cost	Fertiliser inputs cost	Crop Irrigation cost
2015	3.62B	1.95B	1.8B	1.56B	251M	2.88M	479M	941M	2M	1B
2016	3.68B	2.49B	1.85B	1.58B	254M	3.7M	479M	959M	2.57M	1.02B
2017	3.34B	2.64B	1.69B	1.42B	228M	4.97M	511M	1.02B	3.36M	1.07B

2018	3.35B	2.71B	1.71B	1.41B	227M	6.51M	524M	1.05B	4.39M	1.09B
2019	3.37B	2.78B	1.73B	1.41B	226M	8.54M	537M	1.08B	5.73M	1.12B
2020	3.52B	2.82B	1.81B	1.46B	234M	11.1M	543M	1.09B	7.48M	1.14B
2021	3.54B	2.9B	1.84B	1.45B	233M	14.5M	558M	1.12B	9.76M	1.16B
2022	3.61B	2.97B	1.89B	1.47B	235M	19M	570M	1.15B	12.7M	1.19B
2023	3.68B	3.04B	1.93B	1.48B	236M	24.8M	584M	1.18B	16.6M	1.22B
2024	3.75B	3.13B	1.98B	1.49B	238M	32.4M	599M	1.21B	21.7M	1.25B
2025	3.81B	3.22B	2.03B	1.5B	238M	42.5M	615M	1.25B	28.4M	1.28B
2026	3.9B	3.32B	2.08B	1.52B	240M	55.6M	631M	1.28B	37.2M	1.32B
2027	4.02B	3.41B	2.15B	1.55B	243M	72.7M	647M	1.31B	48.6M	1.35B
2028	4.12B	3.53B	2.21B	1.56B	245M	95.1M	666M	1.35B	63.6M	1.39B
2029	4.22B	3.65B	2.27B	1.58B	246M	125M	686M	1.4B	83.2M	1.43B
2030	4.37B	3.78B	2.35B	1.61B	249M	163M	706M	1.44B	109M	1.47B
2031	4.5B	3.94B	2.41B	1.63B	250M	214M	729M	1.49B	143M	1.52B
2032	4.67B	4.11B	2.48B	1.65B	252M	281M	753M	1.54B	187M	1.57B
2033	4.86B	4.3B	2.56B	1.68B	253M	368M	778M	1.59B	245M	1.62B
2034	5.08B	4.52B	2.64B	1.71B	255M	483M	806M	1.65B	321M	1.68B
2035	5.36B	4.77B	2.72B	1.74B	257M	634M	835M	1.71B	421M	1.74B
2036	5.68B	5.06B	2.81B	1.78B	259M	833M	866M	1.77B	553M	1.8B
2037	6.08B	5.41B	2.9B	1.82B	261M	1.09B	899M	1.84B	726M	1.87B
2038	6.57B	5.82B	3B	1.86B	263M	1.44B	935M	1.91B	953M	1.95B
2039	7.17B	6.32B	3.1B	1.91B	265M	1.89B	974M	1.99B	1.25B	2.03B
2040	7.89B	6.94B	3.19B	1.95B	266M	2.49B	1.02B	2.08B	1.64B	2.11B

Table B1.4: Livestock Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL Livestock adaptation revenue	TOTAL Livestock adaptation Cost	Livestock farmer training cost	Livestock extension officer cost
2015	2.65495B	702.9M	703M	55.7M
2016	2.75564B	784.352M	729M	55.7M
2017	2.85876B	813.092M	755M	57.7M

2018	2.96442B	842.885M	783M	59.9M
2019	3.07276B	873.77M	812M	62M
2020	3.18391B	905.787M	841M	64.3M
2021	3.29799B	938.977M	872M	66.7M
2022	3.41514B	973.382M	904M	69.1M
2023	3.5355B	1.00905B	937M	71.7M
2024	3.65922B	1.04602B	972M	74.3M
2025	3.78644B	1.08435B	1.01B	77M
2026	3.91731B	1.12408B	1.04B	79.8M
2027	4.052B	1.16527B	1.08B	82.7M
2028	4.19066B	1.20797B	1.12B	85.8M
2029	4.33346B	1.25223B	1.16B	88.9M
2030	4.48058B	1.29812B	1.21B	92.2M
2031	4.63219B	1.34568B	1.25B	95.6M
2032	4.78848B	1.39499B	1.3B	99.1M
2033	4.94963B	1.4461B	1.34B	103M
2034	5.11585B	1.49909B	1.39B	106M
2035	5.28734B	1.55402B	1.44B	110M
2036	5.46431B	1.61096B	1.5B	114M
2037	5.64698B	1.66999B	1.55B	119M
2038	5.83557B	1.73118B	1.61B	123M
2039	6.03032B	1.79462B	1.67B	127M
2040	6.23147B	1.86038B	1.73B	132M

Table B1.5: Livestock Subsector Revenues and Costs (RCP4.5 Scenario)

Year	TOTAL Livestock adaptation revenue	TOTAL Livestock adaptation Cost	Livestock farmer training cost	Livestock extension officer cost
2015	2.65495B	843.48M	843M	66.8M
2016	2.67081B	941.222M	874M	66.8M
2017	2.68242B	985.477M	915M	70M

2018	2.69999B	1.02242B	950M	72.6M
2019	2.72194B	1.06228B	987M	75.4M
2020	2.74766B	1.10036B	1.02B	78.1M
2021	2.77622B	1.14283B	1.06B	81.2M
2022	2.806B	1.18998B	1.11B	84.5M
2023	2.83713B	1.23484B	1.15B	87.7M
2024	2.86943B	1.28292B	1.19B	91.1M
2025	2.90293B	1.33162B	1.24B	94.6M
2026	2.9376B	1.382B	1.28B	98.1M
2027	2.97314B	1.43532B	1.33B	102M
2028	3.00922B	1.49092B	1.39B	106M
2029	3.04613B	1.54687B	1.44B	110M
2030	3.08401B	1.60363B	1.49B	114M
2031	3.12272B	1.66499B	1.55B	118M
2032	3.16168B	1.73024B	1.61B	123M
2033	3.20134B	1.79367B	1.67B	127M
2034	3.2418B	1.8609B	1.73B	132M
2035	3.28298B	1.93063B	1.79B	137M
2036	3.32473B	2.00378B	1.86B	142M
2037	3.36696B	2.08033B	1.93B	148M
2038	3.4097B	2.15873B	2.01B	153M
2039	3.45316B	2.24049B	2.08B	159M
2040	3.49717B	2.32463B	2.16B	165M

Table B1.6: Livestock Subsector Revenues and Costs (RCP8.5 Scenario)

Year	TOTAL Livestock adaptation revenue	TOTAL Livestock adaptation Cost	Livestock farmer training cost	Livestock extension officer cost
2015	2.65495B	1.68696B	1.69B	134M
2016	2.59261B	1.88244B	1.75B	134M
2017	2.51791B	2.00526B	1.86B	142M

2018	2.46538B	2.08569B	1.94B	148M
2019	2.42483B	2.16914B	2.02B	154M
2020	2.3965B	2.23848B	2.08B	159M
2021	2.37634B	2.32807B	2.16B	165M
2022	2.36092B	2.41439B	2.24B	171M
2023	2.35025B	2.50547B	2.33B	178M
2024	2.34309B	2.6004B	2.42B	185M
2025	2.33871B	2.70024B	2.51B	192M
2026	2.33695B	2.80156B	2.6B	199M
2027	2.33795B	2.90295B	2.7B	206M
2028	2.34114B	3.01277B	2.8B	214M
2029	2.34609B	3.12724B	2.91B	222M
2030	2.35282B	3.24247B	3.01B	230M
2031	2.36105B	3.36664B	3.13B	239M
2032	2.37065B	3.4927B	3.24B	248M
2033	2.38157B	3.62411B	3.37B	257M
2034	2.39385B	3.76043B	3.49B	267M
2035	2.4073B	3.90139B	3.62B	277M
2036	2.42177B	4.04823B	3.76B	287M
2037	2.43728B	4.19965B	3.9B	298M
2038	2.45386B	4.35595B	4.05B	309M
2039	2.47134B	4.52011B	4.2B	321M
2040	2.48942B	4.69501B	4.36B	333M

Table B1.7: Fisheries Subsector Revenues and Costs (Baseline Scenario)

Year	TOTAL Fisheries adaptation revenue	TOTAL Fisheries adaptation Cost	Fish Revenue[Marine]	Fish Revenue[Inland]	Fish Revenue[Aquaculture]	Fish farmers training cost	Fish extension officers cost
2015	887M	40.6M	625M	173M	89M	40.6M	12.5M
2016	931M	56.4M	646M	187M	97.8M	43.9M	12.5M

2017	977M	60.9M	669M	202M	107M	47.4M	13.5M
2018	1.03B	65.9M	691M	218M	118M	51.3M	14.6M
2019	1.08B	71.2M	715M	236M	129M	55.5M	15.7M
2020	1.14B	77M	739M	255M	142M	59.9M	17M
2021	1.2B	83.2M	765M	275M	156M	64.8M	18.4M
2022	1.26B	89.9M	791M	298M	171M	70.1M	19.9M
2023	1.33B	97.2M	818M	322M	188M	75.7M	21.5M
2024	1.4B	105M	846M	348M	207M	81.9M	23.2M
2025	1.48B	114M	875M	376M	227M	88.5M	25.1M
2026	1.56B	123M	904M	407M	249M	95.7M	27.2M
2027	1.65B	133M	935M	440M	273M	103M	29.4M
2028	1.74B	144M	967M	475M	300M	112M	31.7M
2029	1.84B	155M	1B	514M	330M	121M	34.3M
2030	1.95B	168M	1.03B	555M	362M	131M	37.1M
2031	2.07B	181M	1.07B	600M	397M	141M	40.1M
2032	2.19B	196M	1.11B	649M	436M	153M	43.4M
2033	2.33B	212M	1.14B	702M	479M	165M	46.9M
2034	2.47B	229M	1.18B	759M	526M	178M	50.7M
2035	2.62B	248M	1.22B	820M	578M	193M	54.8M
2036	2.79B	268M	1.27B	886M	634M	209M	59.2M
2037	2.96B	290M	1.31B	958M	697M	226M	64M
2038	3.15B	313M	1.35B	1.04B	765M	244M	69.2M
2039	3.36B	338M	1.4B	1.12B	840M	264M	74.8M
2040	3.58B	366M	1.45B	1.21B	922M	285M	80.9M

Table B1.8: Fisheries Subsector Revenues and Costs (RCP4.5 Scenario)

Year	TOTAL Fisheries adaptation revenue	TOTAL Fisheries adaptation Cost	Fish Revenue[Marine]	Fish Revenue[Inland]	Fish Revenue[Aquaculture]	Fish farmers training cost	Fish extension officers cost
2015	887M	48.7M	625M	173M	89M	48.7M	15M
2016	911M	67.6M	634M	182M	95.5M	52.7M	15M
2017	935M	73.8M	641M	192M	102M	57.5M	16.3M
2018	960M	79.9M	648M	203M	109M	62.2M	17.7M
2019	986M	86.6M	656M	214M	117M	67.4M	19.1M
2020	1.01B	93.5M	663M	225M	125M	72.8M	20.7M
2021	1.04B	101M	671M	238M	134M	78.9M	22.4M
2022	1.07B	110M	679M	250M	143M	85.6M	24.3M
2023	1.1B	119M	686M	264M	153M	92.7M	26.3M
2024	1.14B	129M	694M	278M	164M	100M	28.5M
2025	1.17B	140M	701M	293M	175M	109M	30.9M
2026	1.2B	151M	709M	309M	187M	118M	33.4M
2027	1.24B	164M	716M	325M	200M	127M	36.2M
2028	1.28B	177M	723M	342M	213M	138M	39.2M
2029	1.32B	192M	731M	360M	228M	149M	42.4M
2030	1.36B	207M	738M	379M	243M	161M	45.8M
2031	1.4B	224M	745M	399M	260M	175M	49.6M
2032	1.45B	243M	752M	419M	277M	189M	53.8M
2033	1.5B	263M	759M	441M	296M	205M	58.1M
2034	1.55B	284M	767M	464M	316M	222M	62.9M
2035	1.6B	308M	774M	488M	337M	240M	68.1M
2036	1.65B	333M	781M	513M	359M	259M	73.7M
2037	1.71B	361M	788M	540M	383M	281M	79.7M
2038	1.77B	390M	795M	567M	409M	304M	86.3M
2039	1.83B	422M	802M	596M	436M	329M	93.4M
2040	1.9B	457M	809M	627M	464M	356M	101M

Table B1.9: Fisheries Subsector Revenues and Costs (RCP8.5 Scenario)

Year	TOTAL Fisheries adaptation revenue	TOTAL Fisheries adaptation Cost	Fish Revenue[Marine]	Fish Revenue[Inland]	Fish Revenue[Aquaculture]	Fish farmers training cost	Fish extension officers cost
2015	887M	97.4M	625M	173M	89M	97.4M	29.9M
2016	893M	135M	621M	178M	93.3M	105M	29.9M
2017	890M	150M	611M	182M	96.6M	117M	33.2M
2018	889M	163M	602M	187M	100M	127M	36M
2019	888M	177M	593M	191M	104M	138M	39.1M
2020	887M	190M	584M	195M	108M	148M	42.1M
2021	887M	206M	576M	200M	112M	161M	45.6M
2022	888M	223M	567M	204M	116M	174M	49.3M
2023	888M	241M	559M	209M	120M	188M	53.4M
2024	889M	261M	550M	214M	124M	204M	57.8M
2025	889M	283M	542M	219M	129M	220M	62.6M
2026	890M	306M	533M	224M	134M	238M	67.7M
2027	892M	331M	525M	229M	138M	258M	73.2M
2028	893M	358M	516M	234M	143M	279M	79.2M
2029	895M	388M	508M	239M	148M	302M	85.7M
2030	897M	419M	500M	244M	154M	326M	92.7M
2031	899M	454M	492M	249M	159M	353M	100M
2032	902M	491M	483M	254M	164M	382M	109M
2033	905M	531M	475M	259M	170M	414M	117M
2034	907M	575M	467M	265M	176M	448M	127M
2035	911M	622M	459M	270M	182M	484M	138M
2036	914M	673M	451M	275M	188M	524M	149M
2037	918M	728M	443M	281M	194M	567M	161M
2038	922M	788M	435M	286M	201M	613M	174M
2039	926M	852M	427M	292M	207M	664M	188M
2040	930M	923M	419M	297M	214M	719M	204M

Table C1.1: Water Sector Revenues and Costs (Baseline Scenario)

Year	TOTAL Water Revenue	TOTAL Water cost	GW Revenue total	SW Revenue total	Management total cost - W	Infrastructure total cost - W	GW Revenue [Agriculture]	GW Revenue [Municipal]	GW Revenue [Industry]	SW Revenue [Agriculture]	SW Revenue [Municipal]	SW Revenue [Industry]	Cost of SW infrastructure	Cost of GW infrastructure	Cost of SW management	Cost of GW management
2015	1.05B	360M	821M	230M	30M	330M	1.31M	500M	320M	24.8M	125M	80M	245M	84.6M	22.3M	7.69M
2016	1.13B	387M	883M	247M	32.2M	355M	1.4M	537M	344M	26.6M	134M	86M	264M	90.9M	24M	8.26M
2017	1.21B	416M	948M	265M	34.6M	381M	1.51M	577M	370M	28.6M	144M	92.4M	283M	97.6M	25.8M	8.88M
2018	1.3B	447M	1.02B	285M	37.2M	409M	1.62M	620M	397M	30.8M	155M	99.3M	305M	105M	27.7M	9.54M
2019	1.4B	480M	1.1B	306M	40M	440M	1.74M	667M	427M	33.1M	167M	107M	327M	113M	29.8M	10.3M
2020	1.51B	516M	1.18B	329M	43M	473M	1.87M	716M	459M	35.5M	179M	115M	352M	121M	32M	11M
2021	1.62B	554M	1.26B	354M	46.2M	508M	2.01M	770M	493M	38.2M	192M	123M	378M	130M	34.4M	11.8M
2022	1.74B	596M	1.36B	380M	49.6M	546M	2.16M	827M	530M	41M	207M	132M	406M	140M	36.9M	12.7M
2023	1.87B	640M	1.46B	409M	53.3M	587M	2.32M	889M	569M	44.1M	222M	142M	436M	150M	39.7M	13.7M
2024	2.01B	688M	1.57B	439M	57.3M	631M	2.49M	955M	611M	47.4M	239M	153M	469M	162M	42.6M	14.7M
2025	2.16B	739M	1.69B	472M	61.6M	678M	2.68M	1.03B	657M	50.9M	257M	164M	504M	174M	45.8M	15.8M
2026	2.32B	794M	1.81B	507M	66.2M	728M	2.88M	1.1B	706M	54.7M	276M	177M	542M	187M	49.2M	17M
2027	2.49B	854M	1.95B	545M	71.1M	782M	3.09M	1.19B	759M	58.8M	296M	190M	582M	201M	52.9M	18.2M
2028	2.68B	917M	2.09B	586M	76.4M	841M	3.33M	1.27B	815M	63.2M	318M	204M	625M	215M	56.9M	19.6M
2029	2.88B	986M	2.25B	629M	82.1M	904M	3.57M	1.37B	876M	67.9M	342M	219M	672M	232M	61.1M	21M
2030	3.09B	1.06B	2.42B	676M	88.3M	971M	3.84M	1.47B	942M	73M	368M	235M	722M	249M	65.7M	22.6M
2031	3.32B	1.14B	2.6B	727M	94.9M	1.04B	4.13M	1.58B	1.01B	78.4M	395M	253M	776M	267M	70.5M	24.3M
2032	3.57B	1.22B	2.79B	781M	102M	1.12B	4.43M	1.7B	1.09B	84.2M	425M	272M	834M	287M	75.8M	26.1M
2033	3.84B	1.31B	3B	839M	110M	1.2B	4.76M	1.83B	1.17B	90.5M	456M	292M	896M	309M	81.5M	28.1M
2034	4.12B	1.41B	3.22B	902M	118M	1.29B	5.12M	1.96B	1.26B	97.3M	490M	314M	963M	332M	87.5M	30.2M
2035	4.43B	1.52B	3.46B	969M	126M	1.39B	5.5M	2.11B	1.35B	105M	527M	337M	1.03B	357M	94.1M	32.4M
2036	4.76B	1.63B	3.72B	1.04B	136M	1.5B	5.91M	2.27B	1.45B	112M	566M	362M	1.11B	383M	101M	34.8M
2037	5.12B	1.75B	4B	1.12B	146M	1.61B	6.35M	2.43B	1.56B	121M	609M	389M	1.19B	412M	109M	37.4M
2038	5.5B	1.88B	4.3B	1.2B	157M	1.73B	6.83M	2.62B	1.67B	130M	654M	419M	1.28B	442M	117M	40.2M
2039	5.91B	2.02B	4.62B	1.29B	169M	1.86B	7.34M	2.81B	1.8B	139M	703M	450M	1.38B	475M	125M	43.2M
2040	6.35B	2.17B	4.96B	1.39B	181M	1.99B	7.88M	3.02B	1.93B	150M	755M	483M	1.48B	511M	135M	46.4M

Table C1.2: Water Sector Revenues and Costs (RCP4.5 Scenario)

Year	TOTAL Water Revenue	TOTAL Water cost	GW Revenue total	SW Revenue total	Management total cost - W	Infrastructure total cost - W	GW Revenue [Agriculture]	GW Revenue [Municipal]	GW Revenue [Industry]	SW Revenue [Agriculture]	SW Revenue [Municipal]	SW Revenue [Industry]	Cost of SW infrastructure	Cost of GW infrastructure	Cost of SW management	Cost of GW management
2015	841M	432M	657M	184M	36M	396M	1.04M	400M	256M	19.8M	100M	64M	295M	101M	26.8M	9.23M

2016	904M	464M	706M	198M	38.7M	426M	1.12M	430M	275M	21.3M	107M	68.8M	316M	109M	28.8M	9.91M
2017	956M	504M	747M	209M	42M	462M	1.19M	455M	291M	22.6M	114M	72.8M	344M	118M	31.2M	10.8M
2018	1.03B	542M	802M	224M	45.2M	497M	1.27M	488M	313M	24.2M	122M	78.1M	369M	127M	33.6M	11.6M
2019	1.1B	584M	859M	240M	48.6M	535M	1.36M	523M	335M	25.9M	131M	83.7M	398M	137M	36.2M	12.5M
2020	1.18B	627M	924M	259M	52.2M	574M	1.47M	563M	360M	27.9M	141M	90M	427M	147M	38.8M	13.4M
2021	1.27B	675M	990M	277M	56.2M	618M	1.57M	603M	386M	29.9M	151M	96.4M	460M	158M	41.8M	14.4M
2022	1.35B	728M	1.06B	296M	60.7M	668M	1.68M	643M	412M	31.9M	161M	103M	496M	171M	45.1M	15.6M
2023	1.45B	783M	1.13B	317M	65.3M	718M	1.8M	690M	442M	34.2M	173M	110M	534M	184M	48.6M	16.7M
2024	1.55B	844M	1.21B	340M	70.3M	773M	1.93M	739M	473M	36.6M	185M	118M	575M	198M	52.3M	18M
2025	1.67B	908M	1.3B	364M	75.6M	832M	2.07M	793M	507M	39.3M	198M	127M	619M	213M	56.3M	19.4M
2026	1.79B	977M	1.4B	391M	81.4M	895M	2.22M	850M	544M	42.2M	213M	136M	666M	229M	60.5M	20.9M
2027	1.91B	1.05B	1.5B	419M	87.6M	964M	2.38M	911M	583M	45.2M	228M	146M	717M	247M	65.2M	22.5M
2028	2.05B	1.13B	1.6B	448M	94.3M	1.04B	2.55M	976M	624M	48.4M	244M	156M	772M	266M	70.2M	24.2M
2029	2.2B	1.22B	1.72B	481M	101M	1.12B	2.73M	1.05B	670M	51.9M	262M	168M	830M	286M	75.5M	26M
2030	2.36B	1.31B	1.85B	517M	109M	1.2B	2.94M	1.12B	720M	55.8M	281M	180M	892M	307M	81.1M	27.9M
2031	2.53B	1.41B	1.98B	554M	117M	1.29B	3.15M	1.21B	772M	59.8M	301M	193M	960M	331M	87.3M	30.1M
2032	2.71B	1.52B	2.12B	593M	126M	1.39B	3.37M	1.29B	826M	64M	323M	206M	1.03B	356M	94M	32.4M
2033	2.92B	1.63B	2.28B	637M	136M	1.49B	3.62M	1.39B	888M	68.8M	347M	222M	1.11B	383M	101M	34.8M
2034	3.13B	1.75B	2.44B	684M	146M	1.61B	3.88M	1.49B	952M	73.8M	372M	238M	1.2B	412M	109M	37.4M
2035	3.36B	1.89B	2.62B	734M	157M	1.73B	4.17M	1.6B	1.02B	79.2M	399M	256M	1.29B	443M	117M	40.3M
2036	3.6B	2.03B	2.81B	787M	169M	1.86B	4.47M	1.71B	1.1B	84.9M	428M	274M	1.38B	477M	126M	43.3M
2037	3.86B	2.18B	3.02B	844M	182M	2B	4.79M	1.84B	1.18B	91.1M	459M	294M	1.49B	513M	135M	46.6M
2038	4.14B	2.35B	3.24B	905M	196M	2.15B	5.14M	1.97B	1.26B	97.7M	492M	315M	1.6B	552M	146M	50.2M
2039	4.44B	2.53B	3.47B	971M	211M	2.32B	5.51M	2.11B	1.35B	105M	528M	338M	1.72B	594M	157M	54M
2040	4.77B	2.72B	3.72B	1.04B	226M	2.49B	5.92M	2.27B	1.45B	112M	567M	363M	1.85B	638M	168M	58M

Table C1.3: Water Sector Revenues and Costs (RCP8.5 Scenario)

Year	TOTAL Water Revenue	TOTAL Water cost	GW Revenue total	SW Revenue total	Management total cost - W	Infrastructure total cost - W	GW Revenue [Agriculture]	GW Revenue [Municipal]	GW Revenue [Industry]	SW Revenue [Agriculture]	SW Revenue [Municipal]	SW Revenue [Industry]	Cost of SW infrastructure	Cost of GW infrastructure	Cost of SW management	Cost of GW management
2015	631M	504M	493M	138M	42M	462M	783k	300M	192M	14.9M	75M	48M	344M	118M	31.2M	10.8M
2016	678M	542M	530M	148M	45.1M	496M	841k	322M	206M	16M	80.6M	51.6M	369M	127M	33.6M	11.6M
2017	648M	610M	506M	142M	50.8M	559M	804k	308M	197M	15.3M	77M	49.3M	416M	143M	37.8M	13M
2018	685M	659M	536M	150M	54.9M	604M	851k	326M	209M	16.2M	81.5M	52.2M	449M	155M	40.8M	14.1M
2019	725M	712M	567M	159M	59.3M	652M	901k	345M	221M	17.1M	86.3M	55.2M	485M	167M	44.1M	15.2M

2020	796M	759M	622M	174M	63.2M	696M	989k	379M	242M	18.8M	94.7M	60.6M	517M	178M	47M	16.2M
2021	843M	820M	658M	184M	68.3M	752M	1.05M	401M	257M	19.9M	100M	64.1M	559M	193M	50.8M	17.5M
2022	904M	882M	706M	198M	73.5M	808M	1.12M	430M	275M	21.3M	107M	68.8M	601M	207M	54.7M	18.8M
2023	966M	949M	755M	211M	79.1M	870M	1.2M	460M	294M	22.8M	115M	73.5M	647M	223M	58.8M	20.3M
2024	1.03B	1.02B	807M	226M	85.2M	937M	1.28M	491M	314M	24.4M	123M	78.6M	697M	240M	63.4M	21.8M
2025	1.1B	1.1B	860M	241M	91.8M	1.01B	1.37M	523M	335M	26M	131M	83.7M	751M	259M	68.3M	23.5M
2026	1.18B	1.19B	920M	257M	98.8M	1.09B	1.46M	560M	358M	27.8M	140M	89.6M	808M	278M	73.5M	25.3M
2027	1.27B	1.27B	991M	277M	106M	1.17B	1.57M	603M	386M	29.9M	151M	96.5M	868M	299M	78.9M	27.2M
2028	1.35B	1.37B	1.06B	296M	114M	1.26B	1.68M	645M	413M	32M	161M	103M	934M	322M	84.9M	29.3M
2029	1.45B	1.48B	1.13B	316M	123M	1.35B	1.8M	688M	440M	34.1M	172M	110M	1.01B	347M	91.5M	31.5M
2030	1.55B	1.59B	1.21B	340M	132M	1.45B	1.93M	739M	473M	36.6M	185M	118M	1.08B	373M	98.3M	33.9M
2031	1.66B	1.71B	1.29B	362M	142M	1.57B	2.06M	788M	504M	39.1M	197M	126M	1.17B	402M	106M	36.5M
2032	1.77B	1.84B	1.38B	387M	153M	1.69B	2.2M	843M	540M	41.8M	211M	135M	1.25B	432M	114M	39.3M
2033	1.9B	1.98B	1.48B	414M	165M	1.81B	2.35M	902M	577M	44.7M	225M	144M	1.35B	465M	123M	42.3M
2034	2.03B	2.13B	1.58B	443M	178M	1.95B	2.52M	964M	617M	47.8M	241M	154M	1.45B	500M	132M	45.5M
2035	2.17B	2.29B	1.69B	474M	191M	2.1B	2.69M	1.03B	660M	51.2M	258M	165M	1.56B	539M	142M	49M
2036	2.32B	2.47B	1.81B	507M	206M	2.26B	2.88M	1.1B	706M	54.7M	276M	177M	1.68B	580M	153M	52.7M
2037	2.48B	2.65B	1.94B	543M	221M	2.43B	3.08M	1.18B	756M	58.6M	295M	189M	1.81B	624M	165M	56.7M
2038	2.66B	2.86B	2.08B	582M	238M	2.62B	3.3M	1.27B	810M	62.8M	316M	203M	1.95B	671M	177M	61M
2039	2.84B	3.07B	2.22B	622M	256M	2.82B	3.53M	1.35B	866M	67.1M	338M	216M	2.1B	722M	191M	65.6M
2040	3.02B	3.31B	2.36B	661M	276M	3.04B	3.76M	1.44B	921M	71.4M	360M	230M	2.26B	778M	205M	70.8M

D1. Health Sector

All values are in USD (B = billion, M = million)

Table D1.1: Health Sector Revenues and Costs - Baseline Scenario

Year	TOTAL Health Revenues	TOTAL Health Cost	Health Facilities Revenue	Health workforce Revenue	Health Monitoring Revenue	Health facilities total cost	Health Workforce total cost	Monitoring and response total cost	Lost HF total cost
2015	3.12B	898M	2.1B	204M	815M	579M	102M	217M	0
2016	3.27B	934M	2.21B	214M	845M	600M	107M	225M	913k
2017	3.43B	970M	2.33B	225M	876M	622M	112M	234M	1.87M
2018	3.59B	1.01B	2.45B	236M	908M	645M	118M	242M	2.88M
2019	3.77B	1.05B	2.58B	247M	942M	669M	124M	251M	3.95M
2020	3.95B	1.09B	2.71B	259M	976M	693M	130M	260M	5.07M
2021	4.14B	1.13B	2.85B	272M	1.01B	719M	136M	270M	6.24M
2022	4.33B	1.17B	3B	285M	1.05B	745M	143M	280M	7.48M
2023	4.54B	1.22B	3.16B	299M	1.09B	772M	150M	290M	8.78M
2024	4.76B	1.27B	3.32B	314M	1.13B	800M	157M	301M	10.2M
2025	4.99B	1.32B	3.49B	330M	1.17B	830M	165M	312M	11.6M
2026	5.23B	1.37B	3.67B	346M	1.21B	860M	173M	323M	13.1M
2027	5.48B	1.42B	3.86B	363M	1.26B	892M	181M	335M	14.7M
2028	5.75B	1.48B	4.06B	381M	1.3B	924M	190M	347M	16.4M
2029	6.02B	1.54B	4.28B	399M	1.35B	958M	200M	360M	18.1M
2030	6.32B	1.6B	4.5B	419M	1.4B	993M	210M	373M	20M
2031	6.62B	1.66B	4.73B	440M	1.45B	1.03B	220M	387M	22M
2032	6.94B	1.72B	4.98B	461M	1.5B	1.07B	231M	401M	24M
2033	7.28B	1.79B	5.24B	484M	1.56B	1.11B	242M	416M	26.2M
2034	7.63B	1.86B	5.51B	508M	1.62B	1.15B	254M	431M	28.4M
2035	8B	1.93B	5.79B	533M	1.67B	1.19B	266M	447M	30.8M
2036	8.39B	2.01B	6.09B	559M	1.74B	1.23B	279M	463M	33.3M
2037	8.8B	2.09B	6.41B	586M	1.8B	1.28B	293M	480M	36M

2038	9.22B	2.17B	6.74B	615M	1.87B	1.32B	308M	498M	38.8M
2039	9.67B	2.25B	7.09B	645M	1.93B	1.37B	323M	516M	41.7M
2040	10.1B	2.34B	7.46B	677M	2B	1.42B	339M	535M	44.8M

Table D1.2: Health Sector Revenues and Costs - RCP4.5 Scenario

Year	TOTAL Health Revenues	TOTAL Health Cost	Health Facilities Revenue	Health workforce Revenue	Health Monitoring Revenue	Health facilities total cost	Health Workforce total cost	Monitoring and response total cost	Lost HF total cost
2015	2.5B	1.17B	1.68B	163M	652M	791M	122M	261M	0
2016	2.61B	1.23B	1.76B	171M	681M	826M	128M	272M	1.36M
2017	2.68B	1.31B	1.8B	177M	701M	880M	136M	288M	2.86M
2018	2.79B	1.37B	1.88B	185M	732M	921M	143M	301M	4.4M
2019	2.9B	1.44B	1.95B	194M	762M	966M	150M	315M	6.01M
2020	3.03B	1.5B	2.03B	204M	797M	1.01B	158M	329M	7.68M
2021	3.16B	1.58B	2.11B	213M	830M	1.06B	166M	344M	9.44M
2022	3.27B	1.66B	2.19B	222M	862M	1.11B	174M	361M	11.3M
2023	3.4B	1.74B	2.27B	232M	899M	1.17B	183M	378M	13.2M
2024	3.54B	1.83B	2.36B	243M	936M	1.22B	193M	396M	15.3M
2025	3.68B	1.92B	2.45B	254M	977M	1.28B	202M	414M	17.4M
2026	3.84B	2.01B	2.55B	267M	1.02B	1.34B	213M	434M	19.6M
2027	3.99B	2.11B	2.65B	279M	1.06B	1.41B	223M	454M	21.9M
2028	4.15B	2.22B	2.75B	292M	1.11B	1.48B	235M	476M	24.4M
2029	4.32B	2.32B	2.86B	305M	1.16B	1.55B	247M	498M	26.9M
2030	4.5B	2.43B	2.97B	320M	1.21B	1.62B	259M	520M	29.5M
2031	4.68B	2.55B	3.09B	335M	1.26B	1.7B	272M	545M	32.3M
2032	4.86B	2.68B	3.2B	350M	1.31B	1.79B	286M	571M	35.2M
2033	5.07B	2.8B	3.33B	368M	1.37B	1.87B	300M	597M	38.2M
2034	5.28B	2.94B	3.46B	385M	1.43B	1.96B	315M	625M	41.3M
2035	5.5B	3.08B	3.6B	404M	1.5B	2.05B	331M	654M	44.6M
2036	5.72B	3.23B	3.74B	423M	1.56B	2.15B	348M	685M	48M

2037	5.95B	3.39B	3.88B	442M	1.63B	2.25B	365M	717M	51.6M
2038	6.2B	3.55B	4.03B	463M	1.7B	2.36B	383M	751M	55.4M
2039	6.45B	3.73B	4.19B	485M	1.78B	2.48B	403M	787M	59.3M
2040	6.71B	3.91B	4.35B	508M	1.85B	2.6B	423M	824M	63.3M

Table D1.3: Health Sector Revenues and Costs - RCP8.5 Scenario

Year	TOTAL Health Revenues	TOTAL Health Cost	Health Facilities Revenue	Health workforce Revenue	Health Monitoring Revenue	Health facilities total cost	Health Workforce total cost	Monitoring and response total cost	Lost HF total cost
2015	2.25B	1.31B	1.52B	147M	587M	900M	131M	278M	0
2016	2.34B	1.37B	1.57B	154M	615M	943M	137M	291M	1.61M
2017	2.28B	1.54B	1.52B	151M	604M	1.07B	149M	317M	3.57M
2018	2.35B	1.63B	1.56B	157M	628M	1.13B	157M	334M	5.55M
2019	2.42B	1.73B	1.6B	164M	654M	1.2B	165M	352M	7.62M
2020	2.54B	1.79B	1.67B	174M	694M	1.24B	172M	367M	9.67M
2021	2.62B	1.9B	1.72B	181M	722M	1.32B	182M	387M	11.9M
2022	2.72B	2B	1.77B	189M	757M	1.39B	191M	406M	14.1M
2023	2.82B	2.1B	1.83B	198M	792M	1.46B	200M	427M	16.5M
2024	2.92B	2.21B	1.88B	207M	829M	1.54B	211M	449M	18.9M
2025	3.02B	2.34B	1.94B	217M	866M	1.62B	221M	472M	21.5M
2026	3.13B	2.46B	2B	227M	907M	1.71B	233M	496M	24.1M
2027	3.26B	2.58B	2.07B	238M	953M	1.79B	244M	520M	26.8M
2028	3.38B	2.72B	2.13B	249M	997M	1.88B	256M	547M	29.6M
2029	3.5B	2.86B	2.19B	260M	1.04B	1.98B	269M	575M	32.6M
2030	3.63B	3.01B	2.27B	273M	1.09B	2.08B	283M	604M	35.6M
2031	3.76B	3.17B	2.33B	285M	1.14B	2.2B	297M	636M	38.8M
2032	3.9B	3.34B	2.4B	299M	1.2B	2.31B	312M	668M	42.1M
2033	4.04B	3.51B	2.48B	312M	1.26B	2.44B	328M	702M	45.5M
2034	4.19B	3.7B	2.55B	327M	1.31B	2.57B	344M	738M	49M
2035	4.35B	3.89B	2.63B	342M	1.38B	2.7B	361M	776M	52.7M

2036	4.51B	4.1B	2.71B	358M	1.44B	2.85B	380M	816M	56.5M
2037	4.67B	4.31B	2.79B	375M	1.51B	2.99B	399M	858M	60.4M
2038	4.85B	4.53B	2.87B	393M	1.59B	3.15B	419M	901M	64.4M
2039	5.03B	4.78B	2.96B	411M	1.66B	3.32B	440M	948M	68.6M
2040	5.2B	5.04B	3.03B	429M	1.73B	3.51B	463M	998M	73.1M

E1. Cities Sector

All values are in USD (B = billion, M = million)

Table E1.1: Cities Sector - Baseline Scenario

Year	TOTAL Cities Revenue	TOTAL Cities Cost	Total Roads Revenues	Total Buildings Revenue	Total Roads Cost	Total Buildings Cost
2015	15.7B	5.34B	8.99B	6.76B	3.64B	1.71B
2016	16.4B	5.69B	9.24B	7.11B	3.86B	1.83B
2017	17B	6.04B	9.49B	7.49B	4.08B	1.96B
2018	17.6B	6.41B	9.75B	7.89B	4.31B	2.1B
2019	18.3B	6.79B	10B	8.31B	4.55B	2.25B
2020	19B	7.19B	10.3B	8.76B	4.79B	2.4B
2021	19.8B	7.6B	10.6B	9.22B	5.04B	2.56B
2022	20.6B	8.03B	10.9B	9.71B	5.3B	2.73B
2023	21.4B	8.47B	11.2B	10.2B	5.57B	2.91B
2024	22.2B	8.93B	11.5B	10.8B	5.84B	3.1B
2025	23.1B	9.41B	11.8B	11.4B	6.12B	3.29B
2026	24.1B	9.91B	12.1B	12B	6.4B	3.5B
2027	25B	10.4B	12.4B	12.6B	6.7B	3.72B
2028	26B	11B	12.8B	13.3B	7B	3.95B
2029	27.1B	11.5B	13.1B	14B	7.31B	4.2B
2030	28.2B	12.1B	13.5B	14.7B	7.63B	4.45B
2031	29.4B	12.7B	13.9B	15.5B	7.96B	4.73B
2032	30.6B	13.3B	14.3B	16.3B	8.3B	5.01B
2033	31.8B	14B	14.6B	17.2B	8.65B	5.31B
2034	33.2B	14.6B	15B	18.1B	9.01B	5.63B
2035	34.5B	15.3B	15.5B	19.1B	9.37B	5.96B
2036	36B	16.1B	15.9B	20.1B	9.75B	6.31B
2037	37.5B	16.8B	16.3B	21.2B	10.1B	6.68B
2038	39.1B	17.6B	16.8B	22.3B	10.5B	7.07B

2039	40.7B	18.4B	17.2B	23.5B	10.9B	7.48B
2040	42.4B	19.3B	17.7B	24.7B	11.4B	7.91B

Table E1.2: Cities Sector Revenues and Costs - RCP4.5 Scenario

Year	TOTAL Cities Revenue	TOTAL Cities Cost	Total Roads Revenues	Total Buildings Revenue	Total Roads Cost	Total Buildings Cost
2015	12.6B	6.41B	7.19B	5.4B	4.36B	2.05B
2016	13B	6.82B	7.33B	5.66B	4.63B	2.2B
2017	13.2B	7.32B	7.35B	5.84B	4.94B	2.38B
2018	13.6B	7.76B	7.47B	6.11B	5.22B	2.54B
2019	14B	8.23B	7.58B	6.38B	5.51B	2.72B
2020	14.4B	8.69B	7.72B	6.69B	5.79B	2.9B
2021	14.8B	9.19B	7.84B	6.99B	6.09B	3.1B
2022	15.2B	9.72B	7.93B	7.27B	6.41B	3.31B
2023	15.7B	10.2B	8.05B	7.6B	6.72B	3.52B
2024	16.1B	10.8B	8.17B	7.93B	7.04B	3.75B
2025	16.6B	11.4B	8.29B	8.29B	7.37B	3.99B
2026	17.1B	11.9B	8.42B	8.66B	7.7B	4.23B
2027	17.6B	12.5B	8.55B	9.04B	8.04B	4.49B
2028	18.1B	13.2B	8.67B	9.44B	8.39B	4.77B
2029	18.7B	13.8B	8.8B	9.87B	8.73B	5.05B
2030	19.3B	14.4B	8.96B	10.3B	9.08B	5.34B
2031	19.9B	15.1B	9.09B	10.8B	9.44B	5.66B
2032	20.5B	15.8B	9.21B	11.2B	9.82B	5.99B
2033	21.1B	16.5B	9.37B	11.8B	10.2B	6.33B
2034	21.8B	17.3B	9.51B	12.3B	10.6B	6.69B
2035	22.5B	18B	9.66B	12.9B	11B	7.06B
2036	23.2B	18.8B	9.81B	13.4B	11.4B	7.45B
2037	24B	19.6B	9.95B	14B	11.8B	7.87B
2038	24.8B	20.5B	10.1B	14.7B	12.2B	8.3B
2039	25.6B	21.4B	10.3B	15.3B	12.6B	8.76B

2040	26.4B	22.3B	10.4B	16B	13B	9.23B

Table E1.3: Cities Sector Revenues and Costs - RCP8.5 Scenario

Year	TOTAL Cities Revenue	TOTAL Cities Cost	Total Roads Revenues	Total Buildings Revenue	Total Roads Cost	Total Buildings Cost
2015	11B	6.95B	6.29B	4.73B	4.73B	2.22B
2016	11.3B	7.39B	6.38B	4.94B	5.01B	2.38B
2017	10.7B	8.14B	5.97B	4.78B	5.5B	2.64B
2018	10.9B	8.66B	5.96B	4.93B	5.82B	2.84B
2019	11B	9.19B	5.95B	5.08B	6.15B	3.04B
2020	11.4B	9.64B	6.08B	5.37B	6.42B	3.22B
2021	11.6B	10.2B	6.08B	5.54B	6.75B	3.44B
2022	11.9B	10.7B	6.12B	5.76B	7.07B	3.66B
2023	12.1B	11.3B	6.16B	5.98B	7.39B	3.88B
2024	12.4B	11.8B	6.19B	6.21B	7.72B	4.12B
2025	12.6B	12.4B	6.21B	6.43B	8.06B	4.38B
2026	12.9B	13B	6.24B	6.68B	8.39B	4.64B
2027	13.3B	13.6B	6.3B	6.96B	8.71B	4.9B
2028	13.6B	14.2B	6.33B	7.22B	9.06B	5.18B
2029	13.8B	14.9B	6.36B	7.49B	9.41B	5.48B
2030	14.2B	15.5B	6.4B	7.79B	9.75B	5.78B
2031	14.5B	16.2B	6.42B	8.07B	10.1B	6.1B
2032	14.8B	16.9B	6.46B	8.38B	10.5B	6.43B
2033	15.2B	17.6B	6.49B	8.7B	10.8B	6.78B
2034	15.5B	18.3B	6.52B	9.03B	11.2B	7.14B
2035	15.9B	19.1B	6.55B	9.37B	11.5B	7.52B
2036	16.3B	19.8B	6.58B	9.72B	11.9B	7.91B
2037	16.7B	20.6B	6.61B	10.1B	12.3B	8.32B
2038	17.1B	21.4B	6.65B	10.5B	12.7B	8.74B
2039	17.5B	22.2B	6.68B	10.9B	13B	9.18B
2040	17.9B	23.1B	6.68B	11.2B	13.4B	9.66B