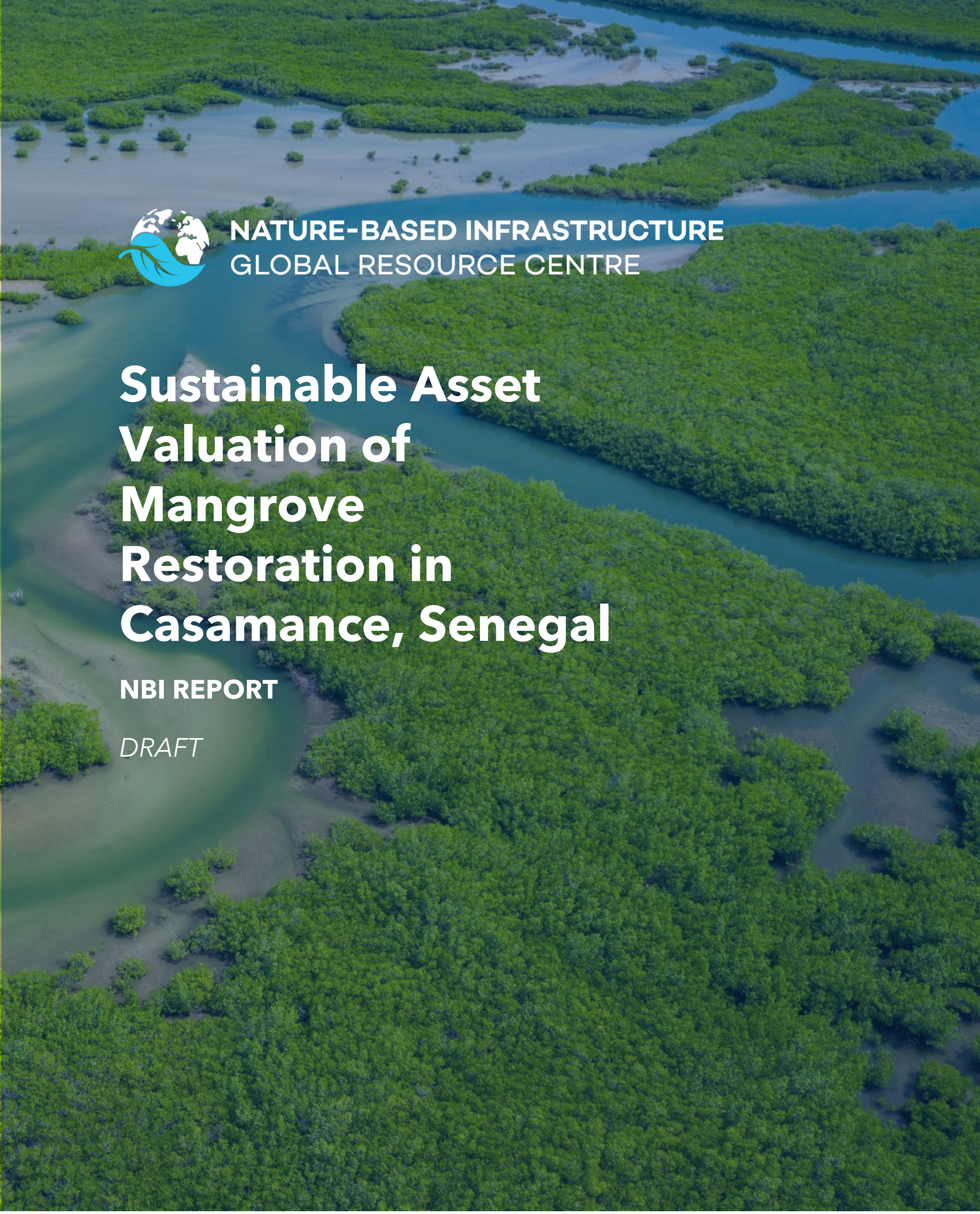

NATURE-BASED INFRASTRUCTURE
GLOBAL RESOURCE CENTRE

Sustainable Asset Valuation of Mangrove Restoration in Casamance, Senegal

NBI REPORT

DRAFT

IISD International Institute for Sustainable Development

Socodevi

En partenariat avec Canada

Edoardo Carlucci

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The **Nature-Based Infrastructure (NBI) Global Resource Centre** aims to improve the track record of NBI to deliver infrastructure services and adapt to climate change while delivering other environmental, social, and economic benefits. We provide data, training, and customized valuations of NBI projects, based on the latest innovations in systems thinking and financial modelling.

The Centre is an initiative led by IISD, with the financial support of the Global Environment Facility (GEF) and the MAVA Foundation, in partnership with UNIDO.

Sustainable Asset Valuation (SAVi) of Mangrove Restoration in Casamance, Senegal

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Written by Edoardo Carlucci (IISD)

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NATURE-BASED INFRASTRUCTURE GLOBAL RESOURCE CENTRE

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Executive Summary

The Casamance region, located in southwestern Senegal, is home to approximately 752,900 hectares of mangroves, globally recognized for their exceptional biodiversity. However, these ecosystems have declined by about 35% since the 1980s, with a biodiversity loss rate three to five times higher than that observed in terrestrial forests (PMO-NATURELLES). This degradation results from the interaction of environmental and socio-economic pressures, notably rainfall variability linked to climate change and the salinization of agricultural land. It is also exacerbated by gender inequalities that limit women's adaptive capacities, particularly their access to land, water, credit, equipment, climate information, and decision-making spaces. The burden of domestic work, low literacy levels, and limited participation in natural resource governance increase their dependence on mangrove resources and reduce their ability to adopt sustainable practices, thereby intensifying pressure on this ecosystem. This ecological crisis threatens both biodiversity and the resilience of local communities dependent on mangrove ecosystems (PMO-NATURELLES).

Figure ES1. Mangroves in Casamance

Source: International Institute for Sustainable Development.

This Sustainable Asset Valuation assesses mangrove restoration over the period from 2024 to 2050 under a range of flood hazard and climate scenarios. Flood hazard scenarios are defined based on the frequency of major flood events. Accordingly, the analysis compares moderate flood-frequency scenarios, in which major flood events occur less often (approximately once every five years), with severe flood-frequency scenarios, in which major flood events occur more often (approximately once every two years). In parallel, the valuation examines future climate conditions under two emissions pathways:[1] SSP3-7.0,[2] representing an intermediate emissions trajectory, and SSP5-8.5,[3] representing a high-emissions trajectory.

Each of the four resulting scenario combinations is evaluated under four levels of assumed infrastructure damage reduction: 2.5%, 5%, 7.5%, and 10%. These values reflect uncertainty in how effectively restored mangroves can reduce flood-related damage. The 2.5% level represents a conservative, low-protection case, while the 10% level reflects an optimistic upper limit of mangrove protection efficiency (Table ES1).

This approach captures the uncertainty associated with restoration success and helps decision-makers understand how variations in protective performance influence the overall viability of the project.

Table ES1. Reduction to infrastructure damage due to the protection efficiency of the mangrove restoration project

Protection efficiency	Reduction in infrastructure damage
High	10%
Medium/high	7.5%
Medium/low	5%
Low	2.5%

Source: Author.

The results demonstrate consistently positive economic outcomes across all scenarios.

Under moderate flood-frequency scenarios, the net present value (NPV) ranges from XOF 6.47 billion under a 2.5% reduction in infrastructure damage to XOF 12.45 billion under a 10% reduction in infrastructure damage. Under severe flood-frequency scenarios, NPVs are higher, ranging from XOF 9.3 billion at 2.5% damage reduction to XOF 24.10 billion under a 10% reduction in infrastructure damage combined with more frequent (severe) flooding.

Benefit-cost ratios (BCR) consistently exceed 2.0, with returns ranging from 2.27 to 5.71, meaning each XOF invested generates XOF 2.27 to XOF 5.71 in avoided damage and ecosystem benefits.

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[1] SSPs are scenarios that imagine different ways in which the world could evolve in the future, such as economic growth, population, technologies, or public policies. They are used to estimate how these developments may influence greenhouse gas emissions and, therefore, the climate.
[2] SSP3-7.0 corresponds to a scenario in which greenhouse gas emissions remain high throughout the century.
[3] SSP5-8.5 corresponds to a scenario in which emissions remain very high, leading to even greater warming.

Performance improves markedly with both higher flood frequency and greater protection efficiency, confirming that mangrove restoration provides increasing returns in high-risk environments where climate hazards intensify.

Across climate emission pathways, the project demonstrates strong and consistent performance under both SSP scenarios. The net present value (NPV) ranges from XOF 6.01 billion under SSP5 8.5 with a 2.5% reduction in infrastructure damage, to XOF 14.13 billion under SSP3 7.0 with a 10% reduction. The SSP3 7.0 pathway consistently delivers higher returns than SSP5 8.5, reflecting the earlier and more frequent flood events projected for the mid-century period (2024 to 2050).

Even under conditions of low protection efficiency (2.5% damage reduction) and high emissions, the project remains economically viable, achieving a benefit-cost ratio (BCR) of 2.18. These results confirm the robustness of mangrove restoration as a climate adaptation strategy across a range of future climate scenarios.

Beyond flood protection, mangrove restoration delivers a wide range of benefits and avoided costs, valued as follows:

- **Jobs creation**: Restoration activities generate XOF 2.8 billion in local employment, with communities leading planting, monitoring, and maintenance while building practical nursery and restoration skills that strengthen stewardship and social cohesion.
- **Local economic growth**: Economic activities increase by about XOF 958 million, driven by revitalized fisheries (XOF 592 million), higher agricultural production (XOF338 million), and added seafood harvesting (XOF 28 million). Healthier soils and groundwater stabilize crop yields and incomes, while expanded nursery habitats raise juvenile fish survival and support artisanal fishers and cooperatives.
- **Essential resources for households**: The supply of food, wood, and safer water totals XOF 2.0 billion in value. Households secure XOF 1.8 billion in food for direct consumption, sustainable wood contributes modestly (XOF 29,283), and improved water quality yields XOF 173 million, reducing market dependence and freeing time for education and other income generation.
- **Health gains and cost savings**: Improved air quality from restored mangroves lowers respiratory disease, reducing clinic visits and medical costs. Over 27 years, avoided health expenditures total XOF 919 million.
- **Climate mitigation and finance**: Carbon sequestration is valued at XOF 2.8 billion, using a social cost of carbon of USD 50 per tonne of CO_2e. This captures global welfare benefits and positions the project for voluntary carbon market opportunities.

This diversified range of benefits demonstrates that nature-based infrastructure simultaneously addresses coastal protection, livelihood security, climate mitigation, and ecosystem health.

A gender-differentiated analysis reveals that women capture approximately XOF 735 million (15.7% of total benefits),[4] substantially less than their proportional population representation. Women's primary benefits derive from avoided health care costs (60.7%, XOF 446 million), reflecting disproportionate climate vulnerabilities and restricted health care access, followed by agricultural revenues (12.9%, XOF 95 million) and fishery-related income comprising artisanal fishing (12.2%, XOF 89 million) and seafood harvesting (3.8%, XOF 28 million). Job creation provides 10.3% (XOF 75 million) in direct restoration employment. However, persistent barriers including limited resource rights, exclusion from governance decision making, and restricted access to technical knowledge and finance severely constrain women's ability to fully leverage these opportunities. Patriarchal norms and customary mobility restrictions create systemic obstacles preventing economic gains from translating into meaningful improvements in women's autonomy and well-being.

The findings from this assessment offer valuable insights for a range of stakeholders involved in the management and development of Casamance ecosystems:

- **For coastal communities and marine conservation authorities**, these findings establish mangrove restoration as a multifunctional adaptation strategy that strengthens flood defences, improves water quality, and enhances carbon storage, while generating measurable social and economic gains. Community stewardship through active participation in restoration design and management, combined with transparent and equitable benefit-sharing mechanisms, is essential to sustain both ecosystem health and social resilience.
- **Environmental agencies and public authorities** can use these results to demonstrate progress on mangrove restoration—a priority under Senegal's National Adaptation Plan (NAP). The Natur'ELLES initiative operationalizes the plan's vision of a productive, diversified, clean, and climate resilient coastline by tackling coastal erosion, salinization, and livelihood vulnerability through reforestation in Sine-Saloum.
- **For local communities**, mangrove restoration results in tangible improvements in livelihoods through paid jobs created by the project in planting and maintenance, improved access to fisheries and agricultural resources, and diversified sources of income. Women can particularly benefit from increased opportunities in shellfish harvesting, aquaculture, fish processing, and restoration-related jobs. To ensure equitable outcomes, it is essential to establish mechanisms that promote women's participation in governance structures, strengthen their rights of access to resources, and ensure a transparent distribution of benefits.
- **Private sector investors and development financiers** will recognize strong potential for revenue streams through enhanced fishery and agricultural productivity, carbon credit markets, and employment generation, making outcome-based financing, payment for ecosystem services, and public-private partnerships attractive

[4] The percentage of 15.7% represents the share of total benefits allocated to women. It is obtained by dividing the amount of benefits attributed to women (XOF 735,340,848) by the total amount of overall benefits (XOF 4,682,117,201).

vehicles for scaling restoration at landscape levels while aligning commercial interests with ecosystem and community well-being.

By aligning economic incentives with ecological stewardship, social inclusion, and gender equality, mangrove restoration in Casamance offers a replicable blueprint for nature-based infrastructure that simultaneously safeguards coastal infrastructure, supports sustainable livelihoods, and advances climate adaptation for vulnerable populations dependent on mangrove ecosystems.

Table ES2. Summary table of integrated cost-benefit analysis based on flood frequency scenarios, figures in millions XOF, discounted at 3.5%

Reduction in damage to infrastructure	Reduction in damage 10%		Reduction in damage 7.5%		Reduction in damage 5%		Reduction in damage 2.5%	
Flood frequency	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**
Direct costs								
Construction costs	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Operational and maintenance costs	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1
Total costs	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**
Avoided costs								
Avoided damage to infrastructure	7,979.7	19,630.0	5,984.8	14,722.5	3,989.9	9,815.0	1,994.9	4,907.5
Avoided health-related costs	919.8	919.8	919.8	919.8	919.8	919.8	919.8	919.8
Added benefits								
Fishery revenue	592.9	592.9	592.9	592.9	592.9	592.9	592.9	592.9
Agricultural revenue	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0
Seafood harvest revenues	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Drinking water supply	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5
Food supply	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1
Wood supply	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Job creation	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4
Carbon sequestration	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3

Reduction in damage to infrastructure	Reduction in damage 10%		Reduction in damage 7.5%		Reduction in damage 5%		Reduction in damage 2.5%	
Total benefits and avoided costs	**17,575.8**	**29,226.0**	**15,580.8**	**24,318.5**	**13,585.9**	**19,411.0**	**11,591.0**	**14,503.5**
KPIs								
Net present value (NPV)	**12,459.7**	**24,109.9**	**10,464.7**	**19,202.4**	**8,469.8**	**14,294.9**	**6,474.8**	**9,387.4**
Benefit-to-cost ratio (BCR)	**3.44**	**5.71**	**3.05**	**4.75**	**2.66**	**3.79**	**2.27**	**2.83**
Internal rate of return (IRR)	**138.1%**	**217.2%**	**128.8%**	**191.7%**	**117.7%**	**163.3%**	**103.9%**	**130.0%**

Source: Author.

Table ES3. Summary table of integrated cost-benefit analysis based on SSP scenarios, figures in millions XOF, discounted at 3.5%

	Reduction in damage 10%		Reduction in damage 7.5%		Reduction in damage 5%		Reduction in damage 2.5%	
	SSP5-8.5	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**
Direct costs								
Construction costs	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Operational and maintenance costs	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1
Total costs	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**
Avoided costs								
Avoided damage to infrastructure	6,142.9	9,658.3	4,607.2	7,243.7	3,071.5	4,829.1	1,535.7	2,414.6
Avoided health-related costs	919.8	919.8	919.8	919.8	919.8	919.8	919.8	919.8
Added benefits								

	Reduction in damage 10%		Reduction in damage 7.5%		Reduction in damage 5%		Reduction in damage 2.5%	
Fishery revenue	592.9	592.9	592.9	592.9	592.9	592.9	592.9	592.9
Agricultural revenue	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0
Seafood harvest revenues	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Drinking water supply	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5
Food supply	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1
Wood supply	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Job creation	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4
Carbon sequestration	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3
Total benefits and avoided costs	**15,739.0**	**19,254.3**	**14,203.2**	**16,839.7**	**12,667.5**	**14,425.2**	**11,131.8**	**12,010.6**
KPIs								
Net present value (NPV)	**10,622.8**	**14,138.2**	**9,087.1**	**11,723.6**	**7,551.4**	**9,309.0**	**6,015.6**	**6,894.5**
Benefit-to-cost ratio (BCR)	**3.08**	**3.76**	**2.78**	**3.29**	**2.48**	**2.82**	**2.18**	**2.35**
Internal rate of return (IRR)	**137.1%**	**162.3%**	**126.6%**	**146.7%**	**114.9%**	**129.4%**	**101.5%**	**109.7%**

Source: Author.

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Glossary

Benefit-to-cost ratio (BCR)	A ratio that measures the efficiency of an investment by comparing the economic benefits (including externalities) to the economic costs associated with a project or initiative over a specified period. It provides a holistic view of the investment's economic viability, considering broader impacts beyond direct financial returns.
West African CFA franc	Official currency of eight West African countries, including Senegal. Issued by the Central Bank of West African States (BCEAO), it is formally called the West African CFA franc. The CFA originally stood for Communauté Financière Africaine (African Financial Community).
Discounting	A financial technique used to adjust the value of future costs or benefits to their present value, reflecting the time value of money. It involves applying a discount rate to future cash flows to determine their current worth, facilitating comparisons and decision making across different time periods. Discounting allows analysts to account for the opportunity cost of capital and the preference for receiving benefits sooner rather than later.
Indicator	Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (UNEP, 2014).
Internal rate of return (IRR)	The discount rate that makes the net present value (NPV) of the economic benefits (including externalities) of a project or initiative equal to zero. It indicates the rate of return at which the project's economic benefits balance its costs, encompassing all economic impacts.
Methodology	The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).
Model validation	The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net benefits	The cumulative amount of monetary benefits accrued across all sectors and actors over the lifetime of investments compared to the baseline, reported by the intervention scenario.
Net present value	The difference between the present value of the economic benefits (including externalities) and the present value of the economic costs associated with a project or initiative over its lifetime. It quantifies the net monetary impact of the economic aspects of the project, considering all relevant costs and benefits.
Scenarios	Expectations about possible future events used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

1.0 Introduction

1.1 Natur'ELLES Project

Natur'ELLES is a climate adaptation initiative designed to strengthen vulnerable coastal communities in Senegal, with particular emphasis on women who depend on mangrove ecosystems. Operating across the Sine-Saloum Delta and Casamance region, the project pursues three interconnected objectives: enhancing ecosystem biodiversity through nature-based infrastructure, establishing more equitable resource governance structures, and expanding economic returns communities receive from conservation activities. By addressing these dimensions simultaneously, the initiative helps coastal populations build resilience to climate change while protecting the environmental functions that mangroves provide (PMO-NATURELLES).

Led by Socodevi and implemented with international partnership (IUCN, IISD, and Tayo Climate Partners), this three-year program runs from March 2023 through March 2026 with a budget of CAD 20 million from Global Affairs Canada. The project directly reaches 8,000 individuals, including at least 5,600 women and young women, across 123 communities situated within designated Indigenous and Community Conserved Areas (APAC, Aires du patrimoine communautaire) and a network of marine protected areas (AMP, Réseau des aires marines protégées)[5] (PMO-NATURELLES).

The mangrove ecosystems targeted by Natur'ELLES encompass a substantial territory: 180,000 hectares in Sine-Saloum and 752,900 hectares in Casamance. These vital ecosystems have contracted approximately 35% since the 1980s due to climate variability and human pressures. To reverse this trajectory, the project integrates traditional ecological knowledge with contemporary restoration techniques, spanning mangrove rehabilitation, sustainable fishing practices, and economic opportunities for women (PMO-NATURELLES).

This provides the analytical foundation for applying the Sustainable Asset Valuation (SAVi) methodology to evaluate the ecosystem services of mangroves restoration and guide investment decisions in nature-based infrastructure (PMO-NATURELLES).

1.2 Environmental and Socio-Economic Challenges in Casamance Region

Casamance, a region in southwestern Senegal, faces interconnected environmental and socio-economic pressures that threaten traditional livelihoods and social security systems (Schönmann, A., & Haller, T., 2025).

Known for its fertile landscape and long tradition of rice cultivation, Casamance experiences significant rainfall variability that directly affects agricultural productivity. Since the 1960s,

[5] Marine protected areas and Indigenous.

reduced rainfall has altered seasonal patterns, with the rainy season now starting later and ending earlier. This compression forces farmers to conduct intensive work within shorter timeframes, while reduced rainfall certainty complicates agricultural planning. Salinization of rice fields compounds this challenge, particularly in areas where inadequate maintenance of irrigation dikes allows saltwater intrusion from nearby rivers, rendering cultivated land less productive (Schönmann, A., & Haller, T., 2025).

These environmental changes have driven a longstanding pattern of labour migration in Casamance. While seasonal migration to urban centers like Dakar or coastal tourist areas for income-generating work has persisted for decades, contemporary environmental pressures make it increasingly difficult for workers to balance temporary urban employment with agricultural obligations. The financial burden of travel combined with shortened agricultural seasons creates practical barriers to returning home for critical farming tasks, resulting in persistent labour shortages in both private and collective rice fields (Schönmann, A., & Haller, T., 2025).

1.3 Gender-Based Vulnerabilities

Women in Casamance face multiple vulnerabilities that constrain their adaptive capacity in the context of climate change. They bear primary responsibility for water and energy provisioning while experiencing limited access to paid employment, creating high dependence on natural resources. Work overload and low literacy levels restrict their ability to develop income-generating activities, access climate adaptation information, seek employment, or occupy decision-making positions. Patriarchal systems exclude them from governance structures managing protected areas and local fisheries committees, limiting their participation in public life. Gender-based violence, including early pregnancy and female genital mutilation, remains prevalent in targeted zones and constitutes a significant barrier to women's empowerment. Women's economic activities are characterized by difficult working conditions, inadequate protective equipment, and mobility constraints for accessing fisheries resources. Low productivity of income-generating activities constrains revenues and increases vulnerability, exposing women more directly to climate change effects and food insecurity (PMO-NATURELLES).

Conservation measures and restrictions on natural resource exploitation in marine-protected areas are often perceived as limiting economic activities and food security for populations dependent on fishing. Women face particular vulnerability due to limited access to knowledge, equipment, and income needed for adaptation, weak organizational capacity, and minimal involvement in decision-making spaces regulating resource access and local development. The value chain systems for sectors dominated by women operate within unfavorable market conditions that limit profitability, perpetuating an inability to meet their diverse practical and strategic needs (PMO-NATURELLES).

Given the intertwined ecological and socio-economic challenges facing the Casamance region, integrating ecosystem restoration with community-based sustainable management strategies is essential to protect mangrove ecosystems, enhance resilience to climate change, and support the well-being of dependent populations (WIACO, 2025).

1.4 Climate Change and Integrated Coastal Zone Management in Senegal

Senegal's National Adaptation Plan for the Coastal Zone (PNAZC) sets national priorities to strengthen the resilience of coastal ecosystems, communities, and infrastructure. It identifies risk hotspots and adaptation needs, defines investment and policy priorities, and establishes roles for national, regional, and local institutions to implement coastal adaptation effectively. The plan is structured around four pillars:

1. improving coastal protection and land use planning,
2. strengthening the adaptive capacity of coastal communities,
3. enhancing multi-level governance and coordination,
4. and improving climate information, monitoring, and knowledge sharing.

It promotes integrated coastal management and emphasizes nature-based solutions alongside hard and soft protection measures, guiding project design, budgeting, and sequencing across Senegal's coastline. By aligning technical measures with community participation and gender-responsive approaches, the PNAZC aims to safeguard natural habitats and livelihoods while reducing physical, social, and economic vulnerabilities as climate pressures intensify (MEDD, 2022).

1.5 About This Report

This report constitutes the Casamance component of a two-part Sustainable Asset Valuation (SAVi) assessment of mangrove restoration in Senegal, with the companion report covering the Sine-Saloum region (see Sine-Saloum report here).

The intervention zones in Casamance include 82 villages with a total population of 155,806 people across:

- Marine Protected Areas: AMP Kalolaal-Blouf-Fogny with 45 villages and 106,365 people, and AMP Kalone-Bliss-Kassa with 14 villages and 31,400 people
- Community Indigenous Heritage Areas: APAC Kawawana with eight villages and 12,000 people, APAC Kamite with six villages and 3,947 people, and APAC Kourye with three villages and 847 people

Local populations depend heavily on fishing and natural resource exploitation, particularly women who derive substantial income from fishing and seafood harvesting, especially oysters.

Across these five sites, the project plans to restore 207 hectares of degraded mangroves and preserve 28,796 hectares of existing mangroves. Although approximately 47,851 people live directly within these protected areas, the report also examines potential impacts at the broader scale of the departments of Bignona and Bounkiling, recognizing that improvements in ecosystem services benefit coastal communities beyond the project's immediate boundaries.

Figure 1. Site visits

Source: International Institute for Sustainable Development (IISD).

Figure 2. Causal loop diagram workshop

Source: IISD.

The report applies the SAVi methodology to assess the economic, environmental, and social value generated by mangrove restoration in Casamance. The analysis combines systems mapping, climate scenario modelling, and an Excel-based model to produce an integrated cost-benefit analysis, providing key performance indicators such as the benefit-cost ratio, net present value, and internal rate of return.

This analysis is based on a partnership coordinated between Socodevi and the project's implementing partners: Casades, Carem, Nebeday, Refepas, Tayo, and IUCN. Field visits and participatory workshops helped ground the analysis in local ecological, social, and institutional realities. By integrating stakeholder perspectives with quantitative modelling, the SAVi results demonstrate how mangrove restoration in Casamance can strengthen coastal resilience, support sustainable livelihoods, and contribute to national climate change adaptation objectives.

Participatory workshops held in Kafountine and Baïla brought together a diverse group of stakeholders: 31 participants in Kafountine (25 men and six women) and 29 in Baïla (18 men and 11 women). The workshops included representatives from NGOs, academic institutions, community leaders, women's associations, fisheries cooperatives, and agricultural groups. These collaborative workshops facilitated the co-creation and validation of the causal loop diagram, enriched by stakeholder insights on seasonal constraints, informal resource governance, and emerging local threats. The fieldwork captured place-specific dynamics, ensuring that priorities such as equitable benefit sharing and women's empowerment were integrated into project design and that the assessment accurately reflects community realities and needs.

By integrating stakeholder insights with quantitative modeling, the SAVi results demonstrate how mangrove reforestation in Casamance can strengthen coastal resilience, support sustainable livelihoods for women and vulnerable groups, and advance climate adaptation goals.

This report is structured to provide a cohesive analysis of the potential benefits of mangrove reforestation in Casamance.

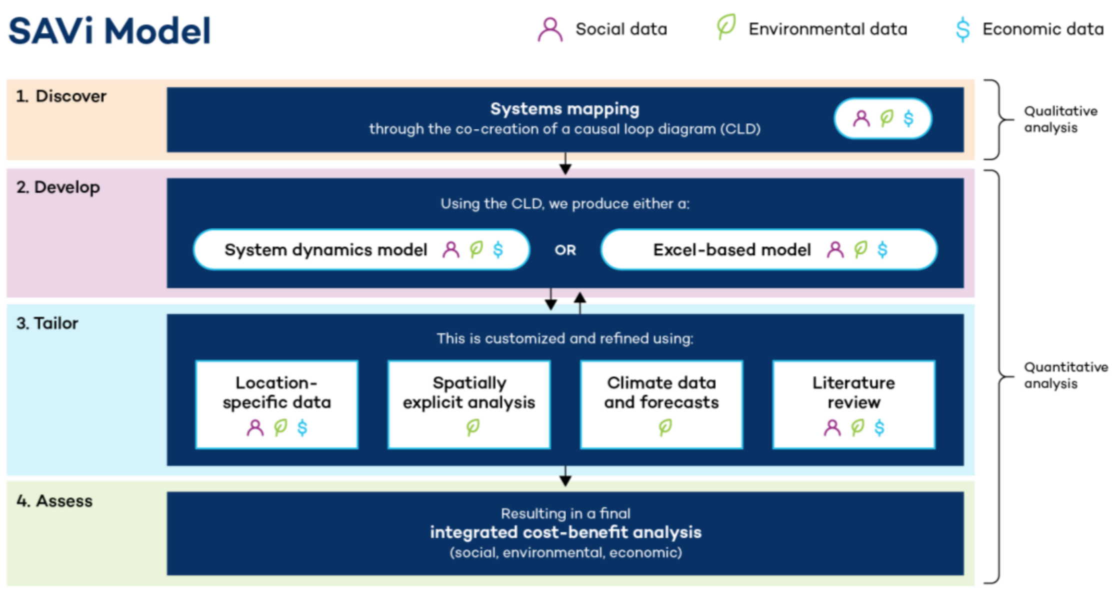
- It begins by introducing the SAVi methodology, which integrates social, economic, and environmental assessments to evaluate the outcomes of investing in nature-based infrastructure (section 2). Building on this, the report emphasizes the importance of systems thinking, showing how this approach can be used to capture the interconnectedness of natural, social, and economic systems in Casamance (section 2.1).
- To demonstrate this concept in practice, a systems map, developed in collaboration with local stakeholders in Casamance, is presented, highlighting key relationships and feedback loops that influence mangrove ecosystems, economic activities, climate-related hazard events and health (section 2.2).
- This is followed by an analysis of local climate data, including patterns of extreme weather, temperature fluctuations, and precipitation trends, which sets the stage for understanding the region's climate risks (section 2.3).
- The report then proceeds with an integrated CBA, detailing the methodology, scenarios, indicators, and results, providing a comprehensive assessment of the NBI impact according to climate change and flood risks scenarios (section 2.4).
- In the conclusion, the key findings are summarized (section 3), with additional detailed results and modelling assumptions provided in the Annex. Together, these sections form a coherent narrative that builds from theoretical approaches to practical assessments of mangrove reforestation in Casamance.

2.0 Sustainable Asset Valuation

This chapter outlines the methodology and findings of the Sustainable Asset Valuation (SAVi), as shown in Figure 3. It begins by situating the interventions within a broader context through the use of systems thinking and systems mapping. Building on this qualitative narrative, the chapter incorporates quantitative methods, including climate scenario projections and a comprehensive cost-benefit analysis (CBA), to evaluate the long-term effects of the proposed interventions. This integrated approach facilitates a detailed assessment of both immediate and future outcomes of the mangrove restoration in Casamance.

SAVi is an assessment methodology that equips policy makers and investors with a thorough life-cycle analysis of nature-based infrastructure projects. It addresses social, environmental, and economic impacts often neglected in conventional project evaluations. By combining systems thinking with diverse quantitative modelling tools, SAVi captures the full spectrum of costs, including environmental, social, economic, and governance risks. It assigns monetary values to externalities, enabling a refined and holistic evaluation. This comprehensive approach supports investment decisions that align with regional development goals, climate adaptation strategies, and the United Nations Sustainable Development Goals (SDGs), ensuring outcomes that are both financially viable and sustainable.

Figure 3. Sustainable Asset Valuation methodology



Source: IISD.

2.1 Systems Thinking

Systems thinking provides decision-makers with a comprehensive framework that highlights the interconnections among social, environmental, and economic dimensions (Meadows &

Wright, 2011; Sanneh, 2018; Stroh, 2015). Instead of concentrating on linear or short-term solutions, it promotes a deeper comprehension of how various elements interact over time, often uncovering both synergies and trade-offs (Sterman, 2000). By focusing on these interrelationships, systems thinking aids in identifying the root causes of issues and ensures that interventions are crafted within the context of long-term strategies (Jackson, 2019). It also clarifies the intricate web of cause-and-effect linkages, making it easier to recognize unintended consequences such as temporary remedies that may escalate problems later (Moallemi et al., 2022). This methodology integrates qualitative understanding with quantitative models, offering both clarity and accuracy for thorough analysis (Probst & Bassi, 2014).

When applied to sustainability, systems thinking broadens the perspective beyond immediate concerns (Voulvoulis et al., 2022). Each choice transforms into more than a momentary decision, becoming instead a catalyst for enduring growth. Maintaining this balance between present needs and future outcomes requires breaking down barriers, connecting different sectors, disciplines, and timescales. Challenges do not exist in isolation, and solutions cannot succeed without collaboration. Systems thinking nurtures this holistic viewpoint, fostering the cross-boundary cooperation essential to addressing today's complex problems (Senge, 2006).

In practical terms, systems thinking serves both as a guide and safeguard for decision-makers. It maps the causal connections between actions and outcomes, revealing feedback loops and behavioural patterns that might otherwise go unnoticed. This broad perspective helps prevent short-sighted measures that could cause greater harm over time, redirecting attention from isolated fixes toward enhancing the system's resilience (Chroust & Finlayson, 2016). Decisions extend beyond addressing immediate issues to establishing frameworks that promote sustainability, equity, and flexibility for the future. Ultimately, systems thinking reminds us that every action is embedded within a larger interconnected web, spanning time and space, empowering decision-makers to craft strategies that address pressing challenges while fortifying the system's adaptive capacity for long-term flourishing.

Applied to the Casamance region, systems thinking makes it possible to adopt a long-term perspective in which immediate actions, such as mangrove restoration, are viewed as components of an integrated strategy aimed at restoring ecological balance and promoting sustainable development. Mangrove restoration is not limited to strengthening coastal protection; it also helps increase ecosystem resilience, preserve biodiversity through experimental fishing, and maintain essential ecosystem services, including water salinity regulation, support for fishery reproduction, and the preservation of local communities' livelihoods, such as fishing and the sustainable farming of oysters and other shellfish.

The complex dynamics captured in the causal loop diagram highlight how changes in one part of the system can have cascading effects throughout. Population growth and increased demand for wood and agricultural land contribute to mangrove degradation, which in turn reduces fish stock regeneration and aggravates coastal erosion. Furthermore, rising sea levels, decreased freshwater availability, and higher evaporation rates disrupt the delicate balance of water salinity, further stressing mangrove ecosystems and local communities. Recognizing these interconnected challenges, systems thinking emphasizes the need for holistic planning that integrates environmental conservation with social and economic considerations.

2.2 Systems Mapping

One effective way to apply systems thinking is by summarizing the different components and their interactions through a process known as systems mapping. Systems mapping is a collaborative and analytical method used to visualize and understand the elements and interconnections within a complex system. This approach serves various purposes, such as analyzing how a system functions and identifying potential interventions to improve its performance (Barbrook-Johnson & Penn, 2022).

For this SAVi assessment, a systems map, represented through a causal loop diagram, was created for both the Casamance and Sine-Saloum regions (as illustrated in Figure 4), given the similarity in their dynamics. The CLD examines the key variables within the system, their cause-and-effect relationships, and the feedback loops that drive behaviour. It was developed through an iterative workshop process involving consultations with local communities to capture region-specific dynamics. The process included three field visits to the mangroves and three workshops with local communities. Workshop participants represented diverse groups, including NGOs, representatives from fisheries associations, farmers, women's associations, municipal authorities, academics, and local community leaders. Attendance included 31 participants in Kafountine (25 men and six women), 29 in Baïla (18 men and 11 women), and 24 in Palmarin (17 men and seven women).

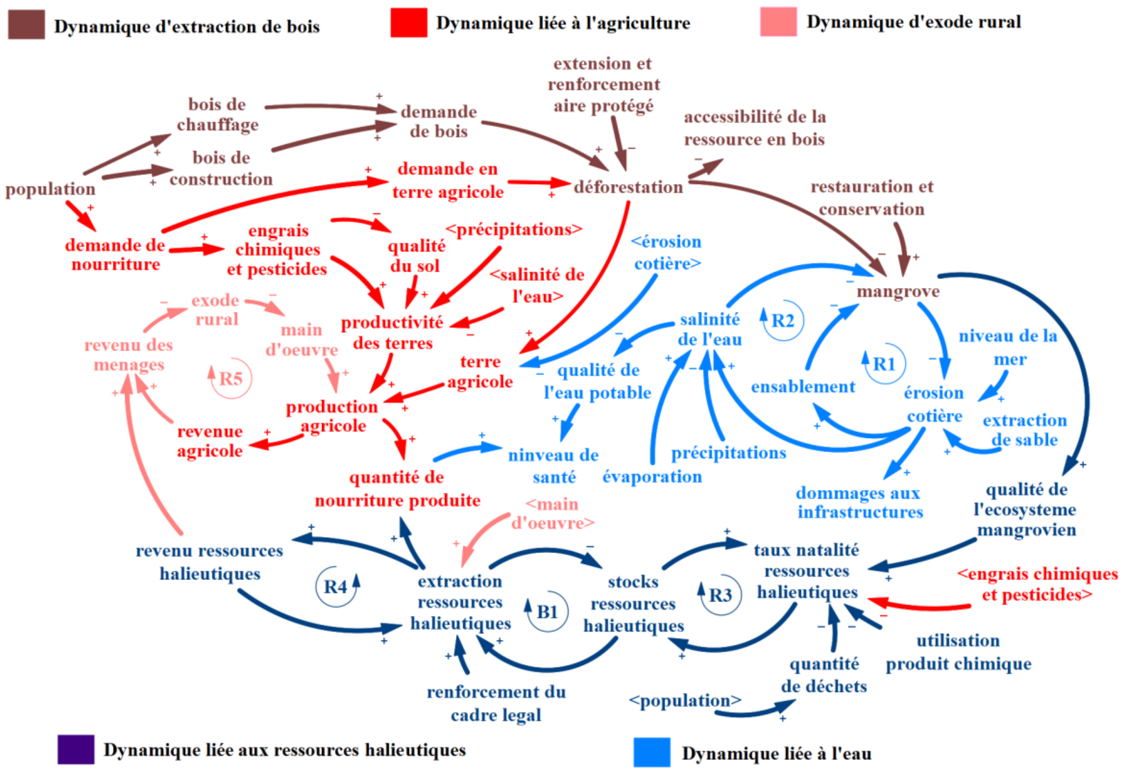
The results comprised a qualitative analysis that gathered local knowledge, validated the causal loop diagram, and identified values and priorities. Additionally, the process identified needs for quantitative analysis, including data, maps, and indicators necessary for the cost-benefit analysis. This participatory and iterative approach ensured that the systems map accurately reflected the complex social-ecological dynamics influencing mangrove conservation and restoration in the regions, forming a solid foundation for the quantitative assessments.

As previously mentioned, the SAVi methodology aims to provide decision-makers with both qualitative and quantitative evidence. The knowledge described here serves as the foundation for the quantitative analysis that follows. In particular, the elements and relationships highlighted through the CLD are closely aligned with the indicators quantified in the integrated cost-benefit analysis. To enhance understanding of the CLD, we recommend referring to the color coding in the diagram as you follow the narrative.

Box 1. Reading a CLD

A CLD is a tool that supports systems thinking. It shows relationships between the components of a system. Arrows indicate causality and plus and minus signs are used to show the direction of causality. A plus sign means that two variables change in the same direction (a positive correlation), while a negative sign means that they change in opposite directions (a negative correlation). Feedback loops are labelled as either reinforcing (R) or balancing (B). A reinforcing loop indicates that a change in one variable will lead to further change in the same direction, whereas a balancing loop dampens change.

Figure 4. Causal loop diagram of Casamance and Sine-Saloum regions



Source: Author.

The causal loop diagram (CLD) described in this report aims to represent dynamics within the communities of the Casamance and Sine-Saloum. The boundaries of the diagram are defined by the limits of the conservation and restoration projects. It is the result of discussions with various stakeholders in the two regions, including representatives of collectives and associations, village chiefs, and protection agents. The methodology used to develop this diagram follows these steps: (1) drafting of causal links prior to field visits; (2) workshops with focus groups of 5 to 10 participants each, moderated to identify problems, causes, and potential solutions; (3) interviews of moderators by the modeller to establish an overview; (4) adjustments of the CLD by the modeller based on interview outcomes; (5)

presentation and validation of the updated CLD with all participants; and (6) final modifications following the presentation.

Causal links are annotated with either a plus (+) or minus (-) sign. A plus sign between element A and element B indicates that an increase in A causes an increase in B, and conversely, a decrease in A causes a decrease in B. A minus sign indicates the opposite: an increase in A causes a decrease in B, and a decrease in A causes an increase in B.

Water-related dynamics: Climate change brings several consequences to the waters and soils of the mangrove ecosystem: (1) decreased rainfall, (2) rising sea levels, and (3) accelerated evaporation. The drop in precipitation disrupts the natural balance between fresh and saltwater in the delta. Normally, a regular flow of freshwater from rainfall and infiltration of saltwater from the sea defines the ecosystem's salinity. This imbalance negatively impacts mangroves and local populations struggling increasingly to find freshwater. Rising sea levels cause coastal erosion, with the sea swallowing significant coastal sand stocks and allowing saltwater to penetrate deeper into the delta. This erosion is exacerbated by domestic sand extraction for housing construction. These shifts in sand and sediment and changes in water salinity harm mangroves' ability to survive and regenerate. Lastly, higher temperatures and evapotranspiration also affect water salinity, as shallow mangrove environments lose water through evaporation faster, which increases salinity and compounds negative effects on mangroves. Damage to mangroves reduces coastal retention capacity, amplifying erosion and creating a cycle of ongoing ecosystem degradation.

Fisheries-related dynamics: Mangroves are crucial for the survival of fish stocks because they provide nursery habitats. When mangroves degrade, their capacity to support juvenile fish diminishes, reducing fish reproduction rates. This reduced natural replenishment leads to smaller fish stocks, which in turn limits the resources communities can extract for sustenance and income. Pollution from plastics, fertilizers, and chemicals further cut reproductive rates and stock survival. The level of extraction depends on stock size: larger stocks enable communities to harvest more, generating livelihoods; smaller stocks lead to extraction difficulties. Increased incomes from resource sales can drive further exploitation, often worsened by unregulated overharvesting due to limited enforcement capabilities. Notably, oysters and shellfish, which are key resources for women, represent major income sources for them.

Wood extraction dynamics: Population growth increases demand for wood for fuel and construction, directly pressuring mangrove deforestation. As wood resources become scarcer, access becomes more difficult since extraction exceeds natural regeneration. Mangrove wood remains the primary source of energy and construction material for island populations.

Agricultural dynamics: Negative impacts on mangroves are intensified by rising food demand due to population growth. To meet this demand, agricultural lands expand, causing partial deforestation of mangroves and forests for pasture and crop fields. Intensification through fertilizer and pesticide use boosts short-term productivity but degrades soils long-term, leading to yield losses. Soil productivity is also affected by availability of freshwater and salinity levels. During droughts, reduced harvests lead to increased fishing efforts, linking agricultural and fishery dynamics.

Rural exodus dynamics: Household income, primarily from agricultural and fishery product sales, strongly influences quality of life. If incomes stagnate or fail to keep up with living costs, locals increasingly migrate to seek work elsewhere. Educated youth find it difficult to return and engage in local, low-income sectors. This rural exodus reduces labour availability for production activities, correlating strongly with resource depletion and limiting income generation. Moreover, this migration causes loss of ancestral traditions and cultural identity, which are especially important to women.

Restoration and conservation dynamics: Restoration and conservation activities promote a virtuous cycle of natural regeneration: the more mangroves there are, the more seedlings they produce, which leads to further mangrove growth. This benefits communities by enhancing: (1) resilience to rising waters and climate events, (2) marine ecosystem quality and water salinity stability, and (3) fish stock reproduction rates. Moreover, expanding and reinforcing protected areas ensures restoration success, maintains natural ecosystem regeneration, and slows or halts conversion of mangrove areas to agriculture or pasture, as well as deforestation from wood demand.

2.3 Climate Data Analysis

Climate data considered in this analysis are based on the Shared Socio-economic Pathways (SSPs) scenarios. The SSPs define different baselines that might unfold according to underlying factors such as population growth, technological innovation, economic development, and resulting greenhouse-gas emissions trajectories (Carbon Brief, 2018). Each SSP builds on narrative storylines that capture broad socio-economic trends shaping future societies. Specifically, this study examines three pathways as characterized by Meinshausen et al. (2020):

- **SSP1-2.6 ("2°C scenario")**: This pathway envisions a world committed to sustainability, featuring low population growth, rapid diffusion of clean energy technologies, and strong international cooperation on climate policy. This scenario assumes substantial investment in renewable energy, reforestation efforts, and energy efficiency improvements that together drive down emissions (Meinshausen et al., 2020).
- **SSP3-7.0 (medium-high emissions reference)**: Characterized by regional rivalry, slow technological progress, and fragmented policy responses. Population growth remains high in developing regions while economic growth and education levels lag, constraining mitigation capacity. Under this scenario, reliance on coal and other fossil fuels persists, and land-use pressures increase, leading to elevated greenhouse gas emissions and warming of approximately 3°C by century's end (Meinshausen et al., 2020).
- **SSP5-8.5 (high-fossil-fuel scenario)**: This pathway depicts a world driven by rapid economic expansion, heavy reliance on fossil fuels, and limited climate mitigation. Energy demand soars, met primarily through unabated coal, oil, and gas consumption. Technological advancements focus on productivity and consumption rather than decarbonization, resulting in global temperature increases exceeding 4°C above preindustrial levels. SSP5-8.5 thus represents a high-emissions future with

severe climate impacts and heightened risks to ecosystems and human systems (Meinshausen et al., 2020).

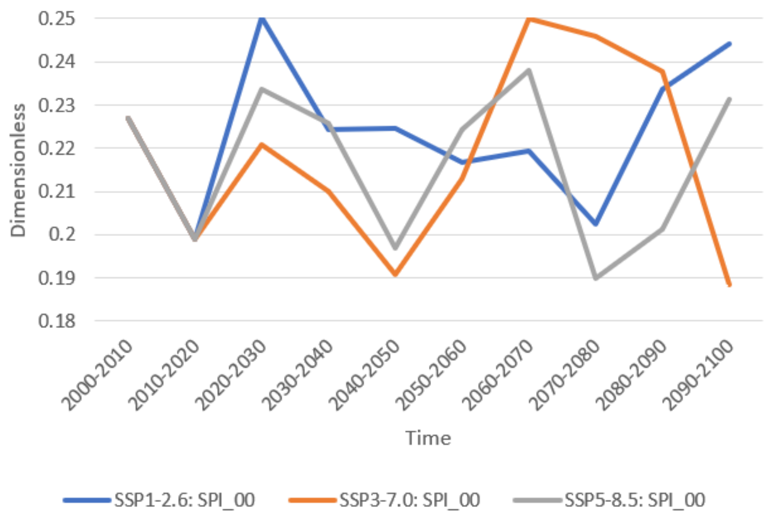
Each SSP presents a distinct trajectory that affects how climate risks, such as extreme wet and dry events, may unfold in Casamance, guiding the evaluation of future adaptation strategies. While these global scenarios offer valuable insights, it is crucial to recognize that regional impacts can vary significantly. Local factors, such as geography, socio-economic conditions, and environmental characteristics, can modify the way these broad trends are experienced. As a result, while the SSPs provide a useful framework for understanding possible futures, localized climate analysis is vital to capture the unique challenges and risks faced by local communities in Casamance. With this context in mind, the following sections explore four key climate indicators: extreme dry events, extreme wet events, average temperature, and average monthly precipitation. The data for these indicators comes from the European Union's Copernicus database.[6]

Extreme Dry Events

As illustrated in Figure 5, patterns of extreme dryness evolve distinctly across the three emission scenarios throughout the century. Under SSP1-2.6, the extreme dry percentile shows notable variability, with a sharp peak around 2020 to 2030, followed by relative stabilization at moderate levels through mid-century, before rising again toward 2090 to 2100. SSP3-7.0 displays a pronounced increase during the 2060 to 2070 and 2070 and 2080 periods, reaching the highest values across all scenarios during this timeframe, before declining sharply in the final decades. In contrast, SSP5-8.5 exhibits considerable fluctuations throughout the century, with a significant mid-century peak around 2030 and elevated values in the 2060 to 2070 period, followed by a notable decline toward 2070 to 2080. These divergent patterns indicate that extreme dry events under the intermediate emissions pathway (SSP3-7.0) intensify most dramatically during the latter half of the century, while the high-emissions scenario (SSP5-8.5) shows greater variability. Such trajectories could amplify drought-related impacts in the region, undermining ecosystem stability, threatening water availability, and exposing communities to greater vulnerability and resource insecurity, particularly during periods of peak dryness.

[6] Available at https://www.copernicus.eu/en.

Figure 5. Extreme dry percentile



Source: EU Copernicus data.

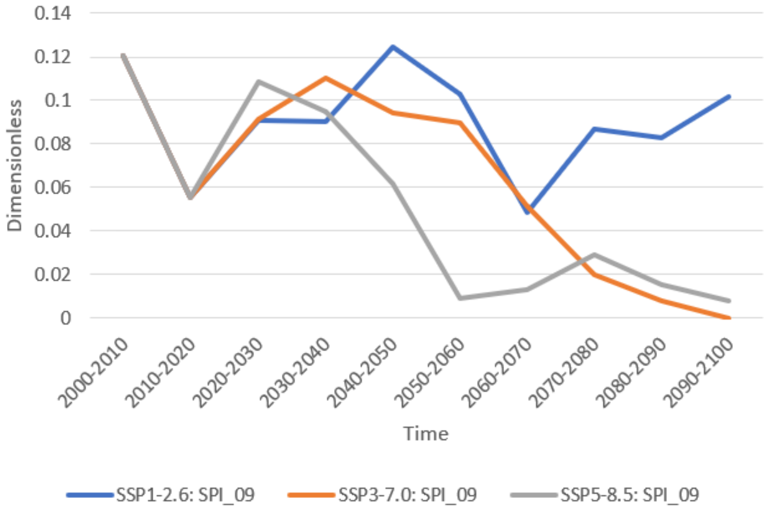
Extreme Wet Events

As depicted in Figure 6, the progression of extreme wet events diverges markedly across emission scenarios throughout the century. Under SSP5-8.5 (the high-emissions scenario), the extreme wet percentile begins at a relatively high level in the early 2000s but undergoes a sharp and sustained decline, dropping by 2050 to 2060 and remaining minimal through 2100. SSP3-7.0 follows a similar declining trajectory, initially rising and peaking around 2030 to 2040 before experiencing a rapid decrease, with extreme wet events becoming progressively rarer in the latter half of the century. In contrast, SSP1-2.6 (the low-emissions scenario) exhibits a more resilient pattern, characterized by a peak in the 2070 to 2080 period, followed by stabilization at moderate levels, suggesting sustained capacity for extreme precipitation events.

Under high-emissions scenarios (SSP5-8.5), declining extreme wet percentiles indicate fewer intense precipitation events. This scenario reflects a critical shift in precipitation distribution and intensity rather than simply total volume. This reduction in extreme wet events has significant hydrological consequences: decreased event intensity may limit groundwater recharge and reduce river flows, fundamentally altering regional hydrology and compromising water security for both people and ecosystems.

As described in the system dynamics framework, these hydrological shifts interact with other environmental stressors, affecting flood risks, soil moisture dynamics, and agricultural productivity. These cascading effects have far-reaching consequences for community resilience and livelihood sustainability, highlighting the complex interdependencies between climate variability and ecosystem-dependent livelihoods.

Figure 6. Extreme wet percentile



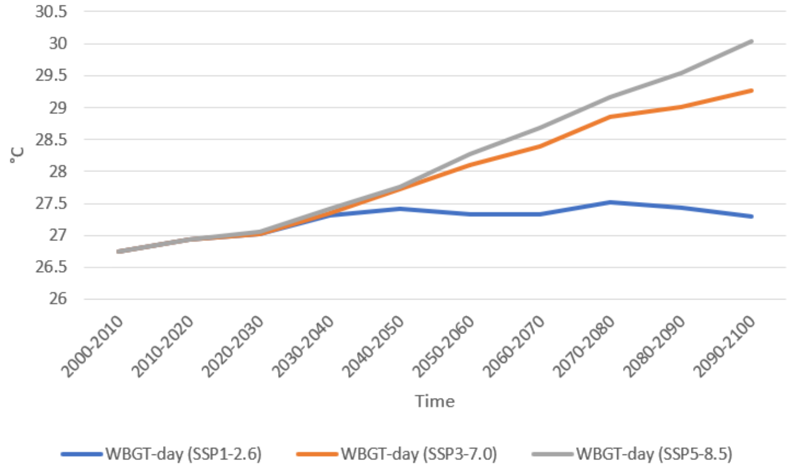
Source: EU Copernicus data.

Average Monthly Temperature

As shown in Figure 7, temperature projections reveal different trajectories across the three emission scenarios. Under the low-emissions scenario (SSP1-2.6), average monthly temperatures remain relatively stable throughout the century, hovering between approximately 27.2°C and 27.5°C. This modest and stabilized warming pattern reflects successful climate mitigation efforts that effectively constrain temperature increases. The medium-emissions pathway (SSP3-7.0) demonstrates a steady and sustained warming trend, rising from approximately 27°C at the beginning of the century to around 29.2°C by 2100. In sharp contrast, the high-emissions scenario (SSP5-8.5) exhibits the most pronounced warming, with temperatures climbing continuously from approximately 26.8°C to exceed 30°C by 2100, representing a warming differential of more than 3.2°C across the century.

This escalating temperature trend under higher emission scenarios presents significant threats to regional ecosystems and communities. Increased temperatures accelerate evapotranspiration rates, intensify water stress, and disrupt the delicate salinity balance critical to mangrove ecosystem health. Rising temperatures reduce soil moisture retention capacity, exacerbating drought conditions and triggering cascading environmental and socio-economic effects. Higher temperatures also stress fishery productivity, reduce agricultural yields, compromise water quality, and directly threaten livelihoods of communities dependent on natural resource-based activities such as fishing, aquaculture, and agriculture.

Figure 7. Average monthly temperature



Source: EU Copernicus data.

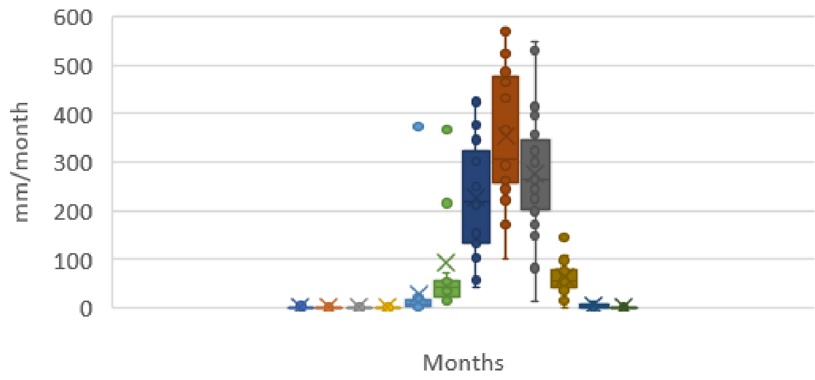
Average Precipitation

Figure 8 compares average precipitation for the period from 2000 to 2020, while Figure 9 shows mid-century projection from 2040 to2060, revealing important patterns and shifts in seasonal rainfall dynamics. During the period from 2000 to 2020, the study area exhibits a pronounced wet season concentrated between June and October, with peak rainfall occurring around August to September, when monthly precipitation reaches approximately 300 mm to 500 mm. The dry season is equally distinctive, extending from November through May.

The mid-century projections from 2040 to 2060, maintain the fundamental seasonal distribution, yet reveal notable shifts. While the wet season timing remains anchored between July and October, the data suggest increased precipitation consistency and reduced variability during these peak months, indicated by tighter uncertainty ranges. This greater predictability contrasts sharply with the historical period's marked year-to-year fluctuations. However, during transition months and the dry season, precipitation uncertainty may increase

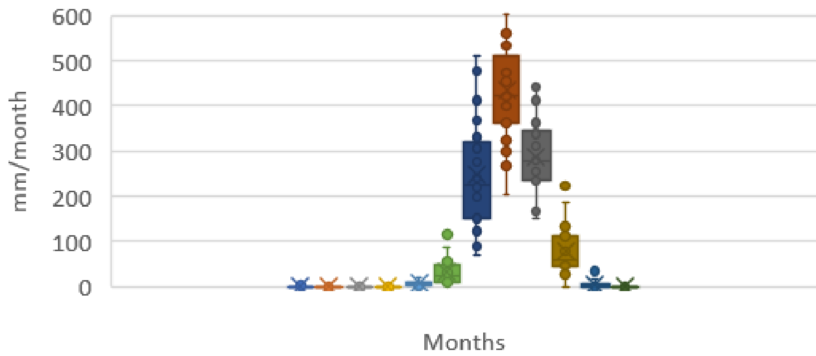
These precipitation changes carry profound implications for the region's social-ecological systems, as articulated in the causal loop diagram. Shifts in seasonal timing or intensity directly disrupt agricultural planting and harvesting cycles, compromise freshwater availability for communities, and alter the delicate salinity balance essential to mangrove ecosystem functioning. Rainfall variability, particularly the wider uncertainty ranges projected for mid-century, may exacerbate adaptation challenges faced by women and vulnerable populations who depend fundamentally on predictable seasonal patterns for their principal livelihood activities, including fishing, agriculture, and resource collection.

Figure 8. Average precipitation (2000 to 2020)



Source: EU Copernicus data.

Figure 9. Average precipitation (2040 to 2060)



Source: EU Copernicus data.

In the cost-benefit analysis, we will examine how variations in extreme weather patterns across SSP scenarios translate into infrastructure damage costs and economic risks. By analyzing the frequency and intensity of flood events under different SSP pathways (extreme wet events) over the project lifecycle, we can quantify potential impacts on critical infrastructure and assess the economic value of mangrove reforestation in reducing climate-related damage. This approach allows us to estimate avoided costs from flooding, coastal protection benefits, and enhanced resilience, thereby capturing the full range of protective services that restored mangrove ecosystems provide under different climate futures. By exploring how key metrics such as benefit-cost ratio (BCR), net present value (NPV), and internal rate of return (IRR) evolve under these different scenarios, we gain deeper insights into the potential economic implications of flood risks.

2.4 Integrated CBA

The following section presents an integrated cost-benefit analysis (CBA) aimed at evaluating the economic viability of mangrove restoration under various flood and SSP scenarios. This analysis is divided into three key subsections.

- First, the methodology subsection outlines the approach and key assumptions used to assess the costs and benefits, providing a clear understanding of how the results were derived.
- Second, the indicator subsection goes through the definition of all indicators present in the CBA. This allows the reader to better grasp the true meaning of the elements quantified.
- Finally, the CBA results subsection presents the monetized outcomes, comparing the costs and benefits across the different flood risks and climate scenarios. Through this analysis, we aim to provide insights into the long-term economic implications of adopting NBI strategies versus maintaining the status quo.

2.4.1 Methodology

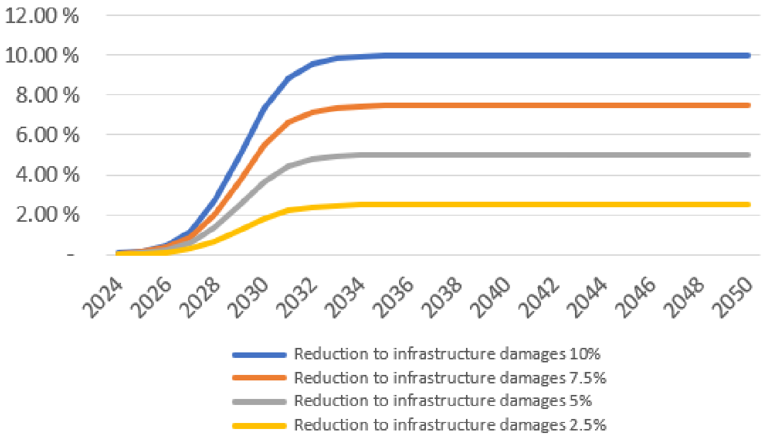
The CBA study employs an Excel-based model spanning 27 years (2024 to 2050) to evaluate mangrove restoration benefits and avoided costs. The model begins by defining and projecting key parameters annually, including asset exposure, costs, and ecosystem service values. These inputs feed into two scenarios: a business-as-usual (baseline) scenario representing current conditions, and a nature-based infrastructure (NBI) scenario reflecting mangrove restoration outcomes. (See Annex B for complete modelling assumptions.)

For each scenario, the model computes annual values of key indicators. For instance, for determining flood damage costs, baseline values are calculated to reflect current conditions without intervention, while NBI values account for enhanced coastal protection from mangrove restoration. The model quantifies avoided costs by subtracting baseline values from NBI values, thereby capturing direct intervention benefits. Results presented throughout this report represent the net difference between scenarios.

To explore how climate change and flood frequency influence outcomes, the NBI scenario is evaluated across two climate trajectories, SSP3-7.0 (medium-high emissions) and SSP5-8.5 (high emissions), and two flood scenarios. Under the severe flood scenario, extreme flood events are assumed to recur every two years. Under the moderate flood scenario, extreme flood events are assumed to recur every five years. (See Annex A for the methodology on flood scenario calculations.)

Each of the resulting four scenario combinations is further examined under four levels of assumed infrastructure damage reduction, 2.5%, 5%, 7.5%, and 10%, reflecting uncertainty in the protective performance of restored mangroves (Figure 10). These percentages correspond to the proportional reduction in flood-related damage costs that the project can avert: the 2.5% threshold models a conservative, minimal protection case, while the 10% threshold represents an optimistic upper bound on mangrove efficiency protection. This approach accounts for uncertainty in restoration success and provides decision-makers with a better understanding of how restoration performance influences overall project viability (Table 1).

Figure 10. Protection efficiency from 2.5% to 10% reduction to infrastructure damage[7]



Source: Author.

Table 1. Reduction to infrastructure damage due to protection efficiency of the mangroves restoration project

Protection efficiency	Reduction in infrastructure damage
High	10%
Medium/high	7.5%
Medium/low	5%
Low	2.5%

Source: Author.

Together, these metrics allow the model to simulate flood risk under different severity assumptions by specifying both the likelihood of extreme floods and the practical frequency at which they might occur.

The model aggregates annual costs and benefits across the entire project timeline to calculate totals, then applies three complementary financial indicators. The net present value (NPV)

[7] This graph shows how the effectiveness of mangroves in protecting infrastructure evolves over time, based on different assumptions. At the beginning, between 2024 and 2026, mangroves provide almost no measurable protection. From 2027 onward, their effect begins to appear, then increases rapidly between 2028 and 2031. This corresponds to the period when the mangroves become sufficiently developed to reduce damages.
Then, from the early 2030s onward, their effectiveness stabilizes, meaning that their protective capacity remains in place. For example, one scenario assumes that mangroves reduce damages by 7.5%. In this case, protection gradually increases from the late 2020s, reaches its maximum level in the early 2030s, and then remains stable. This scenario represents one possibility among others, depending on the actual level of mangrove effectiveness observed in the field. The graph therefore illustrates different possible trajectories and shows that mangroves can become an important and sustainable way to protect infrastructure once they are sufficiently developed.

converts all future cost and benefit flows into present-day monetary values, determining whether the project generates net social, environmental, and economic value. A positive NPV indicates project viability, while a negative NPV signals that costs exceed benefits and the project should not proceed. Additionally, the benefit-cost ratio (BCR) measures the relationship between benefits and costs, and the internal rate of return (IRR) indicates the implicit annual return on investment. Together, these metrics provide comprehensive economic assessment of project feasibility. All future cash flows are discounted to present value using a 3.5% annual social discount rate, consistent with the United Kingdom's Green Book guidance on public sector appraisal (HM Treasury, 2020). This discount rate reflects the opportunity cost of capital and ensures that benefits and costs occurring in different time periods are comparable on equivalent terms.

This narrative approach, together with sensitivity testing across SSP climate scenarios, flood frequency, and varying levels of infrastructure damage reduction, provides a clear framework for understanding how mangrove restoration generates economic value through avoided flood damage and enhanced resilience.

2.4.2 Indicators

To evaluate the costs and benefits of the baseline and the NBI scenario, a range of indicators were identified through the systems mapping process to capture the direct and indirect impacts of the interventions. These indicators provide a comprehensive picture of the economic, social, and environmental implications of mangrove restoration. Below is a brief definition of each indicator used in the CBA:

Table 2. List and definitions of CBA indicators

Direct costs	
Implementation costs (CAPEX)	The initial costs associated with carrying out the mangrove restoration in APAC Kamite, APAC Badala, APAC Koureye APAC Kawawana, AMP KBK, AMP KBF.
Maintenance costs (OPEX)	Ongoing costs required to conserve mangroves over time, such as community stewardship via patrols and sustainable-harvest, bank-stabilization structures to control erosion, and ongoing field records and annual technical reviews.
Avoided costs/loss	
Avoided damage to infrastructure	Savings resulting from reduced damage to residential buildings, public buildings, and roads due to flood mitigation measures provided by the NBI.
Avoided health-related costs	Reduction in health care expenditures from fewer respiratory illnesses attributable to mangrove restoration.
Added benefits	
Fishery revenue	Benefits from preserving fish nurseries and biodiversity within the mangrove restoration, as healthy ecosystems contribute to the sustainability of fisheries.

Agricultural revenue	Benefit from enriching soil fertility through the buildup of organic material and improving water availability via enhanced groundwater recharge, leading to more productive and resilient crop yields. Agricultural production includes rice, peanut production, oil processing, and beans.
Seafood harvest revenues	Enhanced seafood harvest through the restoration of mangrove nursery habitats that support fish, crustaceans, and mollusks; improved water quality from natural filtration of sediments and pollutants; and increased coastal ecosystem productivity leading to higher and more sustainable fishing yields.
Drinking water supply	Improved drinking water supply by filtering sediments and contaminants, stabilizing coastal aquifers through enhanced groundwater recharge, and protecting watershed integrity, ensuring cleaner, more reliable freshwater sources.
Food supply	Additional food produced by mangrove-supported systems that is retained for household consumption and community redistribution rather than sold in markets.
Wood supply	Increased wood supply by expanding forest area enabling sustainable harvesting of fuelwood and construction materials through managed regrowth cycles and community stewardship.
Job creation	New jobs generated through the implementation of the mangrove restoration project.
Carbon sequestration	The social cost value assigned to carbon dioxide captured and stored by restored ecosystems, contributing to climate change mitigation.

Source: Author.

2.4.3 Results

This subsection begins by presenting the cumulative results of the integrated CBA for each combination of SSP climate pathway and flood scenario, thereby capturing the full range of flood-frequency scenarios from 2024 through 2050. All monetary figures are expressed in present-value terms, discounted at 3.5% as described in the Methodology section. First, we compare NBI outcomes across different climate and flood-frequency scenarios, evaluating performance through key performance indicators (KPIs), including the benefit-cost ratio (BCR) and net present value (NPV). This comparison particularly examines how avoided infrastructure damage costs influence NBI performance variations, determining the added value generated for communities and their resilience. Second, we analyze the broader composition of benefits and cost avoidances beyond infrastructure protection, assessing the project's comprehensive impact across multiple benefit categories. Finally, we conduct a targeted analysis of gender-differentiated outcomes, examining the specific benefits and avoided costs generated for women and quantifying the added value created for them.

We begin by evaluating the NBI overall performance using the net present value (NPV) and benefit-cost ratio (BCR). Variation in these indicators across climate and flood frequency scenarios is driven by differences in avoided infrastructure damage costs. All other benefits, such as health savings and ecosystem-service revenues, remain constant. Consequently, the NPV and BCR fluctuate in direct proportion to how much flood damage the restored mangroves prevent under each scenario.

Table 3 presents the analysis across four protection efficiency scenarios (2.5%, 5%, 7.5%, and 10% in infrastructure damage reduction) evaluated under two flood frequency scenarios: moderate (floods every five years) and severe (floods every two years). Results demonstrate a strong positive relationship between protection efficiency and economic returns.

Under the moderate flood scenario, the NPV ranges from XOF 6.4 billion at minimum efficiency (2.5% damage reduction) to XOF 12.4 billion at maximum efficiency (10%), representing an almost twofold increase in economic value. The severe flood scenario generates substantially higher returns, with the NPV escalating from XOF 9.3 billion at 2.5% efficiency to XOF 24.1 billion at 10% efficiency. This pronounced differential underscores how mangrove protection becomes increasingly valuable as flood frequency intensifies, demonstrating the critical importance of ecosystem-based adaptation in high-risk coastal environments.

The benefit-cost ratio (BCR) consistently reinforces the economic viability of mangrove restoration across all scenarios. At the most conservative scenario, moderate flood frequency with 2.5% protection efficiency, the BCR reaches XOF 2.27, indicating that each XOF invested in mangrove restoration generates XOF 2.27 in returns across the project lifecycle. This ratio increases substantially across higher efficiency scenarios, peaking at XOF 5.71 under the severe flood scenario with 10% damage reduction efficiency. This scenario demonstrates that each XOF invested yields XOF 5.71 in societal benefits, confirming strong economic returns for mangrove restoration investments in high-risk flood environments.

The project performance consistently improves under scenarios characterized by higher flood frequency. This pattern holds true regardless of the assumed protection efficiency level, indicating that the benefits of mangrove restoration become increasingly valuable as flood events become more frequent. In other words, even if infrastructure damage is only moderately reduced at 2.5%, the cumulative avoided infrastructure damage costs rise substantially, from XOF 1.9 billion under moderate flood scenarios to XOF 4.9 billion under severe scenarios. This dynamic further enhances the economic viability and resilience outcomes of the project.

Table 4 evaluates the economic performance of mangrove restoration under two climate emissions pathways, SSP5-8.5 (high-emissions) and SSP3-7.0 (intermediate-emissions), across four protection efficiency levels. As demonstrated in the climate analysis, these pathways exhibit markedly different temporal patterns of flood risk. The SSP5-8.5 pathway intensifies flood hazards most sharply toward the end of the century, concentrating major flood events in later decades. In contrast, SSP3-7.0 produces more frequent flooding throughout the mid-century period (2024 to 2050), enabling mangrove restoration to generate immediate and cumulative avoided damage during this critical window.

NPVs under SSP3-7.0 (medium-high emissions) consistently exceed those under SSP5-8.5 (high emissions) across all protection efficiency levels, reflecting the economic advantage of earlier and more frequent damage avoidance. At 10% infrastructure damage reduction, the project achieves an NPV of XOF 14.1 billion under SSP3-7.0, compared to XOF 10.6 billion under SSP5-8.5, a 33% increase. Even at minimum protection efficiency (2.5%), the divergence remains substantial: SSP3-7.0 yields XOF 6.9 billion versus XOF 6.0 billion, under SSP5-8.5. Critically, even under the most conservative scenario (SSP5-8.5 with 2.5% damage reduction), the project delivers a positive NPV, confirming economic viability across all climate pathways.

The BCR reinforces these findings. Under SSP5-8.5, with low protection efficiency (2.5%), the BCR reaches 2.18, meaning each XOF invested generates just over twice its costs in revenue. This ratio strengthens substantially under SSP3-7.0, reaching 3.76 at 10% protection efficiency, indicating communities gain nearly XOF 3.76 in avoided damage and benefits for every XOF invested.

These results confirm that investing in mangrove restoration in Casamance delivers robust economic performance under both climate futures and flood scenarios. The clear linkage between protection efficiency, flood frequency patterns, and economic returns underscores the critical importance of targeting restoration investments in vulnerable flood-prone zones with near-term climate hazards. Crucially, the project's success depends on sustained community engagement, adaptive management practices that ensure high mangrove survival rates, and inclusive governance structures that empower local stakeholders in decision making and benefit distribution.

Table 3. Summary table of integrated cost-benefit analysis based on flood frequency scenarios, figures in millions (XOF) discounted at 3.5%

Reduction in damage to infrastructure	Reduction in damage, 10%		Reduction in damage, 7.5%		Reduction in damage, 5%		Reduction in damage, 2.5%	
Flood frequency	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**
Direct costs								
Construction costs	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Operational and maintenance costs	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1
Total costs	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**
Avoided costs								
Avoided damage to infrastructure	7,979.7	19,630.0	5,984.8	14,722.5	3,989.9	9,815.0	1,994.9	4,907.5
Avoided health-related costs	919.8	919.8	919.8	919.8	919.8	919.8	919.8	919.8
Added benefits								
Fishery revenue	592.9	592.9	592.9	592.9	592.9	592.9	592.9	592.9
Agricultural revenue	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0
Seafood harvest revenues	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Drinking water supply	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5
Food supply	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1
Wood supply	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Job creation	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4
Carbon sequestration	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3

Reduction in damage to infrastructure	Reduction in damage, 10%		Reduction in damage, 7.5%		Reduction in damage, 5%		Reduction in damage, 2.5%	
Total benefits and avoided costs	**17,575.8**	**29,226.0**	**15,580.8**	**24,318.5**	**13,585.9**	**19,411.0**	**11,591.0**	**14,503.5**
KPIs								
Net present value (NPV)	**12,459.7**	**24,109.9**	**10,464.7**	**19,202.4**	**8,469.8**	**14,294.9**	**6,474.8**	**9,387.4**
Benefit-to-cost ratio (BCR)	**3.44**	**5.71**	**3.05**	**4.75**	**2.66**	**3.79**	**2.27**	**2.83**
Internal rate of return (IRR)	**138.1%**	**217.2%**	**128.8%**	**191.7%**	**117.7%**	**163.3%**	**103.9%**	**130.0%**

Source: Author.

Table 4. Summary table of integrated cost-benefit analysis based on SSP scenarios, figures in millions discounted at 3.5%

	Reduction in damage, 10%		Reduction in damage, 7.5%		Reduction in damage, 5%		Reduction in damage, 2.5%	
	SSP5-8.5	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP3-7.0**
Direct costs								
Construction costs	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Operational and maintenance costs	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1	5,046.1
Total costs	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**	**5,116.1**
Avoided costs								
Avoided damage to infrastructure	6,142.9	9,658.3	4,607.2	7,243.7	3,071.5	4,829.1	1,535.7	2,414.6
Avoided health-related costs	919.8	919.8	919.8	919.8	919.8	919.8	919.8	919.8
Added benefits								
Fishery revenue	592.9	592.9	592.9	592.9	592.9	592.9	592.9	592.9

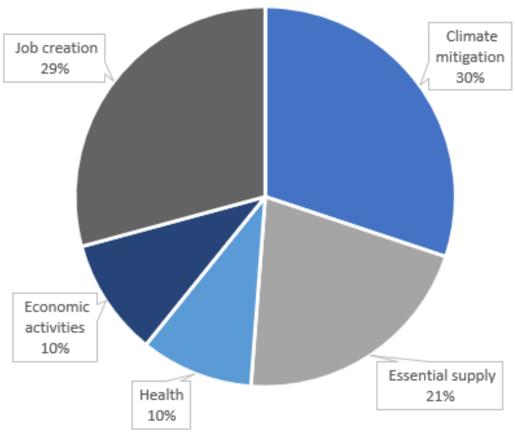
	Reduction in damage, 10%		**Reduction in damage, 7.5%**		**Reduction in damage, 5%**		**Reduction in damage, 2.5%**	
Agricultural revenue	338.0	338.0	338.0	338.0	338.0	338.0	338.0	338.0
Seafood harvest revenues	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Drinking water supply	173.5	173.5	173.5	173.5	173.5	173.5	173.5	173.5
Food supply	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1	1,851.1
Wood supply	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Job creation	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4	2,803.4
Carbon sequestration	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3	2,889.3
Total benefits and avoided costs	**15,739.0**	**19,254.3**	**14,203.2**	**16,839.7**	**12,667.5**	**14,425.2**	**11,131.8**	**12,010.6**
KPIs								
Net present value (NPV)	**10,622.8**	**14,138.2**	**9,087.1**	**11,723.6**	**7,551.4**	**9,309.0**	**6,015.6**	**6,894.5**
Benefit-to-cost ratio (BCR)	**3.08**	**3.76**	**2.78**	**3.29**	**2.48**	**2.82**	**2.18**	**2.35**
Internal rate of return (IRR)	**137.1%**	**162.3%**	**126.6%**	**146.7%**	**114.9%**	**129.4%**	**101.5%**	**109.7%**

Source: Author.

Beyond preventing infrastructure damage, mangrove restoration generates a diverse array of benefits that strengthen the resilience and prosperity of coastal communities. The nine identified benefits and avoided costs can be categorized into five main impacts (Figure 11).

First, job creation, from implementation and restoration, accounts for 29% of total benefits. Second, climate mitigation through carbon sequestration delivers 30% of the benefits, highlighting the project's role in offsetting CO_2 emissions. Third, essential supplies, comprising seasonal food production, sustainably harvested wood, and improved drinking-water filtration, together represent 21%. Fourth, economic activities, including additional agricultural revenues, enhanced seafood harvests, and increased fishery revenue contribute 10%, underscoring improved local markets for crops and marine products. Finally, improved health and well-being, driven by pollutant filtration and reduced disease incidence, contribute 10%. This shows that livelihood support, employment generation, and environmental stewardship are the primary impacts of mangrove restoration beyond preventing infrastructure damage, while economic gains, resource provisioning, and health improvements further reinforce the value of the nature-based infrastructure investment.

Figure 11. Distribution of benefits (excluding avoided costs to infrastructure damage)



Source: Author.

A detailed examination of benefits and avoided costs reveals the following impacts:

Job creation is a major outcome, with restoration activities yielding XOF 2.8 billion. Local communities lead planting, monitoring, and maintenance tasks, thereby acquiring practical skills in nursery management and restoration. This engagement can foster shared stewardship and strengthen social cohesion within communities.

Economic activities show a combined increase of approximately XOF 958 million, drawn from revitalized fisheries (XOF 592 million), enhanced agricultural production (XOF 338 million), and increased seafood harvesting (XOF 28 million). Soil enrichment and improved groundwater recharge support more reliable crop yields, stabilizing household incomes. At the same time, expanded mangrove nursery habitats elevate juvenile fish survival, benefitting artisanal fishers. The synergy between these land- and sea-based value chains empowers local cooperatives to process and market surplus produce and catch, positioning restored mangrove systems as engines of sustainable economic growth.

The supply of essential resources is significantly enhanced, delivering a total value of XOF 2.0 billion. Households secure XOF 1.8 billion worth of food for direct consumption, reducing reliance on markets. Sustainable wood harvesting (XOF 29,283) contributes marginally for fuel and construction, while improvements to water quality yield XOF 173 million in safer drinking water. By reducing the daily time burden of resource collection, these gains free up opportunities for education and other income-generating activities.

Mangrove ecosystems function as natural air filters, trapping atmospheric particulates and reducing airborne pathogens that exacerbate respiratory diseases. By improving air quality, restored mangrove forests directly reduce respiratory disease incidence within adjacent communities, decreasing clinic visits and associated medical expenses. Healthier populations maintain higher productivity and school attendance, strengthening community resilience and generating substantial health care savings. Over the 27-year project period, these improvements in respiratory health yield XOF 919 million in avoided health-related costs.

Finally, mangrove restoration contributes to climate mitigation and carbon finance. Carbon sequestration is valued at XOF 2.8 billion, creating opportunities within voluntary carbon markets. In the cost-benefit analysis, carbon sequestration has been monetized using a social cost of carbon valuation of USD 50 per tonne of CO_2 equivalent, reflecting the full economic value of climate damage avoided through atmospheric carbon removal. This approach captures the broad societal benefits generated by the mangrove restoration project, extending beyond local communities to encompass global welfare improvements from reduced climate change impacts.

Benefits and Avoided Costs for Women: Gender-based analysis

Women in Senegal depend heavily on mangrove ecosystems for livelihoods, particularly through shellfish and oyster harvesting, yet face disproportionate vulnerabilities. While mangroves provide ecosystem goods and services, their near 50% decline since the 1980s has significantly undermined women's economic security and deepened poverty. Protected-area conservation measures often restrict women's access to these resources while excluding them from governance decisions affecting harvesting rights and community development. Additionally, women's capacity to adapt to climate impacts is constrained by limited access to technical knowledge, equipment, and finance, intensified by their marginalization in decision-making structures. Strengthening women's participation in inclusive governance of nature-based infrastructure investments can simultaneously enhance ecosystem conservation and build women's climate resilience (PMO-NATURELLES).

The gender-based analysis demonstrates that women accrue XOF 735 million in direct project benefits, which is only 15.7% of the total value (XOF 4.6 billion)[8] generated by the project (see Annex A – CBA). These benefits arise from five impacts: avoided health-related

[8] The total value generated by the entire community consider the same avoided costs and benefits: avoided health-related costs, fishery revenue, agricultural revenue, seafood harvest revenues, and job creation. It excludes other benefits that are not monetized in the gender-based analysis.

costs, agricultural revenues, fisheries opportunities, seafood harvesting, and job creation. Together, these gender-differentiated outcomes demonstrate economic gains for women from nature-based infrastructure interventions, yet also highlight the urgent need to strengthen women's participation in economic activities across Casamance through enhanced access to resources, decision-making authority, and market opportunities (Table 5).

Health care: Avoided health-related costs emerge as the dominant benefit category for women, accounting for 60.7% of total gender-differentiated benefits, equivalent to XOF 446 million. Climate change significantly exacerbates health care burdens for women in Senegal by increasing existing barriers to health care access and increasing financial strain on households. Women in underserved regions must travel between 23 to 75 kilometres to reach the nearest health facility, a journey made increasingly difficult and expensive due to flooding during rainy seasons and other climate hazards that damage roads and transportation infrastructure (International Budget Partnership, n.d.). The project generates substantial benefits by reducing health care costs through pollution mitigation provided by mangroves. This analysis focuses on the role of mangrove forests in filtering airborne pollutants, thereby lowering the incidence of respiratory illnesses and associated treatment expenses. These significant preventive health gains ease critical financial burdens on women while improving community health outcomes.

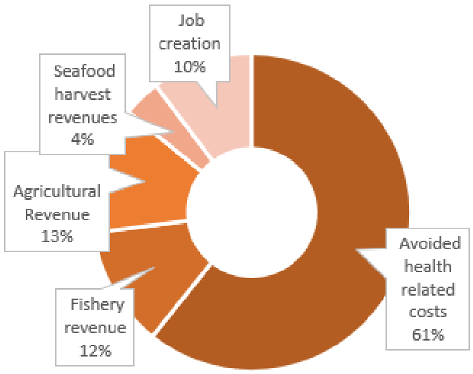
Agriculture: Rural women constitute nearly 70% of Senegal's agricultural workforce and are responsible for producing approximately 80% of the national food supply, underscoring their indispensable role in the country's food security and rural economy. Although they provide the majority of labour, women are frequently marginalized in farm decision-making regarding crop choices, resource allocation, and production methods (Alliance of Bioversity International & CIAT, 2024). Agricultural revenue comprises 12.9% of total gender-differentiated benefits, valued at XOF 95 million. This demonstrates that mangrove restoration can generate new income-earning opportunities for women through improved soil conditions and enhanced groundwater availability supporting more reliable crop production and income diversification.

Fishery: Throughout the fishery value chain, women play indispensable roles in processing and marketing: they smoke, salt, and clean fish; support cooperative transport of processed products; and negotiate sales in local and regional markets (OceanRisk 2023). For this analysis, artisanal fishing represents an important economic activity for women contributing 12.2% of total gender-differentiated benefits through fishery revenue, valued at XOF 89 million. While women's direct participation in formal fishing operations remains constrained by socio-economic barriers, limited access to capital and fishing infrastructure, and in some communities by religious and cultural norms restricting mobility and decision-making authority, mangrove restoration creates new opportunities in artisanal fishery activities through enhanced fish nursery habitats and juvenile fish survival (OceanRisk 2023).

Seafood harvesting: Seafood harvest revenues constitute 3.8% of total gender-differentiated benefits, valued at XOF 28 million. These activities, shellfish gathering, oyster harvesting, and small-scale aquaculture processing, represent areas where women exercise considerable autonomy and technical expertise. Traditionally managed by women in coastal communities, these marine resource activities provide critical income diversification while demonstrating women's substantial engagement throughout the seafood value chain, from harvest through processing and commercialization.

Job creation: Mangrove reforestation activities create significant employment opportunities for women in coastal communities. By involving women in establishing nurseries, growing and planting mangrove seedlings, and maintaining restored areas, the project provides approximately XOF 75 million (10.3% of total benefits) in direct earnings for women. This not only boosts household incomes but also builds local capacity in restoration techniques and ecosystem stewardship. Women's involvement in these roles fosters community ownership of mangrove conservation, ensures higher survival rates for planted areas through regular monitoring, and promotes gender-inclusive economic empowerment.

Figure 12. Composition of added benefits and avoided costs for women



Source: Author.

Table 5. Composition of added benefits and avoided costs for women, figures in billion XOF

Benefits for women	CFA
Avoided health-related costs	446,634,790
Fishery revenue	89,867,126
Agricultural revenue	95,204,772
Seafood harvest revenues	28,043,756
Job creation	75,590,403
Total	**735,340,848**

Source: Author.

To conclude, the gender-based analysis demonstrates that women in Senegal accrue socio-economic gains from mangrove restoration, capturing approximately XOF 735 million in direct benefits. Nonetheless, these gains remain constrained by deeper structural inequalities that limit women's capacity to fully leverage these opportunities. Avoided health costs represent the largest benefit category, reflecting the disproportionate health vulnerabilities women face due to climate change and ecosystem decline. Women's income security continues to be jeopardized by restricted resource access, limited decision-making authority, and systemic exclusion from governance structures. Patriarchal norms, customary restrictions on mobility, and women's marginalization in formal institutions create persistent barriers that prevent these economic gains from translating into meaningful improvements in women's autonomy and well-being. Addressing these structural constraints requires certain action: strengthening women's participation in community management bodies, removing technical and financial barriers to agricultural and fishery activities, formalizing women's resource rights, and ensuring equitable benefit distribution. Such transformative investments will not only safeguard mangrove ecosystems but also advance broader gender equality and social inclusion objectives essential for sustainable development.

3.0 Conclusions

Mangrove restoration in Casamance delivers strong economic returns across all climate and flood-frequency scenarios analyzed through 2050. Under moderate flood scenarios, the NPV ranges from XOF 6.4 billion to XOF 12.4 billion, while severe flood scenarios generate XOF 9.3 to XOF 24.1 billion, depending on infrastructure protection efficiency. Benefit-cost ratios consistently exceed 2.0, with returns ranging from 2.27 to 5.71 depending on the assumptions, confirming that each XOF invested generates XOF 2.27 to XOF 5.71 in societal benefits and avoided damage. Higher benefit-cost ratios are positively correlated to both higher flood frequency and greater protection efficiency, demonstrating that mangrove restoration provides increasing returns in high-risk flood environments where climate hazards intensify.

Under climate emissions pathways, the project performs robustly across both SSP5-8.5 and SSP3-7.0 scenarios. The NPV ranges from XOF 6.0 billion under SSP5-8.5 (2.5% protection efficiency) to XOF 14.1 billion under SSP3-7.0 with 10% protection efficiency. Even under the most conservative conditions (SSP5-8.5 with 2.5% damage reduction), the project maintains positive economic viability, with a BCR of 2.18. This consistency confirms that mangrove restoration delivers sound returns regardless of climate pathway, underscoring its robustness as a climate adaptation strategy.

Beyond flood protection, the project generates benefits and avoided costs totalling XOF 9.5 billion. Climate mitigation through carbon sequestration accounts for 30.1% of total benefits (XOF 2.8 billion), valued using a social cost of carbon of USD 50 per tonne of CO_2. Job creation comprises 29.2% (XOF 2.8 billion), predominantly through community-led planting and maintenance activities that build local restoration capacity and social cohesion. Essential resource provisioning represents 21.1% of benefits (XOF 2.0 billion), including food security (XOF 1.8 billion) and improved water access (XOF 173 million). Economic activities contribute 10.0% (XOF 958 million) through fisheries (XOF 592 million), agriculture (XOF 338 million), and seafood harvesting (XOF 28 million), while health improvements account for 9.6% (XOF 919 million) in avoided disease treatment costs. These diversified benefits demonstrates that nature-based infrastructure simultaneously addresses coastal protection, livelihood security, climate mitigation, and ecosystem health.

Women capture a marginal share (15.7%) of total benefits, as persistent barriers such as limited rights, exclusion from decision-making, and restricted access to financial and technical resources undermine their economic security. Avoided health care costs represent the largest component at 60.7% (XOF 446 million), reflecting disproportionate climate vulnerabilities women face through restricted health care access. Agricultural revenues contribute 12.9% (XOF 95 million), demonstrating enhanced income opportunities through improved soil conditions and groundwater availability. Fishery-related income, comprising artisanal fishing (12.2%, XOF 89 million) and seafood harvesting (3.8%, XOF 28 million), underscores women's critical roles in marine value chains. Job creation provides 10.3% (XOF 75 million) in direct restoration employment.

The findings from this assessment offer valuable insights for a range of stakeholders involved in the management and development of Casamance's ecosystems.

- **Marine conservation zones** should recognize mangrove restoration as a strategic adaptation investment that generates measurable flood protection, livelihood improvements, and resource security. Community stewardship through active participation in restoration design and management, combined with transparent and equitable benefit-sharing mechanisms, is essential to sustain both ecosystem health and social resilience.
- **Environmental agencies and public authorities** can use these findings to show pathways for (and highlight progress in) implementing mangrove restoration programs, which is a key priority of Senegal's National Adaptation Plan (NAP). The Natur'ELLES mangrove restoration initiative directly supports the country's overarching coastal adaptation vision, as introduced in the National Adaptation Plan for the Coastal Zone of Senegal (MEDD, 2022)—a productive, diversified, attractive, clean, and climate-resilient coastline with coastal communities benefitting from available resources while preserving marine and coastal ecosystems. Mangrove reforestation in Casamance operationalizes the NAP's foundational objectives by addressing coastal erosion, salinization, and livelihood vulnerability. The project aligns with the NAP's four strategic adaptation pillars: (1) improved coastal protection and management through soft solutions (nature-based approaches rather than hard infrastructure), (2) enhanced community adaptation through livelihood diversification and reduced infrastructure vulnerability, (3) strengthened coastal governance through multi-stakeholder collaboration and inclusive decision-making, and (4) improved knowledge generation and information sharing through participatory monitoring and ecosystem assessment. The SAVi methodology itself contributes to the fourth axis by generating localized evidence on adaptation effectiveness.
- **Private sector and development financiers** will find mangrove restoration economically attractive through multiple revenue streams: verified carbon credits, employment generation, and enhanced fisheries and agricultural productivity. Outcome-based financing models, including payment for ecosystem services, carbon credit mechanisms, and public-private partnerships, could underwrite restoration while aligning commercial interests with long-term ecosystem and community well-being.
- **For local communities**, mangrove restoration translates into concrete livelihood improvements through paid employment in planting and maintenance activities, enhanced access to fishery and agricultural resources, and strategically planned income diversification across multiple economic sectors. Women can benefit from expanded opportunities in shellfish harvesting, aquaculture management, fish processing, and restoration employment. These activities generate direct income while reducing time burdens for resource collection. Ensuring community stewardship and inclusive decision-making requires deliberate mechanisms: securing women's participation in governance structures, strengthening their resource access rights, and guaranteeing equitable benefit distribution.

Mangrove restoration in Casamance presents a robust nature-based infrastructure investment with strong economic returns, diverse benefits, and significant potential for climate adaptation. The project's viability across multiple climate scenarios, coupled with substantial benefits for livelihoods, health, and carbon mitigation, makes a compelling case for scaling mangrove restoration as a central component of coastal resilience and sustainable development strategies in Senegal.

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Appendix A. Further Results

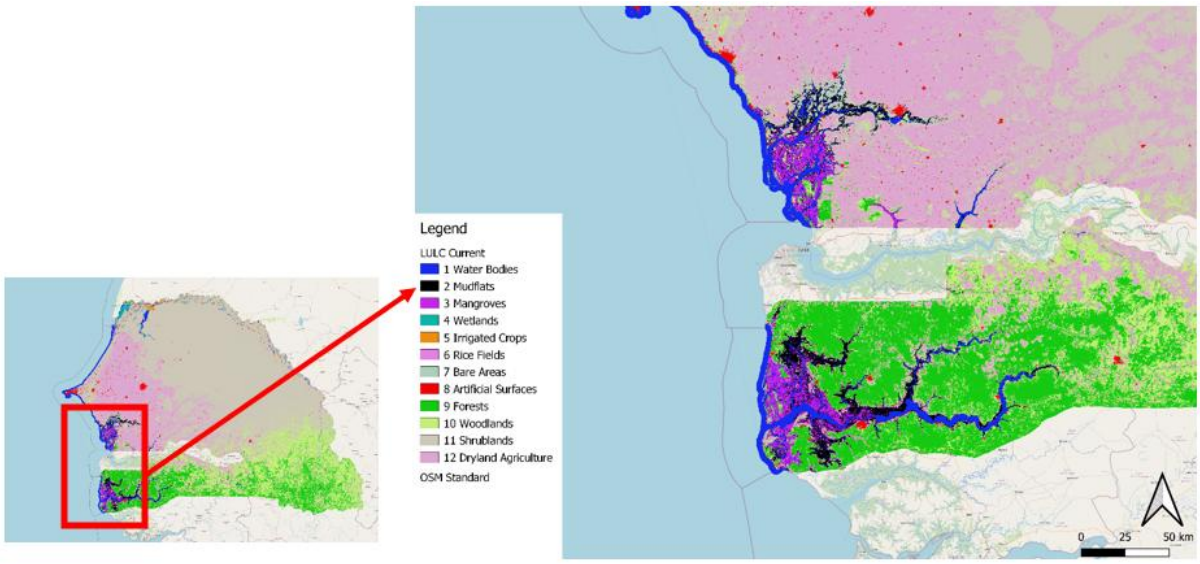
Spatial Analysis

The spatial analysis aims to assess how the NBI performs in the local context by leveraging geographic information system (GIS) data and spatially explicit models. These tools, such as the Integrated Valuation of Environmental Services and Trade-offs (InVEST[9]) model, allow us to quantify, map, and value the ecosystem services provided by natural systems, which include regulating, provisioning, cultural, and supporting services. The spatial models help identify where these services are generated and how they would shift under various land-use scenarios. This spatial information is essential for determining the value of NBI interventions across different scales, from individual urban areas to entire landscapes, and provides critical input for the integrated CBA.

Land-Cover Map

We used a land-cover map from NASA at 30m resolution, (i.e., covers October 2022 to May 2023), as the primary input for the InVEST suite of models.

Figure A1. Land-cover map

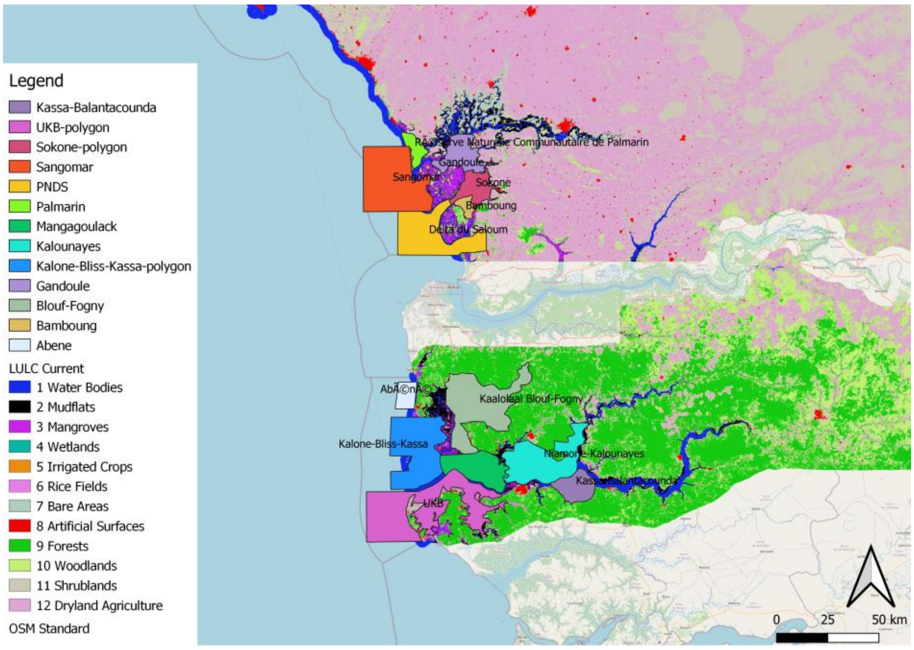


Source: InVEST.

The study areas of this analysis are shown in Figure A2.

[9] Available at https://naturalcapitalproject.stanford.edu/software/invest.

Figure A2. Study area

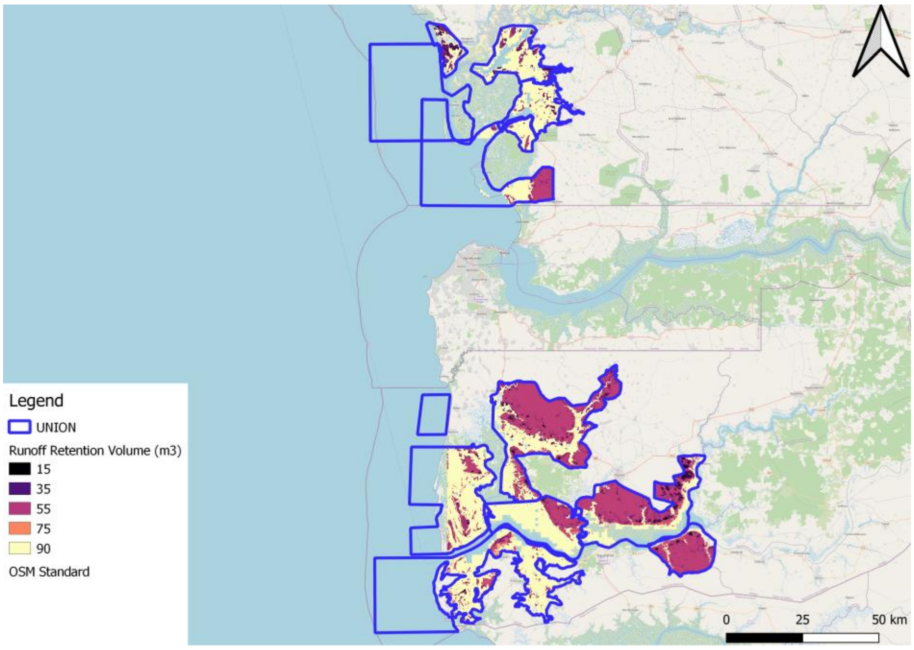


Source: InVEST.

Flood Risk

The model calculates the runoff reduction, i.e., the amount of runoff retained per pixel compared to the storm volume.

Figure A3. Flood risk area



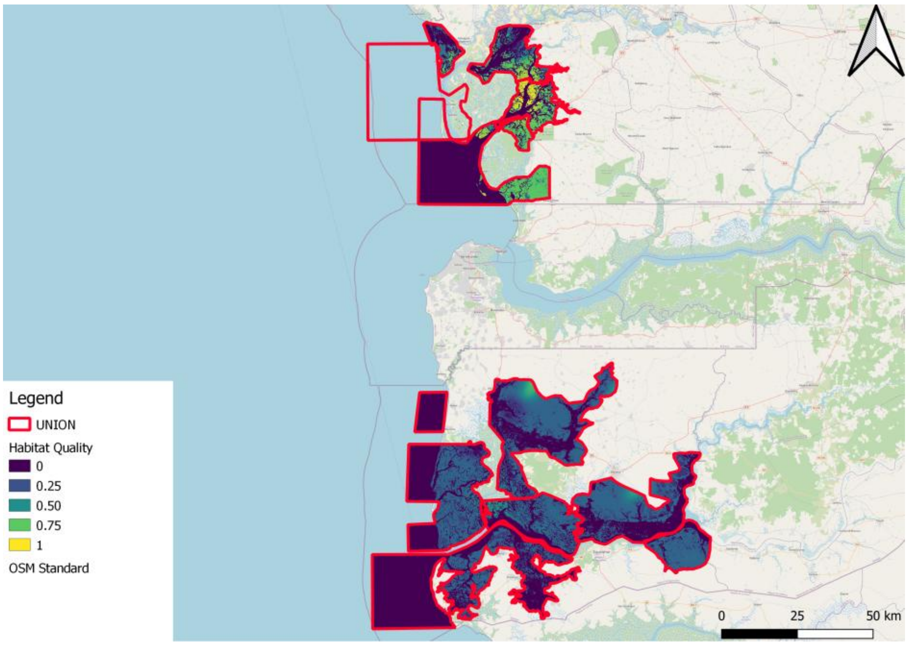
Source: InVEST.

The InVEST flood risk model indicates that retention volume under the current scenario amounts to 291,305,159 m^3.

Habitat Quality

The model estimates the extent of habitat quality across the study area.

Figure A4. Habitat quality area



Source: InVEST.

The InVEST habitat quality model indicates that the mean of habitat quality in the study area under the current scenario is equal to 0.17, on a scale from 0 (lowest level of HQ) to 1 (highest level of HQ).

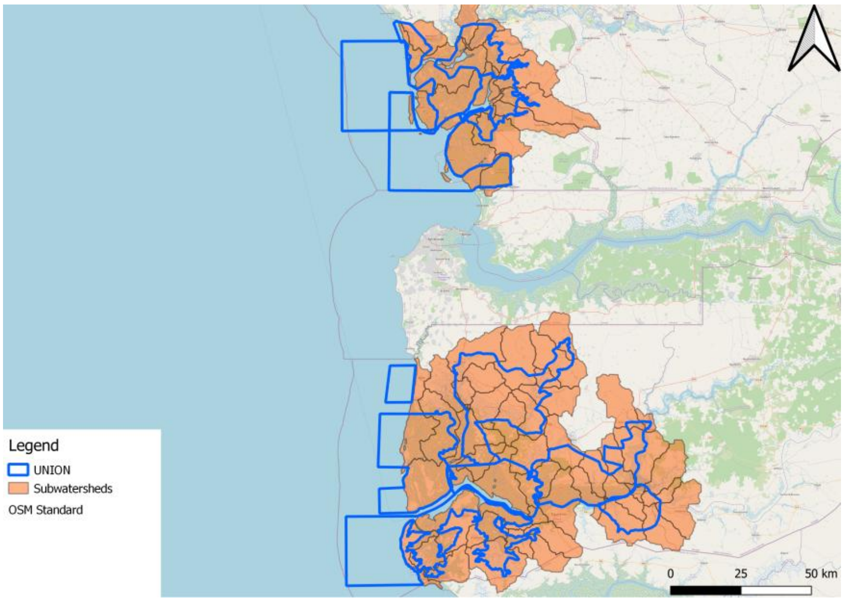
Sediment Export

The model estimates the tonnes of avoided sediment exported in the study area

The InVEST sediment export model indicates that the tonnes of sediments exported in the study area under the current scenario amounts to 205,610 tonnes.

No relevant spatial outputs are generated by this model. The models need the geometries of the sub-watersheds found in the study area to run, and the exported sediments are modelled for those areas.

Figure A5. Sediment export area

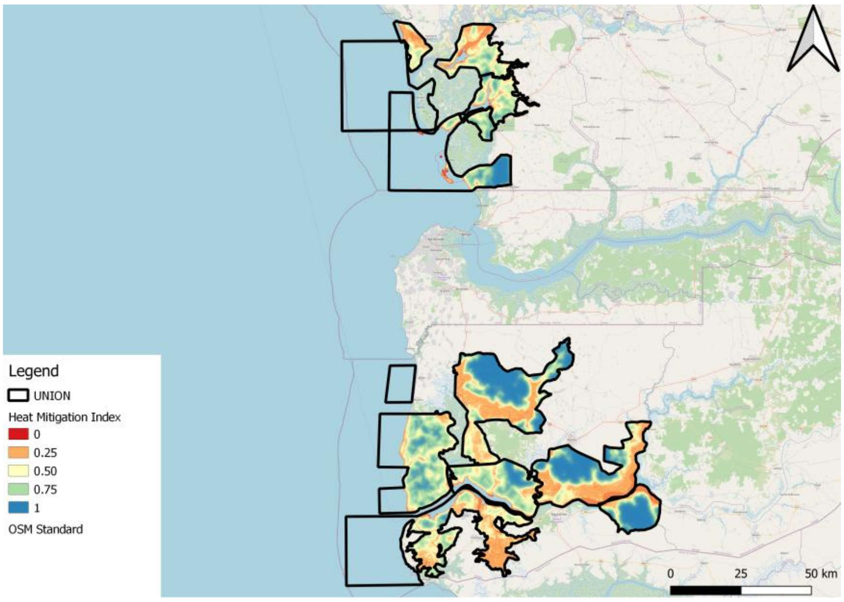


Source: InVEST.

Cooling

The InVEST cooling model indicates that temperature in the study area under the current scenario is equal to 32.58°C, considering an ambient air temperature of 30.00°C and a heat island effect of 5.00°C.

Figure A6. Cooling model area



Source: InVEST.

Methodology

Table A1. Flood scenario parameters

Flood scenario	Average intensity (Intensity 1 in X)	Average recurrence interval	Annual event rate
Severe	1 in 30 years	Every 2 years	1 event per year
Moderate	1 in 30 years	Every 5 years	1 event per year

Source: Author.

The Table A1 defines two flood scenarios (severe and moderate) using three related metrics to describe how often and how intense flood events are expected to occur:

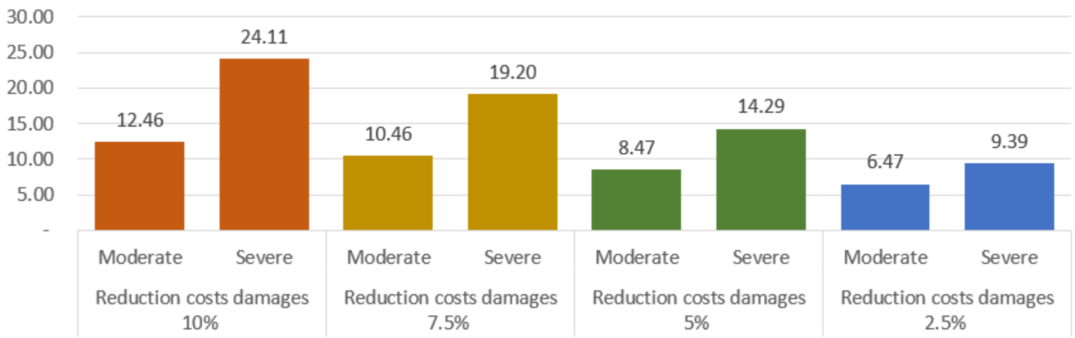
- **Average intensity (intensity 1 in X)**: "One in 30 years" means that the flood magnitude in question, defined by a specific peak flow rate or water depth, is statistically expected to be equaled or exceeded once every 30 years on average. In hydrological terms, it examines long-term flow records and fit them to an extreme-value distribution, for example, Gumbel or Log-Pearson Type III, (Nasir, N. N., 2025). They then identify the flow corresponding to the 1/30 (≈3.3%) annual exceedance probability. That flow value is the "30-year flood" intensity, representing the benchmark magnitude used throughout the analysis.
- **Average recurrence interval**: This describes how frequently floods actually materialize over time. In the severe scenario, a 30-year flood is assumed to recur every two years on average—reflecting factors like changing climate conditions that make large floods more common than their statistical rarity suggests. In the moderate scenario, the same 30-year flood is assumed to recur every five years, representing a lower overall flood frequency.
- **Annual event rate**: This translates the recurrence interval into expected annual occurrences in years when flooding happens. For both scenarios, the model assumes that in each year where flooding occurs, there will be exactly one flood event of the specified intensity.

CBA Results

Figure A7 presents net present value outcomes across eight flood mitigation scenarios, examining how mangrove restoration profitability varies with infrastructure damage reduction efficiency (10%, 7.5%, 5%, and 2.5%) and flood frequency scenarios (moderate: every five years; severe: every two years).

Mangrove restoration generates positive returns across all scenarios, ranging from XOF 6.47 billion under conservative conditions (2.5% protection, moderate flooding) to XOF 24.11 billion under 10% protection and severe flooding scenario. The data reveal a clear positive relationship between both flood frequency and protection efficiency, with the NPV more than doubling when flood scenarios intensify. Within each flood scenario, the NPV scales proportionally with protection effectiveness, demonstrating that targeting high-risk, frequently flooded zones with optimized restoration protocols substantially maximizes project economic value. Even the most conservative scenario remains economically viable, confirming that mangrove restoration delivers robust returns across diverse implementation contexts and climate futures.

Figure A7. Net present value under flood scenarios in billion XOF

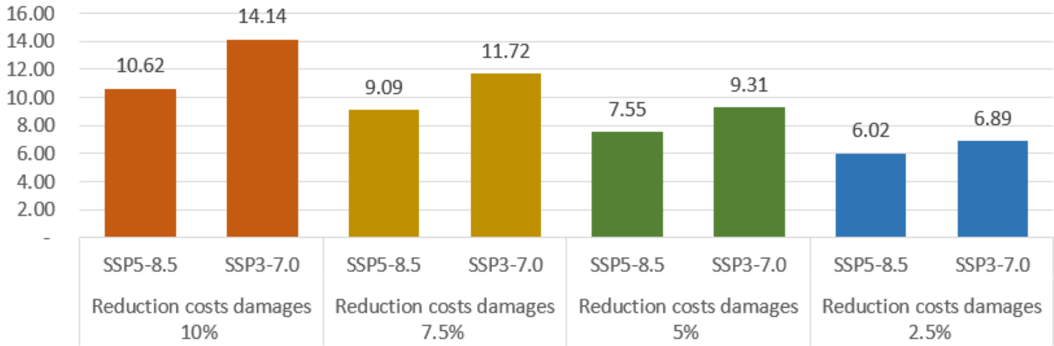


Source: Author.

Figure A8 evaluates mangrove restoration profitability across two contrasting climate emissions pathways, SSP5-8.5 (high emissions) and SSP3-7.0 (intermediate emissions), combined with four levels of infrastructure damage reduction efficiency (10%, 7.5%, 5%, and 2.5%).

The SSP3-7.0 pathway consistently generates higher NPV than SSP5-8.5 across all protection efficiency levels, reflecting earlier and more frequent flood occurrence during the mid-century period (2024 to 2050) when benefits are most heavily weighted in present value terms. Under 10% damage reduction, SSP3-7.0 yields XOF 14.14 billion compared to XOF 10.62 billion under SSP5-8.5, a 33% advantage. This pattern persists across lower efficiency levels: at 2.5% protection, SSP3-7.0 achieves XOF 6.89 billion versus XOF 6.02 billion under SSP5-8.5. The convergence of NPV values at lowest protection efficiency suggests that even under high-emission scenarios with delayed flood intensification, mangrove restoration maintains economic viability. These results confirm that the project's returns are optimized when flood frequency peaks during the active restoration phase, and that both climate futures support strong investment cases for mangrove restoration.

Figure A8. Net present value under climate scenarios SSP5-8.5 vs. SSP3-7.0 in billion XOF

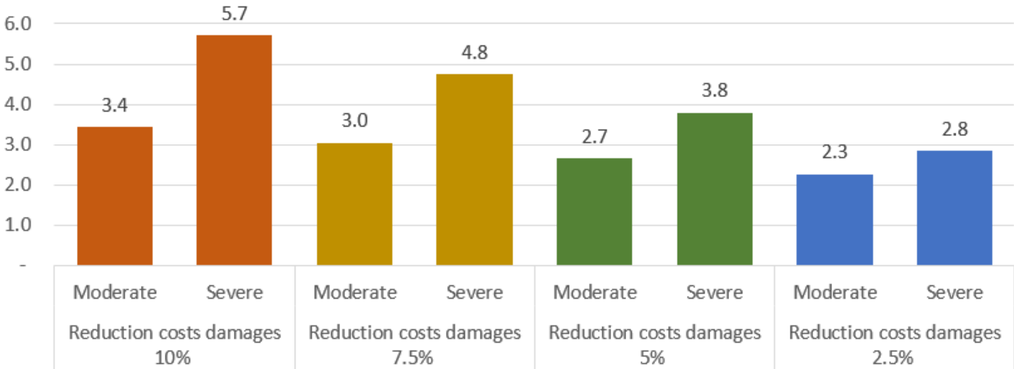


Source: Author.

Figure A9 presents benefit-cost ratios (BCR) measuring the return on each currency unit invested in mangrove restoration across eight flood mitigation scenarios, varying infrastructure damage reduction efficiency (10%, 7.5%, 5%, and 2.5%) and flood frequency scenarios (moderate and severe).

Benefit-cost ratios exceed 2.0 across all scenarios, confirming strong economic returns on restoration investments. Under 10% protection and severe flooding scenario, each XOF invested generates XOF 5.7 in avoided damage and ecosystem benefits. The highest protection efficiency scenario under moderate flooding yields XOF 3.4, while even the most conservative case (2.5% protection, moderate flooding) delivers XOF 2.3. Severe flood scenarios consistently produce 40% to 50% higher BCRs than moderate scenarios at equivalent protection levels, demonstrating that intensified flood hazards substantially enhance project profitability. Protection efficiency drives proportional improvements in returns, with doubling efficiency increasing BCR by roughly 1.0 to 1.5 units. These results indicate that mangrove restoration represents an economically attractive public investment across diverse climate and flood vulnerability contexts, with particularly compelling returns in high-risk, frequently-flooded zones where restoration can achieve maximal damage reduction.

Figure A9. Benefit-cost ratio under flood scenarios

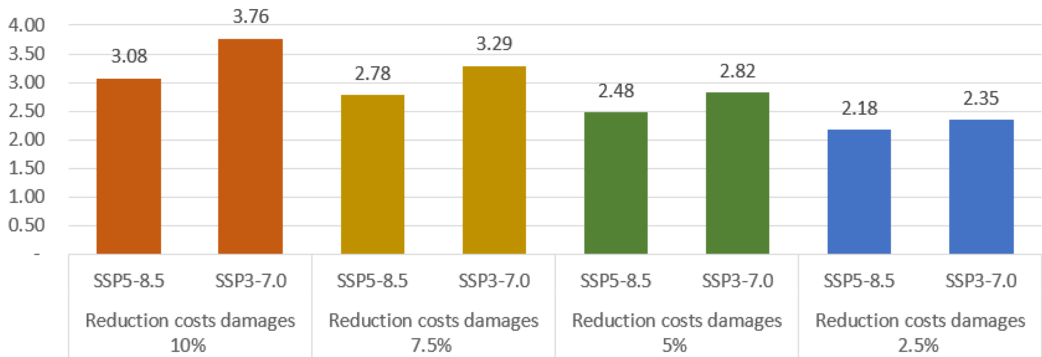


Source: Author.

Figure A10 evaluates mangrove restoration benefit-cost ratios across two climate emissions pathways, SSP5-8.5 (high emissions) and SSP3-7.0 (intermediate emissions), combined with four infrastructure damage reduction efficiency levels (10%, 7.5%, 5%, and 2.5%).

The SSP3-7.0 pathway consistently delivers higher BCRs than SSP5-8.5 across all protection efficiency scenarios, reflecting earlier flood intensification during the project's active phase when avoided damage accumulate most heavily. Under 10% damage reduction, SSP3-7.0 achieves XOF 3.76 compared to XOF 3.08 under SSP5-8.5, representing a 22% improvement in returns. This advantage persists across lower efficiency levels: at 2.5% protection, SSP3-7.0 generates XOF 2.35 versus XOF 2.18 under SSP5-8.5. Even under the high-emissions scenario with delayed flood peaking, BCRs remain robust and above XOF 2.0 across all cases, confirming strong investment viability regardless of climate trajectory. Protection efficiency improvements drive proportional BCR gains in both pathways, with higher efficiency consistently outperforming lower protection across equivalent climate scenarios. These findings demonstrate that mangrove restoration represents a sound economic investment that performs favorably even under divergent long-term climate futures, offering flexible adaptation value for coastal communities confronting multiple climate possibilities.

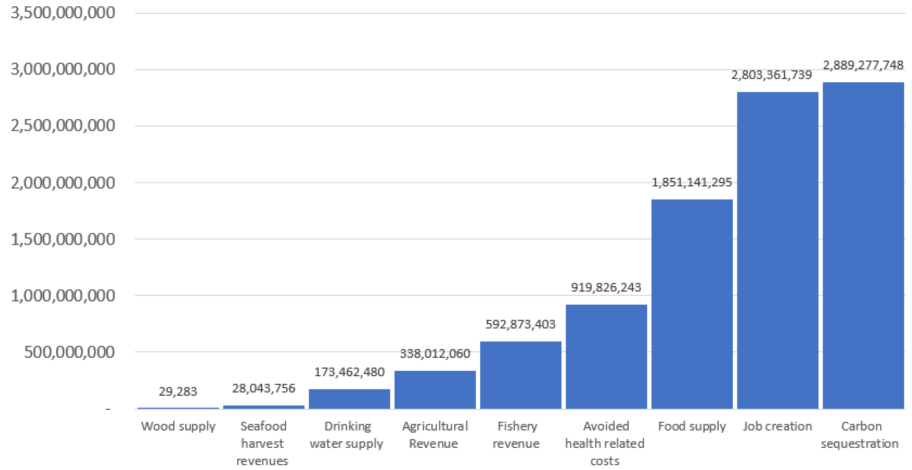
Figure A10. Benefit-cost ratio under SSP scenarios



Source: Author.

Figure A11 shows benefits beyond avoided flood damage. The largest individual benefit categories are carbon sequestration (XOF 2.89 billion, or 30.1% of total), representing global climate mitigation value, and job creation (XOF 2.80 billion, or 29.2% of total), reflecting direct employment during reforestation and ongoing maintenance. Food provisioning, encompassing household consumption of rice, fish, vegetables, and other staples, constitutes the third-largest category at XOF 1.85 billion (19.3%), directly supporting food security for coastal communities. Avoided health-related costs total XOF 920 million (9.6%), reflecting improvements in respiratory and waterborne disease prevention through mangrove-mediated air and water filtration. Fishery revenues contribute XOF 593 million (6.2%), agricultural revenues add XOF 338 million (3.5%) and drinking water supply yields XOF 173 million (1.8%) through improved groundwater recharge and quality. Seafood harvest revenues for women generate XOF 28 million(0.3%), while wood supply (fuelwood and construction materials) provides a nominal XOF 29,283 (0.003%). Collectively, these benefits demonstrate that nature-based infrastructure investments simultaneously deliver climate mitigation, livelihood security, employment generation, and essential ecosystem services, creating substantial returns that extend to all income levels and especially support vulnerable populations dependent on marine and terrestrial resources.

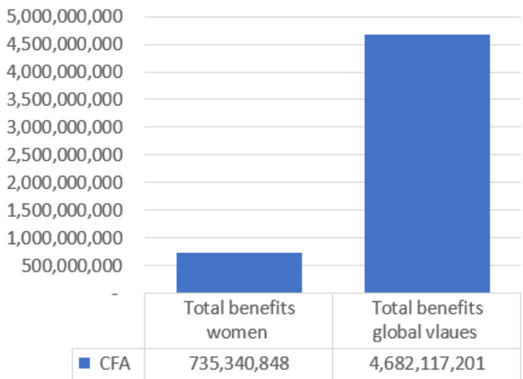
Figure A11. Distribution of benefits (excluding avoided costs to infrastructure damage)



Source: Author.

Figure A12 shows total community benefits valued at approximately XOF 4.68 billion annually, with women capturing a share of XOF 735 million, representing 15.7% of total benefits. This distribution reflects women's concentrated participation in specific livelihood activities, notably shellfish harvesting, agricultural production, and fishery processing, and job creation, where they exercise considerable autonomy and generate substantial income. Despite capturing meaningful absolute benefits exceeding XOF 735 million, the proportional gap between women's and global community benefits (16.4 %-point difference) underscores how structural inequalities, including women's limited access to capital, decision-making authority, and formal employment in higher-value activities, constrain their benefit realization.

Figure A12. Total benefits for women versus total benefits (global values)



Source: Author.

Appendix B. Modelling Assumptions

Direct Costs

Implementation Costs (CAPEX) – Reforestation area (ha)

The reforested area represents the total number of hectares planted each year across the intervention sites in Casamance. Planting targets were defined based on IUCN data and distributed across six protected areas: three Indigenous and Community Conserved Areas (APAC Kamite, APAC Badala and APAC Koureye) and three marine protected areas (AMP Kalone-Bliss-Kassa [AMP KBK] and AMP Kalolaal-Blouf-Fogny [AMP KBF]), in addition to the larger APAC Kawawana conservation area.

In 2024, total reforestation targets amount to 64.2 hectares across all sites: 2.5 ha in APAC Kamite, 2.0 ha in APAC Badala, 4.0 ha in APAC Koureye, 13.3 ha in APAC Kawawana, 10.9 ha in AMP KBK, and 31.5 ha in AMP KBF. In 2025, the planted area will increase to 73.0 hectares, with increases of 3.0 ha in APAC Kamite, 5.0 ha in APAC Badala, 5.0 ha in APAC Koureye, 10.0 ha in APAC Kawawana, 25.0 ha in AMP KBK, and 25.0 ha in AMP KBF. In 2026, planned reforestation will reach a total of 70.0 hectares: 5.0 ha each in APAC Kamite, APAC Badala, and APAC Koureye, 10.0 ha in APAC Kawawana, 25.0 ha in AMP KBK, and 20.0 ha in AMP KBF.

Unit Reforestation Cost (CFA/ha)

The unit reforestation cost includes all expenses required to establish one hectare of mangrove forest, including seedling preparation, planting labour, site preparation and clearing, and delivery to the planting sites (based on information provided by IUCN). This cost is standardized at XOF 350,000 per hectare for all sites and all years.

Reforestation Implementation Cost (CFA)

Reforestation costs are calculated by multiplying the annual reforested area by the unit cost per hectare (XOF 350,000, IUCN source). In 2024, total reforestation costs amount to 64.2 ha × XOF 350,000/ha = XOF 22,470,000. In 2025, costs increase to 73.0 ha × XOF 350,000/ha = XOF 25,550,000. In 2026, reforestation costs reach 70.0 ha × XOF 350,000/ha = XOF 24,500,000. These annual costs are directly included in the cost-benefit analysis as capital expenditure (CAPEX) for reforestation activities in the Casamance intervention area, representing investments in ecosystem restoration and the creation of community livelihoods during the critical initial phase of mangrove restoration.

Maintenance Costs (OPEX)

Operation and maintenance costs cover all annual activities required to maintain restored and protected mangrove areas, including monitoring, seedling maintenance, ecosystem patrols, community management, adaptive maintenance, and stakeholder engagement throughout the Casamance intervention area.

Conserved Area (ha)

The total area under conservation management each year represents the sum of active hectares across six protected areas (data provided by IUCN): three Indigenous and Community Conserved Areas (APAC Kamite, APAC Badala and APAC Koureye), APAC Kawawana, and two marine protected areas (AMP Kalone-Bliss-Kassa and AMP Kalolaal-Blouf-Fogny).

In 2024, the total protected area amounts to 5,100 hectares: 200 ha in each of APAC Kamite, APAC Badala, and APAC Koureye; 1,000 ha in APAC Kawawana; 2,000 ha in AMP KBK; and 1,500 ha in AMP KBF.

In 2025, conservation management expands to 8,700 hectares: 400 ha each in APAC Kamite, APAC Badala and APAC Koureye; 1,500 ha in APAC Kawawana; 3,500 ha in AMP KBK; and 2,500 ha in AMP KBF.

By 2026, the conserved area will reach 14,996 hectares, representing considerable geographic expansion: 606 ha in APAC Kamite, 680 ha in APAC Badala, 710 ha in APAC Koureye, 2,000 ha in APAC Kawawana, 6,000 ha in AMP KBK, and 5,000 ha in AMP KBF.

Unit Conservation Cost (CFA/ha/year)

The average annual cost to maintain and actively manage one hectare of restored mangrove is standardized at XOF 20,000 (assumption confirmed by IUCN) per hectare per year for all protected areas and all years.

Annual Operation and Maintenance Costs (CFA)

Operation and maintenance costs are calculated by multiplying the conserved area by the unit cost per hectare per year:

- In 2024: 5,100 ha × XOF 20,000/ha/year = XOF 102,000,000
- In 2025: 8,700 ha × XOF 20,000/ha/year = XOF 174,000,000
- In 2026: 14,996 ha × XOF 20,000/ha/year = XOF 299,920,000

These annual costs reflect the geographic expansion of conservation activities and the continuous requirements for ecosystem management. Operation and maintenance expenditures are integrated into the cost-benefit analysis as recurring operational expenditure (OPEX), which is essential to maintaining ecosystem health.

Costs of Floods

Cost of Flood Damage - Public Buildings

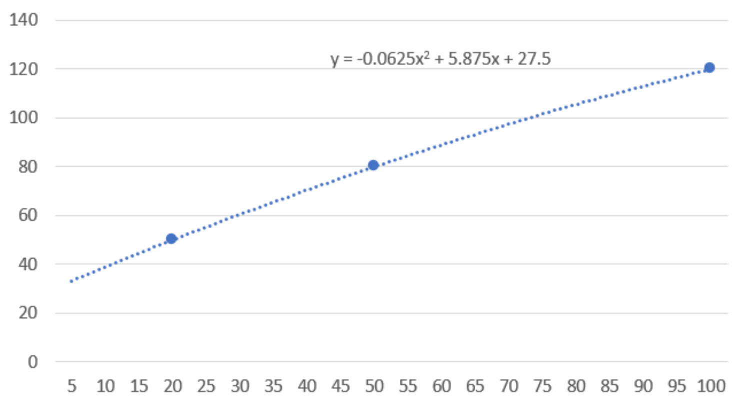
In the baseline scenario, the cost of flood damage to public buildings in the districts of Bignona and Bounkiling occurs only in the event of flooding. Based on flood frequency, we assume a uniform distribution of flood occurrence over the 2024 to 2050 period. In other words, if the flood frequency is one flood every *y* years, the flood occurrence marker would switch to one every *y* years throughout the period. It should be noted that the flood frequency parameter is selected for each simulation.

Using three flood return periods (1:20, 1:50, 1:100), we extrapolated a function between flood intensity and the number of affected buildings. For public buildings, this function is a polynomial defined as follows:

$$f_1(x) = -0.0625x^2 + 5.875x - 27.5$$

Where $f_1(x)$ is the number of residential buildings affected in the event of flooding, and x is flood intensity. Graphically, this function is presented as follows:

Figure B1. Public buildings



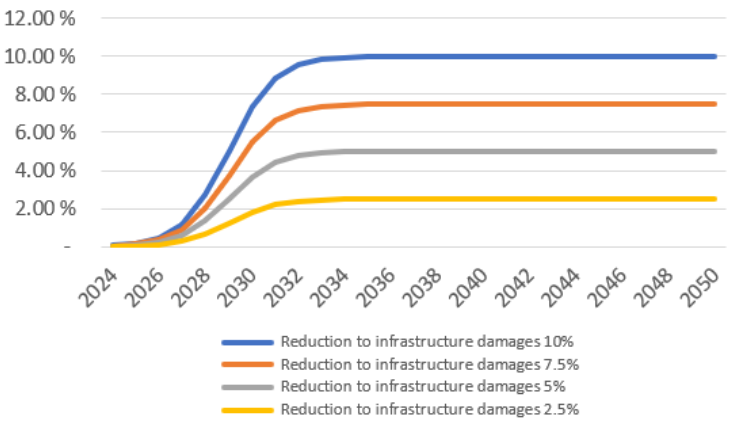
Source: Author.

Finally, we assumed a value of XOF 450,000 per square metre of buildings for which we assumed 50% would be damaged. In other words, we used the following equation:

"Residential building costs when a flood occurs" = "Number of public buildings affected per flood" × "Average size of affected public buildings" × "Unit value of public building" × "Percentage of public buildings damage considered" = $f_1(x) = -0.0625x^2 + 5.875x - 27.5$

Under the NBI scenario, we assumed four levels of flood damage reduction to infrastructure: 10%, 7.5%, 5%, and 2.5%, reflecting the range of intervention effectiveness in lowering flood-related damage. We then assumed it would take 10 years to achieve this percentage decrease given the timeline of implementation. In other words, we assumed the following materialization over time:

Figure B2. Flood damage reduction to infrastructure



Source: Author.

Cost of Flood Damages – Residential Buildings

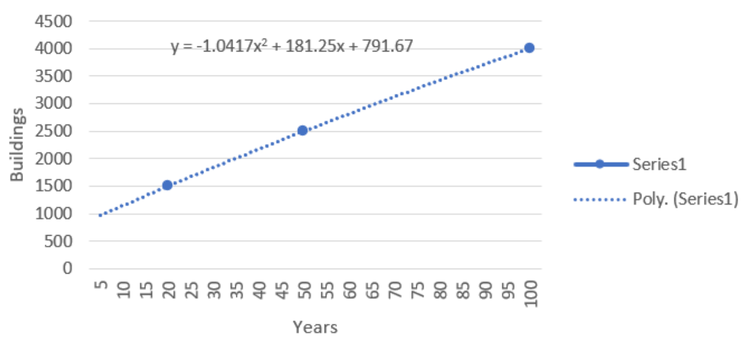
In the baseline scenario, the cost of flood damage to residential buildings in the districts of Foundiougne and Fatick occurs only in the event of flooding. Based on flood frequency, we assume a uniform distribution of floods over the 2024 to 2050 period. In other words, if the flood frequency is one flood every *y* years, the flood frequency marker would switch to one every y years. It should be noted that the flood frequency parameter is selected for each simulation.

Using three flood return periods (1:20, 1:50, 1:100), we extrapolated a function between flood intensity and the affected area. For residential buildings, this function is a polynomial defined as follows:

$$f_1(x) = -1.0417\,x^2 + 181.25\,x - 791.67$$

Where $f_1(x)$ is the area of residential buildings affected when a flood occurs, measured in number of buildings, and x is the flood intensity. Graphically this function looks as follows:

Figure B3. Residential buildings



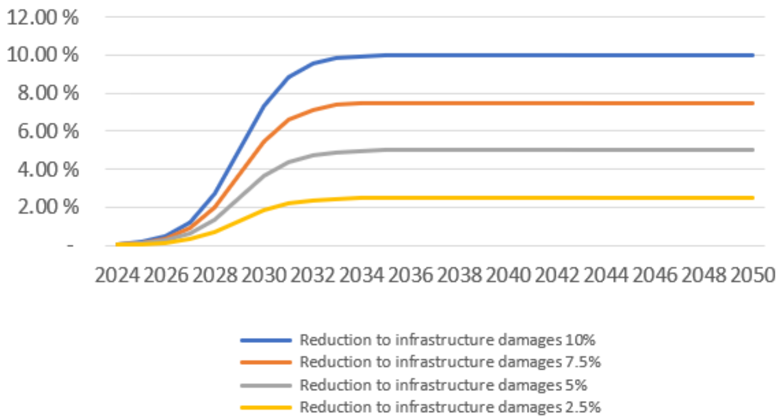
Source: Author.

Finally, we assumed a value of XOF 360,000 per square metre of buildings for which we assumed 50% damage. In other words, we used the following equation:

"Residential building costs when a flood occurs" = "Number of residential buildings affected per flood" × "Average size of affected buildings" × "Unit value of residential building" × "Percentage of residential buildings damage considered" = f_1 (x)= -1.0417 x^2 +181.25 x-791.67

Under the NBI scenario, we assumed four levels of flood damage reduction to infrastructure: 10%, 7.5%, 5%, and 2.5%, reflecting the range of intervention effectiveness in lowering flood-related damage. We then assumed it would take 10 years to achieve this percentage decrease given the timeline of implementation. In other words, we assumed the following materialization over time:

Figure B4. Flood damage reduction to infrastructure



Source: Author.

Cost of Flood Damage – Roads

Under the baseline scenario, the cost of flood damage to roads in the areas of Foundiougne and Fatick occur only when a flood occurs. Based on the flood frequency, we assume homogeneous distribution of flood occurrence across the 2024 to 2050 time horizon. In other words, if there is a flood frequency of one flood every *y* years, then the flood occurrence marker would jump to one every *y* years throughout. Note that the flood frequency parameter is chosen for each simulation.

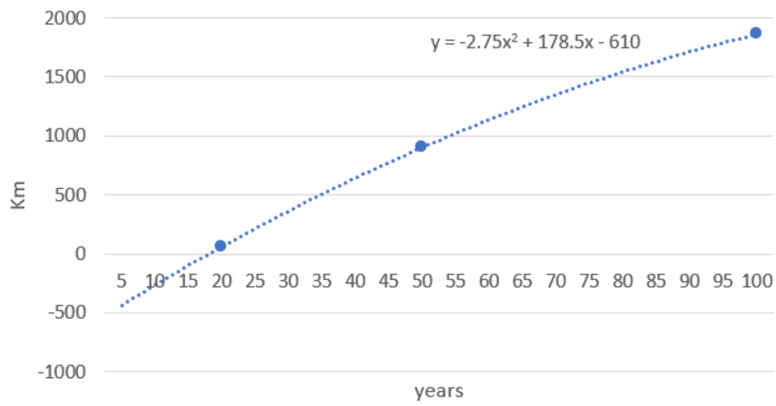
With three flood lines (1:20, 1:50, 1:100), we extrapolated a function between the flood intensity and the kilometres of road impacted. For roads, this function is a polynomial defined as follows:

$$f\_1 (x)= -2.75 x^2 +178.5 x-610$$

Where *f_1 (x)* is the roads affected when a flood occurs, measured in kilometres of roads, and *x* is the flood intensity. Graphically this function looks as follows:

Finally, we assumed a value of XOF 350,000 per square metre of roads. In other words, we used the following equation:

Figure B5. Roads

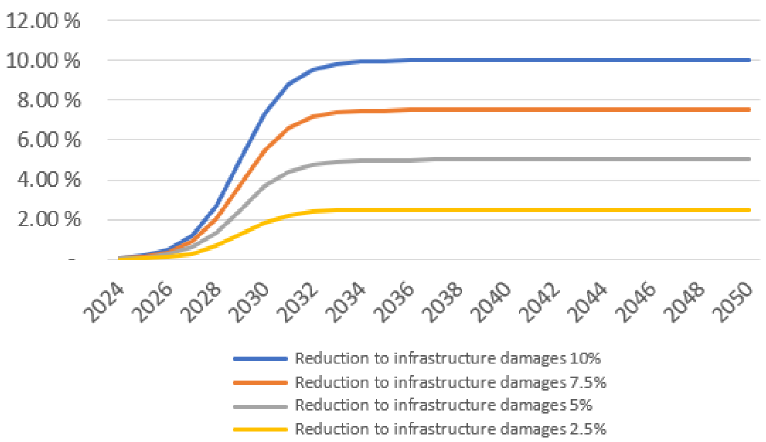


Source: Author.

"Residential building costs when a flood occurs" = "Number of km of roads affected per flood" × "Unit value of damaged road per kilometres" = $f_1(x) = -2.75x^2 + 178.5x - 610$

Under the NBI scenario, we assumed four levels of flood damage reduction to infrastructure: 10%, 7.5%, 5%, and 2.5%, reflecting the range of intervention effectiveness in lowering flood-related damage. We then assumed it would take 10 years to achieve this percentage decrease given the timeline of implementation. In other words, we assumed the following materialization over time:

Figure B6. Flood damage reduction to infrastructure



Source: Author.

Avoided Health-Related Costs

Health-related costs in the baseline scenario are calculated using data from a comprehensive household survey conducted by Senegal's National Agency of Statistics and Demography (ANSD) in the Ziguinchor region, covering the departments of Bignona and Bounkiling.

Direct Health Expenditures

Average monthly direct health expenditures per household amount to XOF 25,000 (ANSD Fatick survey), corresponding to an annualized cost of XOF 60,000 per household (XOF 25,000/month × 12 months). In line with standard environmental health methodology, 20% of total health expenditures are attributed to climate- and environment-related health problems, consistent with epidemiological evidence linking ecosystem degradation to respiratory, waterborne, and vector-borne diseases in coastal regions.

Household and Population Coverage

The analysis covers a total of 38,630 households: 37,730 households in Bignona and 900 households in Bounkiling, based on ANSD census data. These households represent a total population of 287,503 people, calculated using the regional average household size of 7.62 persons. Within this population, women represent 49% of inhabitants, or 139,601 women in the intervention area.

Total Baseline Health Costs

Annual baseline health-related costs are calculated as follows: 38,630 households × XOF 60,000/household/year × 20% (climate-attributable fraction – assumption) = XOF 2,317,800,000/year

Gender-Disaggregated Baseline Health Costs

For women specifically, health-related costs are calculated as follows:

287,503 total people × 49% (share of women) × XOF 60,000/household/year × 20% (climate-attributable fraction - assumption) ÷ 7.62 (average household size) = XOF 1,125,440,945/year

NBI Scenario

In the NBI intervention scenario, mangrove restoration is expected to reduce climate-related health costs by 2.5% through three main mechanisms, reflecting the gradual improvement of ecosystem health as mangroves mature and their ecological functions strengthen.

Fishery Revenue

Fishing income in the baseline scenario is estimated from regional artisanal fisheries production data derived from ANSD surveys covering the departments of Bignona and

Bounkiling in the Ziguinchor region, supplemented by administrative records from local fisheries inspectorates.

Unit Value of Artisanal Fishery Products

The average unit value of artisanal fishery products in the intervention area is XOF 1,325 per kg, based on data from a comprehensive household survey and market price information collected through a direct questionnaire (Socodevi). This valuation reflects regional price variations for common species (ranging from XOF 150 to 2,500 per kg depending on species and market conditions).

Regional Fish Production Volume

- Baseline artisanal fisheries production covers two main departments:
- Bignona: 59,979,413 kg/year (ANSD Senegal statistical surveys)
- Bounkiling: 96,477 kg/year (records from local fisheries inspectors)
- Total regional artisanal fisheries volume: 6,007,589 kg/year

This total represents 10% of overall regional production that is directly affected by ecosystem conditions in the intervention area and could therefore be improved through mangrove restoration.

Production Volume Destined for the Market

Of total artisanal fisheries production, 95% is destined for commercial sale (household survey data), while 5% is retained for subsistence consumption. This results in a marketable fish volume of 5,707,210 kg/year.

Total Baseline Fishing Income

Annual baseline fishing income is calculated as follows:

5,707,210 kg/year × XOF 1,325/kg = XOF 7,562,052,654/year

Gender-Disaggregated Fishing Income

- Women play an essential role in fish processing and marketing throughout the artisanal fisheries value chain. A gender-sensitive analysis shows that:
- Women manage 48% of fish processing and transformation activities, processing 2,883,643 kg/year
- Women sell 30% of processed fish directly in local and regional markets, representing 865,093 kg/year of commercial sales
- Women's income from fishing: 865,093 kg/year × XOF 1,325/kg = XOF 1,146,247,981/year

This substantial income source demonstrates the essential economic role of women in the fisheries sector, even though their benefits remain constrained by limited access to capital, market information, and formal supply chains.

NBI Scenario

In the NBI intervention scenario, mangrove restoration is expected to increase artisanal fisheries productivity by 3.0% through improved juvenile nursery habitats, enhanced ecosystem health, and expanded breeding areas. This productivity gain reflects ecosystem restoration as mangroves mature and ecological connectivity improves. The analysis assumes a 25-year timeframe to achieve this 3.0% productivity increase, reflecting the gradual nature of fish population recovery and ecosystem stabilization. This improvement in fisheries productivity directly benefits artisanal fishing communities and women involved in fish processing, through increased catch volumes and processing opportunities, thereby contributing to livelihood diversification and household income security.

Agricultural Revenue

Agricultural revenues in the baseline scenario are calculated based on comprehensive regional production data from the ANSD and direct household surveys covering Bignona and Bounkiling in the Ziguinchor region. The analysis encompasses four principal crop categories: rice, maize, oil-bearing groundnuts (*arachide huilerie*), and beans, representing the primary agricultural income sources for local communities.

Rice Production and Revenue

Rice cultivation generates baseline revenues of XOF 2,230,547,600 /year. Total rice production spans both departments—26,161,200 kg/year in Bignona (representing 20% of district production impacted by ecosystem conditions) and 10,388,800 kg/year in Bounkiling. Of this production, only 20% in Bignona and 10% in Bounkiling is destined for market sale, reflecting household subsistence consumption patterns. Market prices differ by locality: XOF 400/kg in Bignona versus XOF 132.5/kg in Bounkiling, reflecting regional market variations and transport costs.

Maize Production and Revenue

Maize represents the second-largest agricultural revenue source at XOF 6,094,290,300/year. Regional production totals 22,153,000 kg/year (4,673 tonnes in Bignona and 17,480 tonnes in Bounkiling). Approximately 70% of maize production is marketed at a standardized price of XOF 393/kg, reflecting more consistent market integration compared to rice.

Oil-Bearing Groundnut (Arachide Huilerie) Production and Revenue

Oil-bearing groundnuts are a significant cash crop generating XOF 9,143,595,000/year in baseline revenues. Total production reaches 33,310,000 kg/year (32,800 tonnes in Bignona and 510 tonnes in Bounkiling), with 90% destined for commercial sale at XOF 305 /kg.

Bean Production and Revenue

Bean cultivation contributes XOF 38,850,000/year to agricultural revenues. Total production is 1,110,000 kg/year (600 tonnes in Bignona and 510 tonnes in Bounkiling), with only 5% destined for market sale at XOF 700/kg, reflecting strong household consumption preferences.

Total Baseline Agricultural Revenues

Annual baseline agricultural revenues sum to XOF 17,507,282,900/year across all five crop categories.

Gender-Differentiated Agricultural Revenues

Women play essential roles throughout agricultural production and marketing systems, but with substantial crop-specific variation:

- Rice: Women manage 54% of rice production across both departments, selling 40% of their output, generating XOF 2,557,655,136/year
- Maize: Women manage 54% of maize production, selling 40%, yielding XOF 1,880,523,864/year
- Oil-bearing groundnuts: Women manage 8% of production, selling 40%, generating XOF 325,105,600/year
- Beans: Women manage 54% of bean production, selling 40%, producing XOF 167,832,000/year

Total women's agricultural revenues: XOF 4,931,116,600/year, representing approximately 28% of total baseline agricultural income. This differential distribution reflects women's concentration in certain crop systems (particularly cereals and pulses) and their limited participation in high-value cash crops like groundnuts.

NBI Scenario

Under the NBI intervention scenario, mangrove restoration is projected to increase agricultural productivity by 2.3% through three complementary mechanisms: improved soil quality from enhanced sedimentation and nutrient cycling, enhanced water retention capacity reducing irrigation stress during dry seasons, and reduced salinity intrusion through improved hydrological regulation. This productivity gain materializes gradually over 30 years, reflecting the extended timeframe required for soil improvement, groundwater table recovery, and ecosystem service stabilization. A linear change rate of 0.20 per year captures this progressive realization of agricultural benefits as mangrove stands mature and ecosystem functions strengthen, ultimately increasing household crop yields and farm income security across the intervention zone.

Seafood Harvest Revenues

Baseline Scenario

Annual income from oyster harvesting by women is calculated based on actual participation, daily productivity, sales rates, and local market prices. The data come from the Natur'ELLES project (source: Socodevi) and questionnaire surveys.

The number of women actively engaged in oyster harvesting is estimated at 222, including 111 in Bignona (source: Socodevi) and 111 in Bounkiling (source: Socodevi), for a total obtained by calculation.

Daily productivity is based on data from the Natur'ELLES project (Socodevi): each woman harvests an average of six pots per day, with an average weight of 500 g per pot. This corresponds to a daily production of 3,000 g, or 3 kg per woman per day (calculation).

The average number of harvesting days is estimated at 90 days per year, based on questionnaire surveys. Annual harvest per woman is therefore:

- 3 kg/day × 90 days = 270 kg/year/woman.

The share of production intended for sale is estimated at 98% (source: Socodevi). The quantity sold per woman is therefore:

- 270 kg × 98% = 265 kg/year/woman.

The sales price of processed oysters is estimated at XOF 1,500/kg, based on questionnaire data (fisheries inspectorate).

Individual annual income is therefore calculated as follows:

- 265 kg × XOF 1,500/kg = XOF 396,900/year/woman.

Finally, total income generated by all women is estimated at:

- 222 women × XOF 396,900/year = XOF 88,111,800/year.

NBI Scenario

Under the NBI intervention, improved mangrove and estuarine habitat conditions are expected to increase women's income from shellfish harvesting (oysters) by 10% through the restoration of oyster beds and improved market access.

Drinking water supply volumes and revenues are estimated using available consumption data for Bignona and Bounkiling, as well as the drinking water tariff used in the model.

Average daily consumption is estimated at 2,950,000 litres/day. This value includes 2,500,000 litres/day in Bignona, according to SEN'EAU Ziguinchor data, and 450,000 litres/day in Bounkiling (source: Ps-Eau).

Annual consumption is calculated as follows:

- 2,950,000 litres/day × 365 days/year = 1,076,750,000 litres/year.

The drinking water tariff used is XOF 250/m³, based on news from the water and sanitation sector in Senegal, April 2024.

Overall annual revenues are calculated in the model as follows:

- 2,950,000 × XOF 250 = XOF 737,500,000/year.

Thus, the baseline scenario estimates annual revenues related to drinking water supply at XOF 737,500,000/year.

NBI Scenario

In the NBI scenario, mangrove and ecosystem restoration is expected to result in a net 5% increase in available drinking water through improved recharge, reduced losses, and stabilized source yields.

This scenario quantifies the impact of mangrove restoration not only on ecosystem services, but also in terms of a tangible increase in community water security and municipal revenue potential over time.

Food Supply

In the baseline scenario, annual food supply values are calculated from recent sector revenues and sales proportions derived from available local data, including questionnaire surveys, model working assumptions, and national ANSD data, including the EMTRAS report.

- Fishing: annual fishing income amounts to XOF 7,562,052,654/year. Assuming that 95% of production is intended for sale, the unsold share retained for direct consumption represents 5%.
- Supply – fishing = 7,562,052,654 × 5% = XOF 398,002,771/year.
- Rice: for Bignona, annual rice income amounts to XOF 2,092,896,000/year. Considering that 10% of production is intended for sale, the value of unsold supply is estimated as: Supply – rice (Bignona) = 2,092,896,000 / 10% × 90% = XOF 18,836,064,000/year.
- For Bounkiling, with production intended for sale of 1,038,880 kg/year and an assumption of 10% intended for sale, the supply value is XOF 9,349,920.
- Total supply – rice = XOF 18,845,413,920/year (data provided by Socodevi)
- Maize: with baseline annual income of XOF 6,094,290,300/year and 70% of production intended for sale, according to the questionnaire survey, the unsold share represents 30%. Supply – maize = 6,094,290,300 / 70% × 30% = XOF 2,611,838,700/year.

- Oil groundnut: the sold value is estimated at XOF 9,143,595,000/year. Assuming that 90% of production is intended for sale, the unsold share represents 10%.
- Supply – oil groundnut = 9,143,595,000 / 90% × 10% = XOF 1,015,955,000/year. Source based on ANSD agricultural marketing data, EMTRAS report.
- Beans: annual income from bean sales is estimated at XOF 38,850,000/year. According to the questionnaire survey, 5% of production is intended for sale; the unsold share therefore represents 95%.
- Supply – beans = 38,850,000 / 5% × 95% = XOF 738,150,000/year.
- Seafood harvesting: annual income from seafood harvesting, notably a source of income for women, amounts to XOF 88,111,800/year. Assuming that 98% of production is intended for sale, the unsold share represents 2%.
- Supply – seafood = 88,111,800 / 98% × 2% = XOF 1,798,200/year.

Adding all categories together, the total baseline value of food supply is estimated at:

- XOF 23,611,158,591/year.

NBI Scenario

NBI interventions are expected to increase the overall value of food supply by 3.0% compared with the baseline level once the ecosystem reaches maturity.

Wood Supply

Baseline Scenario

In the baseline scenario, household firewood supply is estimated based on available data for the department of Bounkiling, from the 2020 to 2021 Regional Economic and Social Situation of Sédhiou, published by ANSD.

- Annual firewood production: 7,470 steres/year

Source: ANSD, SES Sédhiou 2020–2021.

- Market price of firewood: XOF 500/stere

Source: ANSD, SES Sédhiou 2020–2021.

Total annual value of wood production:

- 7,470 steres/year × XOF 500/stere = XOF 3,735,000/year.

Share used for household supply: 20% of total production (assumption confirmed by Socodevi).

Annual value of household supply: XOF 3,735,000/year × 20% = XOF 747,000/year.

Thus, annual firewood supply directly available to households is estimated at XOF 747,000/year in the baseline scenario.

NBI Scenario

In the NBI scenario, sustainable management practices (such as community woodlots and agroforestry buffer zones) are expected to increase firewood supply by 2.5% compared with the baseline scenario, linearly over 25 years.

Job Creation

In the NBI scenario, project staffing and gender-sensitive remuneration are derived from the reforestation and conservation cost profiles (based on Socodevi data estimates and surveys):

Reforestation Phase

For the reforestation phase (2024 to 2026), it is assumed that 40% (estimate confirmed by data collected in the field) of all construction costs (planting) are paid as local wages (based on fieldwork and typical project structures):

- Reforestation-related wages in 2024: XOF 22,470,000 (total planting cost) × 40% = XOF 8,988,000
- Reforestation-related wages in 2025: XOF 25,550,000 × 40% = XOF 10,220,000
- Reforestation-related wages in 2026: XOF 24,500,000 × 40% = XOF 9,800,000

Total reforestation-related wages over three years:

XOF 29,008,000

Conservation and Maintenance Operations

For ongoing conservation and restoration operations, 55% of all annual operation and maintenance costs are assumed to be paid as wages (based on household surveys and sector standards):

- O&M-related wages in 2024: XOF 102,000,000 × 55% = XOF 56,100,000
- O&M-related wages in 2025: XOF 174,000,000 × 55% = XOF 95,700,000
- O&M wages in 2026: XOF 299,920,000 × 55% = XOF 164,956,000

In total, this represents XOF 316,756,000 in O&M wages over three years.

Total direct jobs generated through reforestation cycles and annual maintenance amount to XOF 345,764,000 in Casamance.

Gender Analysis – Women's Employment and Income

Reforestation: In Casamance, 445 women participate in restoration activities (according to Socodevi field data), compared with 172 in Sine-Saloum (Casamance/Sine-Saloum ratio approximately 1.2).

Estimated direct wage for reforestation (per woman): XOF 5,000/person/year × 536 women = XOF 2,677,762 per year

Conservation: With the expansion of conservation areas, the number of women involved in maintenance rises to 758 in Casamance, compared with 445 in Sine-Saloum (Casamance/Sine-Saloum ratio 1.7).

Estimated wage per woman for conservation: same wage rate, XOF 5,000/person/year, or XOF 3,791,189 per year for the group

These estimates provide a direct quantification of women's wage income from reforestation and conservation work. The placements reflect the project's deliberate targeting of women's groups and local committees.

Carbon Sequestration

Mangrove restoration in Casamance provides significant climate change mitigation benefits through annual carbon sequestration. The analysis quantifies sequestration rates for young regenerating stands and for aggregated mature mangrove forests, applying current social cost and market-based carbon cost principles to estimate their monetized economic value.

Annual carbon sequestration by year (2024)

- Young mangrove sequestration rate: 14.6 tonnes of CO_2/ha/year (data provided by Tayo).
- Reforested area: 64 ha
- CO_2 sequestered: 14.6 × 64 = 937 tonnes of CO_2/year

Valuation using the social cost of carbon

- Reference carbon price: USD 50/tonne of CO_2 (source: Brookings)
- Exchange rate: XOF 557/USD (02/07/2025 14:36, exchange rate applied)[10]
- Social cost (XOF): USD 50 × XOF 557/USD = XOF27,865/tonne of CO_2

Monetary value for each year:

- 2024: 937 tCO_2 × XOF 27,865 = XOF 26,118,021

[10] 02/07/2025 14h36 https://www.xe.com/currencyconverter/convert/?Amount=1&From=USD&To=XOF.

- 2025: 1,752 tCO_2 × XOF 27,865 = XOF 48,823,080 (table: XOF 74,936,752 appears to include cumulative or compound effects)
- 2026: 1,680 tCO_2 × XOF 27,865 = XOF 46,812,000 (table: XOF 121,749,234 cumulative)

Long term (after 2026) – mature mangroves

- Mature mangrove sequestration rate: 33 tonnes of CO_2/ha/year
- Total reforested area (2024 to 2026): 207 ha
- Total annual sequestration: 33 × 207 = 6,831 tonnes of CO_2/year (table: 6,838 tCO_2)

Monetary value at full maturity:

6,838 tCO_2/year × XOF 27,865 = XOF 190,526,801/year

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