

USER GUIDANCE

COASTAL GREEN GRAY COST BENEFIT ANALYSIS TOOL - USER GUIDANCE

DEVELOPING A COASTAL GREEN- GRAY ECONOMIC EVALUATION TOOL

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APRIL 2024

CONSERVATION
INTERNATIONAL



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Table of Contents

[Acronym Glossary](#)

[1. Introduction](#)

[1.1. Users and use cases of the tool](#)

[2. Coastal Green-Gray Infrastructure Analysis Tool](#)

[2.1. Overview](#)

[2.2. Tool background and setup](#)

[A. Cost benefit analysis framework](#)

[B. Ecosystem services provided by each typology](#)

[C. Ecosystem service valuation methodology](#)

[D. User interface of the tool](#)

[2.3. Inputs & data](#)

[2.3.1. General inputs](#)

[2.3.2. General project inputs](#)

[Construction start date & duration](#)

[Total project area](#)

[Total number of people affected](#)

[Operations duration - Project Lifespan](#)

[Dollar year](#)

[Discount rate](#)

[Currency](#)

[2.3.2.1. Monte Carlo functions and uncertainty](#)

[2.3.3. Typology inputs](#)

[2.3.4. Life-cycle cost analysis \(LCCA\)](#)

[Capital costs](#)

[Operations and maintenance costs](#)

[Replacement costs](#)

[Residual value](#)

[Salvage value and disposal costs](#)

[2.3.5. Ecosystem services](#)

[2.3.6. Carbon Storage, Sequestration & Embodied Carbon](#)

[2.3.6.1. Social cost of carbon](#)

[2.3.6.2. Inputs and instructions](#)

[2.4. Detailed models and inputs](#)

[2.4.1. Fisheries and Habitat Creation](#)

[2.4.1.1. Fishery and habitat increase valuation](#)

[2.4.1.2. Subsistence fishing](#)

[2.4.1.3. Inputs and instructions](#)

- [2.4.2. Raw materials and food](#)
- [2.4.3. Disturbance Moderation \(Flood risk mitigation\)](#)
 - [2.4.3.1. Overview](#)
 - [2.4.3.2. Minimalistic model Inputs](#)
 - [2.4.3.3. H&H valuation model inputs](#)
- [2.4.4. Erosion Control](#)
 - [2.4.4.1. Inputs and instructions](#)
- [2.4.5. Water Flow \(Seawater intrusion\)](#)
 - [2.4.5.1. Inputs and instructions](#)
- [2.4.6. Recreation](#)
 - [2.4.6.1. Inputs and instructions](#)
- [2.5. Results and dashboards](#)
 - [2.5.1. Interpreting Results](#)
 - [2.5.2. Dashboard](#)
- [2.6. Next Steps & Tool Integrations](#)
- [2.7. References](#)

Acronym Glossary

CAC - Criteria Air Contaminants
CBA - Cost-Benefit Analysis
BCR - Benefit-Cost Ratio
CAPEX - Capital Expenditures
CO2 - Carbon Dioxide
DPP - Discounted Payback Period
ES - Ecosystem Services
Ha - Hectares
IRR - Internal Rate of Return
GHG - Greenhouse Gas
LCCA - Life-Cycle Cost Analysis
MC - Monte Carlo
Mg - Million Grams
MT - Metric Tons
NPV - Net Present Value
O&M - Operations and Maintenance
Sq ft - Square Feet
Sq m - Square Meters
TBL - Triple Bottom Line
TBL-BCR - Triple Bottom Line Benefit-Cost Ratio
TBL-CBA - Triple Bottom Line Cost-Benefit Analysis
TBL-NPV - Triple Bottom Line Net Present Value
TEEB - The Economics of Ecosystems and Biodiversity

User Guide

1. Introduction

Green infrastructure refers to natural systems including forests, floodplains, wetlands, and soils that provide additional benefits for human well-being, such as flood protection and climate regulation. Gray infrastructure refers to structures such as dams, seawalls, roads, pipes, or water treatment plants. Green-gray infrastructure mixes the conservation and restoration of nature (including natural coastal buffers such as mangroves and seagrasses) with conventional approaches (such as concrete dams and seawalls) while fortifying communities against climate effects while providing fresh water, clean air, coastal protection, and other natural benefits. Coastal green and gray infrastructure are two different yet complementary approaches to addressing increasing environmental stressors and acute natural hazard event challenges. Green infrastructure involves using natural systems, such as wetlands, forests, and urban green spaces, to manage water, control flooding, enhance air quality, and provide habitats for wildlife.

The UN's Sustainable Development Goals, particularly Goal 11 (Sustainable Cities and Communities), highlight the need to build resilient and sustainable cities, and thereby, preserve natural capital (stock of natural resources, living and non-living environmental components). Green infrastructure works towards preserving natural capital. The concept of natural capital underscores the idea that the environment is not just a source of resources, but a complex system that provides a wide range of benefits. It also emphasizes the need for sustainable management and conservation of these resources to ensure their availability for current and future generations.

Green and natural infrastructure are used as a part of nature-based solutions to play a critical role in achieving this goal by promoting resilient nature-based urban planning, efficient resource use, and improved quality of life for residents. These approaches highlight the benefits of using natural systems, such as wetlands and green spaces, to manage water, reduce pollution, and enhance biodiversity. Green infrastructure also contributes to climate adaptation and resilience by working towards mitigating the effects of extreme weather events, reducing heat stress, and managing water and local habitats more effectively. These benefits, Ecosystem Services, contribute towards the overall well-being of the local community and environmental health.

The purpose of creating this tool is to provide a resource that generates quantified and monetized values that speak to the Ecosystem Services versus the costs incurred by green-gray projects, justifying the budgets and spending towards the conservation of green-gray infrastructure. This tool has therefore been built to fulfill the demand and opportunity to design, prototype, and deploy a comprehensive cost-benefit tool for coastal infrastructure alternatives for use in climate-vulnerable locations. This economic tool and user guide supports the need to more comprehensively and reliably assess the multiple benefits and costs of green, green-gray, and

gray infrastructure alternatives. The wider vision is to assess across multiple locations, multiple benefits of ecosystems like mangroves and wetlands, and different coastal infrastructure types, while leveraging the best available peer-reviewed literature and databases to default data, incorporating climate resilience and risk analysis, across a geospatial cloud-based platform.

This user guide provides literature, reference material, and guidelines for using the Coastal Green-Gray Infrastructure Analysis Tool. Autocase Economic Advisory has developed this enhanced business case tool to provide project managers and stakeholders at Conservation International and other project sponsors and participants with a value-based and risk-adjusted analytical framework (cost-benefit analysis) in an Excel-based valuation tool to assess the financial, social, and environmental impacts over the life-cycle of green-gray coastal infrastructure projects. This user guide is intended to walk the user through using the tool for their project, as well as explain its capabilities and methodological approaches, and identify limitations.

To that effect, in collaboration with Conservation International and stakeholders, a comprehensive list of coastal infrastructure typologies has been incorporated into the tool. The typologies are assessed across elements such as life-cycle costs, ecosystem services, carbon effects from sequestration and embodied carbon, fishery habitat creation, flood risk mitigation, reduced storm surge water intrusion, reduced storm surge erosion, and increased recreation. Ecosystem service research on coastal systems includes a combination of typologies excluding mangroves and tidal marshes. Mangroves and tidal marshes are covered under research as coastal wetlands. The tool covers the following typologies:

- Mangroves
- Seagrass
- Salt Marshes
- Sand Dunes
- Rock Breakwater
- Coral Reefs
- Earthen Levees
- Mudflats
- Gray & Green Seawalls
- Coastal Systems and Wetlands
- Additional costs and benefits from other infrastructures such as water control structures, culverts etc.¹

Coastal systems and wetlands have been included as a catch-all typology for projects that may have multiple features together, or adjoining systems that the project team is interested in evaluating (without inputting details into each typology). The tool user may select coastal systems and wetlands when there are projects with multiple typologies, where the benefits are accrued as a combination of multiple typologies functioning collectively. Alternatively, coastal

¹ While additional research has not been added to cover additional typologies, they may be assessed in the tool using data from the project manager on discrete costs and benefits from the project.

systems and wetlands may also be used in cases where it may be difficult to differentiate inputs between multiple typologies.

The tool is built on an incremental basis where the user is required to provide data and inputs on the expected changes in the local region over the life-cycle of the project. Each model has a set of corresponding required and optional input sections that may be assessed during data collection. For additional guidance, Conservation International was a sponsor of a recent publication titled Practical Guide to Implementing Green-Gray Infrastructure². Autocase Economic Advisory was also a contributor to this guide, which is intended to be used as a resource for selecting, funding, designing, and constructing green-gray infrastructure projects, as well as a tool for education and outreach. Also, a brief case study on a coastal hybrid project, the Cienaga Grande de Santa Marta (CGSM) coastal highway redevelopment project in Columbia, is highlighted by the sustainable infrastructure resource center at Duke University Nicholas School for Energy, Environment, and Sustainability³, which provides capacity building on sustainable infrastructure planning and development principles from United Nations Environment Program (UNEP's) International Good Practice Principles for Sustainable Infrastructure.⁴ Autocase conducted that CGSM analysis and Conservation International was the project evaluation sponsor. These case studies may be used as examples of the data required to run this tool, as well as provide an outlook into the kind of detailed analysis that may be conducted to evaluate project potential.

The input tables listed for each model in the methodology section below detail the various data requirements, with further explanation where necessary, and how they may be altered to suit the needs of the project analysis. The results section and dashboards describe the results that will be produced, and how to interpret them.

1.1. Users and use cases of the tool

This tool is intended to be used by project managers, analysts, and stakeholders invested in understanding the costs and benefits of green-gray coastal projects during different stages of data collection. The results from the tool are intended to be shared with all key stakeholders involved in the approval, evaluation, and monitoring of projects. It is also intended to be used to approve project budgets as the tool provides financial metrics such as internal rate of return and discounted payback period that speak to project feasibility and justify costs incurred. The tool may be used in conjunction with two stages of data availability:

- **Preliminary Ecosystem Services Identifier and Costing Analysis**

² <https://www.conservation.org/docs/default-source/publication-pdfs/ci-green-gray-practical-guide-v08.pdf>

³ <https://nicholasinstitute.duke.edu/sites/default/files/sustainable-infrastructure/CGSM-Case-Study-Sustainable-Infrastructure-Putting-Principle-into-Practice.pdf>

⁴ <https://www.unep.org/resources/publication/international-good-practice-principles-sustainable-infrastructure>

When there is limited project data beyond the project design and rough order of magnitude costs, the tool will provide a preliminary assessment of costs and benefits. Ecosystem service values used in this tool are applied via a benefit transfer, which represents a generic valuation pathway to assess the range of ecosystem service benefits created by a project. The impacts included as a part of the preliminary analysis include:

- Ecosystem services
- Carbon sequestration
- Embodied carbon
- Life-cycle cost analysis

- **Detailed Impact and Costing Analysis**

A detailed project analysis option allows the user to analyze the following project impacts with detailed data when available, thereby overriding the defaulted ecosystem service benefits. The detailed impacts include:

- Flood risk mitigation
- Erosion control
- Seawater intrusion abatement
- Recreation
- Fishery and habitat creation
- Life-cycle cost analysis
- Carbon sequestration
- Embodied carbon

The tool applies to projects in Mexico, Brazil, Suriname, and Guyana. This tool may also be applied to other regions, if the research values for Ecosystem Services and other models are overridden. Additionally, it would be recommended that other locations use USD as the currency while running the tool, since additional exchange rates have not been included in the tool.

The green-gray cost-benefit analysis tool accounts for the multiple benefits of ecosystems using a triple bottom line approach to value the social, environmental, and economic costs and benefits of infrastructure investments. The tool leverages the best available peer-reviewed literature and databases to create a platform for evaluating green, green-gray, and gray infrastructure alternatives. It monetizes incremental costs and benefits between a project baseline and multiple design alternatives to guide investment and design decisions. The extent of project evaluation by this tool depends on the stage of project approval and selection, and the nature of the coastal project. There are a few key project stages for which this tool may be used (listed below). It may also be used iteratively to assess a project as it progresses in development and as more granular data becomes available.

- **Design or Pre-Construction Stage Project Analysis:** to analyze the preliminary list of typologies against costs and ecosystem service benefits.
- **Detailed Green-gray Cost Benefit Analysis:** a full-scale analysis that uses detailed project information, hydraulic-hydrological survey data, storm event analysis, and other project benefits.

- **Performance and Monitoring Stage Support:** retroactive analysis of projects as they start to capture the evolving scale of costs and benefits of the project.

As the project team moves through different stages of data collection, this tool can be used iteratively to update results and retroactively assess progress. As the project nears the final stages of completion, and the user has collected detailed GIS data, this user guide also shows how preliminary results may be compared with tools such as InVEST⁵. This has been done so that project managers can run end-to-end analyses over time without the need for constantly re-assessing data needs. This user guidance and tool are intended to be used as a preliminary evaluation measure for the coastal green-gray project and have been designed to be flexible enough to account for different data availability.

2. Coastal Green-Gray Infrastructure Analysis Tool

2.1. Overview

Evaluating natural capital and green-gray infrastructure involves quantifying the economic value of ecosystem services to help decision-makers make informed choices about resource management and development. Ecosystem services include multiple benefits such as human well-being, biodiversity conservation, and climate change adaptation.

Some of the challenges of implementing green-gray infrastructure are

- **Lack of awareness and knowledge:** Many decision-makers, engineers, and stakeholders are not familiar with the concept and benefits of green-gray infrastructure, and may prefer conventional gray solutions that they are more comfortable with. There is a need for more education, communication, and demonstration of the advantages and feasibility of green-gray infrastructure.
- **Lack of technical guidance and standards:** There are not enough established methods and tools for designing, constructing, and monitoring green-gray infrastructure projects, especially in developing countries. There is a need for more technical guidance⁶ and standards that can help practitioners integrate green and gray solutions systematically and effectively.
- **Lack of financing and incentives:** Green-gray infrastructure projects often face difficulties in securing adequate and long-term financing, as they may have higher upfront costs, longer payback periods, and less tangible benefits than gray infrastructure projects. There is a need for more innovative financing mechanisms and incentives that can support green-gray infrastructure investments and capture their multiple values.

This tool is intended to provide analytics and backing to overcome some of the challenges listed above. The tool assesses the impacts under the Financial, Environmental & Social impact

⁵ [InVEST | The Natural Capital Project \(stanford.edu\)](https://invest.stanford.edu/)

⁶ CGI guidelines for reference: [ci-green-gray-practical-guide-v08.pdf \(conservation.org\)](https://www.conservation.org/ci-green-gray-practical-guide-v08.pdf)

categories (Table 1). Some impacts are estimated on a feature-by-feature basis, whereas some impacts are estimated on an aggregate project-wide basis.

Table 1: List of project infrastructure impacts covered by the Green-Grey Tool

Financial	Environmental & Social
Life-Cycle Cost Analysis*	Ecosystem Services* Carbon Sequestration* Embodied Life Cycle Carbon* Fisheries* Flood Risk Mitigation Erosion Mitigation Avoided Seawater Intrusion Raw Materials and Food Production Recreation & Amenities

*Impacts assessed per typology, the other impacts use aggregated project data

Green and gray infrastructure refers to nature-based solutions and conventional built infrastructure, respectively. The tool closely follows nomenclature and classifications by TEEB (The Economics of Ecosystems and Biodiversity). TEEB uses frameworks such as natural capital accounting to evaluate the value of hidden ecosystem service benefits (TEEB Country Studies, n.d.). Their country studies evaluate the list of ecosystem services that are vital to meeting and maintaining country policies and targets (TEEB Country Studies, n.d.). These benefits include improved water management, enhanced biodiversity, and cost savings, among others, from investing in nature-based solutions over purely built infrastructure; and contributing to sustainability, resilience, and overall environmental well-being. The tool follows the TEEB classification of impacts per typology and ecosystem services, and according to their guidance, segments impacts into four main categories:

- **Provisioning:** These are tangible resources that directly benefit humans, such as food, water, timber, and raw materials.
- **Regulating:** Natural systems help regulate processes like climate, water purification, pollination, flood control, and disease regulation.
- **Supporting:** These services underpin all other ecosystem services by maintaining soil fertility, nutrient cycling, and biodiversity.
- **Cultural:** Natural capital provides cultural, spiritual, and recreational values, including opportunities for tourism, outdoor recreation, and aesthetic enjoyment.

2.2. Tool background and setup

There have been four key segments and workflows used to set up and build this tool: developing the cost-benefit analysis framework as the process for understanding the segmentation of costs

and benefits for the project, identifying research that lists the ecosystem services provided by each typology, expanding the research to set up the ecosystem service valuation methodology and assigning monetary benefits to each service, and finally, developing the tool's user interface to simplify the process of running the tool.

A. Cost benefit analysis framework

A Cost Benefit Analysis (CBA) values an assortment of financial, social, and environmental impacts through the industry-standard cost-benefit analysis framework. This approach looks past the solely financial aspects of a project and dives into the ways that infrastructure decision-making can affect the environment and society at large. It is an analytical and management tool applied to guide the implementation of policies (IUCN, 2020). CBA employs a comparative analysis approach - the benefits and disbenefits of a scenario are all relative to a base case. Given a set of options, a project should be undertaken if the expected benefit is higher than the expected costs of the project (UNEP, 2022). For this analysis, the base case is keeping the existing structures, operations, and the future upgrades/replacements investment required for the status quo. In this tool, the user inputs details directly for the design case to understand the costs and benefits of addressing, rehabilitating, or upgrading different sets of coastal typologies.

Key parameters of this study include the project horizon and the discount rate. These parameters apply to all of the scenarios and models. The discount rate determines how much more valuable a dollar is today as compared to one dollar received tomorrow, with the discount rate defaulted for the tool at 3% in concurrence with guidance provided by the U.S. Office of Management and Budget (OMB, 2023). The project horizon determines the temporal boundaries of the analysis. The project life may be set as the lifespan of the most prominent project asset and defines the cash flows, as well as replacement cycles. All cash flows are discounted to present value using the chosen discount rate.

B. Ecosystem services provided by each typology

This tool covers a variety of coastal green-gray infrastructure typologies that may be implemented individually or in combinations within a project. For instance, while some projects look at mangrove restoration or rehabilitation alone, others may use a combination of mangroves, salt marshes, and seagrass restoration or rehabilitation combined with seawalls as a part of coastal protection efforts. Each typology and/or combination is responsible for contributing toward a variety of ecosystem services generated as a part of the project. These services are assessed using a detailed data-based valuation process or a high-level ecosystem service value across the four categories of ecosystem services: Provisioning, Cultural, Supporting, and Regulating. The tool has a matrix of ecosystem service values attributed to each typology, and the sourced literature uses a combination of techniques including willingness to pay, contingent valuation, and market price. These values are then transferred to the project context using a simple benefit transfer approach. The tool includes close to 20 ecosystem services for which benefit values apply, and the literature review for identified ecosystem services per typology has

been summarized in a tabular format. This has been shown in Table 2 and described in more detail in the methodology section.

Table 2: List of ecosystem service impacts per typology covered by the Green-Gray Tool.

Category	Service	Mangroves	Seagrass	Salt Marshes	Coral Reefs	Sand Dunes ⁷	Grey Seawall	Green Seawall	Rock Breakwater	Earthen Levees	Mudflats
Provisioning	Food	✓	✓	✓	✓			✓			✓
	Raw material	✓	✓	✓	✓	✓	NA	✓			✓
	Fresh Water										
	Genetic resources	✓		✓	✓						
Regulating	Air Quality Regulation	✓									
	Climate Regulation	✓			✓						
	Disturbance moderation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Water flow regulation	✓		✓							✓
	Waste treatment	✓			✓			✓		✓	✓
	Erosion prevention & maintenance of soil fertility	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Supporting	Maintenance of migratory species life cycles		✓	✓	✓	✓					
	Genetic diversity	✓			✓				✓		✓

⁷ Non-vegetated sand dunes

Cultural	Aesthetic Information	✓			✓	✓	✓	✓		
	Recreation & Tourism	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Inspiration for culture				✓	✓	✓	✓	✓	✓
	Cognitive development				✓					
	Nutrient cycling	✓								
	Fisheries	✓								
	Energy resources	✓								

C. Ecosystem service valuation methodology

There were a few distinct steps taken to outline a process and approach to build this tool. First, stakeholder engagements were conducted with a Technical Advisory Group to discuss the list of typologies to be included in the tool. Further, each typology was researched to identify the list of ecosystem services and relevant global values. The list of ecosystem services was then segmented under TEEB's classification of provisioning, cultural, supporting, and regulating services. Additional measures were taken to look up any values available from regional studies; however, there were significant gaps in the literature. The literature review included an in-depth survey of papers published in peer-reviewed journals, white papers, and local impact assessments to understand the individual benefits of each coastal typology, and subsequent published valuations for each project area. Further, global studies assessed as a part of the literature review included aggregated values from local papers, that are meant to be best-practice global thresholds for impact valuation.

Most of the selected values represent global values that have been then adjusted using benefit transfer methods - a method used to estimate the economic value of an ecosystem service by using data from previous studies on similar services. The tool uses a ratio of consumer price index to transfer values between countries using data from the OECD. Global values for each of the typologies have also been adjusted to fit into each of the TEEB categories to form a range of country-specific minimum, maximum, and average estimates. Additionally, as these ecosystem services were added to the tool, the user interface was set up to showcase the list of services most relevant to each typology. The Ecosystem Service section is accompanied by a service-specific dropdown of 'Yes or No', that allows the user to customize the selection of services relevant to the project. In the absence of such information, the tool also has a default setting of 'Yes and No' selections based on the literature review and research.

Besides benefit transfer, there are different methodologies and practices available to analyze the benefits of enhanced ecosystem services. As a secondary part of the literature review, these methodologies and their detailed valuation measures were recorded and added to the tool to allow a location-specific detailed study. These detailed methodologies added to the tool require users and project managers to collect location-specific data. Some alternative methodologies include:

- **Production function:** An input-output methodology that shows the value of typologies in terms of outputs created such as marketable goods
- **Market price:** The economic value of an ecosystem service by using market prices of similar goods or services
- **Marginal costs:** The change in costs and outputs per unit change in the project typology
- **Damage abatement:** The economic value of an ecosystem service by estimating the cost of preventing damage to that service

- **Travel cost:** The economic value of an ecosystem service by estimating the cost of travel to that service
- **Resource rent:** The difference between the total revenue generated by a resource and the total cost of producing it
- **Residual value:** The value of an asset after all liabilities associated with it have been paid off or the value of gray assets

An important consideration, due to limitations in available research on typology specific ecosystem service valuation, the tool has used research values from combined coastal systems and wetlands to supplement and fill in the gaps. These have been highlighted in the tool and the user may turn these services off based on the project. The table below shows the impacts that have been assessed using different detailed methodologies vs benefit transfer methods.

Table 3: List of ecosystem services and their corresponding valuation methodologies used as a part of the tool

List of impacts	Methodology Type
Food & raw material	Market price, Resource rent
Habitat for species (fisheries)	Production function, Market price
Carbon storage & sequestration	Marginal cost
Embodied carbon	Marginal cost
Moderation of extreme events	Damage abatement
Erosion prevention & maintenance of soil fertility	Damage abatement
Freshwater	Market price, Marginal cost, Damage abatement (seawater intrusion)
Recreation, tourism	Travel cost
Life-cycle cost analysis	Residual value
Medicinal resources	
Local climate & air quality regulation	
Water - Waste treatment	Benefit transfer
Biological control	

Pollination

Nutrient cycling

Maintenance of genetic diversity

Aesthetic appreciation

Spiritual experience & sense of place

D. User interface of the tool

The user interface has been set up following guidelines from best practice tools, reports, and interfaces that conduct similar and detailed analyses (Hazus 5.1, 2022.; Natural Capital Project, 2023; APEC, 2018; WRI, 2014). It has been segmented into the following distinct sections, each described in detail below, along with some guidelines.

- **General inputs:** This section is intended to cover basic project details including locations, project durations, discount rate, and currency for the project as a whole.
 - General
 - Typology Inputs
- **General model inputs:** This section covers typology area inputs, concrete usage for gray infrastructure (to calculate embodied carbon), and ecosystem service selections for each typology.
 - Ecosystem Services
 - LCCA
- **Detailed model inputs:** This section includes detailed model inputs intended to be filled out with project-specific data.
 - Fisheries
 - Food & Raw Materials
 - Disturbance Moderation (Flood)
 - Erosion Prevention
 - Water flow (Seawater intrusion)
 - Recreation, Amenities
- **Results and dashboards:** Once the inputs are provided - the user can run the project results and utilize the dashboard and printable one-pager.
 - Dashboard
 - Dashboard Report
- **Models, calculations, research, and miscellaneous:** This section has been kept open for the user to reference assumptions and calculations but requires no action from the user. It is intended to remain unchanged to maintain the tool's functionality.

2.3. Inputs & data

2.3.1. General inputs

This section covers project details and the minimum inputs required to run project results. The tabs included under this section include a project overview, typology inputs, ecosystem services, and life-cycle cost analysis. These inputs are expected to stay consistent through the project analysis and apply to all the typologies selected. The general inputs and other input sections have descriptions and legends at the start of the page, to give the user direction on what is required, default inputs, and optional inputs. The text box also gives a brief description of the intent of each page (Figure 1).

Title: General inputs for the project	
Notes: This sheet is intended to account for general project inputs that do not change as designs change. It is held consistent through the analysis as features are selected and un-selected. The key inputs include those of construction and project durations, project start date, location, and the currency in which the analysis should be computed. Additionally, this sheet allows the user to select impact areas where detailed data and information may be available to the project team.	
Legend:	Required inputs
	Optional inputs
	Defaults not available

Figure 1: Tool legends and page descriptions at the top of each page

2.3.2. General project inputs

The first set of inputs requires the user to enter the project's name, current year, and location of the project. The project's name has no limitations and is at the discretion of the user. The tool covers four countries: Mexico, Brazil, Suriname, and Guyana. The full use of the tool is currently restricted to only these four countries. Details on how this tool may be expanded to future geographies are covered in the 'Next Steps' section. There is a section to input the project city as well. This input does not affect the tool currently but may be linked in the future to city-specific datasets to increase granularity in the tool. Additionally, the user is required to input the project timeline, project area, number of people affected, discount rate, and dollar year of analysis. The following sections cover the individual inputs in the General Input section.

Construction start date & duration

The user can indicate the planned dates for the construction and operation stages of the project. The project start date has no set range and can be adjusted at the user's discretion. When selecting the project start date you must first input the day, then the month, then the year. The construction duration is inputted as the number of months the construction period occurs.

Total project area

The total project area input should align with the extent of green-gray infrastructure. For example, if mangrove rehabilitation is a typology of the project, the project area would be the extent of the mangrove forest rehabilitated at the start of the project, but this would not include the entirety of the surrounding area that would benefit from the project as such inputs are covered under model-

specific inputs. For instance, when the total project area is equated to the area of the mangrove forest rehabilitated, this gives a realistic estimation of the ecosystem services as well as carbon sequestration benefits. However, including areas such as land areas that benefit from reduced flooding due to mangrove rehabilitation in this input would skew benefits and make them higher. Data on surrounding areas benefiting from mangrove rehabilitation should be inputted in detailed model input sections. This input should not include areas affected by the green-gray infrastructure like flood zones.

Total number of people affected

The total number of people affected input may extend beyond the immediate project area to include the number of adults affected as a part of the flood risk, seawater intrusion, and recreational model. The total number of people affected would include the project area population, as well as the surrounding area. For instance, with the flood risk model, mangrove rehabilitation projects reduce the effect of storm-surge-based flooding in the surrounding area, reducing damage to properties, as well as costs of cleaning and repairs in other areas. The number of people affected in the surrounding area (aggregated across impacts) would be added as a part of this input, as well as the number of people benefitting from improved amenities, and availability of freshwater from reduced seawater intrusion.

The subset of people affected per impact This may also include the number of families that may retain their living, and not be required to relocate with coastal rehabilitation and avoided storm surge. The total of these values may be aggregated in this input and then segregated through the individual detailed models if different measures affect different impacts.

Operations duration - Project Lifespan

The user can select the expected project life cycle. All impacts are aggregated over this duration. It is common to set the duration of the operations as the useful life of the most important asset of the project.

Dollar year

This input specifies the year in which inputted dollar values (e.g., capital expenditures, operations & maintenance costs) are assumed to be. The dollar year also indicates the current year to which future values will be discounted into present value.

Discount rate

The discount rate is the interest rate used to determine the present value of future cash flows. It is used to calculate the current worth or Net Present Value of future cash flows of a project and reflects the time value of money. Individuals have a preference for the present over the future and an opportunity cost in using resources today means that they are not invested for later use. The higher the discount rate, the lower the present value of future cash flows.

The discount rate default value has been held consistent with that of best practices at 3%, as recorded in the Office of Management and Budget, NIST Handbook 135. The discount rate used is a real social discount rate (“discount rate”). This means that the effect of inflation is excluded from the determination of future cash flows and the tool compares costs and benefits in “real dollars”. Real dollars reflect the purchasing power of a dollar in the selected year’s currency. Nominal dollars, conversely, are the sum of inflation and real price changes. Literature suggests that the social discount rate can be between 2% and 7% (TBS 2007; U.S. EPA 2010; OMB 1992; U.S. DoT 2015) with the lower bound representing the social rate of time preference and the upper bound representing the social opportunity cost of capital.

Currency

The currency drop-down may be adjusted as the project location changes. This links to the tool dashboard to show all results in the selected currency.

Monte Carlo switch

The Monte Carlo On/Off switch allows for project uncertainty; see the following section for more information.

Table 4 shows the inputs as presented in the tool. The ‘Value (Average)’ is required to be inputted by the user whereas ‘Defaults’ such as the exchange rate may be copied over by the project user.

Variable	Unit	Value (Average)	Defaults
General Project Inputs			
Project name	text		
Country	text	Mexico	
City	text	No	
Construction start date	dd/mm/yyyy	10/02/2023	
Construction duration	months	14	
Operations duration	years	10	
Total project area	km ²	10	
Total number of people affected	#	1500	
Dollar year of analysis	\$Year	2023	Current year
Discount rate	%	3%	3%
Monte carlo switch	On / off	On	Off
Currency displayed	List	US Dollar	US Dollar

Table 4: General project inputs for the Green-Gray Tool

2.3.2.1. Monte Carlo functions and uncertainty

When modeling impacts, it is vital to account for uncertainty to prevent distilling a false sense of precision, as well as to illustrate a potential range in magnitude that the results may take. In this project, uncertainty is observed in a variety of inputs. The tool features a Monte Carlo simulation to incorporate uncertainty. This type of procedure is a best practice in economic analysis, allowing for the model to reflect parameter variability and in turn to generate risk-adjusted results.

A beta/PERT distribution is assigned to each input that has the option of entering a range of values. For this range, the value of the input is never lower than the minimum “min” value, nor higher than the maximum “max” value. This distribution can resemble a normal distribution in certain cases, but the PERT distribution can also be non-symmetric, meaning that the estimated effects may not be linear across the entire range of explanatory values. The PERT distribution is used because values are confined within the ranges for each value, avoiding potential outliers caused by the infinite tails of a normal distribution.

The range for the minimum, average, and maximum value scenarios for data inputs are collected from various sources (where available) as described in each impact section, to reflect the range of uncertainty around input variables. A three-point estimation technique can then be used to construct a probability distribution representing the outcome of future events, based on limited information. In the PERT distribution, a weighting factor of four is applied to the most likely value; which can be interpreted as the ‘most likely’ scenario is four times more likely to occur than the ‘low’ or ‘high’ considerations. The tool runs 1,000 simulations from which the minimum, expected, and maximum results are derived.

Expected results should be interpreted as the average of the 1,000 simulations whereas the minimum and maximum values are precisely that of the 1,000 simulations. To run the Monte Carlo simulation the user is required to click on the ‘Run Results’ button on the General Inputs page, after which the tool simulation begins and will take a few minutes to complete and update the dashboard.

2.3.3. Typology inputs

This section allows the user to input typology-specific information along with any expected growth rate in typology restoration and rehabilitation over time. The user may input multiple typologies for a given project, and input a range of square meters (m²) and/or linear meters (m) for each typology.

For linear typologies, such as rock breakwaters or earthen levees, the project area benefitting from the typology is also required to be inputted so that ecosystem service values may be estimated. The user is required at minimum to provide the expected project area for each typology. There is an option to provide a minimum and maximum project area if there is some uncertainty in the input, the user will have to maintain data inputs such that the minimum and maximum values are aligned correctly. The tool has a built in indicator on the side that shows notes in red when data has been incorrectly inputted. When the data is correctly inputted the indicator is grey with a note that shows “All Data Rules Complied” as shown in Table 5.

Variable	Unit	Value (Average)	Value (Min)	Value (Max)	Value (Default - Autocase)	Autocase comments
MANGROVES						
Project area	m ²	10000.00	0.00	10000.00		All Data Rules Complied
Growth of project area per year	%	0%	0%	0%		All Data Rules Complied
SEAGRASS						
Project area	m ²	100.00	0.00	100.00		All Data Rules Complied
Growth of project area per year	%	0%	0%	0%		All Data Rules Complied
SALT MARSH						
Project area	m ²	100.00	0.00	100.00		All Data Rules Complied
Growth of project area per year	%	0%	0%	0%		All Data Rules Complied
SAND DUNE						
Project area	m ²	400.00	0.00	400.00		All Data Rules Complied
Growth of project area per year	%	0%	0%	0%		All Data Rules Complied
ROCK BREAKWATER						
Surrounding project area affected by breakwaters	m ²	300.00	0.00	300.00		All Data Rules Complied
Length of rock breakwaters	m	10.00	0.00	10.00		All Data Rules Complied
Growth of project area per year	%	0%	0%	0%		All Data Rules Complied

Table 5: Typology inputs per feature inputs and corresponding project area

2.3.4. Life-cycle cost analysis (LCCA)

LCCA expands beyond conventional upfront cost estimation to provide a whole-life perspective of the total cost of ownership over the life of the project. In addition to upfront capital expenditures, it also considers operations & maintenance costs and replacement costs throughout the project’s operational life. LCCA also factors in the project’s end-of-life residual value and salvage value or disposal costs.

Green infrastructure can require lower maintenance costs over time compared to gray infrastructure. Additionally, it can reduce the need for costly engineering solutions to manage issues like flooding or erosion. The tool enables the user to input a range of cost estimates per typology. The tool has the following LCCA functionality:

Capital costs

Upfront capital costs are the initial costs incurred during the construction period. Cost items can include the purchase of assets, systems, and any other materials during construction, including labor costs for installation. This is the only impact that is applied during the construction duration of the project.

Operations and maintenance costs

These are annual costs incurred by the project during the operational cycle. For projects that have multiple typologies, the costs may be entered individually for each typology or aggregated for the entire project. If the costs are to be aggregated, they may be added in for any typology, and the results would follow through to the dashboard - a page in the tool that shows results from all models together, with tables and charts that are useful for reporting purposes. This would, however, make the typology-specific tables on costing irrelevant in the dashboard. If the project is expected to grow over time, these costs are also expected to increase proportionately.

Replacement costs

Replacement costs refer to the costs required to replace a typology during the specified life of the project. An asset may be replaced multiple times over the life of the study period. The

replacement cost may cost more, less, or the same as the upfront capital costs of the asset, which is reflected by the input “% of recurring project cost”.

Replacement costs are estimated using the useful life of each asset procured during the construction period. The user is required to input useful life when entering the capital costs, and the proportion of capital costs that need to be replaced over time. For projects that may not have this level of information, the user may equate the useful life with the project duration. This will indicate no replacement costs.

Residual value

The residual value of a typology refers to the financial benefit arising at the end of the study period for any typology with a remaining useful life. This tool calculates residual values using straight-line depreciation. If the typology’s useful life equates to the duration of the operations then residual value will be zero.

Salvage value and disposal costs

Salvage value is the financial revenue derived from the sale of the remaining typology (e.g., cement from a seawall) at the end of the project life. For assets that have multiple replacement cycles, the salvage value is only applied after the last replacement cycle at the end of the operations cycle. Disposal costs are the financial costs incurred to dispose of a typology at the end of its useful life.

Variable	Unit	Value (Average)	Value (Min)	Value (Max)	Average Value (Default)
MANGROVES					
Project area	km ²	1	1	1	
Growth of project area per year	%	1%	0%	2%	
Capital cost from project	\$	\$500,000	\$200,000	\$1,500,000	
Annual operations & maintenance costs	\$/year	\$20,000	\$10,000	\$50,000	
Other annual project costs	\$/year	\$2,000	\$0	\$10,000	
Useful life	years	8	7	10	10
% of recurring project cost	%	100%	100%	100%	100%
Disposal costs	\$				
Salvage value	\$				
SEAGRASS					
Project area	km ²	0	0	0	
Growth of project area per year	%	1%	0%	2%	
Capital cost from project	\$	\$500,000	\$200,000	\$1,500,000	
Annual operations & maintenance costs	\$/year	\$20,000	\$10,000	\$50,000	
Other annual project costs	\$/year	\$2,000	\$0	\$10,000	
Useful life	years	8	7	10	10
% of recurring project cost	%	100%	100%	100%	100%
Disposal costs	\$				
Salvage value	\$				

Table 6: Life-cycle cost inputs for each feature type addressed in the tool

2.3.5. Ecosystem services

The ecosystem services are categorized across the four service areas of provisioning, regulating, supporting, and cultural; each with individual values per hectare of typology (Table 2). This section is automated and uses only two inputs from the user:

- Typology project area
- Yes/No selection of whether the service is relevant to the project (this is defaulted as a part of the tool but may be adjusted by the user)

The relevant ecosystem services per typology are defaulted as “Yes/No” in column E; the user has the feasibility to tailor which ecosystem services apply to their project using the “Yes/No” selection in column D. In the next few columns, the tool pre-populates a range of ecosystem service values sourced from literature based on the project country. There are three key categories of ecosystem service values in this section:

- **Typology-specific ecosystem service (ES) values:** These values are highlighted in blue and represent ecosystem service values from valuation studies that estimate ecosystem services provided by individual green-gray typologies.
- **General coastal system and wetland values:** The literature review highlighted gaps in the literature to attribute values to typologies independently. The literature does not individually study typologies such as sea grass, earthen levees, or rock breakwater. Benefits for these typologies are specified in conjunction with other investments. There are very few studies published where for instance, only benefits from sea grass are studied. Most studies have a combination of investment with wetlands, seagrass, and salt marshes. Collectively, therefore, these projects represent the rehabilitation of a coastal system or wetlands.

The Ecosystem Service Valuation Database (ESVD) is the largest publicly available database with standardized monetary values for all ecosystem services across various biomes and continents. Their 2020⁸ publication shows the ecosystem service values for coastal systems and wetlands - which have been used to fill in the gaps in this tool. This tool, therefore, uses valuations from coastal systems (including all coastal typologies except mangroves and marshes) and coastal wetlands (for mangroves and marshes) to supplement ecosystem service valuations. This is highlighted with a white background in the tool. To avoid double counting, the tool uses a range between typologies when there is a mix of ecosystem service selections (and their corresponding research - selection between typology specific values and general coastal system values)

- **Defaults not available:** Some ecosystem services have not been extensively studied by literature or have had statistically insignificant results, and are therefore excluded from this tool. They have been highlighted in gray.

⁸ Rudolf de Groot, Luke Brander, Stefanos Solomonides. 2020. Update of global ecosystem service valuation database (ESVD). FSD report No 2020-06 Wageningen, The Netherlands (58 pp).

- **Ecosystem service not applicable:** Ecosystem services that are not identified in the literature to be provided by a typology (see Table 2) are redacted in black.

Legend:	Typology specific ES values
	General coastal system ES values
	Required inputs
	Defaults not available

Variable	Unit	Selection	Default	Value (Average)	Value (Min)	Value (Max)
MANGROVES						
Food	\$/ha	Yes	Yes	\$ 498	\$ 498	\$ 498
Raw Materials	\$/ha	Yes	No	\$ 63	\$ 63	\$ 63
Fresh water	\$/ha	Yes	Yes	\$ 23	\$ 23	\$ 23
Medicinal resources	\$/ha	Yes	Yes	\$ -	\$ -	\$ -
Local climate & air quality regulation	\$/ha	Yes	Yes	\$ 807	\$ 4	\$ 1,610
Carbon sequestration & storage	\$/ha	Yes	Yes	\$ -	\$ -	\$ -
Moderation of extreme events	\$/ha	Yes	Yes	\$ 1,733	\$ 1,733	\$ 1,733
Water-waste treatment	\$/ha	Yes	Yes	\$ 266	\$ 1	\$ 530
Erosion prevention & maintenance of soil fertility	\$/ha	Yes	Yes	\$ 167	\$ 0	\$ 334
Pollination	\$/ha	Yes	Yes	\$ -	\$ -	\$ -
Biological Control	\$/ha	Yes	Yes	\$ 194	\$ 194	\$ 194
Habitat for species	\$/ha	Yes	No			
Maintenance of genetic diversity	\$/ha	Yes	Yes	\$ 1,880	\$ 1,880	\$ 1,880
Recreation & mental and physical health	\$/ha	Yes	Yes	\$ 637	\$ 637	\$ 637
Tourism	\$/ha	Yes	Yes	\$ -	\$ -	\$ -
Aesthetic appreciation	\$/ha	Yes	No			
Spiritual experience and sense of place	\$/ha	Yes	No			
Nutrient cycling	\$/ha	Yes	Yes	\$ 915	\$ 915	\$ 915

Table 7: Ecosystem service value inputs for each feature type with default research ranges

As a part of the extensive literature review conducted, there were significant gaps in sourcing region-specific studies. These values are derived from a meta-analysis of data points from smaller-scale studies and adjusted to provide universal values. Mangroves and coral reefs have shown the highest count of available studies, especially in Mexico (which was then transferred to other regions using a benefit transfer approach). Seagrass and salt marshes have been commonly mentioned in congruence with other typologies, with limited studies that analyze them individually. Sand dunes, rock breakwaters, levees, and seawalls have shown the least quantitative studies, making it a key area where supplemental coastal system values were used.

2.3.6. Carbon Storage, Sequestration & Embodied Carbon

Green infrastructure provides carbon storage and sequestration benefits. This occurs through the accumulation of carbon in above and below-ground plant biomass as well as in the soil beneath the vegetation as soil organic carbon. The greater the area that is covered in vegetation and the longer the vegetation persists, the greater the amount of carbon that is sequestered and stored. The rate at which carbon is sequestered depends on the typology. Larger plants sequester more carbon as they have more above and below-ground biomass, both of which store carbon. Carbon also accumulates in the soil as the vegetation grows. The following typologies have carbon sequestration and storage benefits estimated in the tool:

- Mangroves

- Seagrass
- Salt marsh
- Coral reef

Mangroves are important coastal carbon sinks, responsible for storing large reserves of carbon above and underground (Bertram et al., 2021; Blue Carbon Initiative, 2023). As the mangroves age, they increase storage levels exponentially. Seagrass and salt marshes are also expected to sequester some carbon over time due to low vegetative cover (Miyajima et al., 2021; Burden et al., 2019; Oreska et al., 2019). Coral reefs are responsible for absorbing carbon from water and storing it as a part of their structure. When reefs die or are damaged, they release this carbon into the water (Kault et al., 2022).

Embodied carbon is the carbon footprint of a material, and it includes all the equivalent carbon emissions required to produce it, from extraction to installation, maintenance, and decommissioning (the so-called “cradle to grave” cycle). Choosing sustainable materials with lower embodied carbon over concrete generates societal benefits. Each material requires a certain amount of energy and resources throughout its life-cycle, from extraction to installation that can be translated into equivalent carbon (CO₂) emission. This tool covers the costs and benefits of including concrete as a part of installed gray infrastructure.

2.3.6.1. Social cost of carbon

The social benefit of reduced carbon emissions from sequestration or sustainable materials is monetized by applying the social cost of carbon to the amount of carbon dioxide equivalent emissions reduced. The environmental benefit of reduced GHGs is monetized by applying the social cost of carbon to the amount of carbon dioxide equivalent emissions reduced. The social cost of carbon is taken from the US Government’s Interagency Working Group on Social Cost of Carbon (OMB, 2021). The social cost of carbon is a conservative estimate of the negative effects of climate change. The cost of carbon pollution is an estimate of the damages - of the economic cost of health, agricultural losses, property flooding, and the value of ecosystem services. The estimates, and there are many estimates, are conservative because they do not yet capture all the identified impacts of rising levels of carbon in the atmosphere.

2.3.6.2. Inputs and instructions

The user is required to provide two sets of information to estimate the carbon impacts for a project:

1. Typology project area and growth rate over the project cycle
2. Metric tons (tonnes) of concrete used per linear meter or square kilometer of project area

Materials used in construction					
metric tons of concrete used per km ² of investme	Unit	Value (Average)	Value (Min)	Value (Max)	Value (Default - Autocase)
Rock breakwater	metric tons / linear m	0	0	0	
Earthen levee	metric tons / linear m	0	0	0	
Seawall	metric tons / linear m	0	0	0	
Coastal systems	metric tons / km ²	0	0	0	

Table 8: Embodied carbon inputs for the carbon impact

The following values from literature are then used to automate and calculate the benefits of carbon storage and sequestration or costs from increased concrete usage.

Table 9: Carbon sequestration rates for relevant typology in the tool

Carbon Sequestration Defaults					
Typology	Min	Average	Max	Expected	Source
Mangroves		$23.56 \times \text{Age}^{-0.52} \text{ Mg C ha}^{-1}\text{year}^{-1}$ – $13.20 \times \text{Age}^{-0.64} \text{ Mg C ha}^{-1}\text{year}^{-1}$			This has been taken from previous consulting work with Conservation International in the CGSM project. This estimation was provided by the consulting Mangroves experts - Padilla
Seagrass	0.77	4.80	8.84	1.26	Miyajima et al. (2021); Burden et al., 2019; Oreska et al. (2019)
Salt Marsh	0.51	8.66	16.81	1.59	
Coral Reefs	2.46	2.81	3.16	2.53	

2.4. Detailed models and inputs

The detailed models in the tool require the user to collect project-specific data and input it into the tool to quantify and monetize impacts. Each of these models may be turned on the General Input page, after which, the defaulted ecosystem service model is overridden in favor of this detailed methodology.

2.4.1. Fisheries and Habitat Creation

Green infrastructure supports a diverse range of plant and animal species, contributing to biodiversity preservation (Barbier, 2007). This detailed model evaluates the protection, and increase in fish species in terms of provisioning and supporting services (Barbier, 2007). For instance, coastal systems are responsible for regulating the quality of water and creating habitats for fish spawning and other aquatic life. These benefits are attributed to the mangrove, coral reef, and seagrass typologies.

Each of these typologies is responsible for creating coastal areas where pre-existing fish species thrive, as well as creating habitats for increased spawning. For example, mangroves are responsible for regulating the salinity levels of coastal waters thereby maintaining the fish population (Alburto-Oropeza et al., 2008). This is responsible for also sustaining fishing practices in the coastal areas that are responsible for commercial livelihood as well as maintaining protein and nutritious food as a part of the local diet (Abelson et al., 2002; Blandon et al., 2014). The tool uses market prices to evaluate the benefit of increased tons of fish available in the local catch and for sale. Additionally, the market value of alternative sources of protein is also used to evaluate the benefits of increased subsistence from the increased fish catch. As this model is toggled on in the general input page, the automatic ecosystem service valuation for fisheries and habitats is turned off in favor of location-specific valuations.

2.4.1.1. Fishery and habitat increase valuation

Market price valuation as used for this impact is a process of estimating the value of produce and species increased by the typology in terms of the price at which it would sell in an open, local market. This model applies to projects that have mangroves, sea grasses, or coral reef green infrastructure.

The 20 most popular fish species in Mexico, Brazil, Guyana, and Suriname have been added as defaults in the tool; there are also dropdown buttons allowing the user to include data for any additional fish species included in the Food and Agriculture Organization of the United Nations (FAO) data. To include any fish species not covered by the FAO data, the user will have to manually enter the name of the fish species, average weight, market price, as well as protein content per 100 g of fish.

Once the user provides the area of typology(ies) and selects the relevant fish species from the drop-down ASFIS and Category columns shown in Figure 7, the model calculates the benefit by combining the increase in fish population attributed to mangroves/seagrass/coral reef with the market price using defaulted fish production and market price data. The area of mangroves, sea grasses, and coral reefs are associated with providing fish spawning grounds as demonstrated in Table 5 below. Table 5 shows the multiplier value and different units under which research shows an incremental increase in features is responsible for an increase in fisheries and habitat.

Table 10: Typology-specific relationship between area and fishery increase

Typology	Increase in Species	Units	Source
Coral reef	0.19	Individual species /m ³	Abelson et al., 2002
Mangroves	0.11	Tons of fish/ha	Alburto-Oropeza et al., 2008
Seagrass	0.98	kg/km ²	Blandon et al., 2014

Fish production (only fishery, not aquaculture) data is collected from FAO FishStatJ Software for Fishery and Aquaculture Statistical Time Series (UN FAO, 2023). The FAO’s FishStatJ is the leading source of global fishery and aquaculture sector analysis and monitoring. It allows the user to access FAO’s Fisheries and Aquaculture statistics. It includes datasets on production, trade, and consumption. Data can be extracted and aggregated according to different levels of detail and international standard classifications.

Total fishery and aquaculture production volume (in tonnes) is available from 1950 - 2023 as a part of the “Global production by production source” dataset for Mexico, Brazil, Guyana, and Suriname. Historical data has been averaged over the last five years to estimate the volume of catch and average fish sizes. This tool uses a 5-year average to eliminate any single-year specific outliers in past data, but still keep volume data as close to the present day. The quantities of fish and aquaculture are presented by country, by the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) group and division, by ASFIS (Aquatic Sciences and Fisheries Information System) species, and by FAO major fishing area. Fish from inland waters were not included in the tool as the scope of fish impacts is restricted to coastal areas. The volume and catch size are used to calculate the average weight per fish.

Annual imports and exports of fishery and aquaculture products since 1976 are available from the “Global fish trade - All partners aggregated” dataset for Mexico, Brazil, Guyana, and Suriname. The price is averaged over the last five years (between 2016 and 2020) to estimate an average market price that may be used for the duration of operations (\$/tonne). Averaging the price eliminates any one-time market-related spikes or drops in prices. Five years was selected because it contains enough data to smooth out short-term fluctuations while avoiding potentially outdated data. This timeframe is long enough to include a variety of market conditions without diluting the impact of more recent trends. These species categories were then mapped to the fish species included in the fish and aquaculture production data.

2.4.1.2. Subsistence fishing

Increasing or maintaining the local fish population is responsible for maintaining the availability of fish-based protein that is integral to the diet of residents. This model estimates the value of green-gray infrastructure to subsistence fishing. It compares the protein content for each species with an alternative source, and the volume required to meet similar daily protein needs. The subsistence value is then monetized using the cost of alternative protein sources.

The model uses the average weight and protein content of individual fish species. The weights for most fish species were included in Fishbase, a global species database of fish species coordinated by the GEOMAR - Helmholtz Centre for Ocean Research Kiel (2018). In the case the fish species could not be found in this database, its weight was calculated using other ad hoc sources (Food Data Central, 2018) or as an average of the weights of other species in the same taxonomic family (ie. given the lack of specific data, the weight of a bluefin tuna was estimated as the average weight between a yellowfin tuna and a skipjack tuna).

Protein content data was found using the FoodData Central data system of the United States Department of Agriculture’s (USDA) National Agricultural Library (Food Data Central, 2018). It contains comprehensive data on food nutrients. The data provides the quantity of protein (in grams) in a 100-gram portion of individual fish species. If the fish species was not found in this database, its protein content was calculated as an average of the protein content of other species in the same taxonomic family.

2.4.1.3. Inputs and instructions

There are three key data points required as inputs from the user:

- Square kilometers of project typology
- User selection of relevant fish species for their project
- The total number of people affected

Additional fish species that are relevant to the project will need to be added using the drop-down in the first two columns (“ASFIS species” and “Category”) to automatically pull weights and prices for each species.

Suppose the user inputs additional fish species that are not defaulted in the tool. In that case, the user will need to independently source the protein content of said species and input it into the model to run the subsistence model.

Variable	Unit	Value (Average)	Value (Min)	Value (Max)
Country	text	Mexico		
Fisheries				
Project area mangroves	km ²	1.34	1.34	1.34
Project area seagrass	km ²	0.83	0.83	0.83
Project area coral reef	km ²	-	-	-
Number of people affected by project	#	100	10	200

ASFIS species	Category	Average weight (kgs)	Weight source	Market Price (\$USD/tonne)	Protein (g/100g)
Atlantic seabob	Shrimp	0.03247	Whiteleg shrimp & Northern b	\$ 7.35	20.1
Cachama	Freshwater	40	://www.fishbase.se/summary	\$ 2.16	17.5
Whiteleg shrimp	Shrimp	0.0325	fishery/en/culturedspecies/pe	\$ 7.35	20.1
Yellowfin tuna	Tuna	200	://www.fishbase.se/summary	\$ 3.38	24.4
Bigeye tuna	Tuna	210	://www.fishbase.se/summary	\$ 3.38	23.2
Southern red snapper	Snapper	10	://www.fishbase.se/summary	\$ 5.08	20.5
Swordfish	Swordfish	650	://www.fishbase.se/summary	\$ 2.79	19.7
King mackerel	Mackerel	45	://www.fishbase.se/summary	\$ 2.04	20.3
Skipjack tuna	Tuna	34.5	://www.fishbase.se/summary	\$ 3.38	22
Rainbow trout	Trout	25.4	://www.fishbase.se/summary	\$ 1.81	20.5
Serra Spanish mackerel	Mackerel	6.7	://www.fishbase.se/summary	\$ 2.04	19.3
Nile tilapia	Tilapia	4.3	s://www.fishbase.se/summary	\$ 3.52	20.1
Brazilian sardinella	Sardine	0.24063	://www.fishbase.se/summary	\$ 1.57	24.6
Whitemouth croaker	Croaker	0.0553	://www.fishbase.se/summary	\$ 1.80	17.8
Tambacu, hybrid	Freshwater	0.31875	mmary/SpeciesSummary.ph	\$ 2.16	17.5
Common carp	Carp	40.1	://www.fishbase.se/summary	\$ 0.38	17.8
Blue crab	Crab	0.15117	w.fisheries.noaa.gov/species	\$ 6.33	18.1
Northern brown shrimp	Shrimp	0.03245	urnals/bir/2021/2/BIR_20	\$ 7.35	20.1
Atlantic Spanish mackerel	Mackerel	5.9	://www.fishbase.se/summary	\$ 2.04	18.6
Whitebelly prawn	Shrimp	0.03247	Whiteleg shrimp & Northern b	\$ 7.35	20.1
Brazilian codling	Cod, hake, haddock			\$ 2.84	20.1
Brazilian codling	Cod, hake, haddock			\$ 2.84	20.1
Brazilian codling	Cod, hake, haddock			\$ 2.84	20.1
Brazilian codling	Cod, hake, haddock			\$ 2.84	20.1
Brazilian codling	Cod, hake, haddock			\$ 2.84	20.1

Table 11: Fishery & habitat creation inputs in the Green Grey Tool

2.4.2. Raw materials and food

Raw materials and food are part of an ecosystem's provisioning capacity to provide products such as timber, fiber, crops, etc. These products are valued using the market price for each region. The user is required to input both the tonnes collected and consumed from the project area, as well as the regional market price for each product. There are no default prices for this detailed model and hence will need to be sourced and inputted by the user. The user is allowed to input up to four different raw materials and food products along with their corresponding prices to run this model.

Variable	Unit	Value (Average)	Value (Min)	Value (Max)
Are there inputs on raw material from the project area available?	List	No		
Metric tons of raw material gathered from project area				
1	Metric tons			
2	Metric tons			
3	Metric tons			
4	Metric tons			
Market price of raw material gathered from project area				
1	\$/metric ton			
2	\$/metric ton			
3	\$/metric ton			
4	\$/metric ton			
Are there inputs on food gathered from the project area available?	List	No		
Metric tons of food gathered from project area				
1	Metric tons			
2	Metric tons			
3	Metric tons			
4	Metric tons			
Market price of food				
1	\$/metric ton			
2	\$/metric ton			
3	\$/metric ton			
4	\$/metric ton			

Table 12: Raw materials and food production inputs in the Green Grey Tool

2.4.3. Disturbance Moderation (Flood risk mitigation)

2.4.3.1. Overview

All four countries have faced significant damages and costs from coastal flooding and storm surge events. For instance, in June 2021, Hurricane Grace was responsible for significant damage along the eastern coast, especially in the states of Veracruz and Quintana Roo (Reuters, 2021). In 2023, flash floods in Brazil along the coast affected several municipalities and caused landslides, road closures, and power outages (Guardian, 2023). Storm surges are also responsible for damaged crops, houses, and infrastructure, and cause displacement. This model looks at costs avoided from reduced effects of storm surge and reduced height, and depth of flooding. The user can select from one of two model options:

- **A minimalistic model:** This model uses very basic inputs from the user on the current state of flood risk, damages and costs incurred, and the depth of flooding abated or cost abatements. This is intended for a high-level analysis that still incorporates all different areas of flood damage. The high-level analysis uses data on the extent of baseline flooding, a high-level estimate of current-day damages, and expected reduction to

estimate benefits from the coastal project. Current-day damages can include clean-up costs, neighborhood property damage costs, loss of agricultural land and produce value, and cost of deployed emergency services.

The user is also required to input on surge height addressed by the project. This links to research that uses a meta-analysis of studies to evaluate the benefit of reduced flooding height and abated damage to property, land, and other costs (Bellos et al, 2022). The model also uses the user-inputted value of land and properties surrounding the project to estimate the benefit of maintaining the useability of land.

- **A detailed hydrologic-hydraulic (H&H) input and valuation model:** A detailed H&H input and valuation model allows the user to input data from a detailed H&H storm event simulation at the same time to account for typologies that are resilient to varying magnitudes of storm surges and depths of flooding. While this tool is not an H&H tool, it can use detailed inputs from such models on different 5-100-year storm events and sets of corresponding costs and damages from flooding. The model uses different extents of flooding across each storm event type, land cover assumptions, depth and height of flooding, and damages associated with each storm event type to assess the decrease in damages from managed storm heights. The model then estimates an annual weighted average benefit of reduced flooding.

The tool has collected some default data on flood disasters and damage events to help the user input high-level preliminary values. Data on flood events in Mexico, Brazil, Guyana, and Suriname were pulled from the Emergency event database EM-DAT (2023). This database is a collaborative effort between the Centre for Research on the Epidemiology of Disasters (CRED) and the World Health Organization (WHO). This database serves as a comprehensive collection of information on mass disasters worldwide, spanning from 1900 to the present. It draws data from a variety of reliable sources, such as UN agencies, non-governmental organizations, reinsurance companies, research institutes, and press agencies.

EM-DAT's definition of disasters encompasses situations or events that overwhelm local capacity, resulting in the need for external assistance at the national or international level. These disasters are unexpected and often sudden, inflicting considerable damage, destruction, and human distress. To be included in EM-DAT, a disaster must meet at least one of the following criteria: 10 fatalities, 100 affected individuals, a state of emergency declaration, or a call for international aid.

This country-level data in the last decade was used to calculate metrics such as the average number of flood events per year, as well as the average number of deaths and affected persons per flood event. Using data on economic damages, ratios for the average cost per flood event, cost per square kilometer, cost per day, and cost per affected person were also calculated in the tool. These ratios were individually calculated for each of the four countries included in the tool.

Table 13: Historical Flood Damage Estimates (EM-DAT 2023) Used as an Example for Flood Damages

Flood risk mitigation metrics	Mexico	Brazil	Guyana	Suriname
Average flood event per year	1.03	2.17	0.13	0.07
Average damage per flood event	\$437,413	\$333,909	\$291,277	\$369
Average deaths per flood event	68	59	34	3
Average affected per flood event	83,262	147,048	78,450	11,050
Average damage per square kilometer	\$843.84	\$2.08	\$245.48	\$0.00
Average damage per day	\$103,672	\$232,866	\$7,560	\$369
Average damage per affected person	\$13.58	\$17.56	\$2.97	\$0.08

2.4.3.2. Minimalistic model Inputs

Once the minimalist model is selected, the user is required to enter the following inputs:

- The area flooded under current conditions
- The current storm surge height,
- Current costs incurred in the local area per year to abate, mitigate, repair, or address damaged areas from flooding.

Flood Risk Mitigation					
Variable	Unit	Value			
Do you have project specific inputs on flood risk mitigation?	List	Yes			

Minimal Model					
Variable	Unit	Value (Average)	Value (Min)	Value (Max)	Value (Default - Autocase)
Model selection	List	Yes			
Flooded area in the baseline	km ²	2.17	2.17	2.17	
% of project site unusable due to flooding	%	100%	1.00	1.00	100%
Current storm-surge height	ft	1.213910761	1.017060367	1.410761155	
Property/land value surrounding the project	\$/km ²				
Current costs of flooding, clean-up costs, neighborhood damage costs, loss of agricultural land costs, cost of deployed emergency services	\$/year				
% of flooded area protected by typologies	%	100%			100%
Surge height addressed by the project	%	100%			100%
% unusable land made useable again through protection provided by the typologies	%	100%			100%
Flooding costs and damages abated by the project	%	100%			100%

Table 14: Minimalistic flood model inputs

The user is also allowed to input land areas or properties that are severely affected by flooding. These areas are assumed to be unusable in current conditions due to repeated storm surges. However, with the project investments, some parts of them may be usable again - thereby generating land value benefits.

2.4.3.3. H&H valuation model inputs

A detailed H&H valuation model allows the user to select between five different types of storm events: 5, 10, 25, 50, and 100-year events. Each event represents an intensity and probability of recurrence. The user is allowed to select one to all of the storm events and the model adds them to the annual cash flow using probability-based annual factors. Therefore, a user selecting 5 and 10-year storm events accounts for two types of events per year, one with a probability of 20% and the other with a probability of 10%. The formula used for this evaluation is as follows:

$$\text{Annual probability of flooding} = \frac{1}{\# \text{ year storm event}}$$

H-H Model						
Variable	Unit	5-year	10-year	25-year	50-year	100-year
Recurrence, Probability & Storm Event						
Select Storm Event Type Relevance	List	Yes	Yes	Yes	Yes	Yes
Expected Annual Frequency	#/year	0.2	0.1	0.04	0.02	0.01

Table 15: Flood model storm event inputs

In the next section, the user can enter details per storm event on the baseline flooded area and the depth and height of flooding per event. The user may also give details on land use in the municipal area to run a more detailed flood risk analysis. The percent of surge height addressed by the project directly links to assumptions on reduced damages. An exponential function to assess changes in flooding depth and height to estimate their corresponding changes in damage costs (Theodosopoulou et al. 2022) is used to estimate the expected reduction in damages.

Variable	Unit	Value (Average)	Value (Min)	Value (Max)
Hydrology Simulation				
Flooded area in the baseline				
5-year	km ²	10	5	15
10-year	km ²	10	5	15
25-year	km ²	10	5	15
50-year	km ²	10	5	15
100-year	km ²	10	5	15
Expected area to be protected as a part of the project	km ²	10	5	15
Land use assumptions				
Agricultural	km ²			
Residential	km ²			
Common municipal coastal	km ²			
Depth of flooding across the project area per day				
5-year	m	2	2	2
10-year	m	2	2	2
25-year	m	2	2	2
50-year	m	2	2	2
100-year	m	2	2	2
Surge Height under Analysis				
5-year	m	3	3	3
10-year	m	3	3	3
25-year	m	3	3	3
50-year	m	3	3	3
100-year	m	3	3	3
% of surge height to be addressed by project	%	100%	100%	100%

Table 16: Detailed H&H flood model inputs

Successively, the user has the option to input a range of damaged data in the baseline. The damage data may be inputted in aggregate form or separated under the following categories:

- Municipal cleaning, neighborhood damage costs
- Damages to agricultural land/loss of crops and livestock
- Cost of relocation per household
- Cost of emergency services
- Market value of land affected by recurring flooding

The flood risk model then generates an annualized cash flow per storm event type and aggregates up to estimate benefits from reduced flood risk due to the green-gray infrastructure

2.4.4. Erosion Control

Human activities that affect coastal mangroves and other green infrastructure are responsible for increased levels of annual coastal erosion. In Mexico, the Quintana Roo coast has seen erosion up to 1.2 meters a year, going up to a maximum rate of 4.9 meters during intense storm surge events (Feike de Jong, 2022). The northeastern coast of Brazil as well as has experienced high levels of coastal erosion due to sea level rise (Alisson, 2017). Coastal green-gray infrastructure serves as a key barrier between wave force-related attrition and abrasion over time. This maintains coastal structures and prevents downstream accumulation of sediment, sand, and particles. Damages to coastal mangroves, reefs, and marshes are responsible for enhancing wave attenuation and increasing annual coastal erosion damages.

The model estimates the value of erosion control by using either a general storm model or inputs for detailed storm events. The user may enter storm events between 5-100 year events, and input current-day damages from erosion for each event. The storm surge addressed by the project is similar to that in the flood risk model, wherein the user is required to enter the proportion of erosion addressed by the project. Some of the costs associated with erosion accounted for within the model are dredging, site-work costs, and costs of opening up clogged channels. The user may input one or all costs, any other costs may also be inputted as a part of these categories with text changes.

2.4.4.1. Inputs and instructions

The user can select from one of two model options to estimate the benefits of erosion control:

- **General model:** a general model that allows the user to enter an aggregated annual area of coastline eroded, as well as damages to land value, and costs of erosion control and mitigation. Costs may include site work, dredging, and additional costs to open up clogged channels.
- **Detailed storm event model:** the user can input storm event-related costs and scenario data. Similar to the detailed flood risk model, the user can toggle on 5, 10, 25, 50, and 100-year storm events to estimate the value of erosion control.

The highlighted yellow cells in Figure 11 represent mandatory inputs as a part of the model run, whereas the other inputs are optional. If a cost line item is not relevant to the project, entering '0' can negate that section. The input screenshots show some of the costs required for reference (Figure 11).

Variable	Unit	Value (Average)	Value (Min)	Value (Max)
Do you have project specific erosion inputs?	List	No		
Storm event under analysis				
General	List	No		
5-year	List	No		
10-year	List	No		
25-year	List	No		
50-year	List	No		
100-year	List	No		
Area of coastline eroded per event				
General	km ²		0	0
5-year	km ²	0	0	0
10-year	km ²	0	0	0
25-year	km ²	0	0	0
50-year	km ²	0	0	0
100-year	km ²	0	0	0
Land value affected by erosion	\$/km ²		0	0
% of surge height/erosion levels to be addressed by project	%		0	0
Annual Dredging Costs				
General	\$/year		0	0
5-year	\$/year	0	0	0
10-year	\$/year	0	0	0
25-year	\$/year	0	0	0
50-year	\$/year	0	0	0
100-year	\$/year	0	0	0

Table 17: Erosion control model inputs

2.4.5. Water Flow (Seawater intrusion)

Green infrastructure like mangroves and seagrass help filter pollutants from water, leading to cleaner water sources. They are also responsible for buffering storm surges and thereby reducing saltwater intrusion and contamination of freshwater drinking sources (Hilmi et al. 2017). This model estimates the benefits of reduced seawater intrusion, using the market price of freshwater saved, as well as avoided costs associated with alternative sources of water, additional filtration, and purification requirements.

The project area, and number of people affected by the project, and the per capita consumption of water are used to estimate annual water consumption. Population data was collected from the

World Bank (2020) for each of the four countries. The average water consumption for each country was divided by the average population for 5 years from 2016 to 2020 to obtain water consumption per capita values for each country (Aquastat - UN FAO, 2020).

Using project data on water shortages, and expected savings from coastal restoration, the model estimates gallons of freshwater saved and monetizes it using the market price of bottled water. The price of a 1.5-liter bottle of water was collected for each of the four countries from NationMaster, an online database of industry statistics (NationMaster, 2023). These values were then converted into a price per gallon of water. Annual freshwater withdrawal data was collected for each of the four countries from the United Nations Food and Agriculture Organization’s Aquastat, their global water statistics database (Aquastat - UN FAO, 2020). The average for 5 years from 2016 to 2020 was converted from cubic meters to gallons (the tool uses 5 years as a representation of smoothing of temporal data).

Table 18: Water consumption and price estimates

Country	Water price (\$2023 / gallon)	Water consumption (gallons/person)
Brazil	\$0.2085	83,769.76
Guyana	\$0.5044	488,816.77
Mexico	\$0.2085	188,561.04
Suriname	\$0.3273	273,903.15

2.4.5.1. Inputs and instructions

This model has four key inputs required from the user:

- **Number of people affected:** The user may input population density and project area, or a direct number of people affected by the project. Using default data on per capita consumption, the project estimates water shortages in the region. Data on the number of people affected is used to estimate the total water consumption in the region.
- **Water shortages:** The user is required to input information on water shortage durations and volumes.
- **Current costs of water treatment and purification:** This includes any ongoing costs of water treatment and ongoing infrastructure costs to maintain water supplies. It may also include costs incurred to source water from alternative sources.
- **Targeted reduction in seawater intrusion:** The user's intended reduction in seawater intrusion or targeted water savings is used to estimate benefits for the project.

Estimating the number of people affected or shortages			
Project area / area affected by water shortage	km ²		
Housing density	#/km ²		
Persons per household	#		
OR			
Number of people affected by reduced water availabilities / shortages	#		
<i>Shortages assumptions</i>			
Per capita water consumption per year	liters/person/year	2,704,198	
Duration of annual water shortages during intrusion events	# days		
Annual water shortages in the region	liters		
Current costs			
<i>Community</i>			
Alternative costs of water	\$/liter		
Current cost of water	\$/liter	\$ 0.21	
<i>Treatment and infrastructure costs</i>			
Current ongoing infrastructure costs to prevent saltwater intrusion	\$/year		
Additional alternative water source, delivery & transportation costs (not covered by the cost mentioned above)	\$/year		
Water purification and treatment costs on-site	\$/year		
% of local water consumption sourced from coastline fresh, surface, and groundwater sources	%		
Project targets			
Targeted water conservation/shortage reduction	%		

Table 19: Seawater intrusion model inputs

2.4.6. Recreation

Parks, green spaces, and other natural elements of green infrastructure enhance the quality of life for residents, providing places for recreation and relaxation. Access to green spaces can positively impact physical and mental health by encouraging outdoor activities and reducing stress.

The tool can estimate the value of recreation from sport fishing, general beach recreation, and/or coral reef-related activities (e.g., snorkeling, scuba diving, swimming) by combining the number of annual visitors, the projected change in visitors, and the estimated travel cost of individuals to participate in recreational activities from literature. Valuation for these activities has been studied using the travel cost method to estimate individuals' willingness to pay to participate in a recreational activity. The travel cost method reveals that the time and travel expenses individuals incur to participate in an activity represent the price of access to that activity, and therefore can be used to estimate their willingness to pay (Table 7).

Table 20: Recreation activity travel costs (2023 USD)

Activity	\$ per person	Source
Sport fishing	\$2,318	Almendarez-Hernández et al. (2020)

Coral reef-related activities	\$722	Morales-Zarate et al. (2019)
General beach recreation	\$706	Sarkis et al. (2010)

2.4.6.1. Inputs and instructions

The user is required to provide the following inputs to run this model:

- Expected number of visitors for at least one activity (sport fishing, coral reef-related activities, and/or general beach recreation)
- Average annual change in visitors over the study duration
- Toggle on which activities are provided by the user’s project

If these inputs are provided, this model overrides the general ecosystem service recreation benefit. Users also can override the defaulted travel cost data in the tool if they have site-specific data - such as local travel costs or site admission fees.

Variable	Unit	Value (Average)	Value (Min)	Value (Max)
Do you have project-specific inputs for recreation	List	No		
Number of sport fishing visitors	# of people per year			
Number of reef-related activities like snorkling visitors	# of people per year			
Number of general beach recreation visitors	# of people per year			
Range of increase in useability for recreational purposes (this may be a % based on number of days, people, number of activities etc.)				
Number of users per day increase (sport fishing)	%			
Number of users per day increase (reef-related activities)	%			
Number of users per day increase (beach recreation)	%			
Please toggle the activities provided by your project				
Sport fishing	List			
General beach recreation	List			
Reef-related activities like snorkling	List			
Travel cost per user				
Sport fishing	\$ per person	\$ 2,318.31		
Reef-related activities like snorkling	\$ per person	\$ 722.19		
General beach recreation	\$ per visit	\$ 705.90		

Table 21: Recreation model inputs

2.5. Results and dashboards

2.5.1. Interpreting Results

The section below outlines the results from the cost-benefit analysis for the project. The results are segmented into two core cash flow categories - financial and social/environmental impacts:

- Financial impacts and cash flows include the life-cycle costs associated with the different typologies such as upfront capital costs, ongoing operations and maintenance costs such as utilities, avoided costs, as well as any revenues.
- Social/environmental impacts include the cash flows associated with community benefits from avoided flood damages, erosion control, avoided seawater intrusion, etc.

Results are presented using two key metrics: Net Present Value (NPV) and Benefit-Cost Ratio (BCR). Using the two metrics together, one can get a sense of the scale of the impact (NPV), as well as the value generated per unit invested (BCR).

NPV is the present value of benefits net costs over the project's useful life inclusive of financial, social, and environmental impacts. Future cash flows are discounted into current dollars at rates of 3%, which can be adjusted by the tool user to reflect a specific context. NPV is the principal measure of an investment's economic worth:

- NPV > 0, means benefits are larger than costs
- NPV < 0, means costs are larger than benefits

BCR is estimated as the present value of benefits divided by the present value of costs from capital expenditures and/or operations and maintenance. BCR is intended to illustrate the benefits that are achieved for every dollar invested:

- $0 < \text{BCR} < 1$, the project delivers less than \$1 in benefits for every \$1 in costs
- $\text{BCR} > 1$, the project delivers more than \$1 in benefits for every \$1 in costs

Other metrics included as a part of the dashboard are segmented under financial and additional metrics. Each of these metrics is calculated using the Monte Carlo simulation after 1,000 iterations.

- **Internal Rate of Return (IRR):** This measure allows users to compare different project options based on their uncertainty and riskiness. It is the discount rate that makes the NPV of all cash flows equal to zero. A higher IRR means a more desirable project.
- **Payback Period:** The time taken for the project to recover the initial upfront cost, based on undiscounted cash flows.
- **Triple Bottom Line per Person:** One of the initial project inputs requires the user to state the number of people affected by the project. This metric generates the net benefit or cost per person affected by the project.
- **NPV per square meter of the project area:** One of the initial project inputs requires the user to state the extent of the project area. This metric generates the net benefit or cost per square meter of project area.

Net Present Value	USD	57,381,000
Internal Rate of Return		11%
Benefit Cost Ratio		239
Discounted Payback Period	0	year(s)
TBL Per Person	USD	38,300
NPV Per Sqm of Project Area	USD	57
Total Ecosystem Services	USD	41,760,000
Total Financial Net Present Value	USD	(161,000)
Total Social & Environmental Net Present Value	USD	57,543,000

Figure 2: Dashboard: financial metrics

Additional metrics have also been provided as a part of the tool including:

- **Avoided damages per person:** This metric captures the mitigated damages from the detailed flood risk model per person in the project area.
- **New annual recreational users:** This data is inputted by the user as a part of the detailed recreational model - where new or enhanced amenities attract more annual users.
- **Annual carbon mitigated (tonnes):** As a part of the project's carbon accounting, this value captures the annual tonnage from green infrastructure that stores and sequesters carbon. This value is an annual average as mitigated carbon can grow over the study duration if the project area of green infrastructure typologies also grows.
- **Total carbon mitigated (tonnes):** As a part of the project's carbon accounting, this metric captures the total tonnage from green infrastructure that stores and sequesters carbon over the life of the project.
- **Flood depth abated (meters):** This data is inputted by the user as a part of the detailed flood risk mitigation model - the user provides details on the extent of reduction in flooding depth. The value provided here is a weighted average across the different storm types selected in the flooding model.
- **Raw material/food provided (tonnes):** This data is inputted by the user as a part of the detailed food and raw materials model - the user provides details on the tonnes of raw material and food generation per year.
- **Erosion mitigated (km²):** This data is inputted by the user as a part of the detailed erosion model - the user provides details on the square kilometer of land protected per year across different storm events.
- **Potable water saved:** This data is inputted by the user as a part of the detailed seawater intrusion model - the user provides details on the volume of water conservation per year, which indirectly reduces regional water shortages.

Local Population Affected By The Project	1,000
Avoided Coastal Flooding Damages Per	0
Coastline Flood Depth Abated (Meters)	0
New Annual Recreational Users Benefitting	0
Raw Material / Food Provided (Tonnes) By	0

Figure 3: Dashboard: Social & environmental metrics (partial list)

2.5.2. Dashboard

The dashboard showcases the results from the tool run, key metrics, and some graphics to showcase the highlights of the project. In addition to metrics, the dashboard also provides detailed results tables of the individual impacts (i.e., costs and benefits) covered by the project, with minimum and maximum ranges - the range in costs and benefits are from the Monte Carlo simulation. The dashboard also provides corresponding charts that include data points from these tables. Key metrics, tables and charts are added in as the first part of the sheet. The second half of the sheet includes interactive selector buttons that allows the user to choose from a list of additional tables, and charts. Each of these tables and charts may be copied over to another document, however, the sheet has been protected from any other changes. After running the results on the General Input Page, the user will also be required to click on the 'Refresh Dashboard' Button on the eDashboard page to update the tables and charts.

Triple Bottom Line Cost Benefit Analysis			
Summary Results			
	Expected	Min	Max
Financial	(\$161,000)	(\$787,000)	\$111,000
Environmental & Social	\$57,543,000	\$41,333,000	\$181,356,000
Total Net Present Value	\$57,382,000	\$40,546,000	\$181,467,000
Benefit Cost Ratio	239	51	998

Triple Bottom Line Cost Benefit Analysis			
Summary Results			
	Expected	Min	Max
Upfront Capital Costs	(\$112,000)	(\$390,000)	(\$82,000)
Maintenance Costs	(\$103,000)	(\$283,000)	(\$85,000)
Other Project Costs	(\$4,000)	(\$54,000)	\$0
Replacement Costs	(\$22,000)	(\$77,000)	(\$15,000)
Disposal Costs	\$0	\$0	\$0
Salvage Value	\$0	\$0	\$0
Residual Value	\$80,000	\$16,000	\$293,000
Ecosystem Services	\$41,760,000	\$34,697,000	\$86,121,000
Embodied Carbon	\$0	\$0	\$0
Carbon Sequestration	\$740,000	\$563,000	\$1,494,000
Flood Risk Mitigation	\$2,453,000	\$2,453,000	\$2,453,000
Fisheries (Habitat)	\$12,589,000	\$3,619,000	\$91,287,000
Fisheries (Subsistence)	\$0	\$0	\$1,000
Reduced Water Intrusion	\$0	\$0	\$0
Coastal Erosion Mitigation	\$0	\$0	\$0
Recreation	\$0	\$0	\$0
Total Net Present Value	\$57,381,000	\$40,544,000	\$181,467,000
Benefit Cost Ratio	239	51	998

Table 22: Dashboard: Summary Triple Bottom Line Results Table

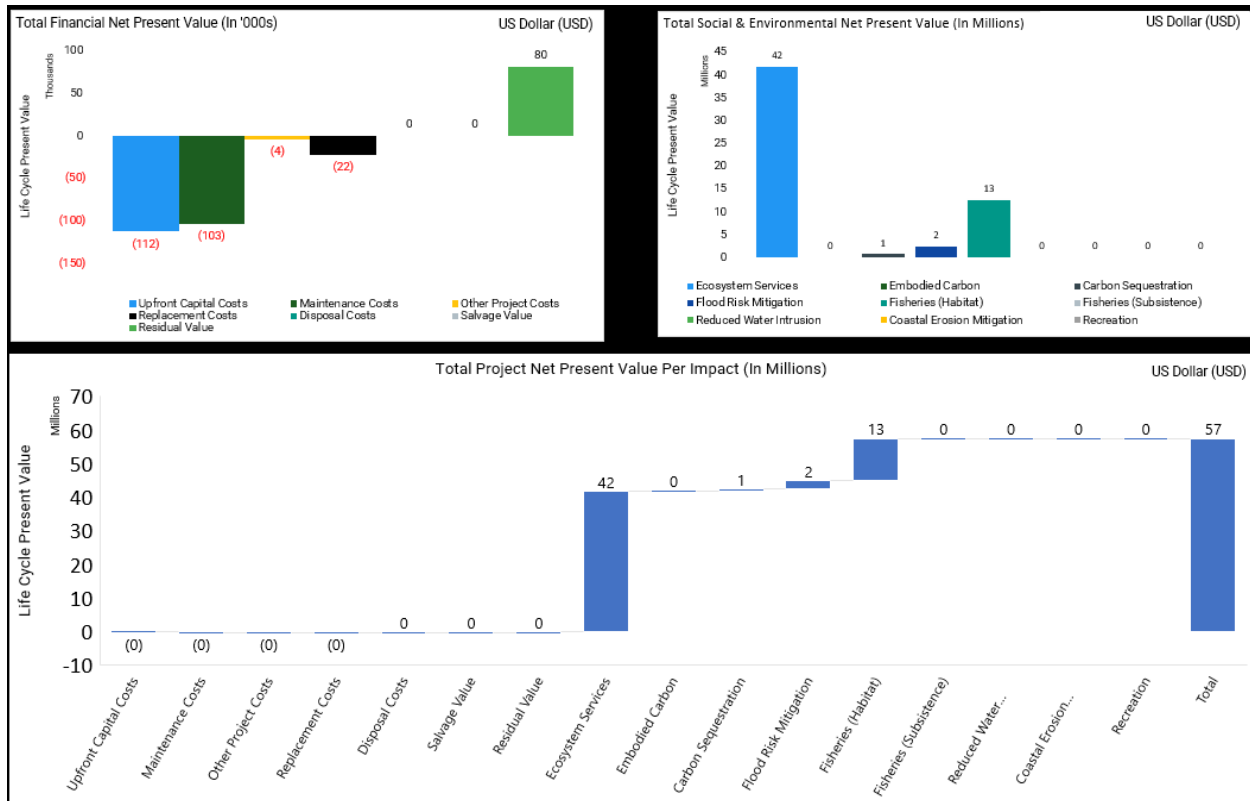


Figure 4: Dashboard: Summary Triple Bottom Line Results Charts

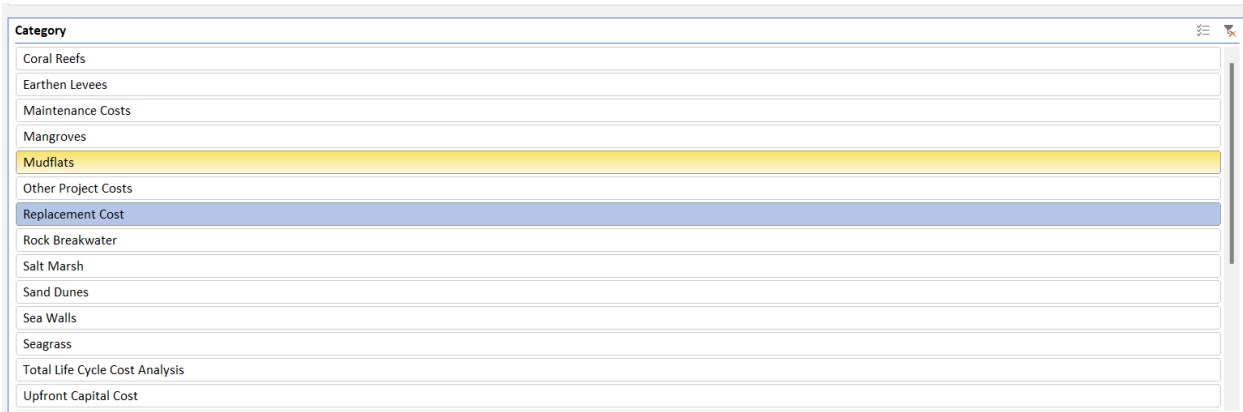
The key tables and charts include summary results segments across Financial, Social and Environmental benefits. The list of optional tables and charts to segment life cycle net present value include:

are as follows:

- Net Present Value Per Financial Impact
- Net Present Value Per Social & Environmental Impact
- Net Present Value Per Ecosystem Service
- Net Present Value Per Feature
- Financial Net Present Value Per Feature
- Social & Environmental Net Present Value Per Feature

An additional set of optional tables and charts available for only project costs that include:

- Feature-specific life cycle costs and benefits
 - Mangroves
 - Seagrass
 - Salt Marsh
 - Sand Dunes
 - Rock Breakwater
 - Earthen Levees
 - Sea Walls
 - Coral Reefs
 - Mudflats
- Total life cycle costs across all features
 - Upfront Capital Cost
 - Maintenance Costs
 - Other Project Costs
 - Replacement Cost
 - Residual Value
 - Salvage Value



Category
Coral Reefs
Earthen Levees
Maintenance Costs
Mangroves
Mudflats
Other Project Costs
Replacement Cost
Rock Breakwater
Salt Marsh
Sand Dunes
Sea Walls
Seagrass
Total Life Cycle Cost Analysis
Upfront Capital Cost

Figure 6: Dashboard: Detailed Feature-Specific Costs and Benefit Table

In a similar manner, a One-Pager Dashboard Report has also been created after the Dashboard sheet that summarises some of the key metrics, results, and project descriptions. This may be printed by the user directly to provide one-page executive summaries on the tool run.

Date:

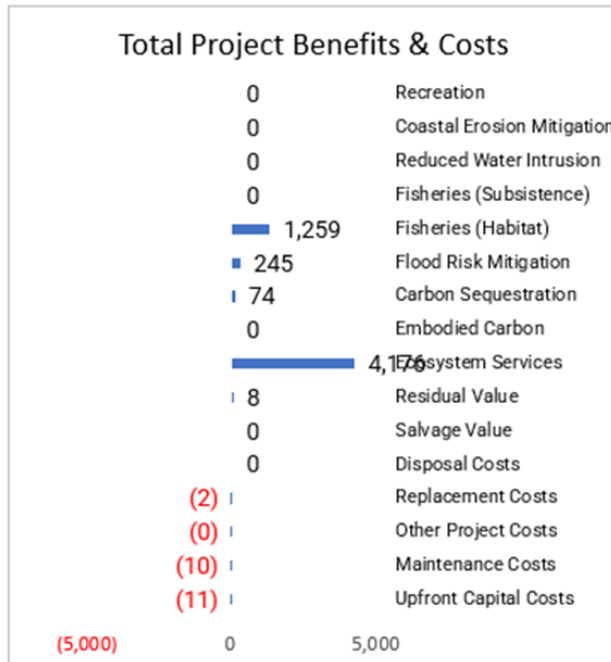
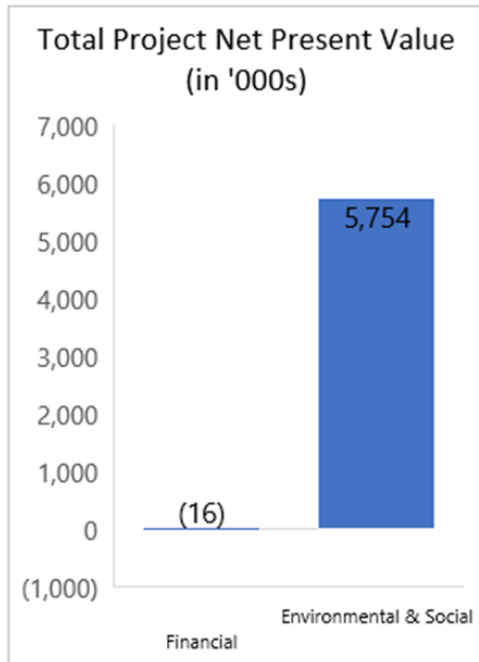
One-Page Summary Report

Project Team Lead:

Project: Isla Arena

Project Summary: This project has been run in No, Mexico starting in year 2023 with a construction duration of 14 months and a project lifecycle of 10 years. The project cashflows, and impacts have been assessed using a discount rate of 0.03. This report shows a summarised list of results and impacts run by this tool, as well as some key metrics.

Net Present Value	USD	57,381,000	Internal Rate of Return	11%	BCR	239
Total Financial Net Present Value	USD	(161,000)	Total Social & Environmental Net	USD		57,543,000



Key takeaways: This project generates a total net benefit at USD 57381000, with a benefit cost ratio estimated at 239 which shows that for every USD spent in capital costs and costs through the lifecycle of the project, the financial, social, and environmental net impacts generate USD239 in net benefits.

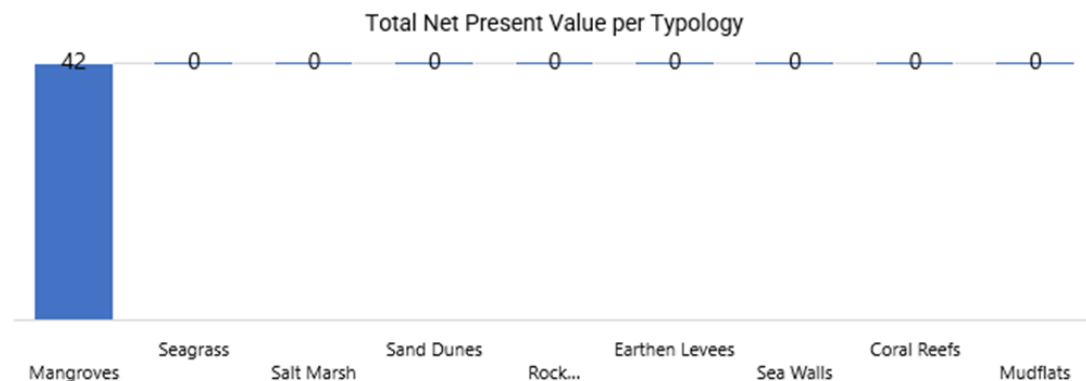


Figure 7: Dashboard: One Pager Report Output Example

2.6. Next Steps & Tool Integrations

This tool currently covers four geographies: Mexico, Brazil, Guyana, and Suriname for a set list of typologies. It may be eventually expanded to include analyses for multiple geographies and typologies as long as the research team expands the list of impacts per new typology, as well as the default data and benefit transfer assumptions to fit new geographies. The highest level of effort required to conduct this would be to compile data on ecosystem services relevant to new typologies, and some additional efforts to conduct a benefits transfer between different geographies (if location-specific studies are not available).

For instance, non-coastal typologies may have a more or less detailed list of ecosystem service ranges that would need to be sourced as a part of the extended literature review. Successively, these valuations would need to be adjusted using the country-specific transfer approach to run the simple models at a minimum. To run the detailed models, the detailed databases would need updating including the list of relevant fish species, pricing, weight, protein content, freshwater pricing and consumption, and historical flood damages. Additionally, an extended literature review would include an analysis of how the new typologies would interact with each other while providing additional regional ecosystem service benefits, as well as any additional detailed models that may have to be developed.

This coastal Green-Gray tool is expected to be used with little data availability or guesstimates on the extent of the project, timelines, and salient features/typologies affected by the project. It is intended to give the project manager an overview of the minimum data required to run a meaningful analysis of the feasibility of different project options. However, this tool has also been built with the intent to allow for a future scope of work that integrates the Green Grey Tool with other sophisticated tools such as InVEST. InVEST, which stands for Infrastructure Valuation, Evaluation, and Sustainability Tool, helps in making informed decisions about investing in infrastructure projects. It is a suite of free, open-source software models used to map and value the nature-based goods and services that sustain and fulfill human life.

Assessing coastal infrastructure as a part of InVEST involves evaluating the condition, resilience, and potential risks of structures like ports, harbors, and coastal defenses. Green infrastructure that supports such gray structures yields a flow of services that are vital to humanity, including the production of goods (e.g., food), life-support processes (e.g., water purification), and life-fulfilling conditions (e.g., beauty, opportunities for recreation), and the conservation of options (e.g., genetic diversity for future use). InVEST enables decision-makers and funders to assess the quantified tradeoffs associated with choices and to identify areas where investment in natural capital can enhance human development and conservation. It considers factors such as environmental impact, economic benefits, and long-term sustainability to guide investment choices in coastal areas. The Green-Gray Tool is meant to be used as a precursor before a tool like InVEST may be used.

Once the Green-Gray tool has been run, and the project has commenced, detailed geospatial data from the site may be used to re-run models in InVEST, and compare result iterations as the data collected is more granular and detailed. The table below shows a comparison with comments on how models from this tool may be used to fill in data for models in InVEST.

Models in InVEST	Can the Green-GrayTool inputs/outputs be used with InVEST?
Carbon, Coastal Blue Carbon	The carbon model in this tool closely follows the sequestration assumptions as undertaken in InVEST (sequestration & storage)
Crop Pollination	NA.
Crop Production	Yes, the food yield output from InVEST may be used in the Food & Raw Materials tab along with pricing
Coastal Vulnerability	InVEST uses a coastal vulnerability index to assess the level of coastal risk. This index may be used in the Green-Gray tool to select storm events relevant to the project. However, the user will need more detailed H-H damage information to run the full model
Habitat Quality & Risk Assessment	This InVEST model requires detailed LULC raster maps to assess vulnerability, and species affected. The selection of fishery species may be linked to the Gree-Gray tool to evaluate the benefits of increased habitat
Offshore Wind Energy	This has not been modeled as a part of the Green-Gray tool. Energy revenue however may be included in the life-cycle cost section as an annual benefit.
Recreation	User day output, and change in recreational visitors may be used in the Green-Gray tool with entry costs or revenue to monetize benefits
Reservoir Hydropower Production	This has not been modeled as a part of the Green-Gray tool. Hydropower revenue however may be included in the life-cycle cost section as an annual benefit.
Scenic Quality	Aesthetic benefits from the project have been modeled using the Benefit Transfer method, and hence cannot be used as a part of the tool.

Seasonal Water Yield & Water Purification	An Increase in water yield outputs from InVEST due to reduced seawater intrusion may be used in the Green-GRay tool to value the benefits of reduced water shortages
Sediment Retention	Sediment retention output, and cubic meters of avoided erosion may be used in the Green-Gray tool to evaluate benefits of reduced coastal erosion.
Urban Cooling	Urban cooling and climate benefits from the project have been modeled using the Benefit Transfer method, and hence cannot be used as a part of the tool.
Urban Flood Risk Mitigation	The Green-Gray tool models the avoided damages from coastal flooding. Outputs from this model such as mitigated depth of flooding (as a part of the raster - GIS file runs) may be used to estimate the benefits of reduced flood-based damages.
Urban Stormwater Retention	Urban stormwater retention from the project has been modeled as a part of the avoided damages from coastal flooding. Additional retention benefits have not been covered as a part of the tool.
Wave Energy	This has not been covered as a part of the Green-Gray tool.

As a next step, this tool will be run across a few pilot studies to demonstrate the functionality of the tool. As a future endeavor, this tool may also be expanded in its capability to incorporate more detailed geospatial data (as collected by project managers), extended geographies, and additional project typologies, and converted into a custom-designed cloud-based interface.

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