# Whole System Modeling of the Relationship Between Tourism Activity and Carrying Capacity in The Canary Islands

November 2023

The Sustainability Laboratory

ULPGC
Instituto Universitario de Turismo y Desarrollo Económico Sostenible

Tides

KnowlEdge

## Introduction

The concept of Sustainability is ultimately related to processes of dynamic equilibrium in the interaction between a population and the carrying capacity of its environment. From this perspective, the issue of tourism, particularly mass tourism, and especially in fragile ecosystems, is emerging as a critical sustainability issue in many parts of the world.

The Canary Archipelago, with its rapid and supercharged growth in tourism activity, is a case in point. As a small, relatively confined region it offers an attractive, handleable subject for a study of this pressing sustainability-related issue—the impacts of tourism on ecosystems and societies. Gaining a better understanding of the underlying dynamics, and a clearer view of likely outcomes under different scenarios of growth and different management options is of vital importance for the Canaries. It can also provide important lessons to other parts of the world.

The obvious and immediate economic gains from tourism-related development tend to dominate the prevailing perspective, and priority is put on ongoing expansion and growth. The promise of short-term economic gains discourages more thoughtful consideration with the inevitable result that attention to long-term viability and enduring sustainability is largely ignored.

Developing a system dynamics model of the interface between tourist activities and the broader context within which they take place will introduce a timely, system-based perspective to the urgent questions that are involved. It will empower our partners in Tides, and provide a tool for launching, then expanding, a pioneering discussion with authorities, local inhabitants, and industry groups.

This report will hopefully offer an opportunity for important innovation. Not innovations in the tools and methods to be employed in themselves in regulating tourism activities, but rather, in introducing, encouraging, and implanting a systemic perspective in a domain where it is still rarely employed.

The Canary Islands offer an excellent, logical site for establishing sustainability-related initiatives as a general model for island ecosystems. Not only because of the diverse nature of the islands in the archipelago, but also because the Canaries embody all the major sustainability-related challenges that characterize fragile island ecosystems in other parts of the world. Such challenges include issues related to climate change, energy, water and waste management, soil productivity, food security, adverse impacts of mass tourism, the question of carrying capacity, and more. Addressing the interplay between tourism and sustainability in the Canary Islands as developed under the collaboration of the Sustainability Laboratory and The ULPGC and TIDES, can be an important step in this direction.

Michael Ben Eli
The Sustainability Laboratory
November 2023

## Table of Contents

## Project Development Team

Project Directors: **Dr. Michael Ben-El**, Founder, The Sustainability Laboratory and **Professor Carmelo J. León**, Professor of Environmental and Applied Economics, Director of UNESCO Chair of Tourism and Sustainable Economic Development, University of Las Palmas de Gran Canaria.

Lead Modeler: **Dr. Andrea M. Bassi**, Founder and CEO of KnowlEdge Srl (KE) and Academic Fellow, Institute of Management, Innovation and Partnerships, University of Geneva, Switzerland.

**Vanessa Armendariz**, Global Sustainability Fellows Program Director and Faculty of The Sustainability Laboratory.

**Nathalia Nino Giraldo**, Project Manager, KnowlEdge Srl (KE).

**Marco Guzzetti,** Sustainability Analyst, KnowlEdge Srl (KE).

**Matías M. González**, Professor of Tourism and Applied Economics, Institute of Tourism and Sustainable Economic Development, University of Las Palmas de Gran Canaria.

**Juan M. Hernández**, Professor of Quantitative Methods for Economics and Business, Institute of Tourism and Sustainable Economic Development, University of Las Palmas de Gran Canaria.

**Jaime Blázquez Valerón**, Ph. D. Researcher, Institute of Tourism and Sustainable Economic Development, University of Las Palmas de Gran Canaria.

**Yen Lam-González**, Post Doc Researcher, Institute of Tourism and Sustainable Economic Development, University of Las Palmas de Gran Canaria.

**Antonio Garzón Beckmann**, Associate Researcher, Institute of Tourism and Sustainable Economic Development, University of Las Palmas de Gran Canaria.

## Acknowledgement

The project was partially funded by the Foundation for the Advancement of System-Oriented Management Theory. St. Gallen, Switzerland (Stiftung zur Forderung der Systemorientierten Managementlehre, St Gallen).

## Executive Summary

**Overview:**

The Canary Islands have undergone substantial tourism growth, with the sector now contributing over 35% to the region's GDP. This transformation represents a significant shift from a traditional agricultural economy to one centered around tourism. Massive increase in tourism activity brought about many economic benefits but some adverse impacts as well. For example, in many cases, coastal areas that have been extensively developed for tourism infrastructure have also seen a large increase in energy and water consumption, as well as waste generation and pressure on the pristine environment. Current trends raise concern about the possibility of overshooting the island ecosystem's carrying capacity, with the related consequences for the local community, and the long-term economic potential of the islands, including the tourism industry itself.

**Project Context:**

This project represents a collaborative effort between The Sustainable Laboratory (The Lab) and the Institute of Tourism and Sustainable Economic Development (Tides). The initiative focused on developing a system dynamics model designed to dissect the intricate relationship between tourism and sustainability. The model assesses the impact of tourism on the islands' carrying capacity in two steps: the first utilizes a Causal Loop Diagram (CLD) for qualitative analysis, while the second employs a Systems Dynamics methodology to develop a quantitative simulation model incorporating stock and flow variables.

The system dynamics methodology is used to support decision-making where the context is highly complex. Questions of future economic and social development in the Canary Islands and their impact on the islands' fragile ecosystem is a case in point.

By identifying and highlighting the key variables underlying the relevant context as well as the causal relations between them the behavior of the system over time can be explored. The model presented in this document was designed to integrate environmental, economic, societal, geographic, and governance variables, and better understand the relationship between them as well as the impacts of their interactions.

The development and testing of this model allowed for a deeper understanding of the consequences of the direction of current development. Additionally, it allowed the testing of policies for mitigating the adverse impacts of low-cost tourism by analyzing various “what if” scenarios. These scenarios would then provide the basis for further in-depth analysis of specific development conditions and needs for each island or for the archipelago as a whole.

The relevance of this project for a sustainability assessment of the islands is enriched by the dynamic way of analyzing ´carrying capacity’ which is defined as the ability of an environment to support life activities in general, and at a particular level of quality. The model itself offers a tool for testing different scenarios and policies and better understanding their impact on economic and social development as well as on the environment.

**Understanding complexity:**

The impacts of tourism on the islands' ecosystem represent a complex web of interacting factors. In a detailed analysis of factors affecting carrying capacity in the Canary Islands, several interconnected dynamics were explored with a focus on qualitative aspects and a distinction between "mass tourism" and "ecotourism."

*Marine Habitat Quality*: A decrease in quality and diversity of marine habitat quality leads to a reduction in carrying capacity, making the marine ecosystem less attractive and resulting in a possible decline in tourist arrivals. Conversely, an improvement in marine habitat quality can increase carrying capacity, attracting more tourists. This relationship is driven by factors such as decreasing fish stocks, increasing wastewater and solid waste generation in the former case, and sustainable practices in the latter, which reduce pollution and enhance fish stock.

*Terrestrial Habitat Quality*: Human activities, particularly solid waste generation, other forms of pollution and land conversion (e.g., loss of forest land), negatively impact terrestrial habitat quality and carrying capacity. As carrying capacity increases, population and tourism grow, which, in turn, exacerbates solid waste generation and habitat degradation. Eco-friendly tourism mitigates this by reducing waste and land use requirements, positively impacting terrestrial habitat quality.

*Urban Environment*: Population growth and conventional tourism contribute to urban environmental issues like traffic congestion and noise pollution, leading to declining urban environment quality and carrying capacity. In contrast, eco-friendly tourism practices reduce congestion and noise pollution, improving the urban environment and preserving and even enhancing carrying capacity.

*Air Quality*: Increased population and tourism raise energy demands, particularly from fossil-based sources, resulting in $CO_2$ and PM2.5 emissions that degrade air quality and decrease carrying capacity. Eco-friendly tourism reduces energy needs, enhances air quality, and consequently, increases carrying capacity.

Altogether the model suggests that high-quality ecosystems and unique features and attractions can increase the appeal of the Canary Islands, drawing more tourists. However, conventional tourism may have detrimental effects on the environment. Sustainable tourism practices minimize these negative impacts, preserving and enhancing the environment's quality and attractiveness.

Further, the influx of hotels, whether eco-friendly or conventional and their development in residential neighborhoods tends to drive up real estate and living costs, prompting local residents to move to more affordable, remote areas. This expansion of land use expands the human footprint, reduces forest cover, diminishes diversity and quality of terrestrial habitat, reducing carrying capacity.

These interrelated dynamics highlight the complex interactions between tourism, environmental quality, and carrying capacity. The adoption of eco-friendly practices emerges as a key strategy to mitigate negative impacts and promote sustainable tourism, thereby preserving the islands' delicate ecosystem and supporting long-term economic growth.

**Scenarios:**

Two main scenarios were explored during this collaborative, co-created and multi-stakeholder exercise:

***Baseline Scenario (BAU)*:** This scenario serves as the reference point, assuming the perpetuation of historical trends in tourism development without any emphasis on sustainable practices.

***Sustainable Tourism Scenario (STS)*:** This scenario envisions the simultaneous implementation of multiple policies aimed at fostering sustainable tourism. These policies aim to (i) mitigate the negative effects of the combined population and tourism activity on the carrying capacity and (ii) conserve natural capital and enhance ecosystem service provision, thereby maintaining and even increasing the carrying capacity.

**Results:**

In the BAU scenario, there is potential for the number of tourists to level off and gradually decline over time due to increased pressure on and consequent decrease of carrying capacity. Conversely, the adoption of sustainable tourism practices, including the regulation of tourism activity and quality and an increase in eco-friendly hotels, leads to a reduction in the adverse impacts of tourism, resulting in increased carrying capacity and renewed tourist interest.

The policies implemented in the STS stimulate tourism-related employment and GDP growth, potentially generating up to 341,600 new jobs by 2050 and contributing an additional 2.17 billion euros to GDP by 2050 compared to the BAU scenario.

A consolidated cost-benefit analysis (CBA) spanning from 2023 to 2050 was developed to estimate the investment required to realize such socioeconomic benefits and related environmental outcomes. Investment levels were estimated for all the investments associated with the STS, encompassing expenditures on wastewater and solid waste management, energy efficiency, reforestation, and other initiatives. These investments amount to 3.13 billion euros (undiscounted) and 1.76 billion euros when using a 3.5% discount rate.

When compared with the added benefits and avoided costs generated in the STS across various sectors, the net benefits are estimated to reach 26.5 billion euros (undiscounted) and 13.8 billion euros with discounting. The benefit-to-cost ratio (BCR), comparing benefits and costs, reach 8.83 when considering all impacts of sustainable tourism (i.e. close to 9 euros in benefits are generated per each euro invested). This high BCR indicates that nature can provide a considerable contribution to the creation of social welfare and to economic resilience in the decades to come.

**Support to policy formulation:**

Even at this preliminary phase, the project can provide the basis for both:

- Informing a discussion on the sustainability of tourism in the Canary Islands, via the use of the system maps that highlight the interconnections between tourism, economic activity and carrying capacity, and
- Promote policy formulation and analysis, via the use of the quantitative model, when calibrated to a specific island, or to the archipelago as a whole, offering forecasts across a variety of indicators combined with a Cost Benefit Analysis that supports the prioritization of policy options and investments.

Either way, the use of Systems Thinking, and the underlying methodology used in this project, support the creation of a richer dialogue, by integrating opinions, knowledge across scientific fields, and views of different interest groups, and highlight synergies that emerge from the implementation of intervention options across several policy domains.

A thoughtful, integrated, systemic dialogue should provide the starting point for a deeper conversation about the future of the islands, and the role that tourism can play in shaping it.

# 1. General

The Canary Islands, renowned for their natural beauty and favorable climate, have experienced significant growth in tourism over the years. Tourism now accounts for over 35% of the region's Gross Domestic Product, with millions of visitors flocking to the islands annually. This has generated a shift from the primary to the tertiary sector, with a traditional agricultural economy transitioning to one centered around tourism, and the rapid expansion of the service sector. However, the rapid growth of the tourism industry has led to social and environmental challenges, such as the occupation of coastal areas by tourist infrastructure and related activities, raising concerns about sustainability and the long-term viability of the islands' ecosystems and carrying capacity.

To address these issues, The Sustainability Laboratory and Institute of Tourism and Sustainable Economic Development (Tides) at the University of Las Palmas of Gran Canaria have come together to propose a project focused on developing a system dynamics model. With the Carrying Capacity Canary Islands (CCCI) model, the project aims to analyze the interplay between tourism and sustainability, explore potential multi-dimensional impacts and assess the carrying capacity of the Canary Islands under different scenarios. By analyzing the interactions between various factors and exploring different scenarios, the project seeks to inform policymakers and stakeholders about the long-term impacts of tourism and contribute to a more holistic and sustainable approach to tourism development in the archipelago. Additionally, by understanding the carrying capacity of the Canary Islands, authorities can implement measures to ensure that human activities and population sizes remain within sustainable limits and preserve the integrity of the ecosystem.

The Sustainability Laboratory (The Lab) is a U.S.-based not-for-profit organization dedicated to researching, developing, and demonstrating groundbreaking approaches to sustainability. Their signature approach combines system thinking and a system-based design strategy, aiming to catalyze transformative change. Tides, the Institute of Tourism and Sustainable Economic Development at the University of Las Palmas de Gran Canaria, is a research institute recognized for its high-quality work and integration of economic, social, and environmental considerations in improving tourism activities. Together, these organizations seek to address the pressing sustainability-related issues in the Canary Islands' tourism sector.

The proposed project consists of two phases: the development of a qualitative model, known as a Causal Loop Diagram (CLD), and the subsequent development of a more detailed, quantitative model using a stock and flow approach. Both models are presented in this report. Specifically, the qualitative serves to explore the interdependencies between tourism, the economy, society, and the environment. It will also be used as a pedagogical tool to educate students and stakeholders about the complex issues involved. The quantitative model provides quantification and an improved understanding of the interrelationships between various sectors, such as demographics, land use, economic activity, and waste generation. These models assess the impact of scenarios of action and inaction on the carrying capacity of the Canary Islands, and support the exploration of alternative strategies for managing tourism in a sustainable way.

# 2. Methodology

## 2.1. Process

The relationship between tourism and the environment in the Canary Islands is complex. Tourism not only creates an impact on the marine environment but also on the terrestrial, urban and atmospheric environment. Considering this complexity, traditional methods of research such as value chain analysis, supply chain assessments and field-based interviews are not able to represent the dynamics of a complex system characterized by feedback loops, delays and non-linearity, as well as non-rationale elements and policy path dependency which characterize sustainable development. As such, this study utilizes Systems Thinking and System Dynamics modelling to identify the dynamic complexity involved in the design and evaluation of interventions for more sustainable tourism. It presents a custom-built system dynamics model that illustrates some of the issues arising from an integrated, systems-oriented analysis of the tourism sector for the Canaries.

The study follows best practices in the System Dynamics field, with a 5-step modelling process. The following tasks have been performed:

1) **Problem identification:** also called agenda setting, this task focuses on the identification of the problem to be modelled. The Canary Islands analysis includes issues with the capacity of the environment to handle the burden of tourism activities, with impacts directly on fish stock, wastewater generation, solid waste generation, forest land, traffic congestion and noise pollution, and energy consumption.
2) **Dynamic hypothesis:** this task consists of the creation of a system map (also called Causal Loop Diagram, CLD) that supports the identification of key variables, their interconnections and the feedback loops that cause changes in the system. This task has been carried out together with the local stakeholders in various iterations to achieve the final version. The CLD supports knowledge integration, and the creation of a shared understanding of the dynamics of the system and the causes of the problem to solve. Section 0 presents the results of this step of the modelling process.
3) **Model formulation:** the creation of the mathematical model, using the CLD as a blueprint. The model uses semi-continuous time and is built using a stock and flow structure to capture feedback loops, delays and non-linearity. At this stage, it is also defined the scenarios that are going to be simulated (see section 3.1).
4) **Model validation:** this step consists of two main types of validation, structural and behavioral. The former refers to the validation of variables, equations and units. The latter regards the results of the model, considering both historical and future trends.
5) **Policy analysis:** with a validated model, representing correctly historical trends and a future baseline scenario, intervention options (e.g. policies, targets, investments) are to estimate effectiveness and efficiency, considering indicators of social, economic and environmental outcomes. The results of the scenarios are presented in Section 4, with biophysical and economic indicators.

## 2.2. Introduction to Systems Thinking

Systems Thinking (ST) is an approach that allows us to better understand and forecast the outcomes of our decisions, across sectors, economic actors, over time and in space (Probst & Bassi, 2014). It emphasizes the system, being made of several interconnected parts, rather than focusing on its individual parts. With ST being an approach, there are several methodologies and tools that support its implementation and hence the identification of the underlying functioning mechanisms of a system and their quantification and evolution over time. In general terms, it can be said that the identification of the components of a system and of the relationships existing among these components (e.g. carried out through the use of Causal Loop Diagrams) represents (i) the *soft* side of Systems Theory. Instead, attempts to quantify these linkages and forecast how their strength might change over time (e.g. carried out using System Dynamics models) represent (ii) the *hard* side of the field.

Concerning the former (i), Causal Loop Diagrams (CLD) allow the creation of a shared understanding of how the system works, and hence identify effective entry points for (human) intervention, such as public policies. When this is done using a participatory approach, it helps to bring people together, creating the required building blocks for the co-creation of a shared and effective theory of change. On the latter (ii), System Dynamics models allow quantifying policy outcomes across social, economic and environmental indicators (UNEP, 2014) providing insights on the relative strength of various drivers of change (scenario analysis) and supporting the identification and prioritization of policy intervention (policy analysis). These models can be bottom-up or top-down (Probst & Bassi, 2014; UNEP, 2011).

In the context of this research, the role of ST is to assess the extent to which the main drivers of change considered (i.e. the main factors affecting carrying capacity in the islands) can shape future trends, affect existing policy effectiveness and require future interventions. This in turn allows us to identify a system's safe operating space and limits, anticipating the emergence of side effects, across social, economic and environmental indicators. In this report, both CLD and System Dynamics model are presented, with the CLD being used as a blueprint for the creation of the customized mathematical model.

## 2.3. How to Read a Causal Loop Diagram (CLD)

A causal loop diagram (CLD) is a map of the system analyzed, or, better, a way to explore and represent the interconnections between the key indicators in the analyzed sector or system (Probst & Bassi, 2014). As indicated by John Sterman, "*A causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram. Variables are related by causal links, shown by arrows. Link polarities describe the structure of the system. They do not describe the behavior of the variables. That is, they describe what would happen if there were a change. They do not describe what actually happens. Rather, it tells you what would happen if the variable were to change."* (Sterman, 2000). As indicated by Sterman, CLDs include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or −) on each link, indicating a positive or negative causal relation (see Table 1. A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction. A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction. Circular causal relations between variables form causal, or feedback, loops. There are two types of feedback loops: reinforcing and balancing. The former can be found when an intervention in the system triggers other changes that amplify the effect of that intervention, thus reinforcing it (Forrester, 2002). The latter, balancing loops, tend towards a goal or equilibrium, balancing the forces in the system (Forrester, 2002).

By highlighting the drivers and impacts of the issue to be addressed and by mapping the causal relationships between the key indicators, CLDs support the identification of policy outcomes using a systemic approach (Probst & Bassi, 2014). CLDs can, in fact, be used to create storylines corresponding to the implementation of policy interventions, by highlighting direct, indirect and induced policy outcomes across social, economic and environmental indicators.

*Table 1. Causal relations and polarity, as presented in a CLD*

| Variable A | Variable B | Sign |
|---|---|---|
| ↑ | ↑ | + |
| ↓ | ↓ | + |
| ↑ | ↓ | - |
| ↓ | ↑ | - |

### 2.4. Causal Loop Diagram

The CLD that is used as a blueprint for the CCCI model represents the carrying capacity (CC) of the Canary Islands to sustain population and tourists (see Figure 1). It can be observed that the Carrying Capacity is impacted by four key factors: (i) marine habitat, (ii) terrestrial habitat, (iii) urban environment and (iv) air environment (atmosphere). At the same time, CC is generating an influence on population and tourists. If the CC increases, it can handle more population and tourists, and if it decreases, population and tourists also decrease.

In general, the model highlights the side effects emerging from population growth and the increase in tourist activities. These are depicted by balancing feedback loops in the CLD. The two main balancing loops affecting carrying capacity are B1 and B2, which represent the side effects on marine, terrestrial, urban and air environment coming from population activities (Loop B1) and from conventional tourism activities (loop B2). Additionally, the attractiveness of the Canary Islands for tourists can be affected by the environmental deterioration from population and tourist activities, dynamic represented by B3 loop.

On the other hand, the CLD portrays how the dynamics change when eco-friendly tourism is enhanced, dynamics represented by reinforcing feedback loops. The first reinforcing loop of the CLD (loop R1) represents the positive side of eco-friendly tourism, which reduces the impacts on the environment through the adoption of sustainable practices. A similar dynamic is represented in loop R2 but focused on the attractiveness of the Islands, which increases when eco-friendly tourism is practiced due to the lower negative impact on the environment.

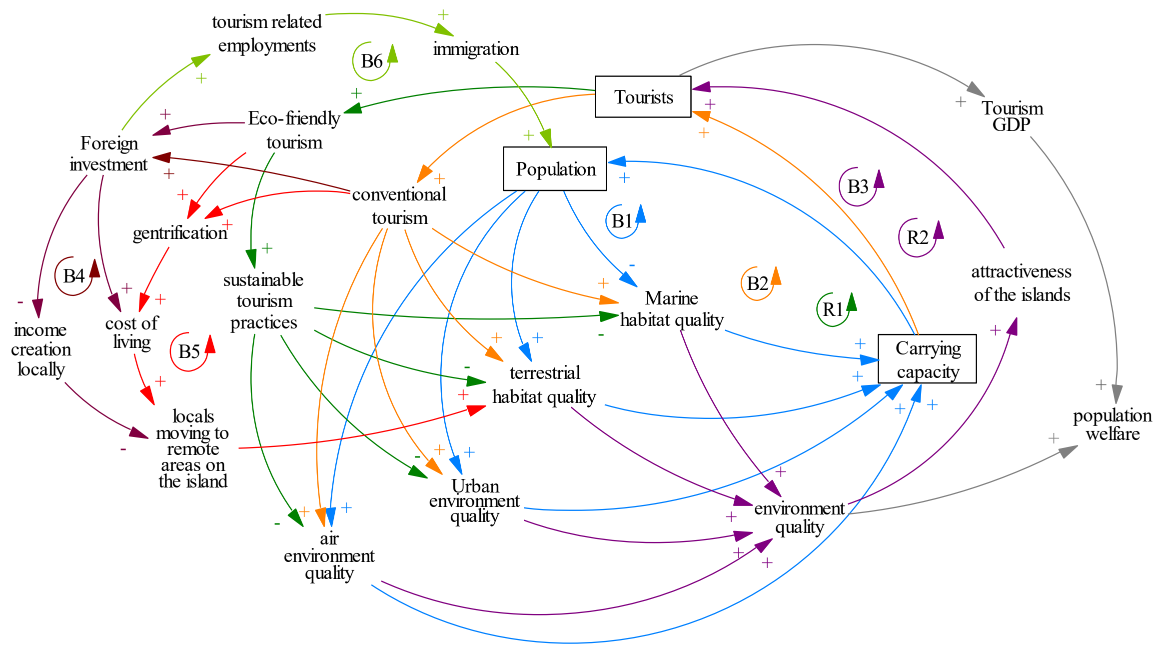


*Figure 1. Causal Loop Diagram of the Canary Islands carrying capacity*

In more detail, regarding the first factor impacting carrying Capacity, marine habitat quality, when marine habitat quality decreases, carrying capacity decreases too, which results in a decline in tourists. A decline in tourism arrivals and tourism activity would reduce the worsening of marine habitat quality. Conversely, if marine habitat quality were to increase, resulting in higher CC, both population and tourists could increase, which would make marine habitat quality decrease (B1 loop). This would happen primarily via three main stressors: (i) fish stock decrease, (ii) wastewater generation increase and (iii) solid waste generation increase. On the other hand, eco-friendly tourism, due to sustainable practices, reduces the negative impacts on the marine environment. Sustainable practices will increase fish stock, and decrease wastewater and solid waste generation, which increases marine habitat quality and CC. The increase in CC increases tourism, which increases eco-friendly tourism as a result. This reinforcing loop (R1) explains how eco-friendly tourism can alleviate the tourism burden on the Canaries via marine environment.

The impacts of human activity on terrestrial habitat, and hence on CC, come from solid waste generation and land conversion (e.g. loss of forest land). If CC increases, population and tourists increase, solid waste generation increases, having a negative impact on terrestrial habitat quality. With population and tourism increasing, forest land decreases due to the increase in settlement land requirements (both for living and hotels), producing a decrease in terrestrial habitat quality. This decrease results in a reduction of carrying capacity and creates two balancing loops (B1 & B2). When eco-friendly tourism is introduced, solid waste generation declines, as does the settlement land required. This creates a positive impact on the terrestrial habitat and increases CC ad a consequence (see R1 loop).

The urban environment is adversely affected by factors such as traffic congestion and noise pollution. When population and conventional tourism increase, generating more traffic congestion and noise pollution, urban environment quality and CC decline. These balancing loops (B1 & B2) shows how the activities of tourism can affect locals in their daily life, which can affect their attitude toward tourists. On the contrary, eco-friendly tourism reduces traffic congestion, via the use of public transport and non-motorized transport, and lowers noise pollution since the hotels are located in more remote areas, reducing population density. These practices reduce the negative impact on the urban environment, increasing CC through a reinforcing feedback loop (R1).

Finally, carrying capacity is also impacted by the quality of air (B1 & B2 loop). When population and tourists increase, energy demand increases as well (e.g. electricity use in hotels, transport needs). Energy use, when fossil-based, generates $CO_2$ and PM2.5 emissions that affect air quality. This negative impact on the air quality will reduce CC. In the case of eco-friendly tourism, the reduction in energy needs due to more efficient energy use and electrification will generate an increase in air quality and in CC as well, explained by the reinforcing loop R1.

When the four components of the environment are perceived as of high quality or some of them are even more appealing than the others, the attractiveness of the Canary Island can increase, which attracts more tourists to the Islands. This increase in tourists can generate positive impacts on the economy such as increasing GDP, but at the same time will impact negatively on Marine habitat quality, terrestrial habitat quality, urban environment and air environment quality (loop B3) if the tourism is conventional. On the other hand, if the tourists apply more sustainable practices, the impact on the environment will be less harmful to the environment, generating a better quality of the environment and more tourist attractiveness next time (loop R2).

Although tourism can bring economic growth for the Canary Islands, it also brings negative consequences for the inhabitants such as gentrification, as indicated in feedback loop B5. As more hotels, either eco-friendly or conventional are located in residence neighborhoods, it can lead to a higher cost of living in the neighborhood. Consequently, some locals may be compelled to relocate to more affordable areas in remote parts of the island. This, in turn, results in an expansion of settlement land and a corresponding reduction in forest land. Such changes adversely affect the quality of terrestrial habitats, contributing to a decline in CC. Another effect of tourism is the attraction of foreign investment for the tourism sector in the Canary Islands, which can represent additional income for Spain rather than at the local level. This can inadvertently contribute to a reduction in income creation and wealth for the local population, as depicted in loop B4. Finally, foreign investment can create tourism-related employment, which can increase immigration, since most of the staff will come from abroad when there is foreign investment. This increase in population due to the immigration of tourism workers can create even more burden on the carrying capacity of the islands (loop B6).

## 2.5. Mathematical Model

The CCCI model is a quantitative model developed in Vensim® with the purpose of analyzing the interplay between tourism and sustainability, exploring potential multi-dimensional impacts and assessing the carrying capacity of the Canary Islands under different scenarios. For the CCCI model, the concept of carrying capacity refers to the capacity of the Canary Islands to endure the negative impacts of population and tourists' actions on the environment. This concept is modelled in CCCI through the "Carrying Capacity Index", which considers four components of the environment: (i) marine environment, (ii) terrestrial environment, (iii) urban environment, and (iv) air environment. For more details on the Carrying Capacity Index, see section 5.19.

The CCCI also estimates population welfare as one of its output indicators, which intends to assess the level of wellbeing and overall quality of life of population in the Canary Islands. This population welfare indicator considers several aspects measured in the model related to the resident's welfare such as the economic situation through tourism GDP, and the effects of the four mentioned components of the environment on population. For more details on this indicator, see section 5.18.

It is relevant to clarify the model limitations in order to see the results in light of what the model is capable of doing. As mentioned, the model is focused on the impacts of population and tourism activities on the carrying capacity of the Canary Islands. Since the model covers all the Canary Islands territories, specific dynamics of one or the other island are not represented in detail, only the general dynamics are represented. As the model focuses on the tourism sector, other sectors of the economy are not considered in the study. Furthermore, the tourism component of the model considers conventional and eco-friendly hotels and hostels and leaves out of the scope the type of accommodation P2P. Finally, it is important to clarify that the model does not include a quantitative estimation of gentrification and its impacts (e.g. impact on cost of living). Gentrification is only considered and discussed in the qualitative component of the model (i.e. Causal Loop Diagram).

# 3. Scenarios, Policies and Assumptions

## 3.1. Scenarios

There are two scenarios established for the modelling exercise, one baseline scenario and one policy scenario. The baseline scenario serves as a reference point to compare the results of the policy scenario. Below there is a description of all scenarios:

- **Baseline scenario (BAU)**: it represents the baseline scenario, without pursuing any ambition on sustainable tourism, assuming historical trends keep dominating the system.
- **Sustainable Tourism Scenario (STS)**: this scenario assumes that several policies for sustainable tourism are implemented simultaneously. Those policies are designed to support both the (i) reduction of the negative impact of population and tourism on CC, and the (ii) conservation of natural capital and the strengthening of ecosystem service provisioning, increasing CC. The policies included in this scenario are presented in Table 2.

The intervention options considered in the STS can be classified and grouped into proactive and reactive measures. Proactive interventions aim to address the root causes of the problem, preventing the emergence of issues in the future, and hence avoiding the impacts of tourism and population activities on CC. These interventions include the promotion of eco-friendly tourism (to reduce resource consumption, among other positive outcomes), the regulation of local fish consumption (to reduce fish stock depletion), expansion of public transport and non-motorized transportation (NMT) infrastructure (to reduce congestion), as well as the implementation of energy efficiency measures (to reduce energy use). On the other hand, reactive interventions respond to the consequences of tourism and population activities, seeking to mitigate their impacts. These measures encompass initiatives such as ecological reforestation efforts, the establishment of protected marine areas, enhancement of solid waste collection systems, expansion of wastewater treatment capacity, and the development of renewable energy sources. By implementing a combination of proactive and reactive interventions, it is possible to address both the causes and the consequences of the challenges faced by the urban environment in relation to tourism and population activities.

*Table 2. Policies included in the Sustainable tourism scenario*

| Policy | Description |
|---|---|
| Eco-friendly tourism | The policy incentivizes eco-friendly tourism through the increase in the share of eco hotels compared to the BAU shares. Eco hotels bring more sustainable practices such as less water use and solid waste generation, small-scale accommodations, low-impact transportation, responsible visitor behavior, and activities less harmful to the environment in general. |
| Reforestation | This policy increases the hectares of forest land with the reforestation of fallow land. More forest land increases carbon capture and the quality of the atmospheric environment in general. |
| Protected marine areas | The protected marine areas policy increases the number of hectares of marine area that are protected from fishing activities, avoiding damage to the fertility rate, and increasing fish stock as a result. |
| Local fish consumption regulation | This policy establishes that a given share of the total fish demand from population and tourists will be imported and not harvested in the surrounding marine areas. This helps to increase fish reproduction and bring fish stock to more sustainable levels. |
| Solid waste collection capacity expansion | It assumes the expansion of the solid waste collection and processing capacity in tons per day. This policy avoids untreated solid waste that will potentially go to the sea and be harmful to the marine environment. |
| Wastewater treatment capacity expansion | It assumes the expansion of wastewater treatment in liters per day. This policy prevents untreated wastewater from going into the sea and its consequences on quality or the marine environment. |
| Noise-free zones | This policy introduces zones that are free from tourism activities or that have a time restriction for tourist activities. This happens especially in residential zones, which are the zones where locals' quality of life is more affected by tourism. |
| Public transport and NMT | This policy refers to the introduction of public transport modes such as Bus Rapid Transit (BRT), and non-motorized transport (NMT) modes such as walking and cycling. The introduction of the mentioned transport infrastructure will reduce traffic congestion and CO2 emissions related to transport. |
| Renewable energy capacity expansion | This policy refers to the expansion of Renewable Energy (RE) power generation, decreasing the least sustainable electricity sources such as diesel and fuel oil, gas turbine, and coal, among others. This reduces the CO2 emissions from energy, improving the quality of the atmospheric environment. |
| Energy efficiency | Energy efficiency measurements in total energy demand are composed of electricity demand and fossil fuels demand from residents and tourists. Energy efficiency reduces energy use and the emissions associated with the consumption. |

Furthermore, it is worth noting that certain interventions necessitate more advanced technology compared to others. For example, the expansion of wastewater treatment capacity, and renewable energy infrastructure are considered high-tech options. Similarly, interventions focused on energy efficiency improvements and public transport enhancements require advanced technological solutions. Conversely, interventions such as eco-friendly tourism promotion, local fish consumption regulation, reforestation initiatives, the establishment of protected marine areas, and creation of noise-free zones can be achieved through low-tech solutions. It is important to consider the appropriate level of technology required for each intervention to ensure effective implementation and maximize their positive impact on the urban environment.

### 3.2. Causal Loop Diagram with Intervention Options

With the identification of intervention options and the creation of scenarios (see section 3), a complete CLD with both the underlying dynamics of change and the intervention options is proposed (see Figure 2). It can be observed how each intervention option generates impacts on one or more variables, often creating a domino (or cascading) effect.

For instance, while protected marine areas focus on increasing fish stock, sustainable tourism practices have an impact on fish stock, wastewater and solid waste, reducing the negative impact of tourism on marine habitat. The CLD shows that each policy is connected to a stressor and the sign (polarity) of the connection indicates a decrease in the strength of the stressor. In general, each intervention option aims at reducing the strength of the balancing loops that affect carrying capacity. On the other hand, if the interventions result in higher attractiveness for the islands, and hence more tourism, continued efforts have to be envisaged to avoid that, with an improvement of CC, more tourists come to the archipelago.

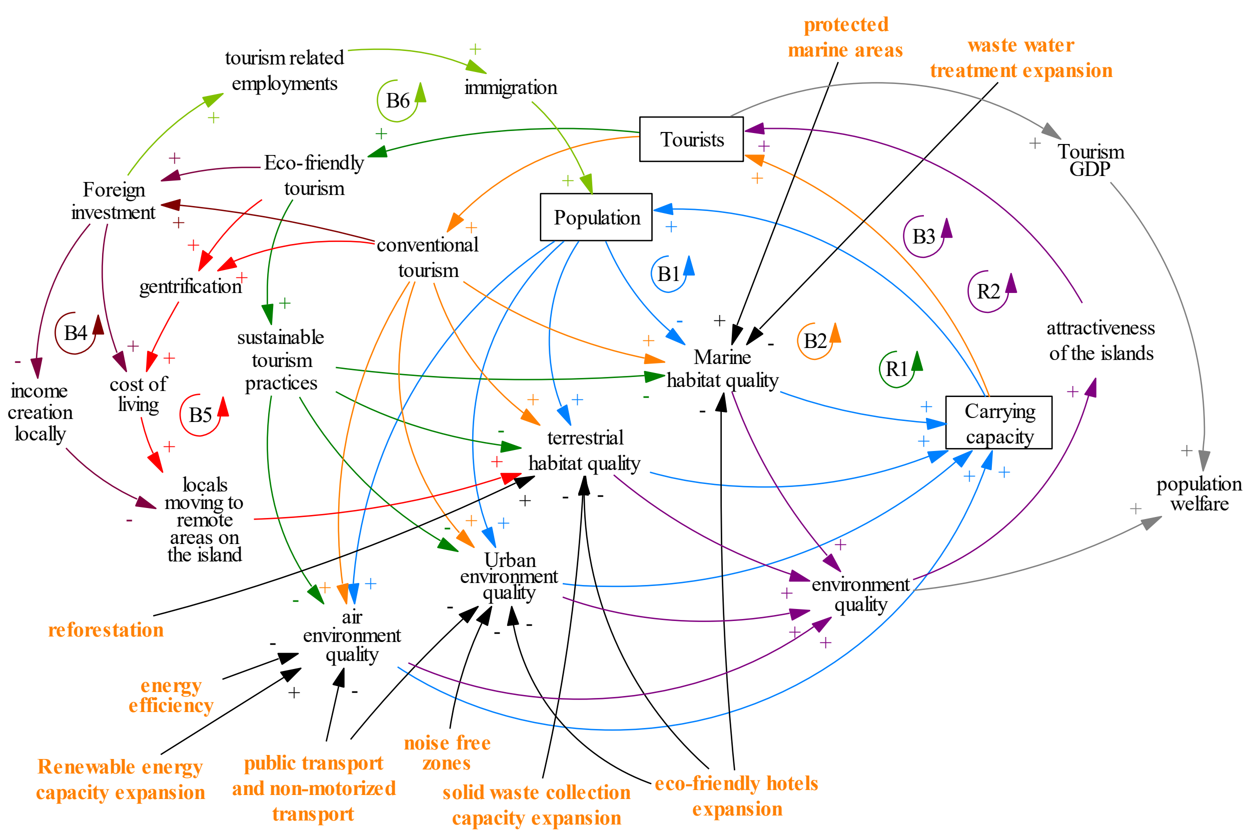


*Figure 2. Causal Loop Diagram of the Canary Islands carrying capacity with policies*

## 3.3. Assumptions for Policy Interventions

Each policy option presented in Table 2 uses data inputs, specifically for the ambition of the policy and its implementation over time. These inputs define how strong the policy is, and will create domino effects across sectors, as mentioned in section 3.2. The higher the ambition, the greater the impact on the direct variables affected, and finally on the carrying capacity index or population welfare. Ambitions for the intervention options of the STS are as follows:

- Eco-friendly tourism: The input that defines the number of conventional hotels and eco-friendly hotels, and consequently the different impacts of eco-friendly tourism is the share of tourism demand, presented in Table 3. This share stays constant for the BAU scenario and increases up to 40% by 2050 for the STS.

*Table 3. share of tourism demand that is eco-friendly tourism for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2022 | 7.5% | 7.5% |
| 2030 | 7.5% | 20% |
| 2050 | 7.5% | 40% |

- Reforestation: The changes in forest land are determined by the reforestation rate in Table 4, which presents a constant reforestation rate of 2,800 hectares per year from 2023 until 2050.

*Table 4. Reforestation rate (ha/year) for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2023 | 0 | 2800 |
| 2050 | 0 | 2800 |

- Protected marine areas: In addition to the current protected marine areas, this policy increases the protected areas, reducing the area available for fishing, as indicated Table 5.

*Table 5. Goal for additional protected marine area (ha) for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2023 | 0 | 1,006,417 |
| 2030 | 0 | 5,001,953 |
| 2050 | 0 | 7,669,531 |

- Local fish consumption regulation: This policy established that 50% of the fish demand will be satisfied by imported fish, not local fish. This is possible with the share of local fish consumed (see Table 6) that reduced direct fish harvest from the Canary Islands marine areas.

*Table 6. Share of local fish consumed for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2000 | 100% | 100% |
| 2022 | 100% | 100% |
| 2030 | 100% | 50% |
| 2050 | 100% | 50% |

- Solid waste collection capacity expansion: this policy assumes that the solid waste collection capacity construction rate increases by 30%, as presented in Table 7, reducing in this way the solid waste that goes into the sea.

*Table 7. Fractional increase in solid waste collection capacity construction rate for different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2023 | 0% | 30% |
| 2030 | 0% | 30% |
| 2050 | 0% | 30% |

- Wastewater treatment facilities (WWTF) expansion: this policy is activated to expand the WWTF capacity beyond the BAU level from 2023, with 100% of wastewater being treated by 2050, as indicated in Table 8.

*Table 8. WWTF satisfaction rate for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2023 | 65% | 69% |
| 2050 | 65% | 100% |

- Noise-free zones: The input that defines the impact of noise-free zones is the reduction in noise perception, as presented in Table 9.

*Table 9. Fractional reduction in noise perception for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2023 | 0% | 10% |
| 2030 | 0% | 15% |
| 2050 | 0% | 30% |

- Public transport and NMT: This policy presents two impacts in different parts of the model. The impact on energy demand is driven by the fractional reduction in fossil fuels demand (see Table 10). The other impact of public transport is on traffic congestion, which is reduced based on the values in Table 11.

*Table 10. Fractional reduction in total fossil fuels demand for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2022 | 0% | 0% |
| 2030 | 0% | 7% |
| 2050 | 0% | 20% |

*Table 11. Fractional reduction of traffic congestion for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2022 | 0% | 0% |

| | | |
|---|---|---|
| 2030 | 0% | 10% |
| 2050 | 0% | 20% |

- Renewable energy capacity expansion: The expansion of electricity generation with renewable sources is set up with the fraction of electricity that is renewable, which increases up to 80% for the STS, while for the BAU scenario, it increases up to 50%, as portrayed in Table 12.

*Table 12. Fraction of electricity generation renewable for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2000 | 5% | 5% |
| 2010 | 5% | 5% |
| 2015 | 15% | 15% |
| 2020 | 20% | 20% |
| 2050 | 50% | 80% |

- Energy efficiency: This policy generates improvements in energy efficiency across all sectors (i.e. electricity and fossil fuels demand) in the range of 1% per year for the BAU scenario, and 2% for the STS (see Table 13).

*Table 13. Energy efficiency rate (dmnl/year) for the different scenarios*

| Year | BAU scenario | Sustainable tourism scenario |
|---|---|---|
| 2000-2022 | 1% | 1% |
| 2023-2050 | 1% | 2% |

### 3.4. Assumptions for Tourism Typology

As presented in the CLD (see Figure 1), conventional tourism and eco-friendly tourism have different impacts and trigger dynamics on the CC of the Canary Islands. In the CCCI model, these differences are represented through parameters in specific modules, where tourists' actions have many and varied impacts, as presented in Table 14. For instance, the average wastewater generation per tourist per day in conventional hotels is 289 liters, while for eco-hotels is 159 liters.

*Table 14. Parameters used for conventional tourism and eco-friendly tourism in the CCCI model*

| Module | Parameter | Unit | Value |
|---|---|---|---|
| Tourism capacity | Initial number of conventional hotels | Hotels | 195 |
| | Initial number of hotels for eco-friendly tourism | Hotels | 20 |
| | Average daily capacity per conventional hotel | Person/day/hotel | 100 |
| | Average daily capacity per eco-hotel | Person/day/hotel | 50 |
| | Baseline share of conventional hotels demand | % | 2000->95%<br>2022->92.5%<br>2050->92.5% |
| | Baseline share of eco-friendly tourism demand | % | 2000->5%<br>2022->7.5%<br>2050->7.5% |
| Tourism waste generation | Average wastewater generation per tourist per day in conventional hotels | Ltr/person/day | 289 |
| | Average wastewater generation per tourist per day in eco hotels | Ltr/person/day | 159 |
| | Average solid waste generation per tourist per day in conventional hotels | tons/person/day | 0.0015 |
| | Average solid waste generation per tourist per day in eco hotels | tons/person/day | 0.0008 |
| Tourism traffic congestion and noise | Traffic congestion and noise with eco-hotels | dmnl | -5% |
| Land use | Settlement land per conventional hotel | Ha/hotel | 2 |
| | Settlement land per eco-hotel | Ha/hotel | 1.5 |
| Energy demand | Average electricity consumption per tourist day in conventional hotels | MJ/person/day | 135 |
| | Average electricity consumption per tourist day in eco hotels | MJ/person/day | 114.75 |

# 4. Results

This section presents the results of the BAU and STS modelled in the CCCI model. First, we present variables related to tourism and its impacts on natural capital, such as for marine, terrestrial, atmospheric and urban habitats. Then, the results for CC are presented. Finally, the economic valuation (cost-benefit analysis) of the intervention options analyzed is presented.

## 4.1. Tourism Impacts

The impact of tourist arrivals and activities can be better understood by examining the number of tourists visiting the Canary Islands, as shown in Figure 3. In the Business-As-Usual (BAU) scenario, the system experiences a turning point regarding the number of tourists, with a decline expected after 2025. This decline is primarily attributed to the reduced appeal of the islands, a consequence of the deteriorating environmental conditions. In contrast, the Sustainable Tourism Scenario (STS) demonstrates that the adoption of sustainable tourism practices mitigates the adverse effects of tourism. As a result, it leads to an increase in the islands' climate resilience, a boost in their attractiveness, and subsequently, a rise in the number of tourists arriving in the Canaries. The projections indicate that by 2050, the region is expected to host approximately 11.56 million tourists annually in the STS scenario, while for the BAU scenario the number of tourists by 2050 will reach 6.98 million tourists.

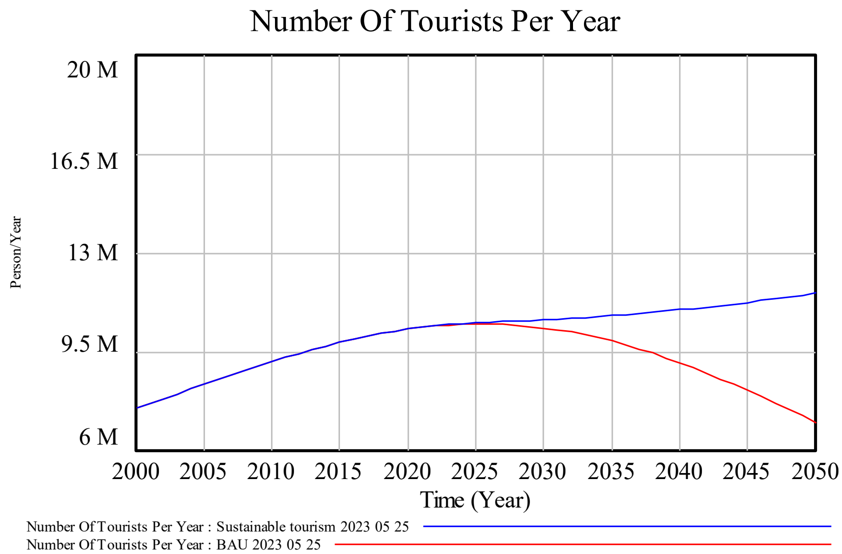


*Figure 3. Number of tourists for the different scenarios*

With the growth in the number of tourists under the Sustainable Tourism Scenario (STS), there is a noticeable uptick in the demand for hotels, as illustrated in Figure 4. In 2022, both scenarios start with a total of 310 hotels. However, their trajectories diverge from that point onward. In the Business-As-Usual (BAU) scenario, the number of hotels begins to decline due to the decrease in tourist visits, ultimately reaching 222 hotels by 2050. On the other hand, for the STS there is an increase in hotel construction as the tourist arrivals increase, leading to a total of 454 hotels by 2050.

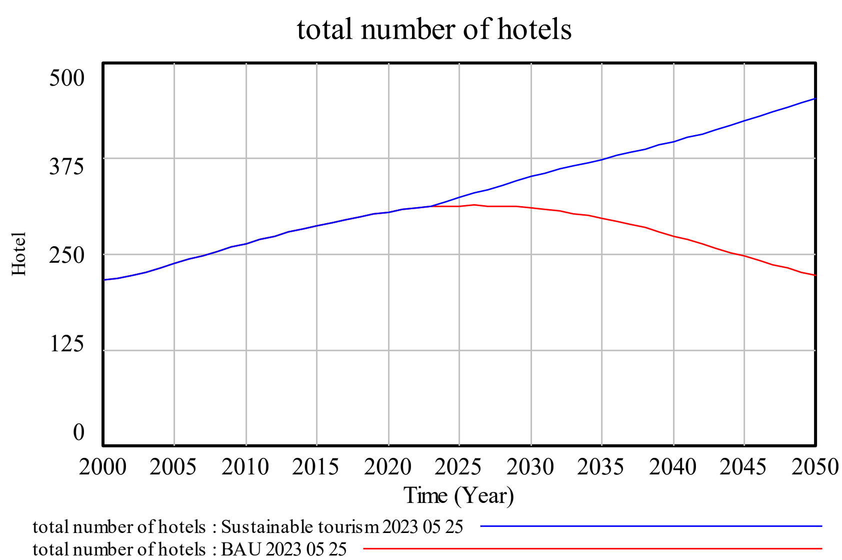


*Figure 4. total number of hotels for the different scenarios*

Most of the hotels built between 2023 and 2050 are hotels for eco-tourism. This is reflected in Figure 5, that shows that for the STS scenario the share of hotels for eco-friendly tourism increase from 13.76% in 2022 to 56% in 2050. For the BAU scenario, the share stays similar until 2050, resulting in 13% by 2050.

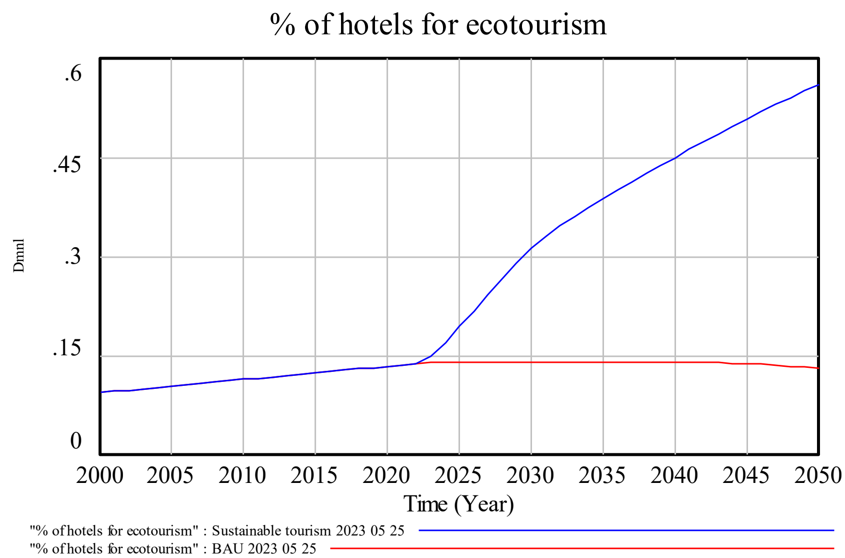


*Figure 5. share of hotels for eco-friendly tourism*

The increase in tourist numbers and hotel establishments in the Sustainable Tourism Scenario (STS) has a notable impact on employment generation when compared to the Business-As-Usual (BAU) scenario. According to Figure 6, the STS scenario is projected to employ as many as 341,600 individuals by the year 2050, compared to 209,000 employment positions by the same year in the BAU scenario.

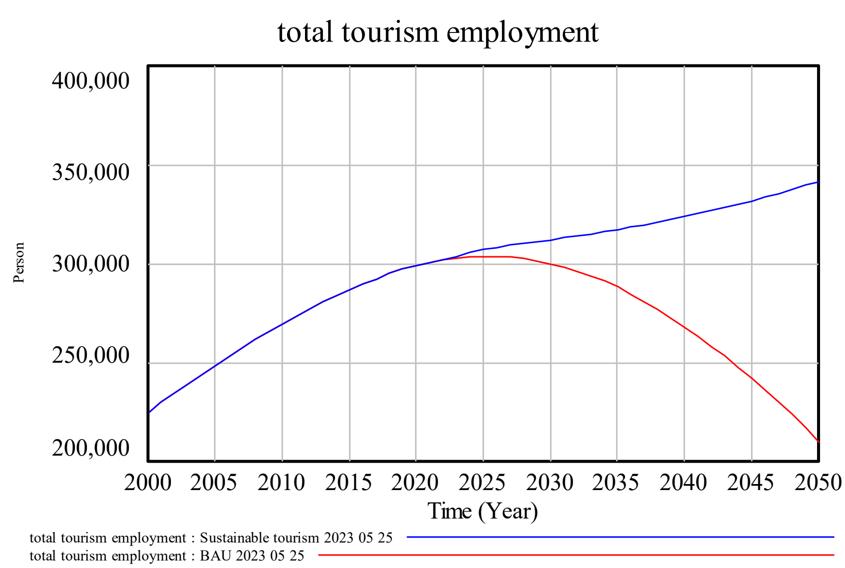


*Figure 6. Total tourism employment for the different scenarios*

**Textbox 1. Regulating tourism**

Regulating tourism is of paramount importance when aiming to achieve a more sustainable tourism industry. By striking a balance between the economic benefits of tourism and safeguarding the environment and local communities, we can create a more harmonious and resilient tourism sector. In the context of the CCCI model, the focus is on four vital components of the environment: marine, terrestrial, urban, and air.

Through the regulation of tourism arrivals to the Canary Islands, we can effectively generate desired outcomes in various crucial variables, such as carrying capacity, population welfare, and GDP, among others. Setting targets for these variables allows us to work backward and identify the ideal value of tourism arrivals that best aligns with the region's needs and sustainability objectives.

A key aspect of setting targets for carrying capacity (CC) is to prioritize sustainability, which would lead to a higher demand for eco-friendly tourism and a lower demand for conventional tourism compared to the Business as Usual (BAU) scenario. The share of conventional vs eco-friendly hotels in the Canary Islands is an input for the model, which can be changed and regulated based on the mentioned goals. However, it is important to note that while targets are established, the optimal number of tourists may fluctuate over time. For example, to achieve the target of improving carrying capacity, there might be a temporary reduction in the number of tourists in the short term. Still, as the environment regenerates and eco-friendly tourism gains popularity, the number of tourists could increase again in the medium and long term.

The model is set up so that tourism is an output that has dynamic relationships with the environmental conditions, accommodations availability and water availability. The model also shares insights on the impact of having a certain tourism level on income, CC, welfare and more. Based on the nature of the model, it cannot optimize the tourism arrivals for regulation purposes. The model is to be used to test intervention options and their multi-dimensional outcomes.

Figure 7 illustrates the economic benefits of tourism, measured in real GDP. The Sustainable Tourism Scenario (STS) exhibits a positive trend, indicating an improvement in economic activity over time, which is opposite to the declining trajectory seen in the Business as Usual (BAU) scenario. In the latter, both the number of tourists and the value added per tourist decline due to reduced environmental quality. By 2022, the total tourism real GDP stands at 3.58 EUR billion/year for both scenarios. However, tourism GDP is projected to increase to 4.39 EUR billion/year for the STS scenario and decrease to 2.22 EUR billion/year for the BAU scenario by the year 2050.

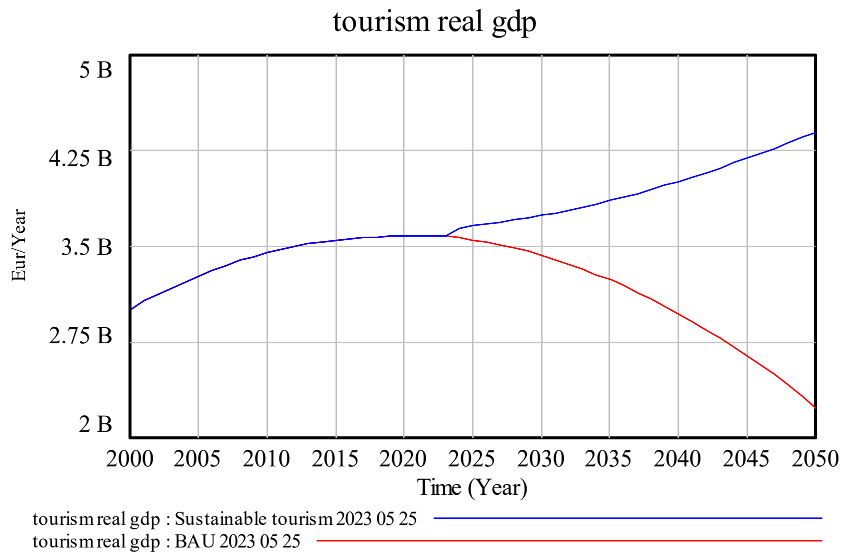


*Figure 7. Tourism real GDP for the different scenarios*

Both traditional and environmentally friendly tourism activities have resource consumption and contribute to climate change impacts. Wastewater generation is one of the consequences of tourism. In 2022, tourism resulted in an annual wastewater generation of 12.6 billion liters per year.

As Figure 8 shows, in the Business as Usual (BAU) scenario, wastewater generation decreases to 9.43 billion liters per year due to a reduction in tourist arrivals. On the other hand, in the Sustainable Tourism Scenario (STS), wastewater generation initially declines at a faster rate in the short term, primarily due to a decrease in wastewater generation per tourist. Subsequently, it stabilizes in the medium and longer term, reaching approximately 11.5 billion liters per year, despite an increase in tourist arrivals in the STS. It's worth noting that for both scenarios, wastewater generation remains below the peak observed in 2022.

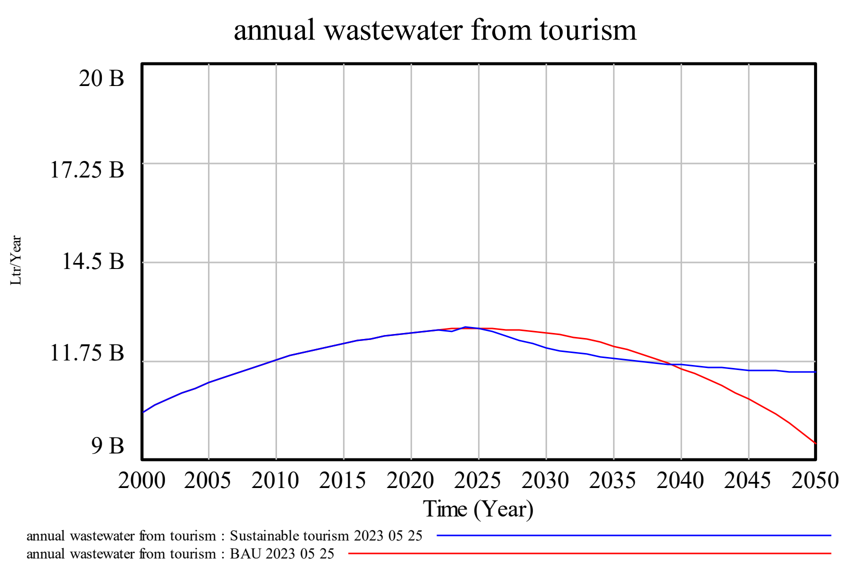


*Figure 8. Wastewater generation from tourism for the different scenarios*

Similar to wastewater, the generation of solid waste from tourism, as depicted in Figure 9, follows a similar pattern. After the implementation of Sustainable Tourism Scenario (STS) policies, there is a rapid decline in the first few years, followed by a stabilization of solid waste generation, which reaches 60,830 tons per year by 2050. In contrast, the Business as Usual (BAU) scenario shows a consistent decline in waste generation over the entire time frame due to the gradual reduction in tourist arrivals. By 2050, total waste generation in the BAU scenario amounts to 49,190 tons per year.

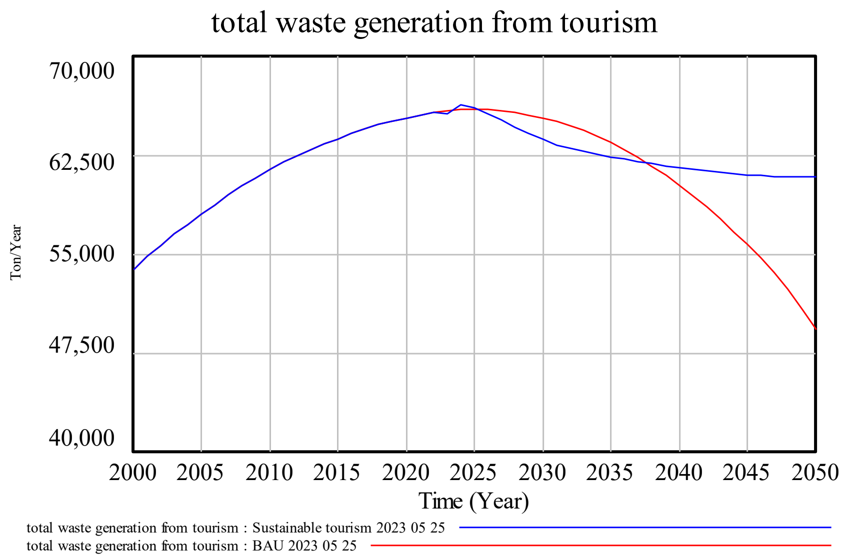


*Figure 9. Solid waste generation from tourism for the different scenarios*

Tourists also affect the urban environment, via traffic congestion and noise pollution. In the case of traffic congestion (see Figure 10), sustainable tourism practices reduce congestion below the BAU level until 2045, despite the higher number of tourists. Regarding noise perception (see Figure 11), the behavior is very similar to the one presented for traffic congestion. In the STS, noise perception declines and reaches a value of 0.75 by 2050, a marked improvement over the current (2022) value of 0.9.

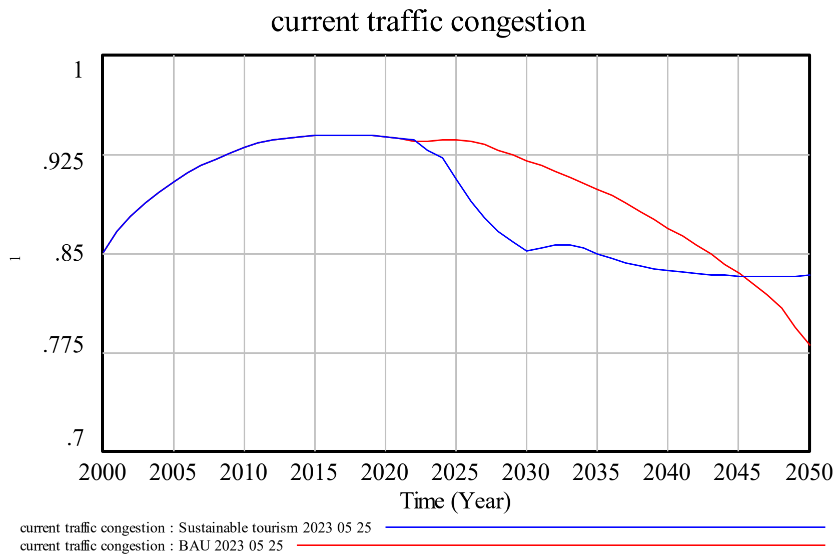


*Figure 10. current traffic congestion for the different scenarios*

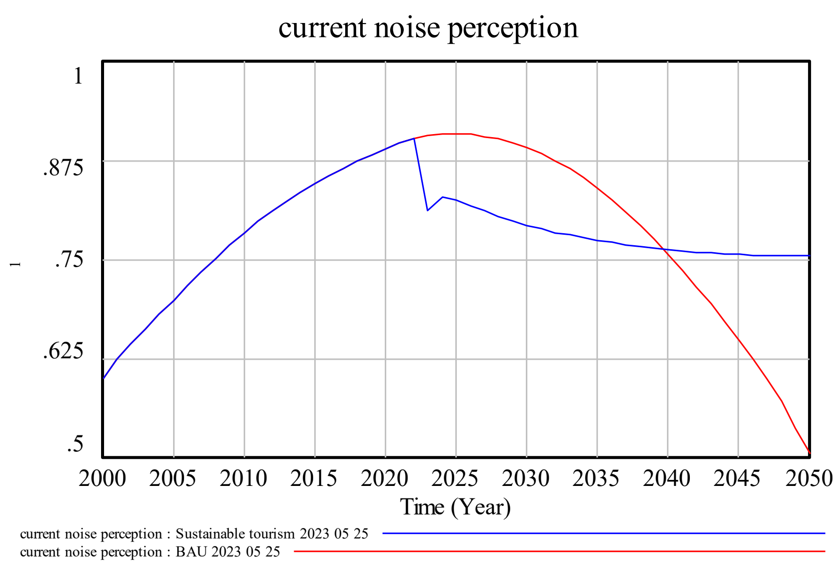


*Figure 11. Current noise perception for the different scenarios*

The total energy demand in the Canary Islands is determined by both the local population and tourists. In 2022, the total energy demand amounted to 8.96 billion kWh per year. Under the Business as Usual (BAU) scenario, despite a decrease in the number of tourists, energy demand is projected to increase driven by population growth. By 2050, the total energy demand is estimated to reach 10.12 billion kWh per year for the BAU scenario.

On the other hand, in the Sustainable Tourism Scenario (STS), thanks to sustainable tourism practices and energy-efficient measures implemented across different sectors, Figure 12 indicates that the total energy demand is anticipated to decrease to 7.17 billion kWh per year by 2050, even with an increase in both the local population and tourists.

Additionally, contributing to the reduction of emissions and air pollution, the STS scenario (as presented in Figure 13) shows an increase in renewable energy adoption, reaching 80% by 2050, in contrast to the 50% seen in the BAU scenario.

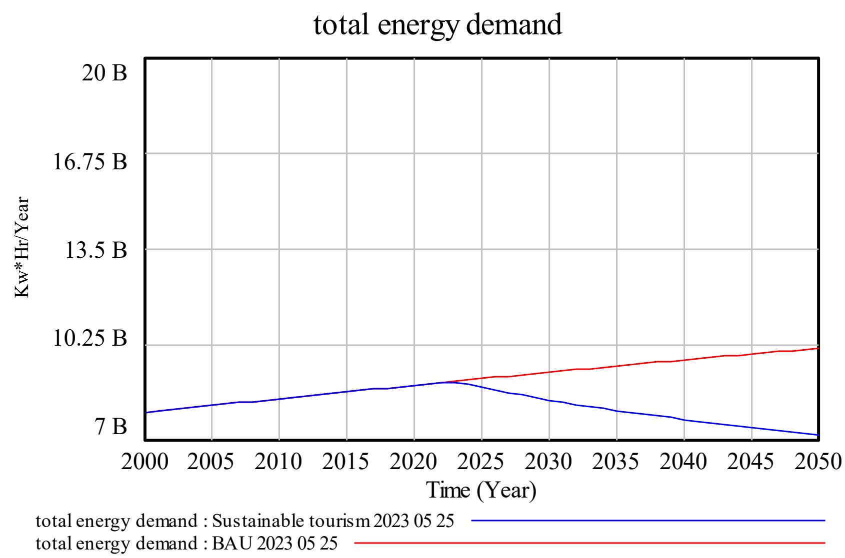


*Figure 12. Total energy demand for the different scenarios*

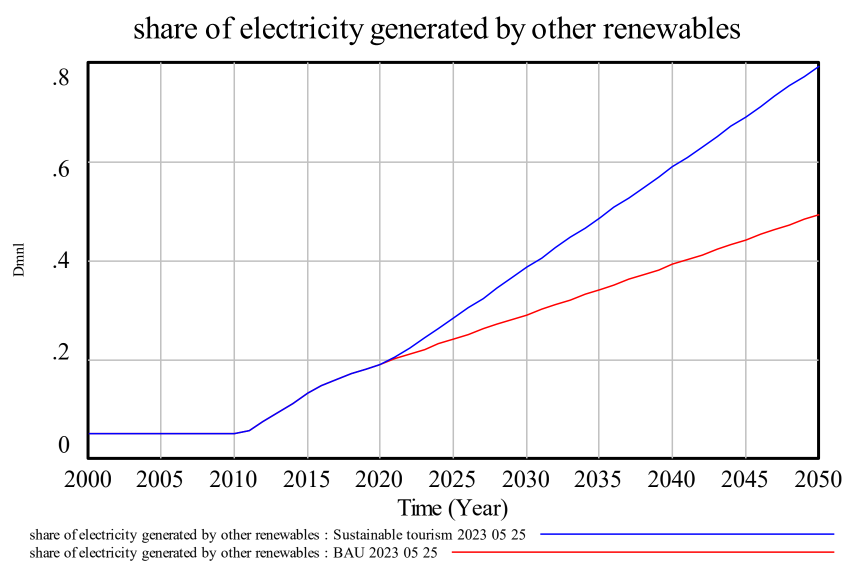


*Figure 13. Share of electricity generates by renewable sources for the different scenarios*

## 4.2. Environmental Indicators

The CCCI model considers marine habitat as a critical environmental indicator, capturing various influences stemming from both the local population and tourists on marine ecosystems. In the Business as Usual (BAU) scenario, the projected Marine habitat index shows a decline from 0.95 in 2000 to 0.87 in 2022, resulting in 0.66 in 2050, as depicted in Figure 14.

However, following the implementation of policies outlined in the Sustainable Tourism Scenario (STS), the decline in the marine habitat index is halted, and it stabilizes at 0.83 in the long term. This suggests that the STS policies have a positive effect on preserving the marine habitat, preventing further degradation.

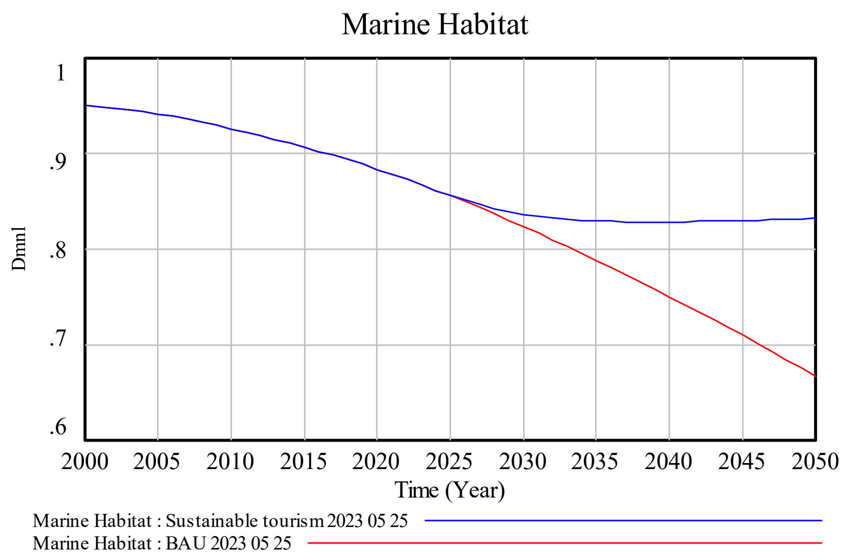


*Figure 14. Marine habitat for the different scenarios*

The state of the marine habitat is significantly influenced by the condition of fish stocks, as depicted in Figure 15. In the STS, the fish stock shows a positive trend, ceasing its decline and even experiencing some recovery in the long term. This recovery can be attributed to the implementation of measures such as the establishment of protected marine areas and reduced consumption of locally harvested fish. By 2050, the fish stock is projected to increase to 15.47 million tons, essentially aligning with the 2020 estimate of 15.46 million tons. Contrary to the STS, in the Business as Usual (BAU) scenario, fish stock levels exhibit a continuous decline over time, reaching 13.45 million tons by 2050. This indicates a worsening condition for fish stocks under the BAU scenario.

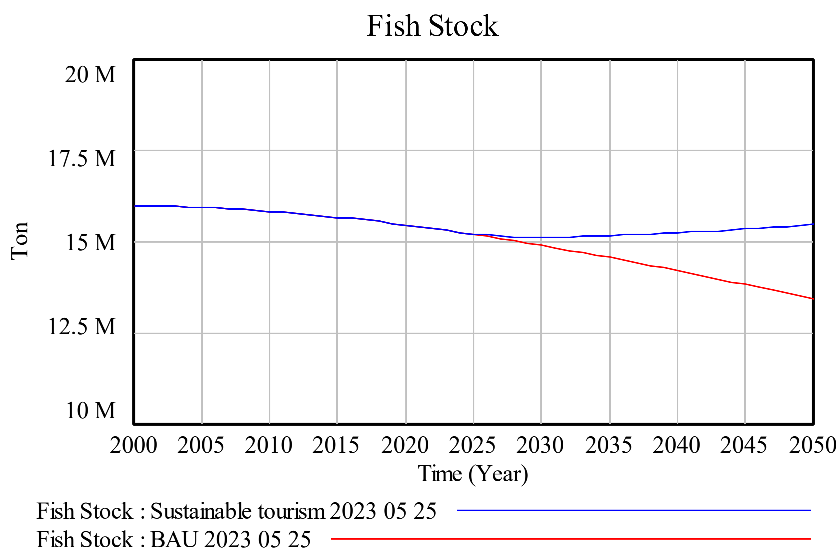


*Figure 15. Fish stock for the different scenarios*

Forest land plays an important role in influencing both marine and terrestrial habitats. In the STS, the inclusion of reforestation policies is expected to bring about a stabilization and gradual increase in forest land over time, as shown in Figure 16. After hitting its lowest point in 2023 at 507,100 hectares, the forest land is projected to expand to 522,100 hectares by 2050 within the STS scenario. In the Business as Usual (BAU) scenario, forest land continues to decline steadily and reaches its historical low of 457,200 hectares by 2050.

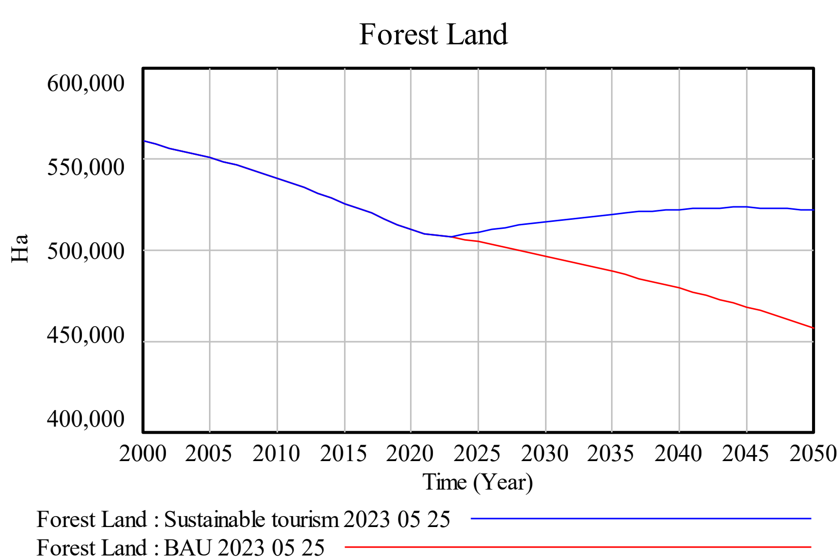


*Figure 16. Forest land for the different scenarios*

The impacts of population and tourists activities on the atmospheric environment is represented in the model by CO2 emissions (see Figure 17) and PM2.5 emissions (see Figure 18), both showing a slight decline over time in the STS, as compared to marked increase in the BAU scenario.

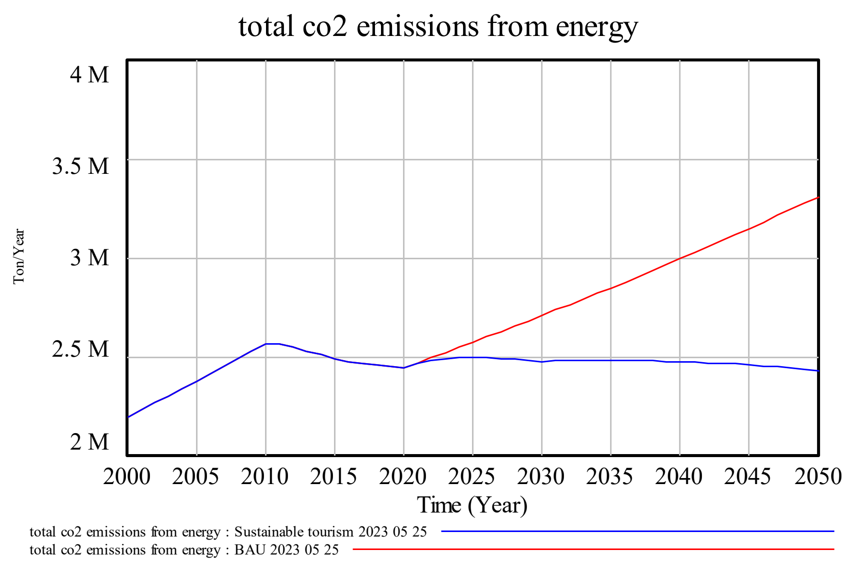


*Figure 17. Total CO2 emissions from energy for the different scenarios*

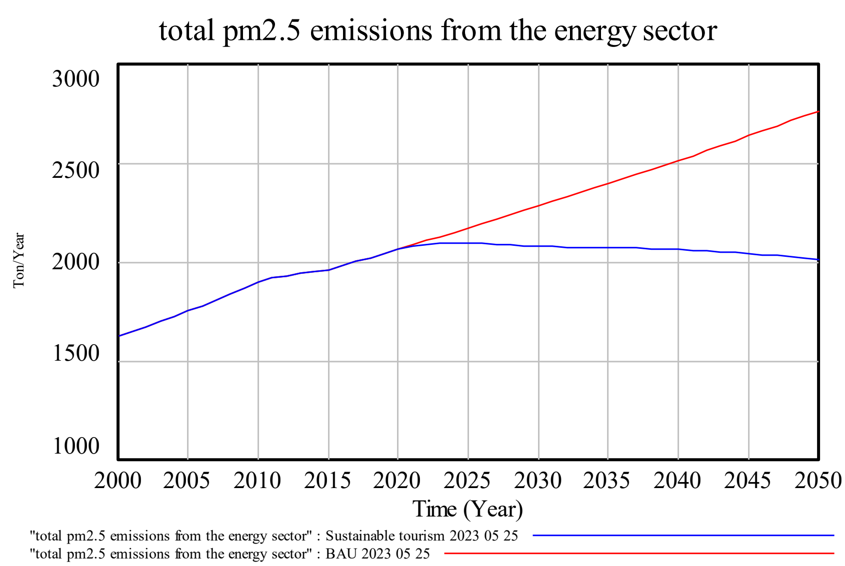


*Figure 18. Total pm2.5 emissions from energy for the different scenarios*

### 4.3. Indices of Population Welfare and Carrying Capacity

The assessment of various environmental indicators and their correlation with GDP offers valuable insights into the population's welfare, as illustrated in Figure 19. In the Business as Usual (BAU) scenario, there's an initial increase observed until 2025, mainly driven by the growth of tourism GDP. However, over time, population welfare experiences a significant decline, with a noticeable drop occurring after 2027, reaching a value of 0.9606 by 2050. This declining trend highlights the negative impacts of unsustainable practices on the overall quality of life for the population.

On the other hand, a more positive outlook is observed with the implementation of the Sustainable Tourism Scenario (STS). As sustainable practices are gradually put into effect, population welfare demonstrates promising improvements, ultimately surpassing a value of 1 in the long term. By 2050, the projected population welfare reaches 1.05, indicating a positive trajectory towards enhanced well-being.

These findings underscore the vital role of eco-friendly tourism in mitigating the adverse effects associated with conventional tourism activities. By adopting environmentally responsible practices, the tourism sector can contribute to the conservation of natural resources, promote socio-economic development, and, most importantly, enhance the overall welfare of the population. This emphasizes the significance of embracing sustainability as a guiding principle for future policymaking and decision-making within the tourism industry.

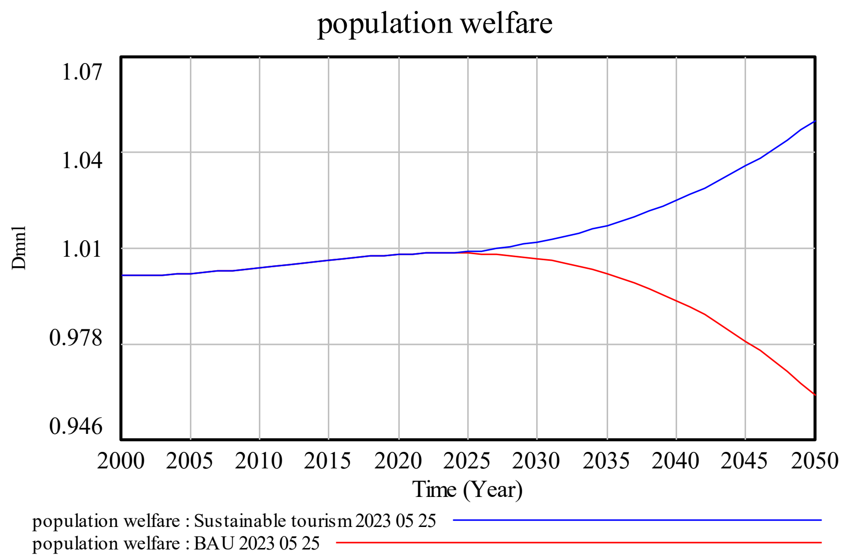


*Figure 19. Population welfare index for the different scenarios*

Finally, the carrying capacity index aggregates all the impacts from the four stressors: air environment, marine habitat, terrestrial habitat and urban environment. It can be observed in Figure 20 how the index goes from declining constantly over time in the BAU scenario to stabilizing and increasing in the STS. In 2022, the CC index was estimated at around 0.57. The CC index continued the decreasing trend in the BAU scenario, reaching a value of 0.38 by 2050. In the ST scenario, the CC index surpassed the value of 2022, resulting in 0.64 by 2050. This means that the Canary Islands will be experiencing less burden from population and tourism activities when sustainable tourism policies are implemented while maintaining growth in the number of tourists and higher GDP. In other words, economic activity will be increasingly decoupled from negative environmental impact.

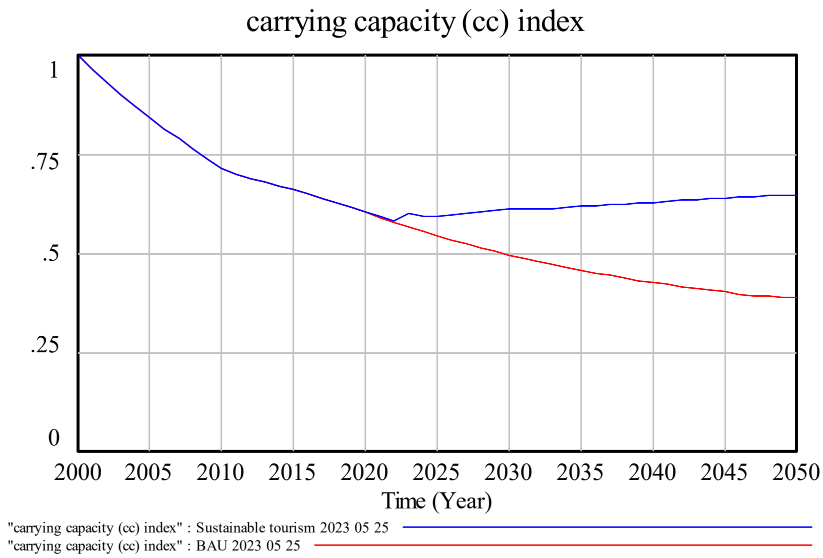


*Figure 20. Carrying Capacity Index for the different scenarios*

**Textbox 2. Modelling alternative BAU scenarios**

The simulations we have presented throughout the report show a rapid decline in tourism arrivals in the future. While this reflect short-term trends it may be overly pessimistic. To show the effects of a more optimistic BAU scenario, a new scenario is created where we math the 10-year trend of tourism growth from historical data, showing further growth potential in the future (see Figure 21). This alternative BAU scenario, represented by the blue line in the graphs included in this textbox, is characterized by a low impact of carrying capacity on the number of tourists and hence a high growth of tourists. On the other hand, the BAU scenario presented along the report, represented by a red line in the graphs included in this textbox, is characterized by a high impact of CC on the number of tourists, which results in a low growth of tourists.

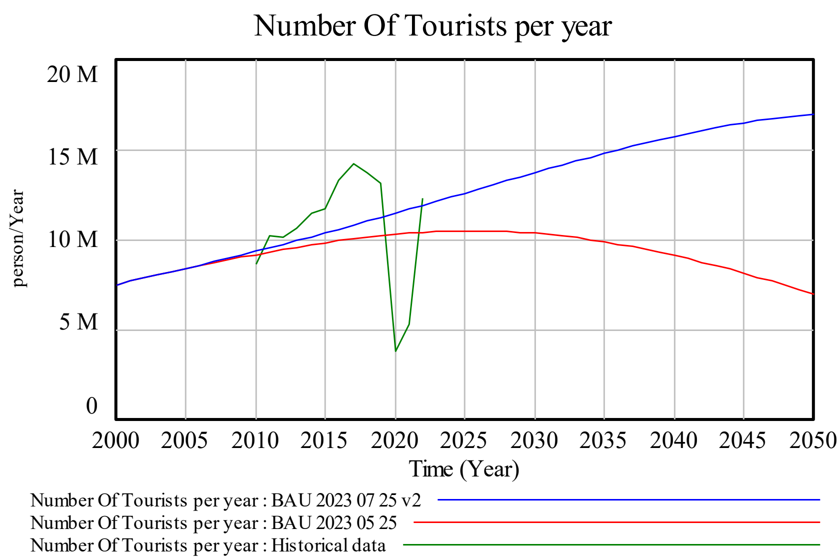


*Figure 21. Number of tourists per year - BAU low growth and high growth scenarios and historical data*

Despite the trends of tourism arrivals is different between both BAU scenarios simulated, the trend is similar for other critical variables in the model. For instance, both scenarios exhibit a decline in environment quality and carrying capacity (see Figure 22) and both scenarios show a decline in population welfare in the medium (BAU low growth scenario) and long term (BAU high growth scenario), as presented in Figure 23. Tourism GDP is also presenting the same declining trend after some point (see Figure 24). For the BAU low growth scenario the decline starts at the year 2020 while for the BAU high growth scenario the decline is delayed, starting after the year 2034.

This similarity in the trends of the critical variables happen because of the strong balancing loops identified and presented in the CLD (see Figure 2). Even if we reduce the strength of the impact of CC on tourism arrivals and the attractiveness of the Islands, the underlying dynamics (and feedback loops) do not change. Hence, whether tourism has a low or high growth, the side effects of tourist's activities are reflected in the environment and welfare of population. Carrying Capacity is the index that reflects more of the burden of tourism volume, since the high growth scenario generates a higher decline for CC of the Canary Islands if compared to the BAU low growth scenario.

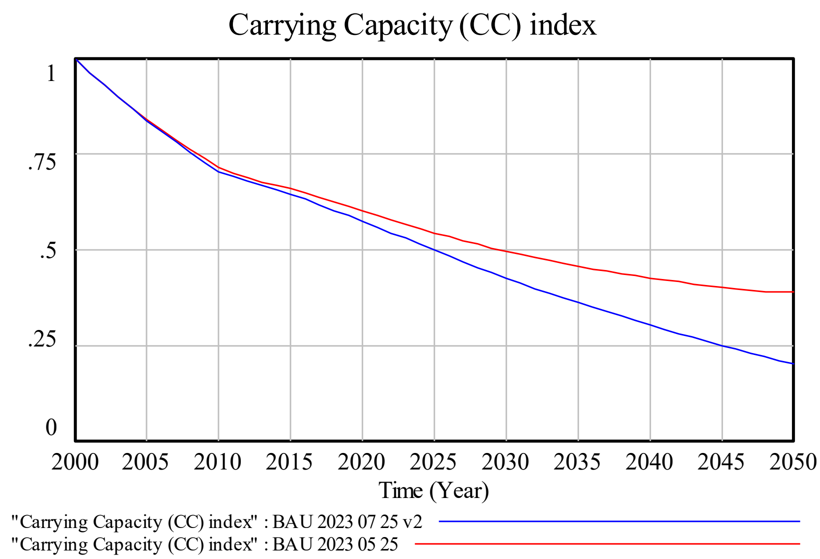


*Figure 22. Carrying Capacity Index - BAU low growth and high growth scenarios*

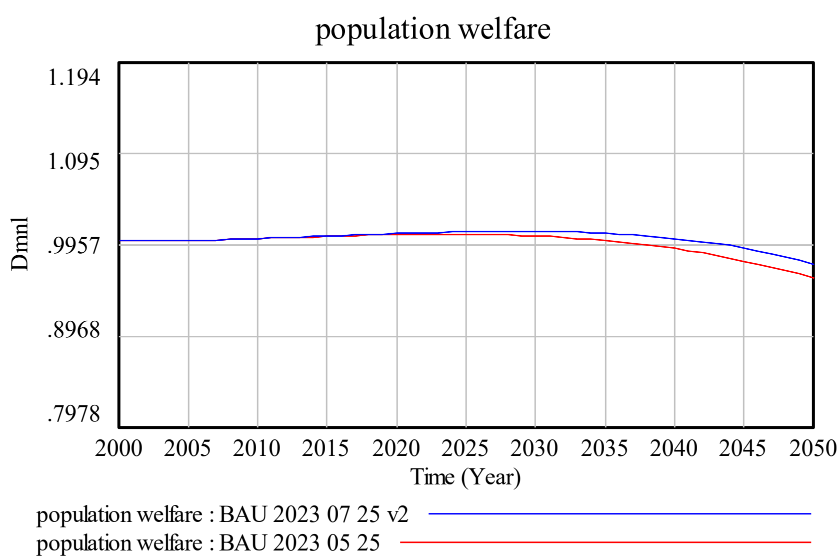


*Figure 23. Population welfare - BAU low growth and high growth scenarios*

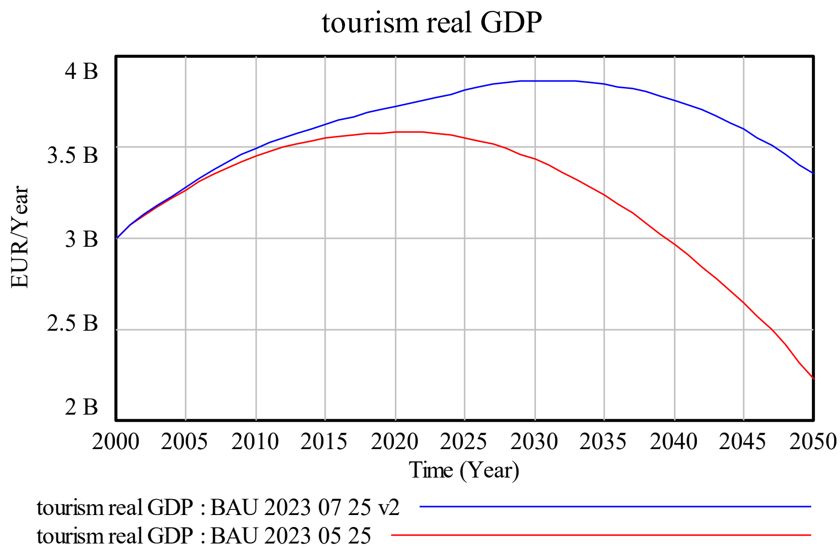


*Figure 24. Tourism GDP - BAU low growth and high growth scenarios*

## 4.4. Integrated Cost-Benefit Analysis

Table 15 provides a comprehensive cost-benefit analysis (CBA) covering the period from 2023 to 2050. This analysis considers all investments made within the Sustainable Tourism Scenario and examines their associated avoided costs and added benefits. The CBA methodology allows for a direct comparison of project costs with the net benefits it yields. These costs encompass various investments and expenditures related to the implementation of policies, including wastewater and solid waste management, energy efficiency, and reforestation, among others. The total costs amount to 3,128.17 million euros without discounting and 1,762.60 million euros with a 3.5% discount.

The added benefits, which influence the tourism sector, the economy, and the marine habitat, total 28,258.30 million euros without discounting and 14,678.05 million euros with discounting. Notably, tourism GDP contributes significantly, with 24,303 million euros undiscounted. Furthermore, the analysis takes into account the costs that are avoided by investing in the STS scenario, encompassing factors related to the urban, air, and terrestrial environment, totalling 1,364.38 million euros undiscounted and 890.39 million euros discounted. Ultimately, by subtracting the investments and costs from the added benefits and avoided costs, the net benefits amount to 26,494.21 million euros undiscounted and 13,805.84 million euros discounted.

The Benefit to Cost Ratio (BCR) is a crucial metric, signifying the returns for every euro invested. The BCR is 8.83 when all impacts are considered, and it slightly decreases to 8.09 when only tangible impacts are assessed. This implies nearly a nine-fold return on each euro invested, highlighting the effectiveness of these investments. Furthermore, the analysis indicates a more substantial economic contribution from nature, primarily due to the intricate connections between tourism, climate change, and ecosystem quality.

*Table 15. Integrated CBA period 2023-2050 with undiscounted and discounted values*

| | | ***Undiscounted*** | ***Discounted*** |
|---|---|---|---|
| **Integrated Cost-Benefit Analysis** | | ***2023-2050*** | ***2023-2050*** |
| **Investment and costs** | **Mn Euros** | **3,128.17** | **1,762.60** |
| Wastewater management | Mn Euros | 485.40 | 285.06 |
| Solid Waste management | Mn Euros | 2.01 | 1.09 |
| Water desalination | Mn Euros | 0.00 | 0.00 |
| Power generation | Mn Euros | 1,635.67 | 929.27 |
| Energy Efficiency | Mn Euros | 928.26 | 498.70 |
| Cost of reforestation | Mn Euros | 76.83 | 48.48 |
| **Added benefits** | **Mn Euros** | **28,258.30** | **14,678.05** |
| Tourism GDP | Mn Euros | 24,303.56 | 12,332.56 |
| Income creation from employment | Mn Euros | 3,085.47 | 1,929.07 |
| value of marine ecosystem services | Mn Euros | 869.28 | 416.42 |
| **Avoided costs** | **Mn Euros** | **1,364.38** | **890.39** |
| Cost of n release into the environment | Mn Euros | 644.28 | 386.79 |
| cost of air pollution | Mn Euros | 241.26 | 128.44 |
| Cost of congestion | Mn Euros | 144.62 | 109.25 |
| Cost of noise pollution | Mn Euros | -106.32 | 33.17 |
| Social cost of carbon | Mn Euros | 440.54 | 232.74 |
| **Annual net benefits** | **Mn Euros** | **26,494.51** | **13,805.84** |
| **Benefit to cost ratio full externalities** | | **9.47** | **8.83** |
| **Benefit to cost ratio only tangible** | | **8.76** | **8.09** |

# 5. Model Description

The CCCI model is composed of several modules that are interconnected with one another. This is required to quantify the feedback relationships that characterized the tourism sector, and its interrelations with social, economic and environmental dynamics in the archipelago. A detailed description of these modules, with selected, relevant tree diagrams and equations, is presented in the next sections.

## 5.1. Climate Assumptions

The climate assumptions module serves for simulating changes in precipitation and temperature over time. It provides information about monthly precipitation and seasonal variability in precipitation and temperature.

Climate impacts in the model depend on the relative changes in precipitation and temperature, estimated as an index. Relative seasonal precipitation, which is calculated as seasonal (or monthly) precipitation divided by normal precipitation, is used to assess potential flood risks or water scarcity impacts.

*relative seasonal precipitation =*
*MAX(seasonal precipitation/normal seasonal precipitation,0.01)*

A MAX function is used to avoid an integration error in case there is a month during which there is no precipitation. In that case, relative seasonal precipitation will take the value of 0.01. All variables that are used to calculate relative seasonal precipitation are presented in Figure 25.

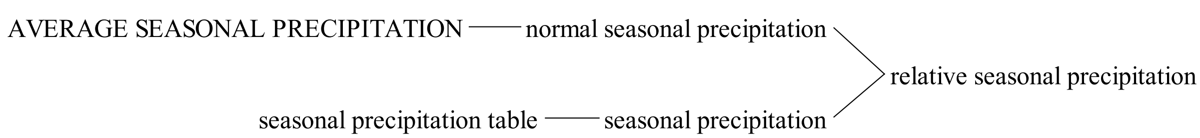


*Figure 25: Causes tree relative seasonal relative precipitation*

Seasonal precipitation receives the exogenous input of precipitation per month (mm/month) and normal seasonal precipitation is equal to the average monthly precipitation.

Variables used to calculate the relative annual temperature are summarized in the causes three displayed in Figure 26. Relative annual temperature is calculated by dividing annual temperature by the initial temperature in the beginning of the simulation.

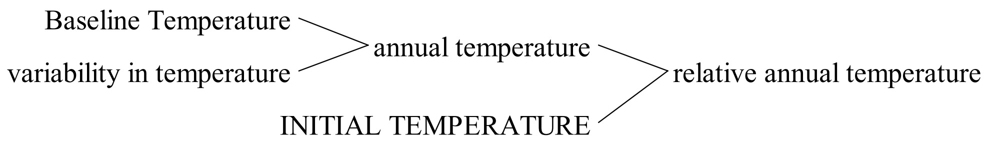


*Figure 26. Causes tree relative annual temperature*

As with precipitation, the model allows to simulate temperature projections endogenously. Annual temperature is the sum of the baseline temperature and the variability in temperature. The stock baseline temperature changes based on an assumed fractional increase in annual temperature, which can be defined by the user of the model. The variability in temperature is represented by a random uniform function with a minimum of -5 C°, maximum of 5C° and seed of 2.  Figure 27 illustrates the causes tree with variables use to calculate annual temperature.

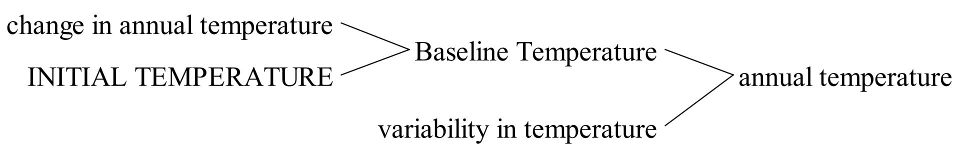


*Figure 27. Causes tree annual temperature*

## 5.2. Population

The population module provides an overview of the development of total population, births, deaths and migration over time. The population module contains the stock of population, which is affected by the three flows births, migration and deaths. The stock of population changes based on the integration of its three flows:

$$Population_{t+1} = Population_{t0} + births_{t0} + migration_{t0} - deaths_{t0}$$

The number of births depends on the population growth rate and the stock level of population. Births are calculated based on the following equation:

$$Births = Population * population\ growth\ rate$$

Migration rate depends on the stock level and the migration growth rate, and the rate depends on the baseline migration growth rate and relative tourism employment, as presented in the equation.

$$Migration = Population * migration\ growth\ rate$$

*Migration growth rate = baseline migration growth rate*relative tourism employment*

The number of deaths depends on the stock level of population and the average life expectancy. Total population is divided by the average life expectancy to obtain the annual numbers of deaths. In the current version of the model, the life expectancy is a time series with values from the year 2000 to 2050.

*Deaths =*
*Population / average life expectancy table*

## 5.3. Tourism

The tourism module provides information about the annual number of tourists, accommodation facilities for tourists and the related benefits from tourism such as employment and GDP, and pressures such as energy consumption, waste generation, traffic congestion, and noise pollution. The module allows to assess tourism development strategies on domestic value added, employment and resource consumption.

### 5.3.1. Number of tourists (demand)

The number of tourists per year for both conventional and eco-friendly tourism is represented as a stock where the only flow is the change in tourists visiting rate (inflow).

$$\textit{Number of tourists per year}_{t+1} = \textit{Number of tourists per year}_{t0} + \textit{Change in tourists visiting rate}_{t0}$$

The change in tourists visiting rate considers a baseline tourism growth rate affected by several effects related to environmental and social aspects that can affect the attraction of tourists in the Canary Islands. The variables influencing the change in the visiting rate are portrayed in Figure 28 and follow the next equation.

*Change in tourists visiting rate=*
*Number Of Tourists Per Year*BASELINE TOURISM GROWTH RATE TABLE(Time) +Number Of Tourists Per Year*BASELINE TOURISM GROWTH RATE TABLE(Time)*(effect of hospitality on tourism+effect of fish stock on tourism+"effect of water pollution (waste) on tourism"+effect of hotel availability on tourism+effect of marine habitat on tourism+effect of co2 emissions on tourism+effect of air pollution on tourism+effect of terrestrial habitat on tourism+effect of water availability on tourism)*

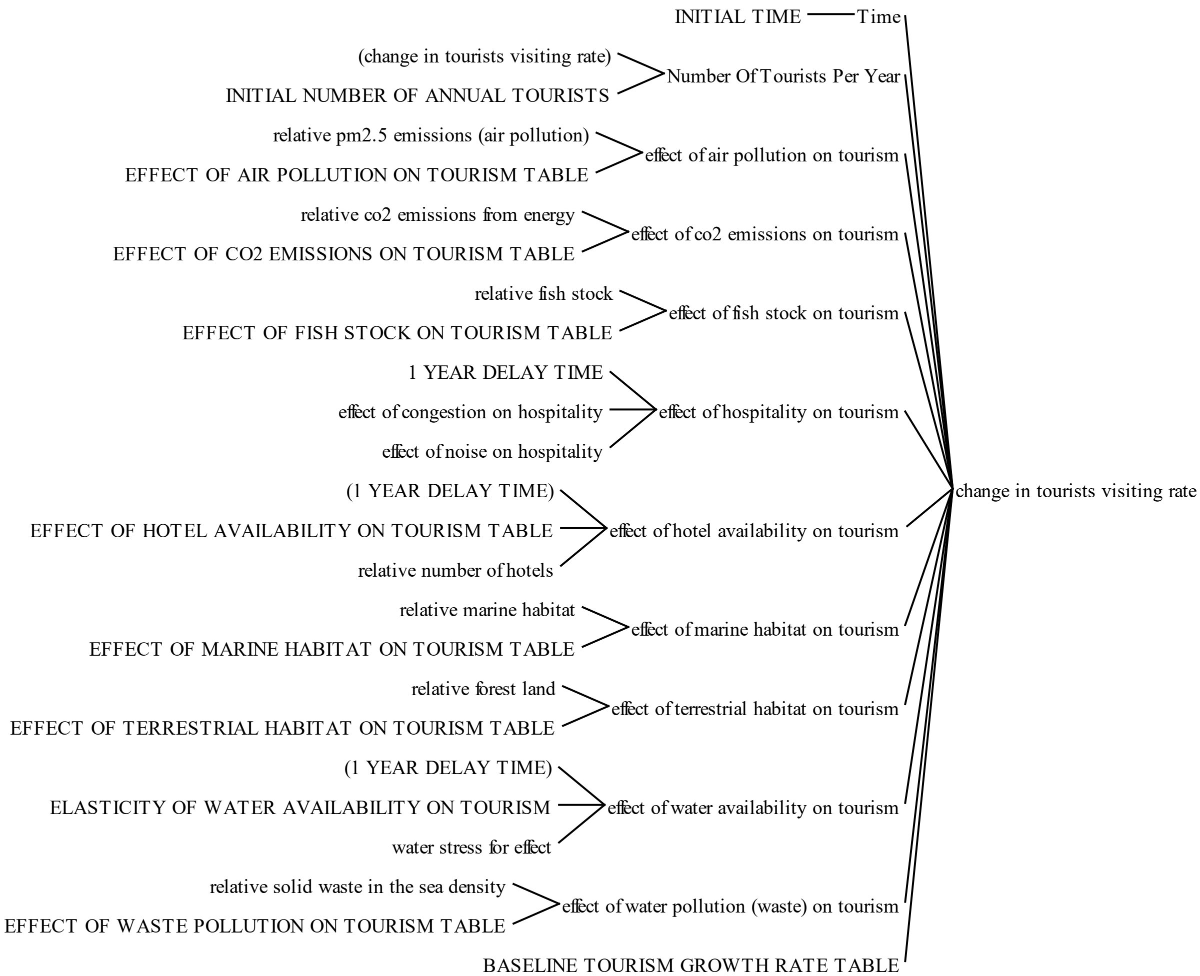


*Figure 28. Causes tree Change in tourists visiting rate*

For instance, the effect of air pollution on tourism is represented as the EFFECT OF AIR POLLUTION ON TOURISM TABLE as a function of the relative pm2.5 emissions, as indicates in the next equation:

*effect of air pollution on tourism = EFFECT OF AIR POLLUTION ON TOURISM TABLE (relative pm2.5 emissions (air pollution))*

In the same way are modelled the effect of co2 emissions, marine habitat, fish stock, waste pollution in the sea, terrestrial habitat, and noise and congestion that affect the effect of hospitality. On the other hand, both the effect of water availability and hotel availability use the next approach with elasticities to be quantified:

*effect of hotel availability on tourism = DELAY3I(relative number of hotels^EFFECT OF HOTEL AVAILABILITY ON TOURISM TABLE, "1 YEAR DELAY TIME", 1)*

### 5.3.2. Accommodation capacity

The number of tourists determines the desired number of hotels, where a percentage of the hotels are for eco-friendly tourism and the remaining percentage for conventional hotels. Both types of hotels stocks have an inflow of construction rate and an outflow of depreciation rate.

The desired number of eco-hotels and conventional hotels is determined with the next equations:

*baseline desired number of eco-hotels = (Number Of Tourists Per Year*share of tourism demand eco-friendly tourism)/(AVERAGE DAILY CAPACITY PER ECO HOTEL*DAYS PER YEAR)*
*baseline desired number of hotels = Number Of Tourists Per Year*(1-share of tourism demand eco-friendly tourism)/(AVERAGE DAILY CAPACITY PER CONVENTIONAL HOTEL*DAYS PER YEAR)*

While the average daily capacity per conventional hotel is assumed to be 100 persons per day, the capacity for eco-hotels is 50 personas per day. The eco-hotels are considered to be less tourist intense.

The investment in accommodation capacity increases when tourism GDP increases. Hence, both the desired number of eco-hotels and conventional hotels is calculated as the baseline number of hotels multiplied by the effect of GDP on hotel infrastructure. The effect of GDP on hotels infrastructure is determined as a delayed function of relative tourism GDP with an elasticity of 0.1.

*effect of gdp on hotel infrastructure = DELAY3I (relative tourism gdp ^ ELASTICITY OF GDP ON HOTEL INFRASTRUCTURE, "1 YEAR DELAY TIME", 1)*

### 5.3.3. Employment

Employment from the tourism sector is the sum of employment from hotels and employment from tourist activities, as portrayed in Figure 29. Total employment from activities is the multiplication of total tourist activities per year and employment per activity. Total employment from hotels is the multiplication of number of tourists per year and employment per tourist.

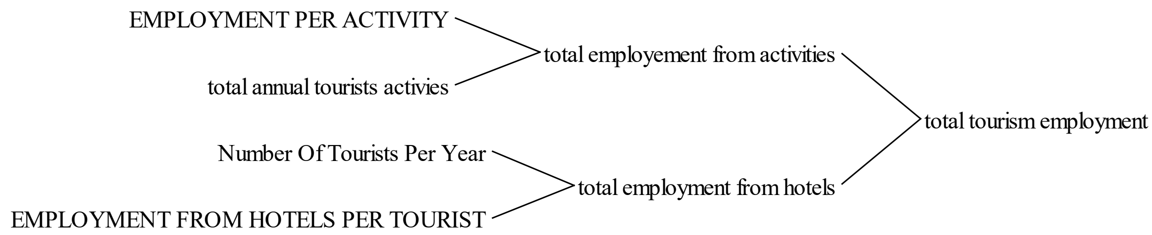


*Figure 29. Causes tree for tourism employment*

### 5.3.4. GDP

Tourism real GDP is driven by GDP from hotels and GDP from activities (see Figure 30).

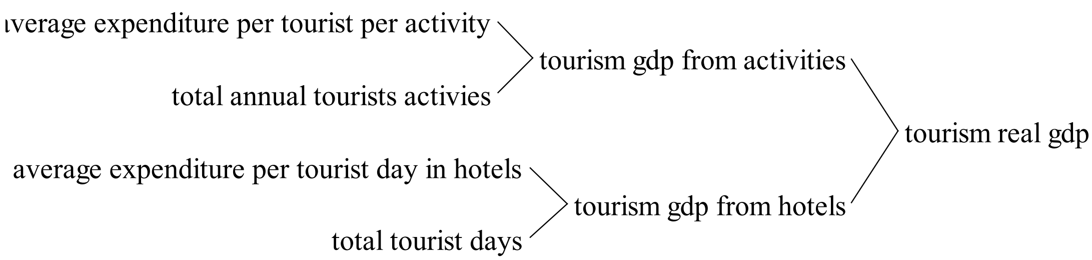


*Figure 30. Tourism real GDP causes tree*

GDP from hotels is driven by total tourists days and average expenditure per tourists. Total tourists days is the multiplication of number of tourists per year and average days of stay. The last one is affected by water availability and hospitality following the next equation:

*real average days of stay = BASELINE AVERAGE DAYS OF STAY * effect of hospitality on tourism * effect of water availability on days of stay*

The average expenditure per tourist for hotels changes with based on a annual growth rate and the effect of different aspects, as indicated next:

*average expenditure per tourist day in hotels= BASELINE AVERAGE EXPENDITURE PER TOURIST DAY IN HOTELS * effect of marine habitat on expenditure * effect of terrestrial habitat on expenditure * effect of water pollution (waste) on expenditure * Growth Rate Real Value Added Per Tourist*

For the case of GDP from tourism activities is driven by average expenditure per tourist per activity and total annual tourist activities. The last one is the multiplication of number of tourists and total tourist activities during stay. Total tourist activities during the stay follows the next equation.

*tourist activities during stay = AVERAGE ACTIVITIES PER TOURIST PER DAY*real average days of stay*

The average expenditure per activity per tourist is impacted by the same effect of the expenditure for hotels. In the next equation, the value of 20 represents the baseline expenditure per activity in euros/activity.

*Average expenditure per activity per tourist = 20*effect of marine habitat on expenditure*effect of terrestrial habitat on expenditure*"effect of water pollution (waste) on expenditure"*Growth Rate Real Value Added Per Tourist*

### 5.3.5. Wastewater generation

Wastewater generated by the tourist sector is calculated as the sum of wastewater from eco-friendly tourism and wastewater from conventional tourism. Both are quantified by multiplying total tourist days, the share of hotels for eco-friendly tourism and the average wastewater generation (see Figure 31). For wastewater from eco-friendly tourism, a reduction in wastewater due to sustainable and efficiency practices in ecohotels is applied.

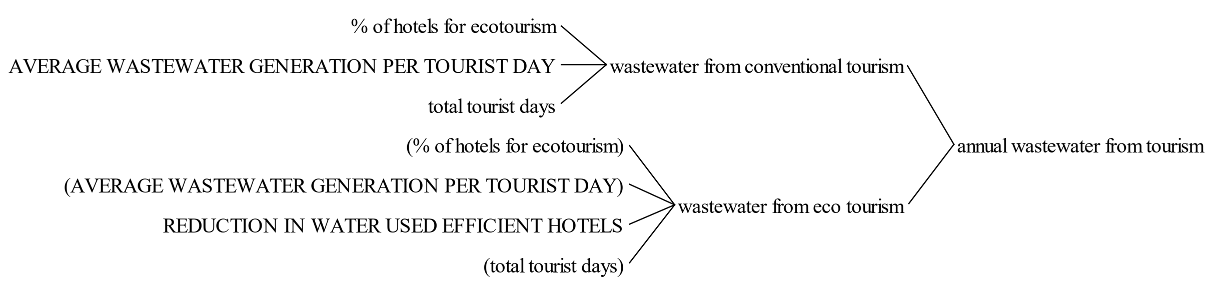


*Figure 31. Total wastewater generation from tourism causes tree*

### 5.3.6. Solid waste generation

The waste generated by the tourist sector is calculated as the multiplication of the number of tourist days, average waste generation per tourist per day and waste generation reduction from eco-friendly tourism, as represented in Figure 32. The average waste generated per tourist has a baseline value for conventional hotels and then waste reduction is applied due to sustainable practices in eco-hotels.

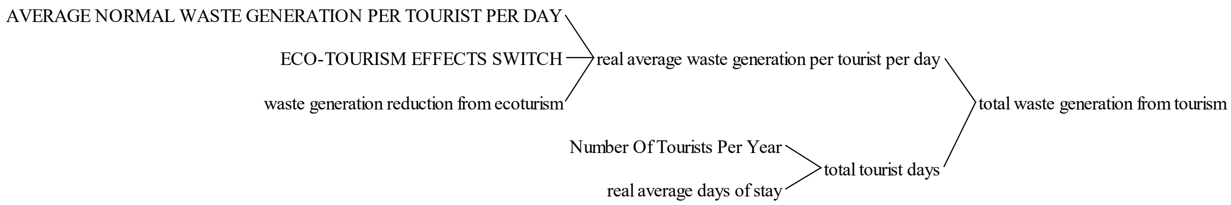


*Figure 32. Total solid waste generation from tourism causes tree*

### 5.3.7. Traffic Congestion

Traffic congestion generated by tourism in the Canary Islands is driven by the days of stay and the roads infrastructure. The model uses de relative km of roads and the relative tourist days, and then based on a stablished initial traffic congestion calculates the current traffic congestion (see Figure 33).

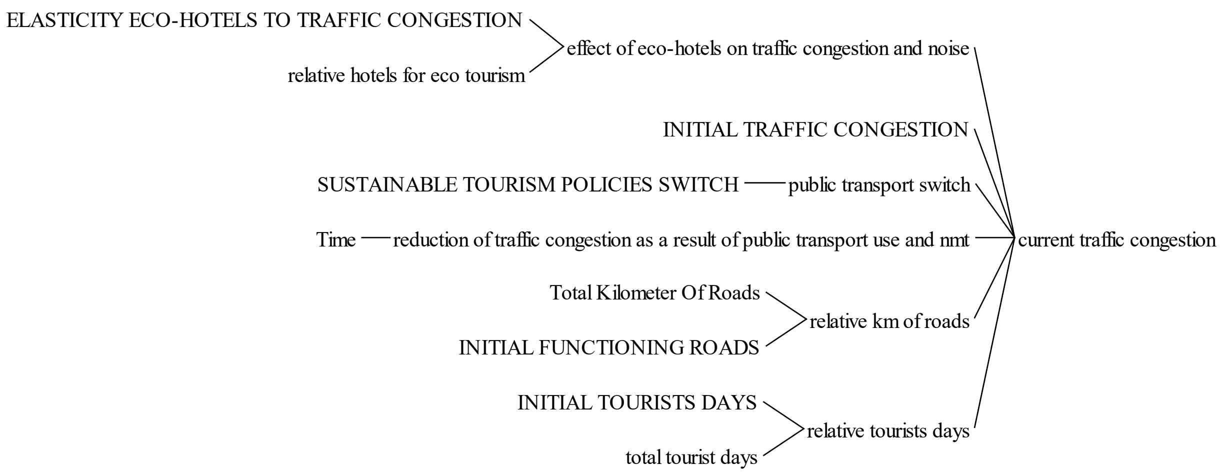


*Figure 33. Causes tree for traffic congestion generated from tourism*

The equation behind the mentioned calculation is:

*current traffic congestion= INITIAL TRAFFIC CONGESTION*relative tourists days/relative km of roads*

### 5.3.8. Noise pollution

The pressure of noise due to tourism is driven by tourist days of stay and tourist activities, as it is portrayed in Figure 34. The current level of noise perception is calculated considering the initial noise perception, the relative tourist activities, and relative tourist days.

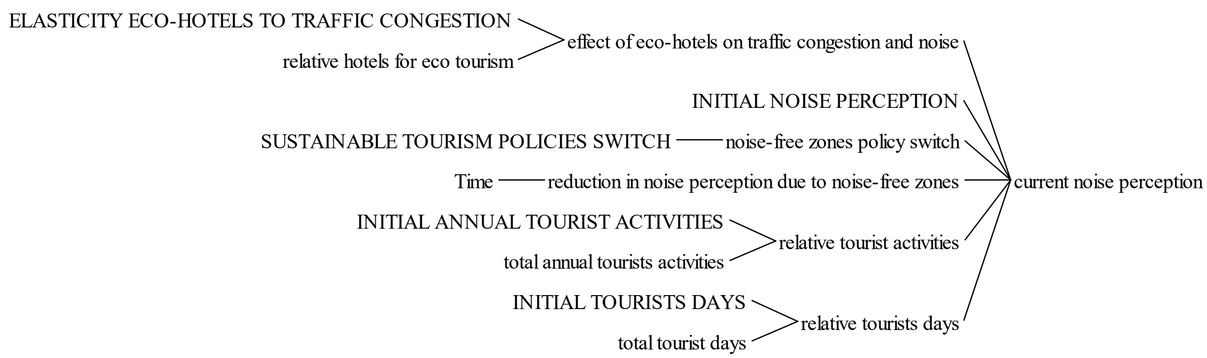


*Figure 34. Causes tree for noise pollution from tourism*

## 5.4. Land Use

### 5.4.1. Aggregate Land Use

The land use module provides information about aggregate land use and land use change over time. This module enables the assessment of development policies' impacts on land use and potential land conversions resulting from policy implementation.

The land use module contains four stocks; forest land, agriculture land, settlement land and fallow land. Five flows are used to capture land use change over time. Stocks and the respective flows are illustrated in Table 16.

| Stock | Inflow(s) | Outflow(s) |
|---|---|---|
| Forest land | • Fallow to forest | • Forest to settlement<br>• Forest to agriculture |
| Agriculture land | • Forest to agriculture | • Agriculture to fallow |
| Settlement land | • Forest to settlement<br>• Fallow to settlement | • None |
| Fallow land | • Agriculture to fallow | • Fallow to forest<br>• Fallow to settlement |

*Table 16. Overview of stocks and flows in the land use module*

Agriculture land, and changes therein, are caused by land conversion for agriculture (forest to agriculture and fallow to agriculture) and the depreciation of agriculture land (agriculture to fallow). The flow forest to agriculture is calculated by the equation below.

*Forest to agriculture =*
*MIN ((desired change in agriculture land+agriculture to fallow)*(1-SHARE OF LAND CONVERSION FROM AGRICULTURE FROM FALLOW LAND),Forest Land/TIME TO CONVERT FOREST LAND)*

A MIN function is used to ensure that land conversion is constrained if the desired change in agriculture exceeds the available forest are for conversion. To ensure that the historical behavior is consistent with documented land use changes, the desired change in agriculture land, representing the total amount to be converted, is multiplied by one minus the share of agriculture land from fallow land. This formulation allows for calibrating how much forest (and in turn fallow land) are used for establishing the desired amount of agriculture land. The desired change in agriculture is the gap between desired agriculture land and currently established agriculture land. If the desired amount of agriculture land is hereby based on population and per capita agriculture land.

*desired agriculture land =*
*Population*agriculture land per capita*

The stock of settlement land has two inflows, assuming that forest and fallow land can be converted for the expansion of urban areas. Land conversion for settlement land is based on the desired settlement land, which is calculated by multiplying population by desired settlement land per capita. The equations are formulated based on the assumption that, as long as there is fallow land available for conversion, there will be no deforestation for establishing settlement land. The following equation is used for calculating the conversion of fallow to settlement land.

*Fallow to settlement =*
*MAX(0, MIN(desired change in settlement land, Fallow Land/TIME TO CONVERT FALLOW LAND))*

A MIN and a MAX function are used for the calculation of land conversion from fallow to settlement land. The MIN function ensures that the conversion of land from settlement land cannot exceed the amount of fallow land currently available (same as for the conversion of forest land for agriculture). In case of the event that the stock of settlement land is higher than the desired settlement land (indicating a negative desired land conversion for settlement and), there would be a flow from settlement land back to fallow land. The MAX function ensures that the current level of settlement land is maintained in case of such an event.

In the case of land conversion for settlement land, forest land serves as a buffer. This means that the conversion of forest to settlement land is only assumed if the amount of fallow land below the amount required for converting the desired amount.

*Forest to settlement =*
*MAX(0,MIN(desired change in settlement land-fallow to settlement, Forest Land/TIME TO CONVERT FOREST LAND))*

As in the case of fallow to settlement, a MIN and a MAX function are used to ensure that land conversion takes place based on land available, and that no reduction of settlement land occurs.

The desired change in settlement land depends on the desired settlement land for living and desired settlement land for tourism, as presented in the equation.

*desired change in settlement land=*
*(desired settlement land for living + desired settlement land for tourism-Settlement Land)/TIME TO CONVERT FALLOW LAND))*

For the case of the desired land for living, it is calculated as the multiplication of population and settlement land per capita. In the case of land for tourism, it is the sum of desired ha of land for conventional hotels and eco-hotels. They are calculated based on the next equations.

*desired ha of land for eco-hotels= desired number of eco-hotels*SETTLEMENT LAND PER ECO-HOTEL*
*desired ha of land for conventional hotels= desired number of hotels*SETTLEMENT LAND PER CONVENTIONAL HOTEL*

The stock of forest land changes based on land conversion for agriculture and settlement land and the regeneration of forests from fallow land. The outflows of the forest stock, forest to settlement and forest to agriculture, are documented above. The regeneration of forests is the sum of forest regeneration, calculated by dividing the stock of fallow land by the average forest regeneration time, and annual reforestation. The equation for the inflow to the forest stock is presented below.

*fallow to forest =*
*Fallow Land / FOREST RECOVER TIME+REFORESTATION*

### 5.4.2. Carbon stock and Land emissions

The carbon stock module provides information about the territory carbon stock and changes therein caused by land conversion. The module is used to assess how policy-induced land use changes affects the country's carbon stock and land emissions.

| Name of variable | Type | Source for estimation |
|---|---|---|
| Carbon factor forest land | Constant | Based on (IPCC, 2006) |
| Carbon factor settlement land | Constant | Based on (IPCC, 2006) |
| Carbon factor agriculture land | Constant | Based on (IPCC, 2006) |
| Carbon factor fallow land | Constant | Based on (IPCC, 2006) |

*Table 17. Overview of data sources for the carbon stock module*

Carbon stocks are calculated by multiplying the four different land use stocks by a respective carbon factor based on IPCC reports (see Table 17). The sum of the four carbon stocks represents the total carbon stock. Figure 35 shows the variables used for the calculation of the total carbon stock.

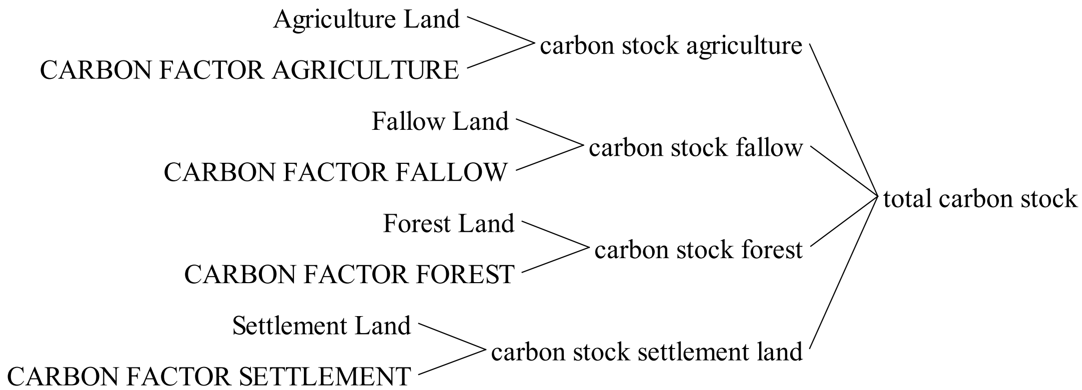


*Figure 35. Causes tree total carbon stock*

Annual emissions from land are calculated based on land conversion. The calculations are based on the five flows described in the documentation of the land use module and the carbon factors applied to the four land use stocks. The causes tree in Figure 36 shows the variables used for the calculation of the net change in carbon stock from land conversion and the CO2e emissions from land.

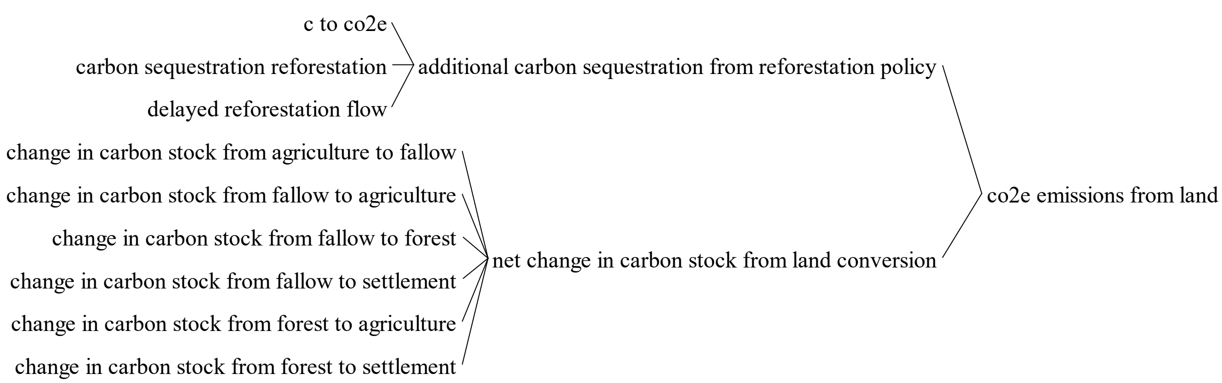


*Figure 36. Causes tree CO2e emissions from land*

To estimate the change in carbon stock caused by land use change, the model calculates the net change in total CO2 that is caused by land conversion. This is done by calculating the difference in carbon stock from the land use class subject to conversion and the target land use class. The equation below illustrates the calculation of the change in carbon stock occurring if forest land is converted to agriculture land.

*change in carbon stock from fallow to agriculture =*
*fallow to agriculture*CARBON FACTOR AGRICULTURE-fallow to agriculture*CARBON FACTOR FALLOW*

The same approach is applied to calculate the changes in carbon stock for the other four flows. The net change in carbon stock is then calculated as the sum of the individual changes in carbon stock caused by the conversion of land.

*net change in carbon stock from land conversion = change in carbon stock from agriculture to fallow + change in carbon stock from forest to agriculture + change in carbon stock from fallow to forest + change in carbon stock from forest to settlement + change in carbon stock from fallow to settlement +change in carbon stock from fallow to agriculture*

## 5.5. Fish stock

The fish stock in the sea is affected by three flows, the inflow of juvenile fish and the two outflows of natural death and fish harvest. Fish harvest in the model depends on the desired fish harvest from both population and tourists. The size of the catch is limited by the available fish stock. The variables affecting the respective flows are presented in Figure 37.

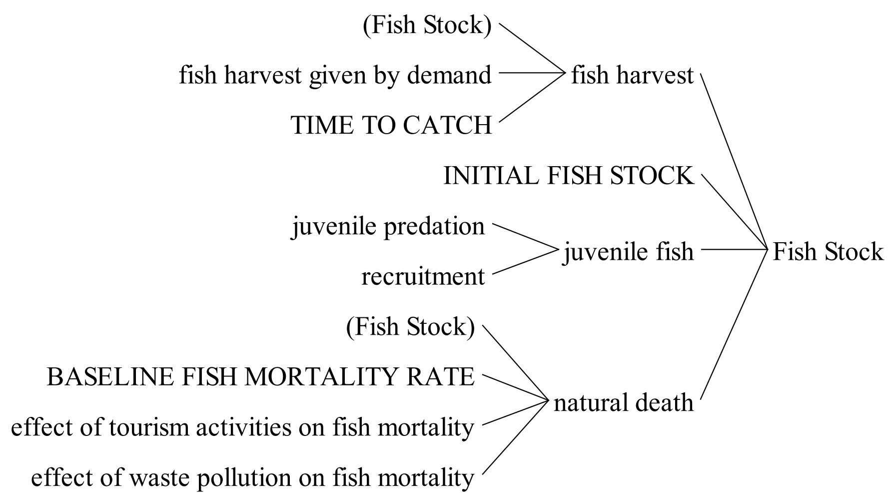


*Figure 37. Causes tree fish stock*

The demand for fish given by population is driven by the total population and annual fish consumption per capita and demand of fish from tourism is driven by total tourist days and fish consumption per tourist per day. The respective equations are:

*desired fish harvest domestic consumption = Population*ANNUAL FISH CONSUMPTION PER CAPITA IN KG*ton per kg*

*desired fish harvest tourism = total tourist days*FISH CONSUMPTION PER TOURIST DAY IN KG*ton per kg*

The outflow of natural death is affected by two main factors: tourism and solid waste pollution. Both effects increase natural death using the next equation:

*Natural death = Fish Stock*BASELINE FISH MORTALITY RATE/effect of waste pollution on fish mortality/effect of tourism activities on fish mortality*

The process of juvenile fish will be driven by the spawning stock, the fertility rate, the recruitment and the juvenile fish predation. This inflow is affected positively by marine protected areas, which increase the fertility rate. The next causes tree illustrate the impacts (see Figure 38):

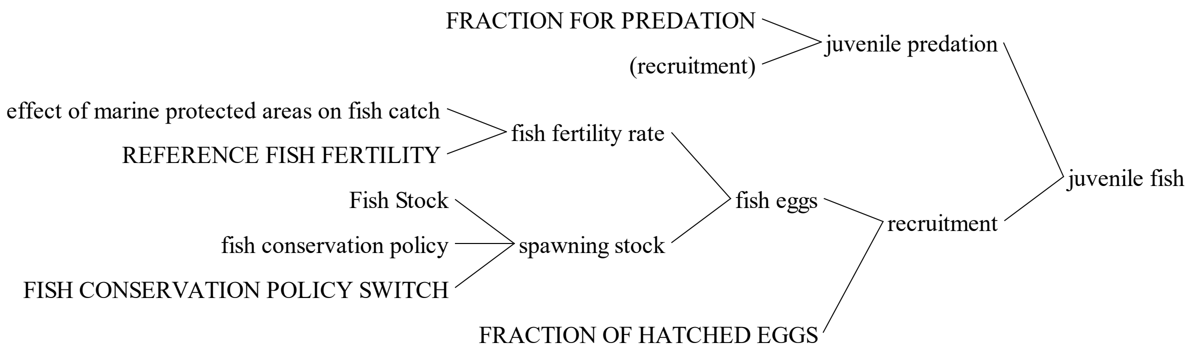


*Figure 38. Causes tree juvenile fish inflow*

## 5.6. Road infrastructureChan

The road infrastructure module offers insights into the overall size of the road network, along with details on new construction projects and ongoing maintenance activities. The module contains the two stocks that keep track of the total amount of kilometers of roads under construction and the total kilometer of roads respectively.

The roads construction rate increases the kilometers of road under construction and depends on the current and desired size of the road network.

*roads construction starts =*
*MAX(0, (desired road network-Total Kilometer Of Roads)/TIME TO BUILD ROADS + roads disruption)*

The difference between the size of the desired road network and the total kilometers of road that are already established assesses whether there is an infrastructure gap. The MAX function is used to ensure that there is no artificial reduction in infrastructure if the current road network is larger than the desired road network. In this case, infrastructure is assumed to be phased out at the end of its lifetime.

Road construction starts is activated when there is desired road network, which is defined as:

*desired road network = IF THEN ELSE ( POLICY SWITCH ROADS SCENARIO = 1, Population * km of roads per capita table + DESIRED ADDITIONAL CONSTRUCTION OF ROADS GE SCENARIO (Time),Population * km of roads per capita table)*

The module further provides information about the costs of road construction and maintenance. The total costs of road construction are calculated by multiplying the road construction rate by the average cost per kilometer of road. Road maintenance costs are calculated based on the stock of total kilometer of roads and a road maintenance cost per kilometer multiplier.

*Road construction cost =*
*ROADS CONSTRUCTION COST PER KM*roads construction starts*EXCHANGE RATE USD TO EUR*

*Road maintenance costs = Total Kilometer Of Roads*ROADS MAINTENANCE COST PER KM*EXCHANGE RATE USD TO EUR*

## 5.7. Water demand and supply

Total water demand for the model is represented as the sum of residential water demand, tourism water demand and agriculture water demand. Tourism water demand is given by the wastewater generation presented in section 5.3.5. Residential water demand is the multiplication of total population, a parameter of average water demand per capita per day, and days per year. Finally, agriculture water demand is the multiplication of the hectares of agriculture land and annual water demand per hectare of agriculture land. The next causes tree illustrates the components of total water demand (see Figure 39).

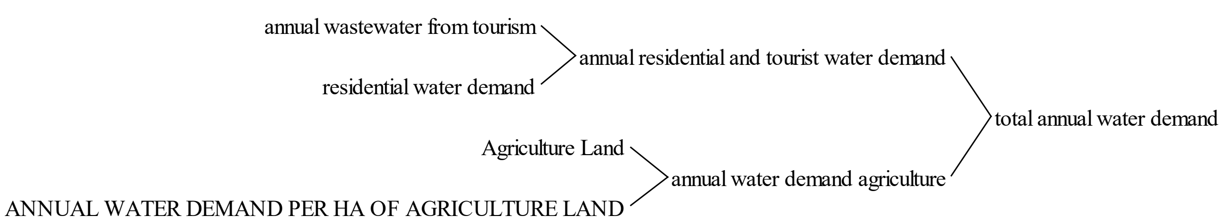


*Figure 39. Causes tree total water demand*

The water supply module provides an estimate of ground- and surface water resources. It is used to simulate the internally produced water resources and the development of ground- and surface water stocks. Furthermore, the water supply module estimates the water demand to supply ratio and the water scarcity and water stress indicators. The water module enables policy makers to see the impact of different policies on water resources and enables them to examine the effects of the respective policies.

Internally produced water resources are estimated using the precipitation per hectare, based on seasonal precipitation, total land and the evaporation fraction.

$$\text{internally monthly produced water resources} = \text{precipitation per hectare} * \text{total land} * (1-\text{FRACTION OF RAIN EVAPORATING IMMEDIATELY})$$

The internally produced water resources are distributed across surface and groundwater using the groundwater precipitation ratio, which is equivalent to the percolation rate. The percolation groundwater inflow is calculated by multiplying the internally produced water resources by the groundwater to precipitation ratio. Overall changes in the groundwater stock are calculated based on the following equation:

$$\text{Ground Water Stock}_{t+1} = \text{Ground Water Stock}_{t0} + \text{percolation groundwater inflow}_{t0} - \text{groundwater use for irrigation}_{t0} - \text{groundwater use for population}_{t0} - \text{natural outflow}_{t0}$$

Natural outflow is formulated as a fixed fraction of the ground water stock and calculated by multiplying the Ground Water stock by the natural outflow share. Groundwater usage is categorized into two primary sectors: population needs and irrigation. The equation for groundwater allocation for population needs is outlined below. The MIN function limits the outflow of water for population to prevent the stock from being negative.

$$\text{ground water use for population} = MAX(MIN(\text{real demand ground water for population}, \text{Ground Water Stock}/\text{time step in months}),0)$$

Groundwater use for irrigation is the minimum value between the demand for irrigation water from groundwater and the water available in the groundwater stock. The demand for irrigation from groundwater is the total agriculture water demand minus the irrigation demand that is already covered by surface water.

$$\text{groundwater use for irrigation} = MAX(MIN(\text{demand for irrigation from groundwater}, \text{Ground Water Stock}/\text{time step in months}),0)$$

The stock of Surface Water considers a surface water inflow and three outflows, (i) irrigation, (ii) water extraction for population and (iii) runoff. They are represented in the following equation:

$$\textit{Surface Water}_{t+1} = \textit{Surface Water}_{t0} + \textit{surface water inflow}_{t0} - \textit{runoff}_{t0} - \textit{surface water extraction for population}_{t0} - \textit{irrigation}_{t0}$$

The surface water inflow is calculated by multiplying the internally produced water resources by one minus the ground water precipitation ratio. Irrigation is formulated as a MIN function that uses the minimum value of total water demand from agriculture and the water available in the stock. The model assumes that water for irrigation is used from Surface Water and that farmers will start using ground water for irrigation as soon as there is no more surface water available.

Runoff is the water that flows out of the country into the sea or other countries. Runoff is calculated as the difference between the surface water inflow and the sum of the water that is used for population and irrigation.

Total water supply is the sum of surface water and groundwater outflows. To assess the capacity of the water resources to meet the demand, two indicators are created: (i) Water balance and (ii) water stress. Water stress is calculated by dividing total water demand by total water supply, which indicates whether there is competition for water between the different consumers. The water balance, which indicates whether the consumption of water exceeds demand, is calculated by deducting total water demand from total water supply.

Due to the lack of fresh water in the Canary Islands, there is a need for taking sea water as a resource for consumption. The difference between water demand and water supply from surface and ground water is the demand for water desalination. The variables affecting water demand for desalination are presented in Figure 40.

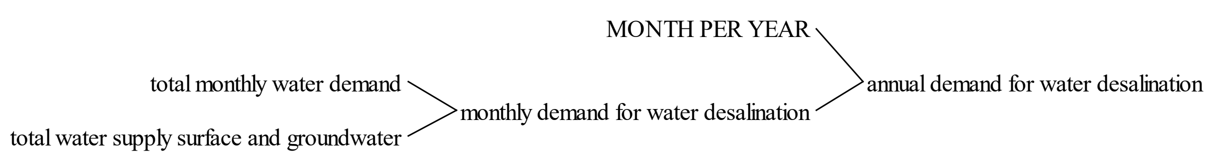


*Figure 40. Causes tree water desalination demand*

Water desalination capacity consists of one stock with an inflow of capacity construction and an outflow of capacity depreciation. The capital and O&M costs derived from water desalination are calculated with the next equations:

*total capital cost desalination plants = water desalination capacity construction*CAPITAL COST PER LTR*EXCHANGE RATE USD TO EUR*

*total o&m cost from water desalination = Desalination Capacity*O&M COST PER LTR DESALINATED*EXCHANGE RATE USD TO EUR*

## 5.8. Wastewater Treatment

The wastewater treatment module serves for calculating total wastewater treatment facility (WWTF) capacity and the share of wastewater treated. It provides information about the coverage and efficiency of wastewater treatment and the N loadings that are removed from wastewater influent.

Wastewater treatment capacity is modeled as a stock that changes based on the construction rate and the depreciation of wastewater treatment capacity. The stock equation can be described as

$$\textit{Wastewater Treatment Capacity}_{t+1} = \textit{Wastewater Treatment Capacity}_{t0} + \textit{construction rate WWTF capacity}_{t0} - \textit{depreciation of WWTF}_{t0}$$

The construction rate of WWTF capacity calculates the difference between the desired and currently installed WWTF capacity. The stock equation of WWTF capacity integrates this difference in capacity over time. In addition to this adjustment process, the construction rate also considers the depreciation of capacity, assuming that new capacity will be operational once the current capacity reaches the end of its lifetime.

*construction of WWTF capacity =*
*IF THEN ELSE (required WWTF capacity> Wastewater Treatment Capacity, desired WWTF adjustment / TIME TO CONSTRUCT WWTF PLANTS + WWTF replacement rate, 0)*

The IF THEN ELSE function ensures that construction of WWTF capacity only occurs if there is a shortage of capacity. It basically serves as a MIN function in that it prevents the construction rate to become negative if the current level of WWTF capacity higher than required. The depreciation rate of WWTF capacity is formulated as a delay function that assumes that capacity will be decommissioned after the end of its intended lifetime.

*Depreciation Of WWTF =*
*DELAY FIXED (construction of WWTF capacity, AVERAGE LIFETIME WWTF, 0)*

The amount of wastewater treated is defined as the current stock level of wastewater treatment capacity, as the unit of capacity is defined as liters per year. The share of wastewater treated and the amount of wastewater untreated are calculated based on the total amount of wastewater from population to treatment and the amount of wastewater treated. The share of wastewater in sewage treated is calculated using the following equation:

*share of wastewater in sewage treated =*
*MIN (SHARE OF WASTEWATER CONVEYED TO TREATMENT FACILITIES TABLE(Time), ZIDZ (amount of wastewater treated, total wastewater from population to treatment))*

The MIN function choses between the share of wastewater for treatment and the potential share of wastewater treatment (formulated as wastewater treated divided by total wastewater). This formulation ensures that only wastewater dedicated for treatment is treated. The ZIDZ function used for the potential treatment share prevents an integration error in case of a division by zero, which would occur if the amount of wastewater from population to treatment would drop to zero. The residual amount of wastewater untreated is calculated by deducting the amount of wastewater treated, defined as wastewater treatment capacity, from the total amount of wastewater for treatment.

The average N concentration in wastewater effluent from WWTF depends on the total amount of wastewater for treatment, the share of wastewater treated and the N concentration of the wastewater reaching the sewage plants.

*average n concentration wastewater from WWTF =*
*n concentration in wastewater for WWTF * (1-share of wastewater in sewage treated) + n concentration of treated wastewater from WWTF * share of wastewater in sewage treated*

It is calculated as a weighted average between the N concentration in water that is not treated (e.g. in case of capacity shortages or blackouts) and the concentration of treated wastewater, which depends on the N concentration of wastewater inflow and the N removal efficiency of WWTF capacity.

*n concentration of treated wastewater from WWTF =*
*n concentration in wastewater for WWTF * (1-WWTF EFFICIENCY)*

The total N loadings in treated wastewater are then calculated by multiplying the total wastewater quantity reaching the treatment plants by the weighted average N concentration of treated wastewater from wastewater treatment.

*total n loadings in treated wastewater =*
*total wastewater from population to treatment * average n concentration wastewater from wwtf*

## 5.9. Solid Waste Generation

This module considers the solid waste that goes into the ocean. It is compound for one stock of solid waste in the sea with one inflow and one outflow, as indicated in Figure 41. The inflow is the sum of two inputs, plastic waste from residents and plastic waste from tourists. The outflow of the stock is plastic waste picked up through programs or campaigns to remove the plastic waste from the ocean.

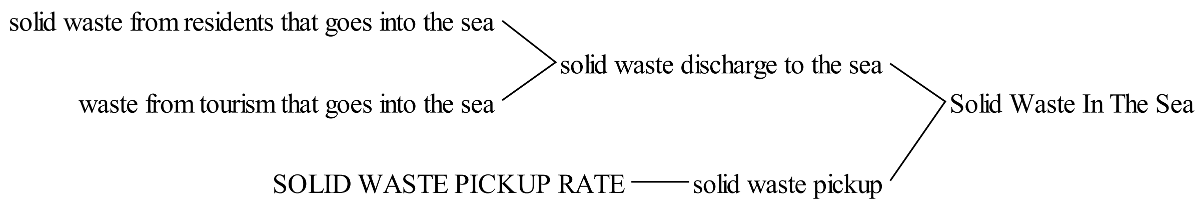


*Figure 41. Causes tree for solid waste in the ocean*

The main output indicator of the module is the solid waste in the ocean density, which measure the tons of solid waste per ha of the ocean as in the next equation:

*solid waste in the ocean density = Solid Waste In The Sea/TOTAL SEA AREA*

Additionally, the relative change of the density is used to model impacts of solid waste pollution on other sectors of the model.

## 5.10. Solid Waste Collection

Solid waste collection capacity is represented as a stock with an inflow of capacity construction and an outflow of capacity depreciation. The construction of solid waste collection capacity is represented in the next equation. The MSW collection capacity satisfaction rate is used to calibrate the model to represent the current collection rate of the territory. The satisfaction rate set up is 0.7 to represent the deficit that the solid waste collection systems presents in the territory.

*msw collection capacity construction = ((total solid waste to be collected-Municipal Solid Waste Collection Capacity)/TIME TO CONSTRUCT MSW COLLECTION CAPACITY)*MSW COLLECTION CAPACITY SATISFACTION RATE + msw collection capacity depreciation*

The capital and O&M costs derived from solid waste collection are calculated with the next equations:

*total capital cost msw plants = msw collection capacity construction*CAPITAL COST PER MSW*EXCHANGE RATE USD TO EUR/DAYS PER YEAR* *total annual o&m cost from msw = Municipal Solid Waste Collection Capacity*O&M COST PER TON*EXCHANGE RATE USD TO EUR/DAYS PER YEAR*

The share of waste collected is the output indicator of this module that is used to produce impacts in other modules, and it is represented by the equation:

*share of waste collected = Municipal Solid Waste Collection Capacity/total solid waste to be collected*

## 5.11. Energy Demand

The energy demand module estimates the demand of electricity and the demand of fossil fuels. The demand of fossil fuels is the multiplication of population and fossil fuels demand per capita, as in the next equation:

*fossil fuels demand = FOSSIL FUELS DEMAND PER CAPITA*Population*

Total electricity demand is the sum of electricity demand from tourists and electricity demand from residents, as portrayed in Figure 42.

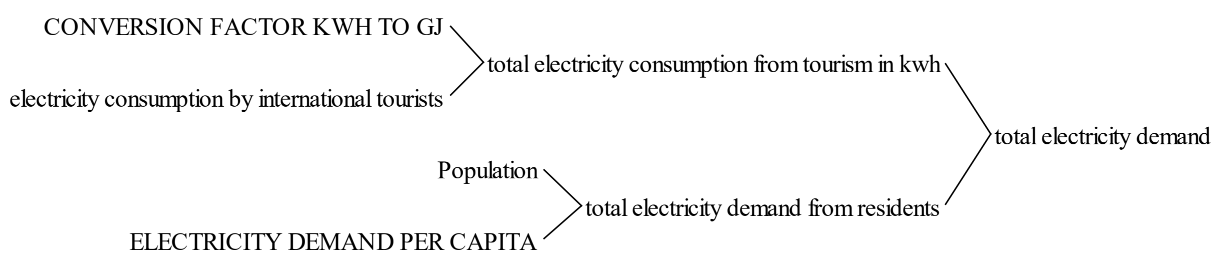


*Figure 42. Causes tree for total electricity demand*

Electricity demand from residents is the multiplication of total population and electricity demand per capita. Electricity consumption from tourists includes the electricity consumption from conventional hotels and eco-hotels, represented by the next equation:

*electricity consumption by tourists =*
*(total tourist days * (1-% of hotels for eco-friendly tourism) * AVERAGE ELECTRICITY CONSUMPTION PER CONVENTIONAL TOURIST DAY*
*+ total tourist days * % of hotels for eco-friendly tourism* AVERAGE ELECTRICITY CONSUMPTION PER*

*CONVENTIONAL TOURIST DAY*(1-"AVERAGE ELECTRICITY EFFICIENCY SAVINGS FROM ECO-HOTELS"))/CONVERSION FACTOR MJ TO GJ*

## 5.12. Power Generation Capacity

The power generation capacity module provides an overview of power generation capacity requirements, electricity generation, electricity related employment and investments. The module distinguishes between renewable and non-renewable technologies and generation and allows for the assessment of policy intervention targeting the electricity generation mix. Renewable and non-renewable capacity are represented as stocks, with inflows and outflows listed in Table 18.

| Stock | Inflow(s) | Outflow(s) |
|---|---|---|
| Conventional power generation capacity | • construction rate conventional | • depreciation rate conventional<br>• conventional damage to capacity |
| Renewable power generation capacity | • construction rate renewables | • depreciation rate renewables<br>• renewables damage to capacity |

*Table 18. Stocks and flows in the power generation module*

The conventional power generation stock is based on the desired fossil fuel power generation capacity, which is represented with the equation:

*desired fossil fuel power generation capacity = (electricity demand in mwh*(1+TRANSMISSION LOSSES(Time))*(1-fraction of electricity generation renewable))/load factor conventional/hours per year*

The renewable power generation capacity is based on the desired renewable power generation capacity, which is represented by:

*desired renewable power generation capacity = (electricity demand in mwh*(1+TRANSMISSION LOSSES(Time))*fraction of electricity generation renewable)/load factor other renewable/hours per year*

Both capacity stocks have one inflow and two outflows (see Table 18). The stock equation for conventional power generation capacity can be described as:

*Conventional Power Generation Capacityt+1 =*
*Conventional Power Generation Capacityt0 + construction rate conventionalt0 - Depreciation Rate Conventionalt0 - CONVENTIONAL DAMAGE TO CAPACITYt0*

The construction rate of capacity is based on the difference between desired capacity and current capacity.

---

*construction rate conventional =*
*MAX((desired power generation capacity * (1 - fraction of power generation capacity renewable) - Conventional Power Generation Capacity) / TIME TO CONSTRUCT POWER GENERATION CAPACITY + replacement rate conventional, 0)*

---

The replacement rate, which is defined as the depreciation rate of conventional capacity, is added to the construction rate. This formulation assumes that power plants will be replaced at the end of their lifetime to maintain the current level of output. The depreciation rate is modeled as a fixed delay, assuming that capacity is decommissioned at the end of its lifetime.

---

*Depreciation Rate Conventional =*
*DELAX FIXED(construction rate conventional, AVERAGE LIFETIME CONVETIONAL, 0)*

---

Damages to conventional capacity is a policy variable that can be operationalized by including the damages of floods and droughts to power generation capacity. In the current version of the model, no damages to capacity are assumed and this flow is hence zero throughout the simulation.

The electricity generation rate for conventional and renewable capacity depends on installed capacity, the respective load factor and the number of hours per year.

---

*electricity generation rate conventional =*
*Conventional Power Generation Capacity * hours per year * load factor conventional*

---

Figure 43 shows the causes tree for total electricity generation, which is the sum of electricity generated by conventional and renewable capacity.

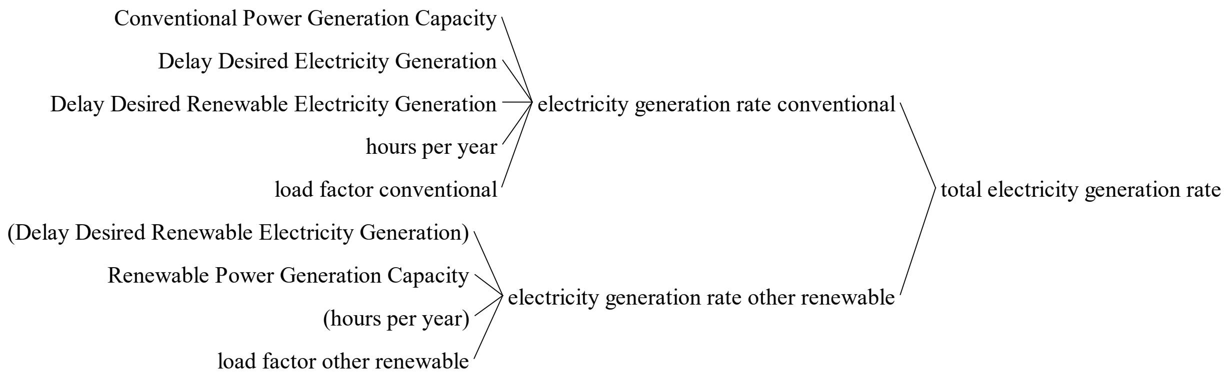


*Figure 43: Causes tree total electricity generation rate*

## 5.13. Power Generation Employment

The power generation module estimates employment from construction and maintenance activities related to capacity. Construction employment is calculated by multiplying the amount of Megawatts (MW) of conventional and renewable capacity by a respective employment factor per MW. Operations and maintenance (O&M) employment is calculated by multiplying the currently installed amount of MW by a respective O&M employment per MW multiplier.

*"O&M employment conventional" =*
*Conventional Power Generation Capacity * "O&M employment per mw of conventional capacity"*

Total employment in the energy sector is calculated as the sum of construction and O&M employment from power generation capacity. The causes tree in Figure 44 shows the variables used.

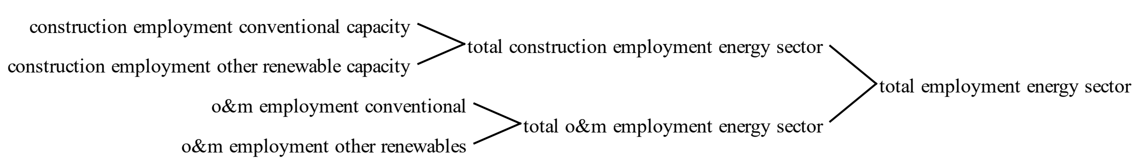


*Figure 44: Causes tree total employment from power generation*

## 5.14. Power Generation Costs

In this section the model quantifies the investment (capital costs) and the Operation and Maintenance costs resulting from the generation of conventional and renewable power. The total annual costs of power generation capacity is the sum of costs from conventional energy and renewable energy costs. The variables and parameters influencing in that costs are presented in Figure 45 and Figure 46.

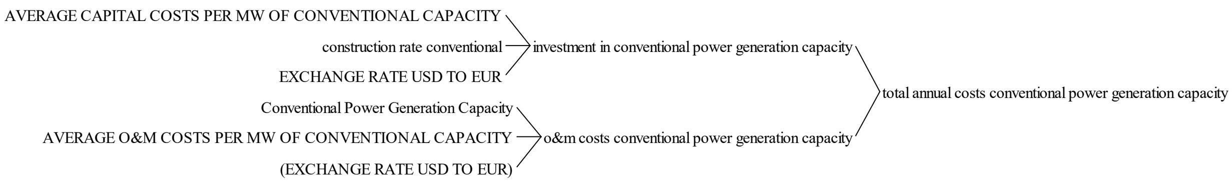


*Figure 45. Causes tree costs conventional power generation capacity*

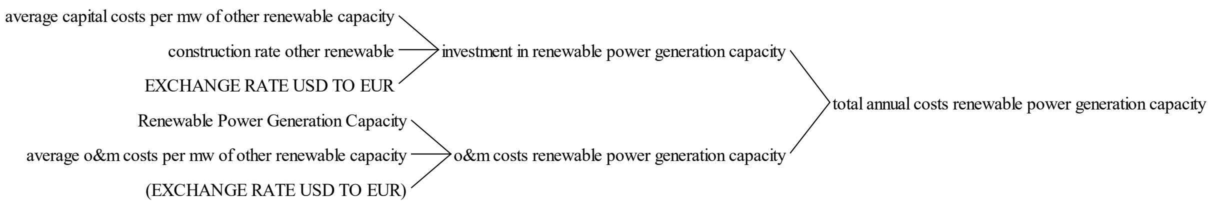


*Figure 46. Causes tree costs renewable power generation capacity*

## 5.15. Energy Emissions

The energy emissions module provides information about the development of energy related CO2e emissions over time. Energy CO2 emissions is the sum of emissions from fossil fuels consumption and electricity consumption. In both cases, emissions factors are used to calculate the total emissions when multiplied by the demand. Figure 47 shows the variables used for emissions from fossil fuel consumption and Figure 48 for emissions from electricity consumption.

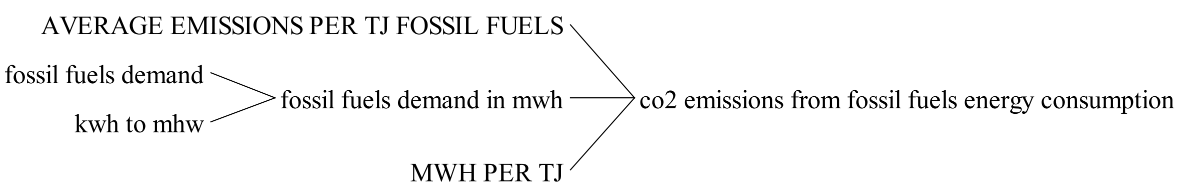


*Figure 47. causes tree emissions from fossil fuel energy consumption*

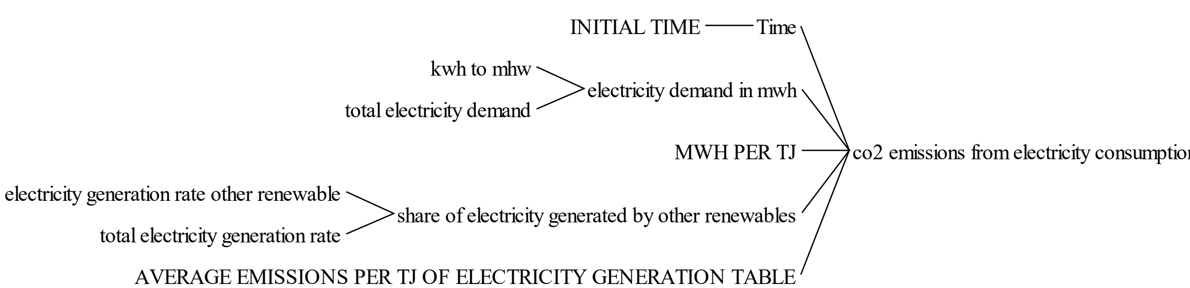


*Figure 48. Causes tree emissions from electricity consumption*

Additionally, the cost of CO2 emissions is calculated using a carbon price per ton, which represents the social cost of carbon, multiplied by the total CO2 emissions from energy.

## 5.16. Air Pollution from Energy Consumption

The air pollution module provides information about the development of energy related air pollution over time. Air pollution is measured through the estimation of pm2.5 pollutant. Total pm2.5 emissions is the sum of pm2.5 emissions from fossil fuels consumption and conventional electricity consumption. In both cases, emissions factors are used to calculate the total pm2.5 emissions when multiplied by energy consumption. Figure 48 shows the variables used to calculate the total pm2.5 emissions from the energy sector.

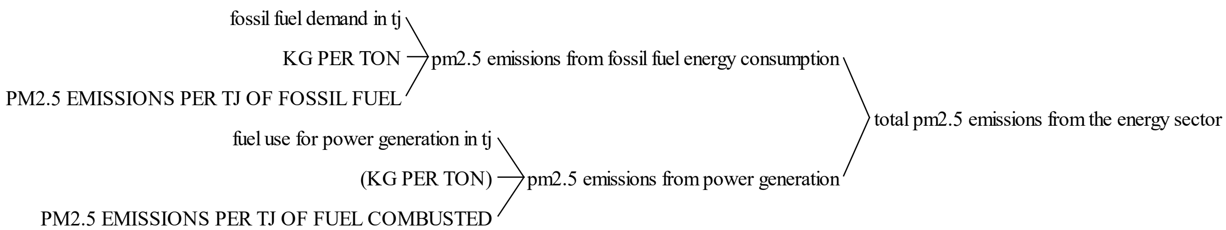


*Figure 49. Causes tree total pm2.5 emissions from the energy sector*

Additionally, the health cost of pm2.5 emissions is calculated using a cost per ton of pm2.5 multiplied by the total pm2.5 emissions from energy.

## 5.17. Marine Habitat

The marine habitat module aims to represent the status of quality of the marine environment with an index that goes from 0 to 1, being 1 the highest status and the goal to have a sustainable marine environment. Marine environment is then represented as a stock with one inflow called regeneration and one outflow called deterioration. The variables affecting the marine environment stock are presented in Figure 50

Marine habitat regeneration has a baseline regeneration rate of 0.1% per year that can be accelerated or slowed down with the effect of fish stock, forest land and protected marine areas. The equation that determines that change is:

*marine habitat regeneration = Marine Habitat*BASELINE MARINE REGENERATION RATE*effect of fish stock on marine habitat*effect of forest land on marine habitat*effect of protected marine area on marine habitat*

Residents and tourist activities create different impacts on the marine environment and affect its deterioration. The reference deterioration rate has a constant value of 0.3% per year and it becomes bigger as the effects impact negatively the marine environment. The next equation explain how those pressures have an impact on marine habitat deterioration.

*marine habitat deterioration = REFERENCE DETERIORATION RATE/effect of settlement land on marine habitat /effect of n release on environment /effect of water desalination on marine habitat /effect of* *tourism activities on marine habitat /effect of wastewater discharged to the sea on marine habitat /effect of solid waste in the sea on marine habitat*

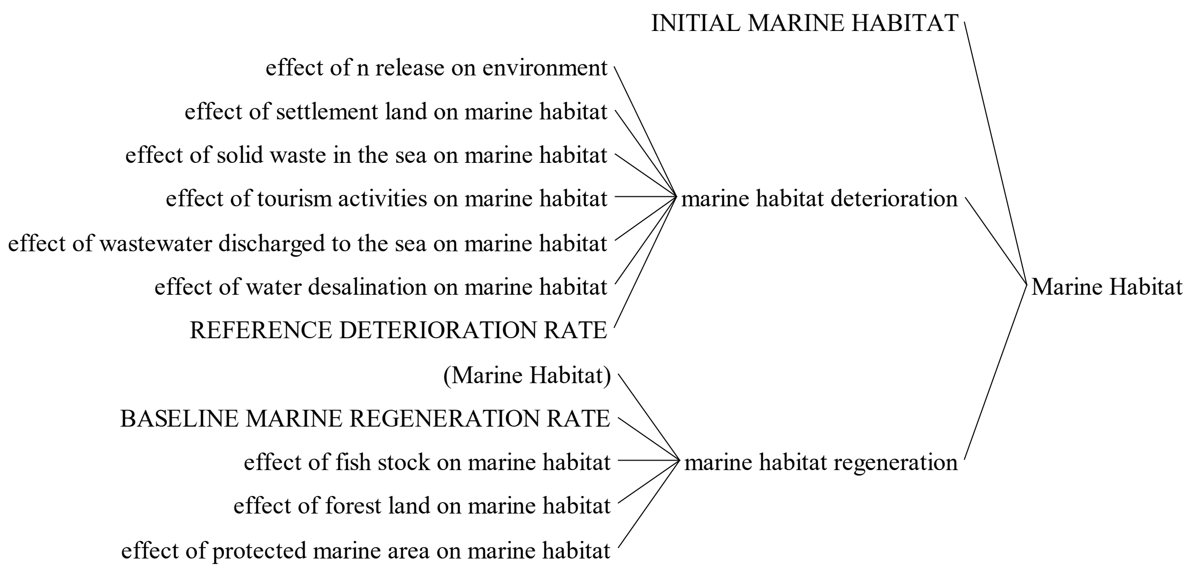


*Figure 50. Causes tree marine environment stock*

Finally, the module calculates the relative marine habitat through the ratio of the current marine habitat status and the initial marine habitat status. This relative change will be used in other sections of the model.

## 5.18. Population Welfare

This module represents the population welfare as an index going from 0 to 1, where 1 is the maximum welfare level. Initially, welfare starts at 1 and changes over time based on the strength of the different impacts on welfare deterioration and regeneration portrayed in Figure 51.

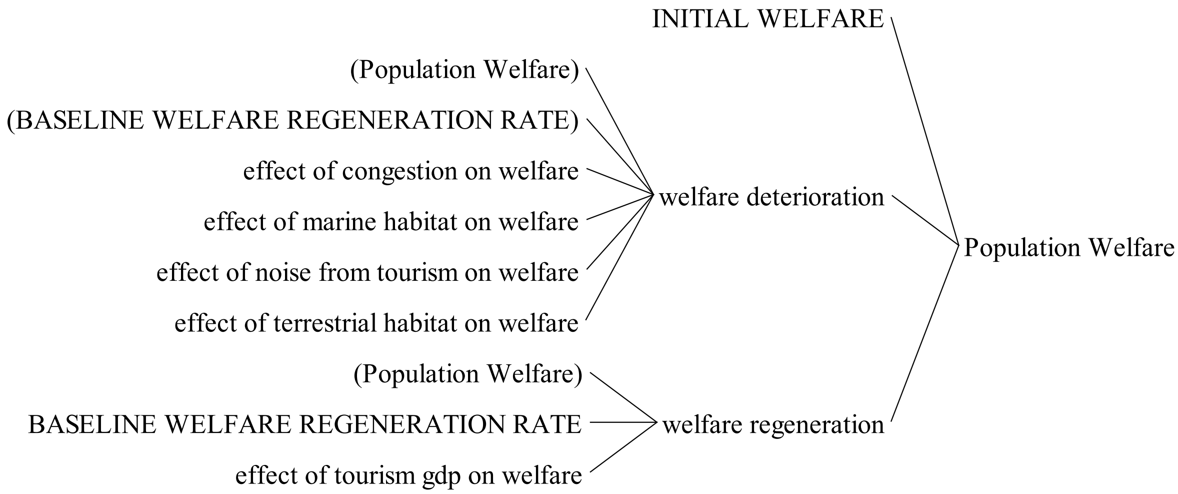


*Figure 51. Causes tree population welfare*

The equation for welfare regeneration, inflow for the population welfare stock, includes a baseline regeneration rate of 1% per year that increases as tourism GDP increases:

*welfare regeneration = Population Welfare*BASELINE WELFARE REGENERATION RATE*effect of tourism gdp on welfare*

Welfare deterioration includes impacts from the environment and from tourist activities, as presented in the equation:

*welfare deterioration = Population Welfare * BASELINE WELFARE REGENERATION RATE * effect of congestion on welfare * effect of noise from tourism on welfare * effect of marine habitat on welfare * effect of terrestrial habitat on welfare*

## 5.19. Carrying Capacity (CC)

The carrying capacity module aims to represent how the burden from tourism and population affects Canary Islands environmental capacity. The CC index goes from 0 to 1, being 1 the full potential to carry the capacity, meaning that the system does not have pressures and being 0 the point where the system cannot handle any pressures. The CC index is the aggregated index of the effect of four stressors: air environment, marine habitat, terrestrial habitat and urban environment (see Figure 52).

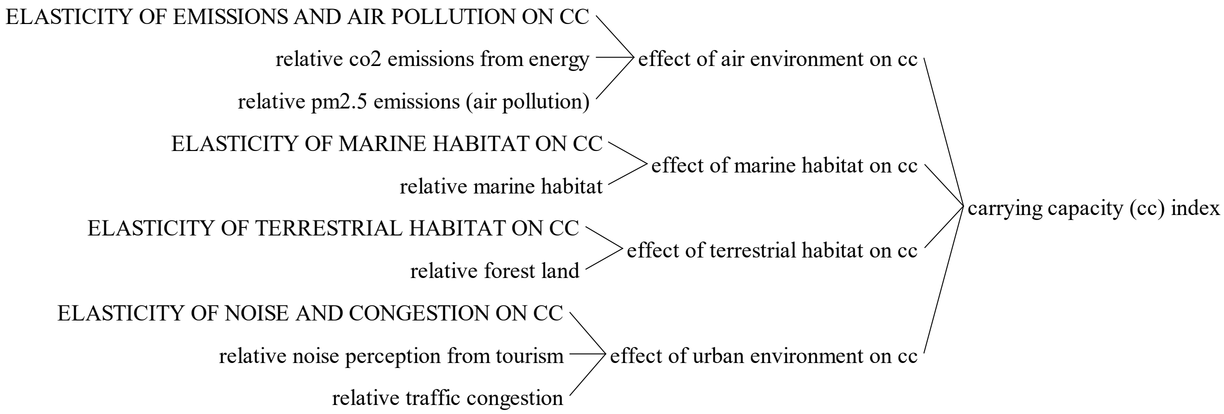


*Figure 52. Causes tree of carrying capacity index*

The variables included in the four effects affecting CC and its mathematical logic are presented in the series of equations below:

---

*effect of air environment on cc = ( (relative co2 emissions from energy + relative pm2.5 emissions (air pollution))/2)^ELASTICITY OF EMISSIONS AND AIR POLLUTION ON CC*
*effect of marine habitat on cc = relative marine habitat^ELASTICITY OF MARINE HABITAT ON CC*
*effect of terrestrial habitat on cc = relative forest land^ELASTICITY OF TERRESTRIAL HABITAT ON CC*
*effect of urban environment on cc = ((relative noise perception from tourism+relative traffic congestion)/2)^ELASTICITY OF NOISE AND CONGESTION ON CC*

---

# References

Bhagabati, N., Barano, T., Conte, M., Ennaanay, D., Hadian, O., McKenzie, E., . . . Wolny, S. (2012). *A Green vision for Sumatra: Using ecosystem services information to make recommendations for sustainable land use planning at the province and district level.* World Wildlife Fund and the Natural Capital Project.

Ciobotaru, N., Laslo, L., Lupei, T., Deák, G., Matei, M., Bara, N., & Noor, N. (2019). Preliminary assessment of the status of Romanian wetlands through the framework of habitat quality analysis. In AIP Conference Proceedings. *AIP Publishing LLC*, IP Conference Proceedings (Vol. 2129, No. 1, p. 020070).

Forrester, J. (2002). *Road Maps: A guide to learning System Dynamics.* Camebridge: Systen Dynamics Group, Sloan School of Management, MIT.

IPCC. (2006). *2006 IPCC guidelines for national greenhouse gas inventories.* Hayama, Japan: Intergovernmental Panel on Climate Change - Institute for Global Environmental Strategies.

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories.* (E. H.S., B. L., M. K., N. T., & K. Tanabe, A cura di) Hayama, Japan: Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC.

Kulsoontornrat, J., & Ongsomwang, S. (2021). Suitable Land-Use and Land-Cover Allocation Scenarios to Minimize Sediment and Nutrient Loads into Kwan Phayao, Upper Ing Watershed, Thailand. *Applied Sciences, 11(21)*, 10430.

Probst, G., & Bassi, A. (2014). *Tackling Complexity: A systematic approach for decision makers.* Sheffield, UK: Greenleaf Publishing.

Salata, S., Ronchi, S., Arcidiacono, A., & Ghirardelli, F. (2017). Mapping habitat quality in the Lombardy Region, Italy. *One Ecosystem, 2*, 1-8.

Sterman, J. D. (2000). *Business Dynamics - Systems Thinking and Modeling for a complex world.* Irwin McGraw-Hill.

Sulistyawan, B., Eichelberger, B., Verweij, P., Hardian, O., Adzan, G., & Sukmantoro, W. (2017). onnecting the fragmented habitat of endangered mammals in the landscape of Riau–Jambi–Sumatera Barat (RIMBA), central Sumatra, Indonesia (connecting the fragmented habitat due to road development). *Global Ecology and Conservation, 9*, 116-130.

Terrado, M., Sabater, S., Chaplin-Kramer, B., Mandle, L., Ziv, G., & Acuña, V. (2016). Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning. *Science of the total environment, 540*, 63-70.

UNEP. (2011). *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers.*

UNEP. (2014). *Using Models for Green Economy Policymaking.*

# Annex 1 - Spatial Analysis

## 1. Model set Up

### a. Study Area

The study area of this analysis is the Canary Islands in Spain (Figure 53).

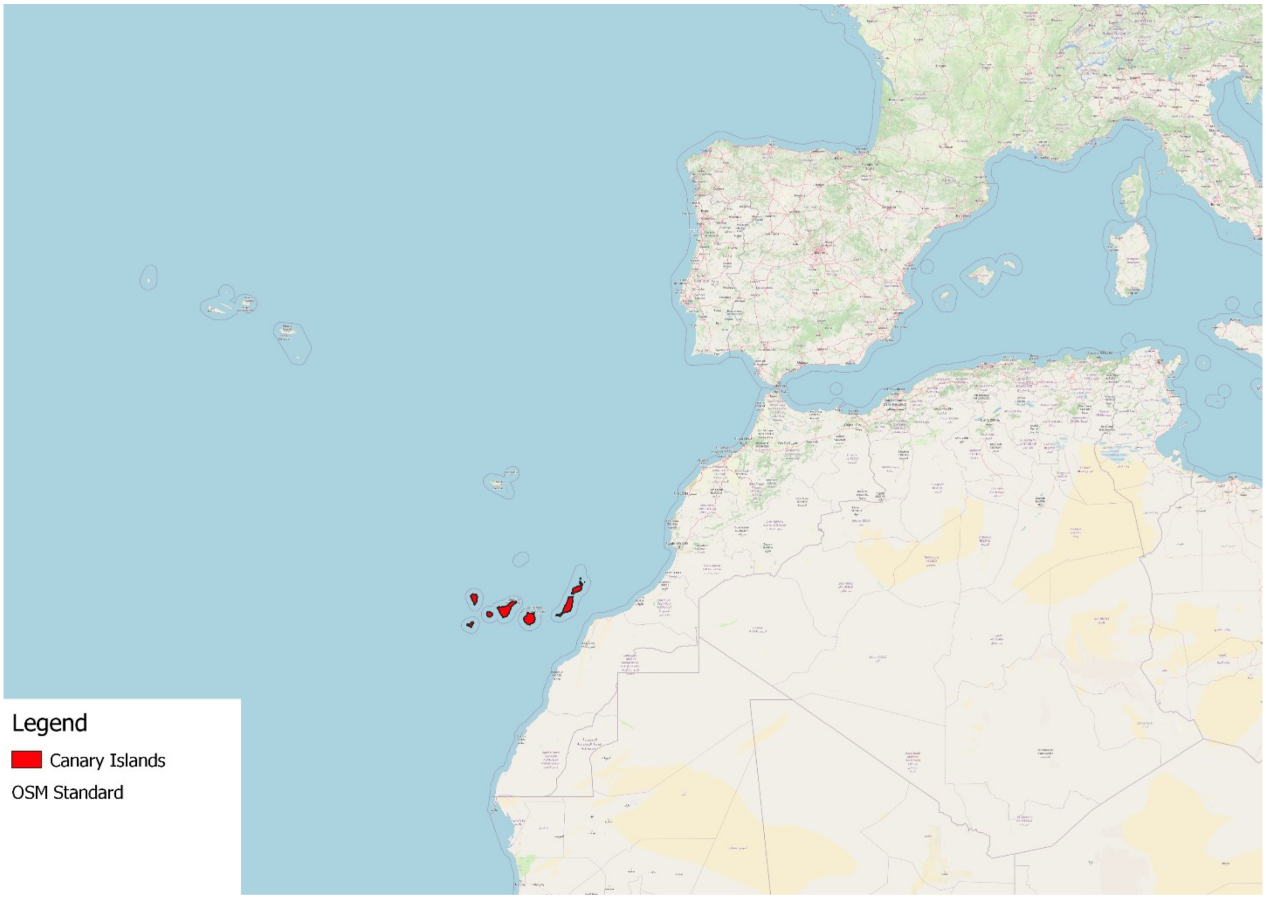


*Figure 53: Location of the Canary Islands*

## b. Coordination System

Based on world project coordinate system called "ETRS89-extended / LAEA Europe – ESPG: 3035"
Here is the detail of the coordinate system:

```
PROJCS["ETRS89-extended / LAEA Europe",
    GEOGCS["ETRS89",
        DATUM["European_Terrestrial_Reference_System_1989",
            SPHEROID["GRS 1980",6378137,298.257222101,
                AUTHORITY["EPSG","7019"]],
            TOWGS84[0,0,0,0,0,0,0],
            AUTHORITY["EPSG","6258"]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.0174532925199433,
            AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4258"]],
    PROJECTION["Lambert_Azimuthal_Equal_Area"],
    PARAMETER["latitude_of_center",52],
    PARAMETER["longitude_of_center",10],
    PARAMETER["false_easting",4321000],
    PARAMETER["false_northing",3210000],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    AUTHORITY["EPSG","3035"]]
```

### c. Land Cover Maps

The land cover maps of the study were downloaded from The CORINE Land Cover (CLC) inventory (https://land.copernicus.eu/pan-european/corine-land-cover).

Figure 55, Figure 56, Figure 57, and *Figure 58* show the LULC of the Canary Islands in 1990, 2000, 2012, and 2018, respectively. Please note that the legend, shown in Figure 54, indicates the numbers corresponding to each land class (e.g. 1 – continuous urban fabric). Please also note that due to differences in the accuracy of the creation of the LULC maps, the ones showing the landscape in 1990 and 2000 show more sclerophyllous vegetation than the most recent ones, which on the other hand, show more sparsely vegetated areas. Therefore, we considered these two land classes the same.

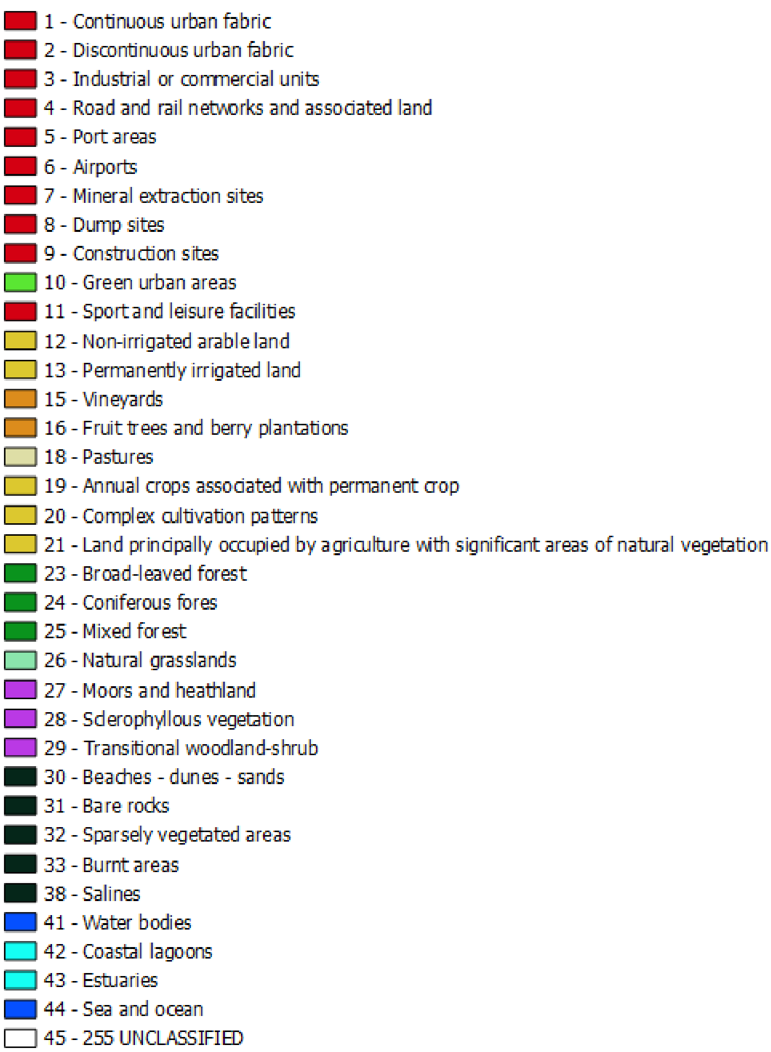

*Figure 54: Legend of the LULCs*

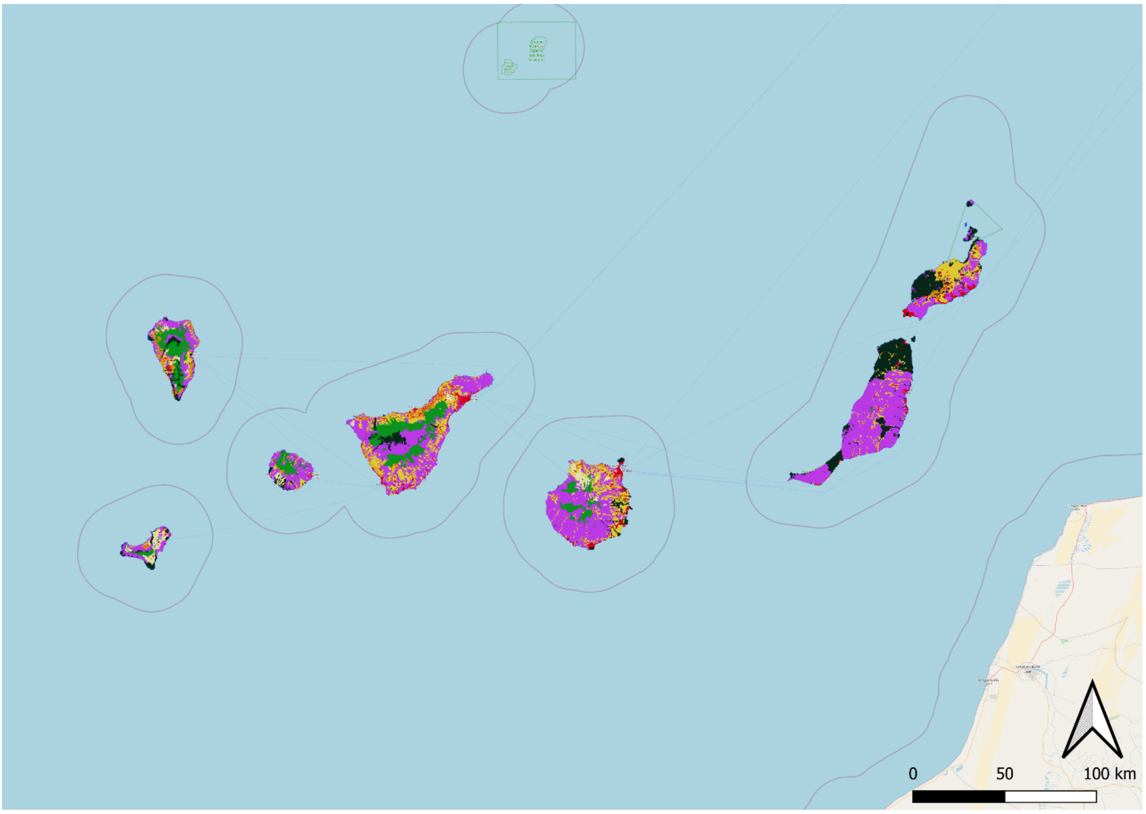


*Figure 55: LULC 1990*

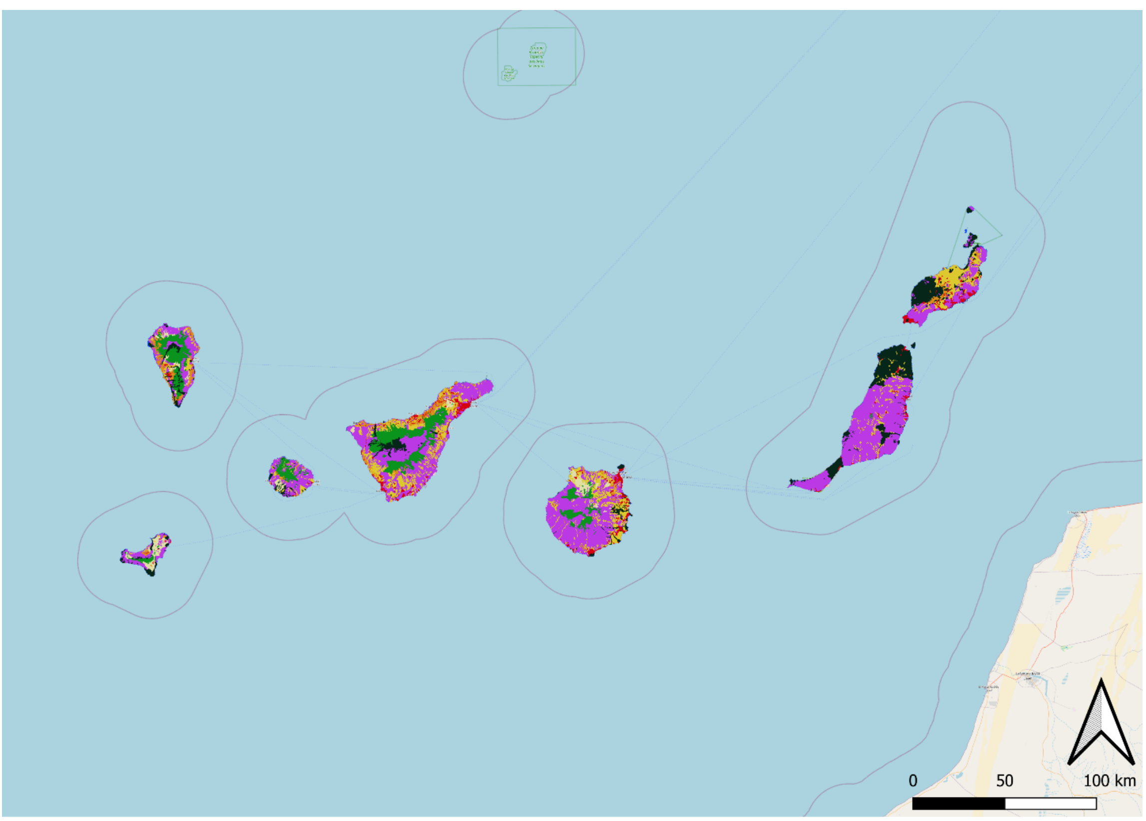


*Figure 56: LULC 2000*

*Figure 57: LULC 2012*

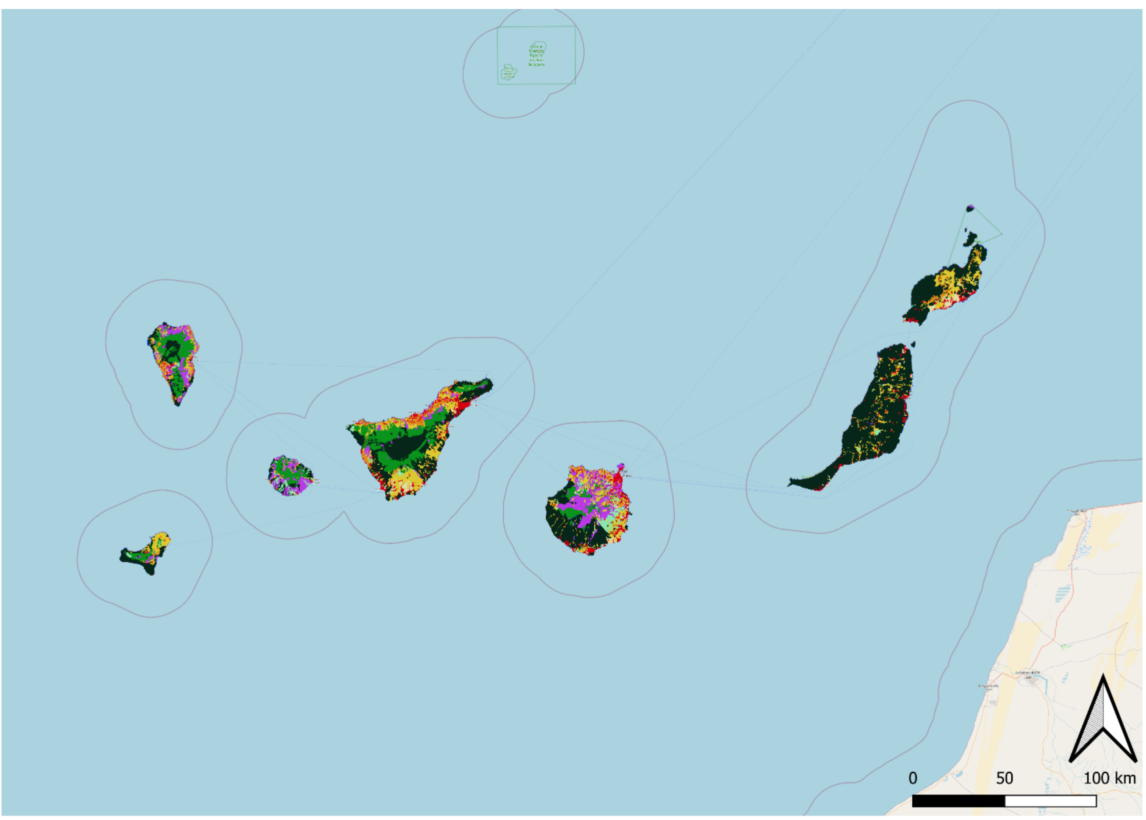

*Figure 58: LULC 2018*

### d. Software and Simulation

The ecosystem services map simulation has been performed using InVEST Software V.3.9.0 (https://naturalcapitalproject.stanford.edu/invest/). The inputs spatial data for the InVEST model have been prepared by utilizing QGIS-OSGeoW-3.4.2-1 (qgis.org/downloads/). The tabulated data will be managed and prepared in Ms. Excel V. 2016.

# 2. Carbon Storage

## 2.1 Input Data Preparation and Processing

3. **Land use/land cover maps –** see section 1c

4. **Carbon Pools –** Table of LULC classes, containing data on carbon stored in each of the four fundamental pools for each LULC class
    - Carbon above ground: The values of carbon density in aboveground mass (Mg/ha or Tons/ha) of each land-use type are shown in *Table 19*
    - Carbon below ground: The values of carbon density in belowground mass ((Mg/ha or Tons/ha) of each land use-type are shown in *Table 19*
    - Carbon stored in organic matter: The values of carbon density in dead mass (Mg/ha or Tons/ha) of each land-use type are shown in *Table 19*
    - Carbon stored in soil: The values of carbon density in dead mass (Mg/ha or Tons/ha) of each land-use type are shown in *Table 19*

The unit of measurement for these coefficients is Mg/ha or Tons/ha. Average carbon coefficients values have been found in the “2006 IPCC Guidelines for National Greenhouse Gas Inventories” report, chapter 4 “Agriculture, Forestry and Other Land Use” (IPCC, 2006).

| lucode | LULC_Name | C_above | C_below | C_soil | C_dead |
|---|---|---|---|---|---|
| 1 | lc_1 | 0 | 0 | 0 | 0 |
| 2 | lc_2 | 0 | 0 | 0 | 0 |
| 3 | lc_3 | 0 | 0 | 0 | 0 |
| 4 | lc_4 | 0 | 0 | 0 | 0 |
| 5 | lc_5 | 0 | 0 | 0 | 0 |
| 6 | lc_6 | 0 | 0 | 0 | 0 |
| 7 | lc_7 | 0 | 0 | 0 | 0 |
| 8 | lc_8 | 0 | 0 | 0 | 0 |
| 9 | lc_9 | 0 | 0 | 0 | 0 |
| 10 | lc_10 | 28.2 | 6.5 | 0.8 | 0 |
| 11 | lc_11 | 0 | 0 | 0 | 0 |
| 12 | lc_12 | 15 | 5 | 0.5 | 0 |
| 13 | lc_13 | 18.8 | 6.2 | 0.7 | 0 |
| 15 | lc_15 | 23.5 | 5.4 | 0.7 | 0 |
| 16 | lc_16 | 28.2 | 6.5 | 0.8 | 0 |
| 18 | lc_18 | 0.8 | 3.1 | 0.7 | 0 |
| 19 | lc_19 | 15 | 5 | 0.5 | 0 |
| 20 | lc_20 | 15 | 5 | 0.5 | 0 |
| 21 | lc_21 | 18.8 | 6.2 | 0.7 | 0 |
| 23 | lc_23 | 94 | 21.6 | 0.7 | 0 |
| 24 | lc_24 | 94 | 21.6 | 0.7 | 0 |
| 25 | lc_25 | 94 | 21.6 | 0.7 | 0 |
| 26 | lc_26 | 0.8 | 3.1 | 0.7 | 0 |
| 27 | lc_27 | 0.8 | 3.1 | 0.7 | 0 |
| 28 | lc_28 | 0.8 | 3.1 | 0.7 | 0 |
| 29 | lc_29 | 15 | 5 | 0.5 | 0 |
| 30 | lc_30 | 0 | 0 | 0 | 0 |
| 31 | lc_31 | 0 | 0 | 0 | 0 |
| 32 | lc_32 | 0 | 0 | 0 | 0 |
| 33 | lc_33 | 0 | 0 | 0 | 0 |
| 38 | lc_38 | 14.1 | 54.1 | 0.7 | 0 |
| 41 | lc_41 | 0 | 0 | 0 | 0 |
| 42 | lc_42 | 14.1 | 54.1 | 0.7 | 0 |
| 43 | lc_43 | 14.1 | 54.1 | 0.7 | 0 |
| 44 | lc_44 | 0 | 0 | 0 | 0 |
| 48 | lc_48 | 0 | 0 | 0 | 0 |
| 49 | lc_49 | 0 | 0 | 0 | 0 |
| 50 | lc_50 | 0 | 0 | 0 | 0 |
| 255 | lc_255 | 0 | 0 | 0 | 0 |

*Table 19: Carbon pools*

## 2.2 Results

Figure 59, Figure 60, Figure 61, and Figure 62 show the amount of carbon stored in tons in each pixel using the LULC maps in 1990, 2000, 2012, and 2018 respectively. They are a sum of all the carbon pools provided by the biophysical table.

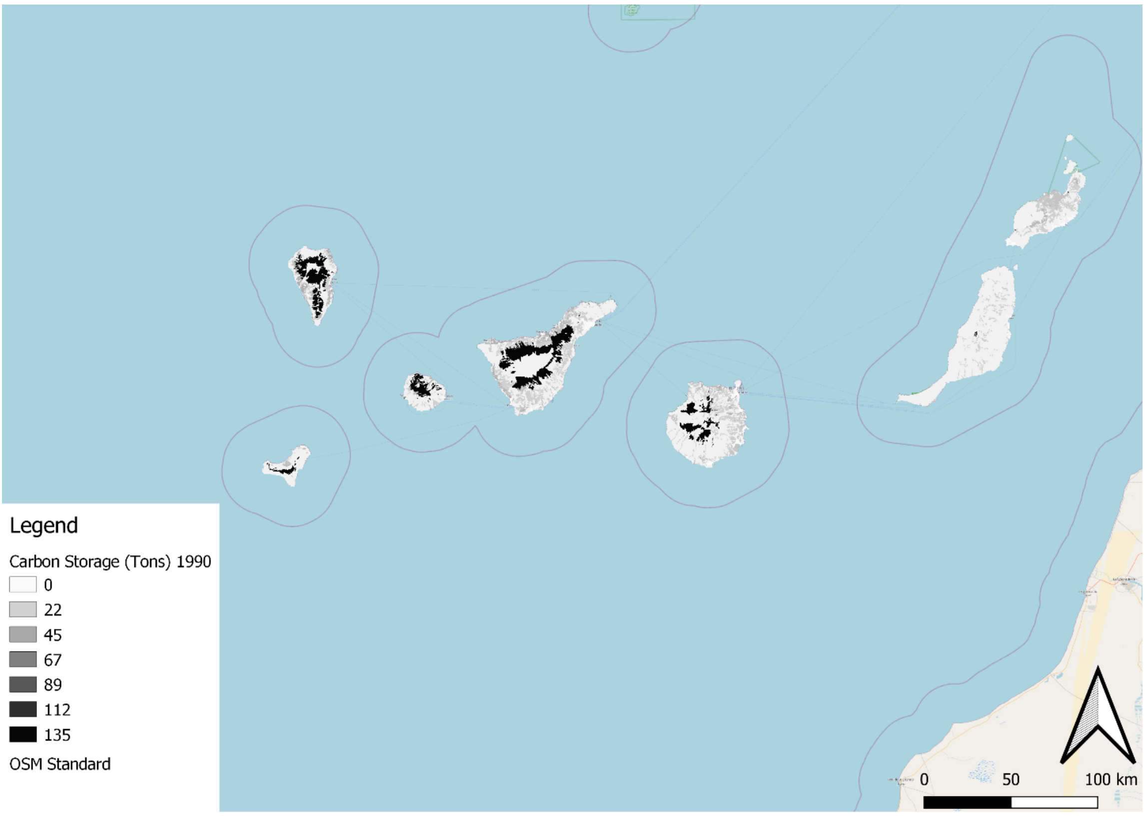


*Figure 59: Carbon model outputs (LULC 1990)*

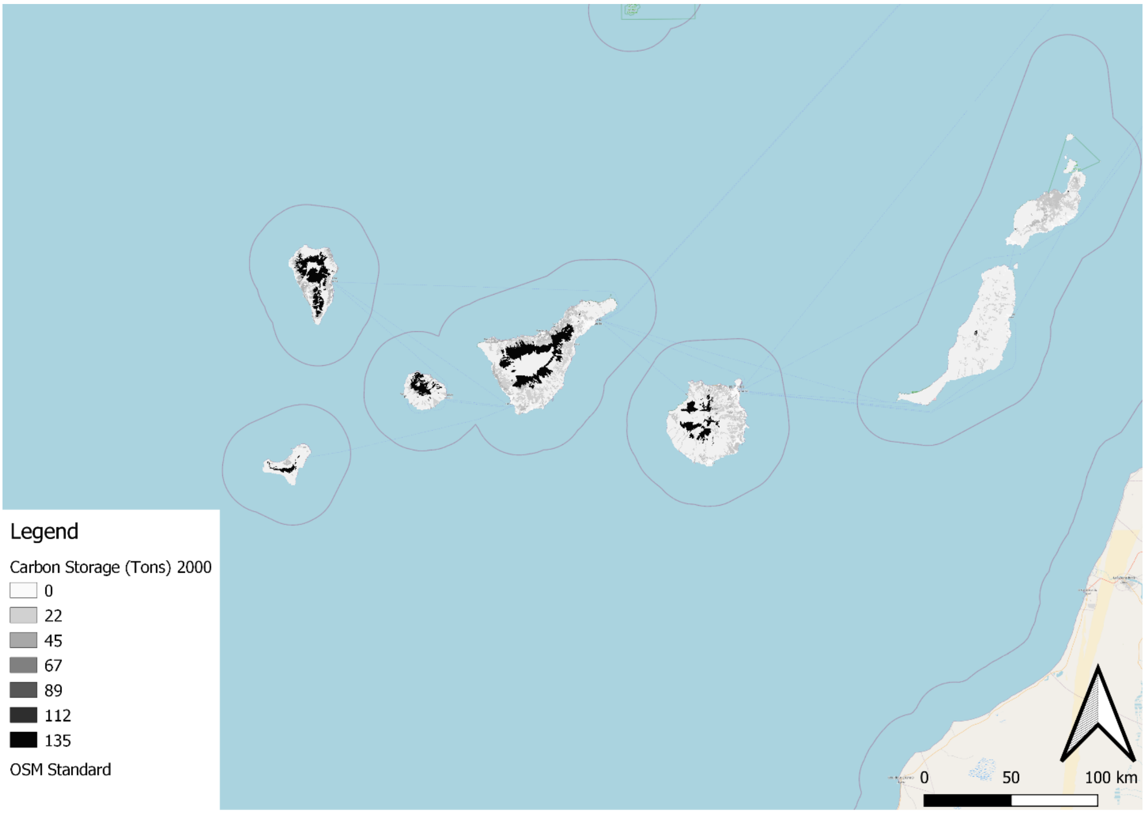


*Figure 60: Carbon model outputs (LULC 2000)*

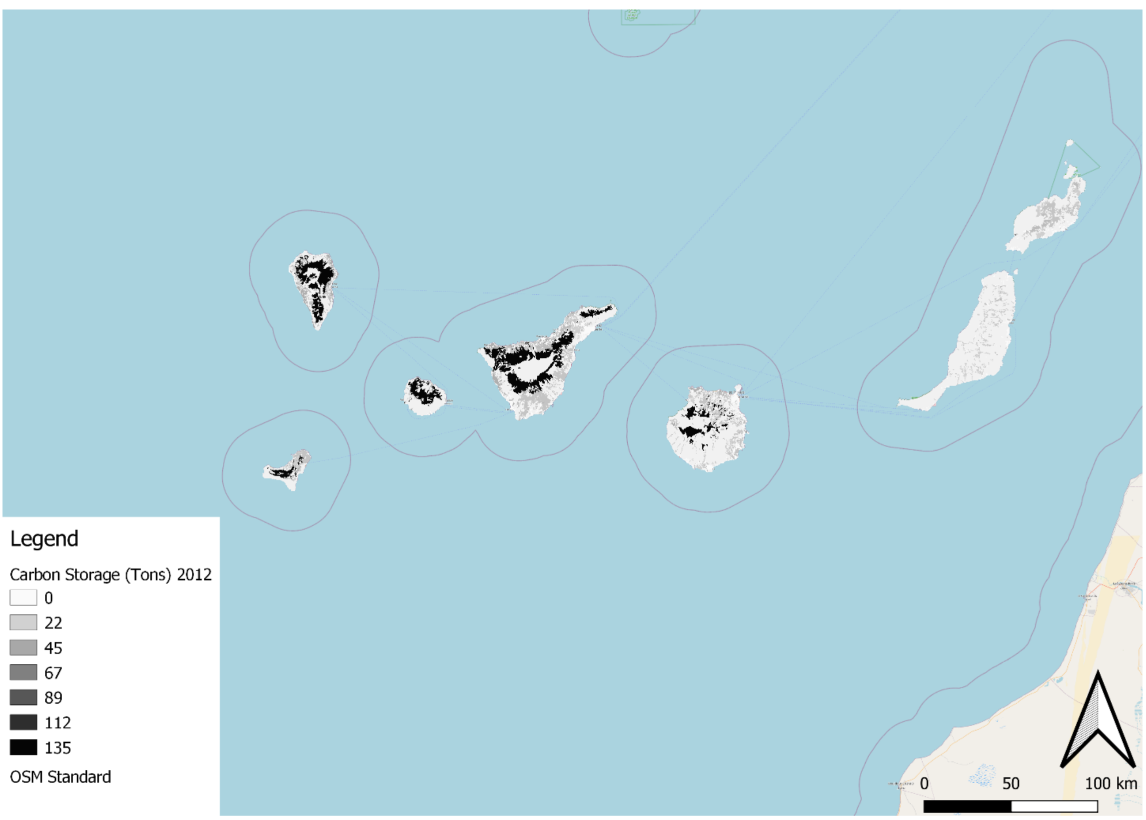


*Figure 61: Carbon model outputs (LULC 2012)*

*Figure 62: Carbon model outputs (LULC 2018)*

| LULC Year | Sum (Tons) | Change from 1990 (%) |
|---|---|---|
| **1990** | 20,684,545 | \| |
| **2000** | 20,635,321 | -0.24% |
| **2012** | 23,113,043 | 11.74% |
| **2018** | 23,113,588 | 11.74% |

*Table 20: Carbon storage statistics*

*Table 20* shows that, relative to 1990, an additional 11.74% of carbon is stored in the restored landscape in 2018. The increase in carbon storage is driven by the additional forest cover. However, the carbon stored in the Canary Islands does not show any relevant increase from 2012 to 2018, indicating that the main changes occurred from 2000 to 2012.

Figure 63 shows the difference in carbon storage between the LULC 1990 and the LULC 2018 scenario. The map indicates the areas where carbon has increased and where it has declined.

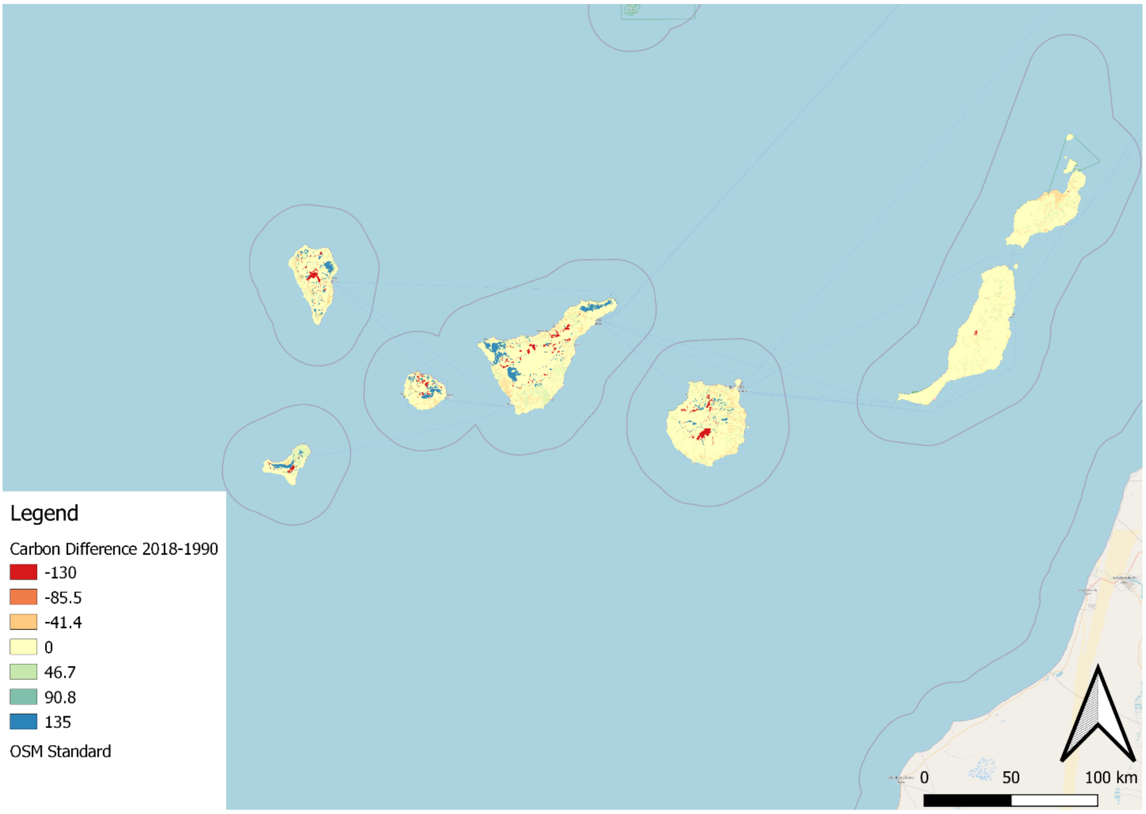


*Figure 63: Difference in Carbon storage (2018-1990)*

# 3. Habitat Quality

## 3.1 Input Data Preparation and Processing

1. **Land use/land cover maps -** see section 1c
2. Half-saturation constraint – the default value of 0.5 was used
3. **Threat Data** - several major threads such as cropland areas and urban areas have been identified as the threat sources to the natural habitat. See table below (Table 21). See Table 34 for data sources. Please note that all the artificial land classes (1, 2, 3, 5, 6, 7, 8, 9, 11) have been grouped under "1 – Urban", all the herbaceous crops (12, 13, 19, 20) have been grouped under "12 – Crop", and all the tree crops (15, 16, 17, 21, 22) have been grouped under "15 – Crop". Roads are classified under land class number 4.

   Please note that:

   - **Max_Distance** is the maximum distance over which each threat affects habitat quality. The impact of each degradation source will decline to zero at this maximum distance.
   - **Weighted value** is the impact of each threat on habitat quality, relative to other threats (ratio from 0 to 1)
   - **Decay function** is The type of decay over space for each threat.

Options:
- exponential: {‘Effects of the threat decay exponentially with distance from the threat.’}
- linear: {‘Effects of the threat decay linearly with distance from the threat.’}

| N. | Threat name | Max_Distance | Weighted value | Decay function |
|---|---|---|---|---|
| **1** | - Urban | 0.4 km | 0.8 | Linear |
| **4** | - Roads | 1 km | 0.65 | Linear |
| **12** | - Crop | 4 km | 0.7 | Linear |
| **15** | - Crop | 0.5 km | 0.3 | Linear |

*Table 21 Table of threat (maximum distance, weighted value, and decay function) for InVEST simulation*

4. **Sensitivity of land cover types to each threat -**Table 22 characterizing each LULC type to be habitat or non-habitat and the type’s sensitivity to the threats (see Table 35). The table contains the following fields:

**4.1 LULC** – codes identify each LULC class

**4.2 Name** – abbreviation of each LULC class

**4.3 Habitat** – score characterizing each LULC as habitat or non-habitat. The values of 0 and 1 are used for the purpose, in which 0 for non-habitat class and 1 for habitat class of LULC.

**4.4 L_urb_1, L_road_4, L_crop_12, L_crop_15** – these are columns for the relative sensitivity of LULC classes to the threat.

| LULC | HABITAT | urb_1 | road_4 | crop_12 | crop_15 |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 11 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 13 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 15 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 16 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 18 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 19 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 20 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |
| 21 | 0.4 | 0.69 | 0.59 | 0.03 | 0.03 |

| | | | | | |
|---|---|---|---|---|---|
| 23 | 1 | 1 | 1 | 1 | 1 |
| 24 | 1 | 1 | 1 | 1 | 1 |
| 25 | 1 | 1 | 1 | 1 | 1 |
| 26 | 0.5 | 1 | 1 | 1 | 1 |
| 27 | 0.5 | 1 | 1 | 1 | 1 |
| 28 | 0.5 | 1 | 1 | 1 | 1 |
| 29 | 0.5 | 1 | 1 | 1 | 1 |
| 30 | 0.5 | 1 | 1 | 1 | 1 |
| 31 | 0.5 | 1 | 1 | 1 | 1 |
| 32 | 0.5 | 1 | 1 | 1 | 1 |
| 33 | 0.5 | 1 | 1 | 1 | 1 |
| 38 | 1 | 1 | 1 | 1 | 1 |
| 41 | 0.3 | 0.8 | 1 | 0.7 | 0.7 |
| 42 | 1 | 1 | 1 | 1 | 1 |
| 43 | 1 | 1 | 1 | 1 | 1 |
| 44 | 0.3 | 0.8 | 1 | 0.7 | 0.7 |
| 48 | 0 | 0 | 0 | 0 | 0 |
| 49 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 0 |
| 255 | 0 | 0 | 0 | 0 | 0 |

*Table 22: Table of Sensitivity of land cover types to each threat for InVEST simulation*

## 3.2 Results

Figure 64, Figure 65, and Figure 66 show the relative level of habitat quality in the Canary Islands considering all scenarios. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. The habitat score values range from 0 to 1, where 1 indicates the highest habitat suitability.

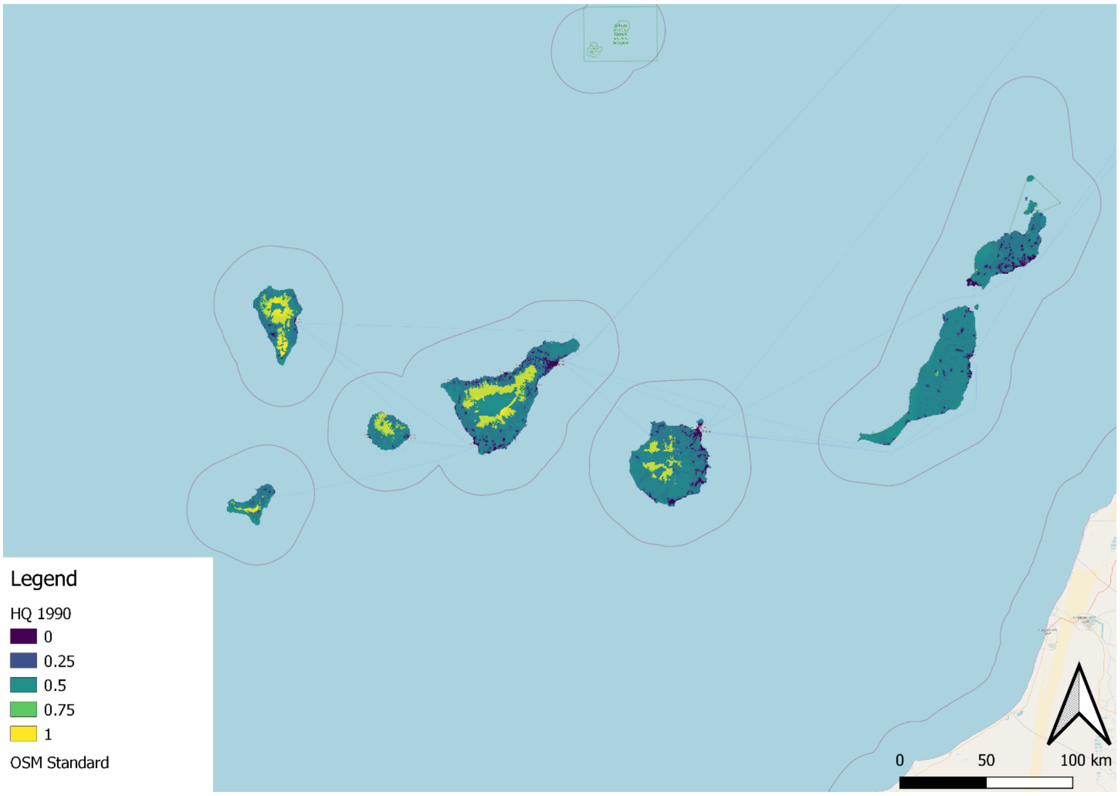


*Figure 64: Scores of habitat quality (1990)*

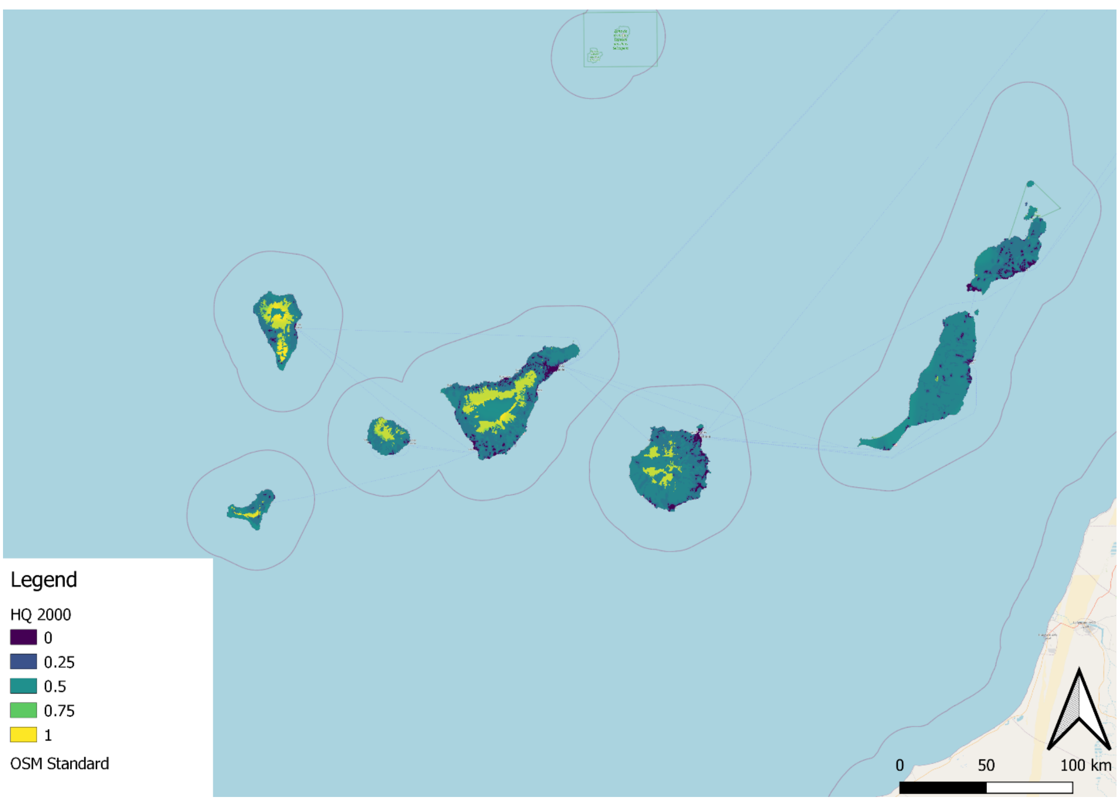


*Figure 65: Scores of habitat quality (2000)*

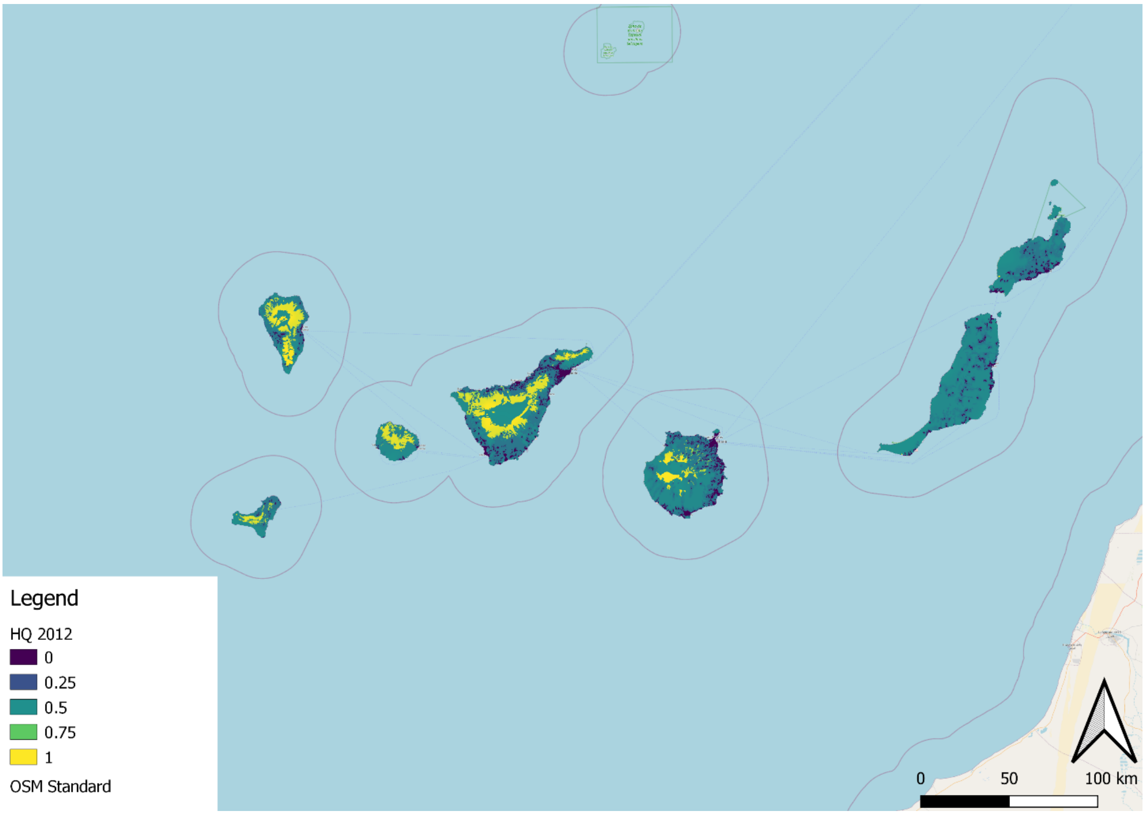


*Figure 66: Scores of habitat quality (2012)*

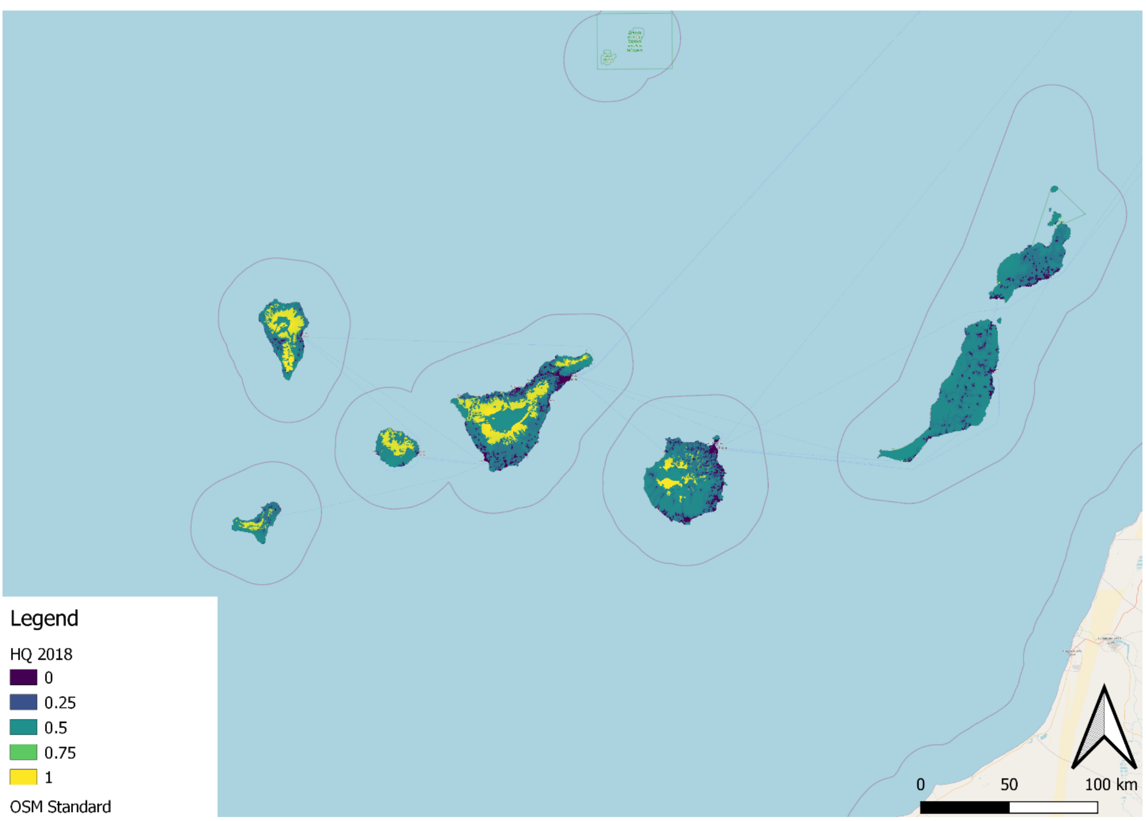

*Figure 67: Scores of habitat quality (2018)*

| LULC Year | Mean of HQ | Change from 1990 (%) |
|---|---|---|
| **1990** | 0.4732 | \| |
| **2000** | 0.4713 | -0.41% |
| **2012** | 0.4919 | 3.96% |
| **2018** | 0.4915 | 3.87% |

*Table 23: Habitat quality statistics*

As Table 23 shows, the mean of habitat quality in the Canary Islands increased by 3.87% from 1990 to 2018, although it slightly decreased from 2012, probably due to habitat fragmentation. It is worth noting that the areas with the highest scores of habitat quality roughly correspond with the ones that capture more carbon (see "results" – Carbon storage), proving the consistency of these results

# 4. Nutrient Export

## 4.1 Input Data Preparation and Processing

1. **DEM Raster** – DEM: the hydrologically conditioned elevation dataset which is distributed by HydroSHEDS (https://www.hydrosheds.org/) was downloaded on January 30th, 2023 for InVEST sediment model input. The data was prepared for hydrological model input purpose mainly for flow direction, accumulation simulation, river network and basin delineation. The dataset was filled with missing data value, and seeded inland sinks and depressions on original SRTM-3 and DTED-1 DEM. The original spatial resolution of the dataset is 3 arc-second (approximately 90 m at the equator). The data is provided in geographic projection (latitude/longitude) referenced to the WGS84 horizontal datum, and EGM96 vertical datum. Its elevation values are in meters. The HydroSHEDS's data technical report can be found in:

2. **Land use/land cover maps –** see section 1c

3. **Nutrient Runoff Proxy Raster (Precipitation)** –A GIS raster dataset with a non-zero value for average annual precipitation for each cell. Its value is expressed in millimeters. The average precipitation (in mm) from 1970 to 2000 downloaded from WorldClim version 2 (www.worldclim.com) was used for this study. The dataset was released on the first of June 2016. The original spatial resolution of the data is 30 seconds x 30 seconds (which is approximately 1 km2).

4. **Watershed Polygons** – This is the polygon shapefile representing the watersheds. The watersheds used for this study were downloaded from https://www.hydrosheds.org/ on January 30$^{th}$. We used subwatershed level 1 for this simulation.

5. **Biophysical Table** – A table of land use/land cover (LULC) classes, containing data on water quality coefficients used in this tool (
6. Table *24*). NOTE: these data are attributes of each LULC class rather than attributes of individual cells in the raster map. These data were derived from Kulsoontornrat & Ongsomwang (2021) and from InVEST samples. The table has the following field:

**6.1 Lucode** – unique identifier for each LULC class.

**6.2** ***load_n / load_p*** – The nutrient loading for each land use. If nitrogen is being evaluated, supply values in load_n, for phosphorus, supply values in load_p. The potential for terrestrial loading of water quality impairing constituents is based on nutrient export coefficients. The nutrient loading values are given as integer values and have units of kg. $ha^{-1}$ $yr^{-1}$.

**6.3** ***eff_n / eff_p*** – The vegetation filtering value per pixel size for each LULC class, as an integer percent between zero and 1. If nitrogen is being evaluated, supply values in eff_n, for phosphorus, supply values in eff_p. This field identifies the capacity of vegetation to retain nutrients, as a percentage of the amount of nutrient flowing into a cell from upslope. For example if the user has data describing that a wetland of 5000 $m^2$ retains 82% of nitrogen, then the retention efficiency that she/he should input into this field for eff_n is equal to (82/5000 * $(\text{cell size})^2$). In the simplest case, when data for each LULC type are not available, high values (60 to 80) may be assigned to all natural vegetation types (such as forests, natural pastures, wetlands, or prairie), indicating that 60-80% of nutrients are retained. An intermediary value also may be assigned to features such as contour buffers. All LULC classes that have no filtering capacity, such as pavement, can be assigned a value of zero

**6.4** ***crit_len_n (and/or crit_len_p)*** (at least one is required): The distance after which is assumed that a patch of a particular LULC type retains nutrient at its maximum capacity, given in meters. If nutrients travel a distance smaller than the retention length, the retention efficiency will be less than the maximum value *eff_x*, following an exponential decay.
This value represents the typical distance necessary to reach the maximum retention efficiency. It was introduced in the model to remove any sensitivity to the resolution of the LULC raster. In the absence of local data for land uses that are not forest or grass, it is possible to simply set the retention length constant, equal to the pixel size: this will result in the maximum retention efficiency being reached within a distance of one pixel only.

**6.5** ***proportion_subsurface_n or p (optional):*** The proportion of dissolved nutrients over the total amount of nutrients, expressed as floating point value (ratio) between 0 and 1. By default, this value should be set to 0, indicating that all nutrients are delivered via surface flow.

| lucode | load_n | eff_n | load_p | eff_p | crit_len_n | crit_len_p | proportion_subsurface_n | LULC_veg |
|---|---|---|---|---|---|---|---|---|
| 1 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 2 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 3 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 4 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 5 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 6 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 7 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 8 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 9 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 10 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 11 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 13 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 15 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 16 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 18 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 1 |
| 19 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 20 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 21 | 13.361 | 0.13 | 1.14 | 0.13 | 100 | 100 | 0 | 1 |
| 23 | 2.89 | 0.51 | 0.077 | 0.51 | 100 | 100 | 0 | 1 |
| 24 | 2.89 | 0.51 | 0.077 | 0.51 | 100 | 100 | 0 | 1 |
| 25 | 2.89 | 0.51 | 0.077 | 0.51 | 100 | 100 | 0 | 1 |
| 26 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 1 |
| 27 | 6.316 | 0.13 | 4.195 | 0.13 | 100 | 100 | 0 | 1 |
| 28 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 1 |
| 29 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 1 |
| 30 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 0 |
| 31 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 0 |
| 32 | 5.855 | 0.36 | 0.583 | 0.36 | 100 | 100 | 0 | 1 |
| 33 | 13.361 | 0.03 | 2.1 | 0.03 | 100 | 100 | 0 | 0 |
| 38 | 6.316 | 0.13 | 4.195 | 0.13 | 100 | 100 | 0 | 1 |
| 41 | 0 | 0.03 | 0 | 0.03 | 100 | 100 | 0 | 0 |
| 42 | 6.316 | 0.13 | 4.195 | 0.13 | 100 | 100 | 0 | 1 |
| 43 | 6.316 | 0.13 | 4.195 | 0.13 | 100 | 100 | 0 | 1 |
| 44 | 0 | 0.03 | 0 | 0.03 | 100 | 100 | 0 | 0 |
| 48 | 0 | 0 | 0 | 0 | 100 | 100 | 0 | 0 |
| 49 | 0 | 0 | 0 | 0 | 100 | 100 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 100 | 100 | 0 | 0 |
| 255 | 0 | 0 | 0 | 0 | 100 | 100 | 0 | 0 |

*Table 24: Biophysical table – Annual Nutrient Delivery Ratio*

7. **Threshold flow accumulation value**: Integer value defining the number of upstream pixels that must flow into a pixel before it is considered part of a stream. This is used to generate a stream layer from the DEM. This threshold expresses where hydrologic routing is discontinued, i.e. where retention stops and the remaining pollutant will be exported to the stream. The value of 100 was used in this simulation.

8. **Subsurface maximum retention efficiency (Nitrogen or phosphorus)**: the maximum nutrient retention efficiency that can be reached through subsurface flow, a value between 0 and 1. This field characterizes the retention due to biochemical degradation in soils. The default value of 0.8 was used for this study.

9. **Subsurface_crit_len (Nitrogen or phosphorus)** (in meter): the distance (traveled subsurface and downslope) after which is assumed that soil retains nutrient at its maximum capacity. If

dissolved nutrients travel a distance smaller than subsubsurface_crit_len, the retention efficiency is lower than the maximum value defined above. The value of 100 was used in this simulation.

10. **Borselli k** parameter: calibration parameter that determines the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). The default value is 2.

## 4.2 Results

| LULC Year | Nitrogen export (Kg) | Change from 1990 (%) |
|---|---|---|
| **1990** | 1,811,379 | \| |
| **2000** | 1,819,480 | 0.45% |
| **2012** | 1,784,102 | -1.51% |
| **2018** | 1,784,121 | -1.50% |

*Table 25: Nitrogen Export Statistics*

| LULC Year | Phosphorus export (Kg) | Change from 1990 (%) |
|---|---|---|
| **1990** | 195,363 | \| |
| **2000** | 197,118 | 0.90% |
| **2012** | 183,464 | -6.09% |
| **2018** | 183,471 | -6.09% |

*Table 26: Phosphorus Export Statistics*

Table 25 and Table 26 show the total Nitrogen and Phosphorus export (Kg/Watershed) in 1990, 2000, 2012, and 2018. The results indicate that both total Nitrogen and Phosphorus exports decreased from 1990 to 2018 (by 1.5% and 6.09% respectively). The only relevant increase occurred from 1990 to 2012, which is a result aligned with the ones of the Carbon and Habitat Quality models. The decrease in nutrient exports is caused by an increase in forest land and/or more sustainable agricultural practices such as agroforestry.

# 5. Urban Flood Risk Mitigation

## 5.1 Input Data Preparation and Processing

1. **Watershed Vectors -** This is the polygon shapefile representing the watersheds.

2. **Land cover maps** — see section 1c

3. **Depth of rainfall in mm –** for this analysis, we used 100 mm as reference.

4. **Soils Hydrological Group Raster -** raster of categorical hydrological groups. Pixel values must be limited to 1, 2, 3, or 4, which correspond to soil hydrologic group A, B, C, or D, respectively (used to derive the CN number). The dataset can be requested by Dr. Gijs Simons MSc - futurewater.eu/about-us/our-team/gijs-simons/

5. **Biophysical Table –** a table containing model information corresponding to each of the land use classes in the Land Cover Map (Table 27). All LULC classes in the Land Cover raster MUST have corresponding values in this table. These values have been derived from sample data provided by InVEST. Each row is a land use/land cover class and columns must be named and defined as follows:
    - lucode: and use/land cover class code. LULC codes must match the 'value' column in the Land Cover Map raster and must be integer or floating-point values, in consecutive order, and unique.
    - Curve number (CN) values for each LULC type and each hydrologic soil group. Column names should be: CN_A, CN_B, CN_C, CN_D, which the letter suffix corresponding to the hydrologic soil group.

| lucode | CN_A | CN_B | CN_C | CN_D |
|---|---|---|---|---|
| 1 | 90 | 90 | 90 | 95 |
| 2 | 90 | 90 | 90 | 95 |
| 3 | 90 | 90 | 90 | 95 |
| 4 | 90 | 90 | 90 | 95 |
| 5 | 90 | 90 | 90 | 95 |
| 6 | 90 | 90 | 90 | 95 |
| 7 | 90 | 90 | 90 | 95 |
| 8 | 90 | 90 | 90 | 95 |
| 9 | 90 | 90 | 90 | 95 |
| 10 | 60 | 75 | 80 | 90 |
| 11 | 90 | 90 | 90 | 95 |
| 12 | 60 | 75 | 80 | 90 |
| 13 | 60 | 75 | 80 | 90 |
| 15 | 60 | 75 | 80 | 90 |
| 16 | 60 | 75 | 80 | 90 |
| 18 | 50 | 70 | 80 | 80 |
| 19 | 60 | 75 | 80 | 90 |
| 20 | 60 | 75 | 80 | 90 |
| 21 | 60 | 75 | 80 | 90 |
| 23 | 40 | 60 | 70 | 80 |
| 24 | 40 | 60 | 70 | 80 |
| 25 | 40 | 60 | 70 | 80 |
| 26 | 50 | 70 | 80 | 80 |
| 27 | 60 | 75 | 80 | 90 |
| 28 | 50 | 70 | 80 | 80 |
| 29 | 50 | 70 | 80 | 80 |
| 30 | 50 | 70 | 80 | 80 |
| 31 | 50 | 70 | 80 | 80 |
| 32 | 50 | 70 | 80 | 80 |
| 33 | 50 | 70 | 80 | 80 |
| 38 | 60 | 75 | 80 | 90 |
| 41 | 1 | 1 | 1 | 1 |
| 42 | 60 | 75 | 80 | 90 |
| 43 | 60 | 75 | 80 | 90 |
| 44 | 1 | 1 | 1 | 1 |
| 48 | 0 | 0 | 0 | 0 |
| 49 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 |
| 255 | 0 | 0 | 0 | 0 |

*Table 27: Biophysical table*

## 5.2 Results

Figure 68, Figure 69, Figure 70, and Figure 71, show the runoff retention volume ($m^3$) in the study area in 1990, 2000, 2012, and 2018, respectively. Natural infrastructure operates mainly by reducing runoff production, slowing surface flows, and creating space for water.

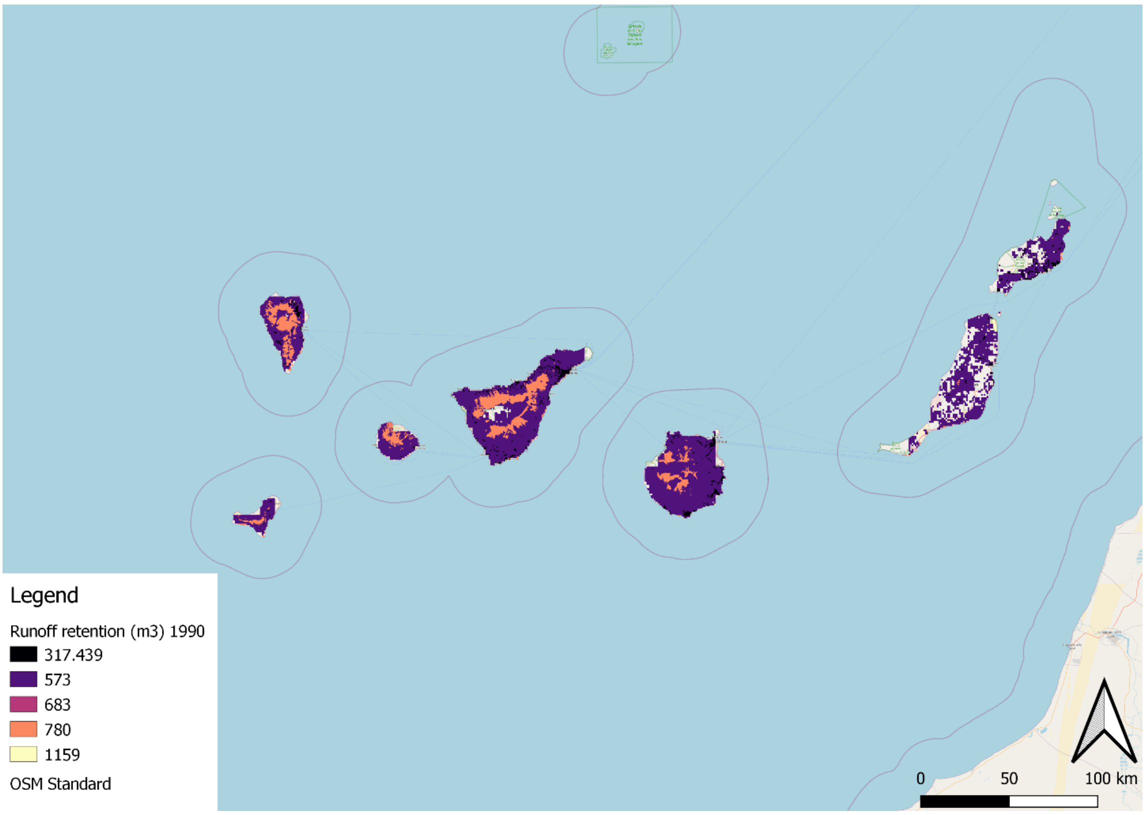


*Figure 68: Runoff retention volume (1990)*

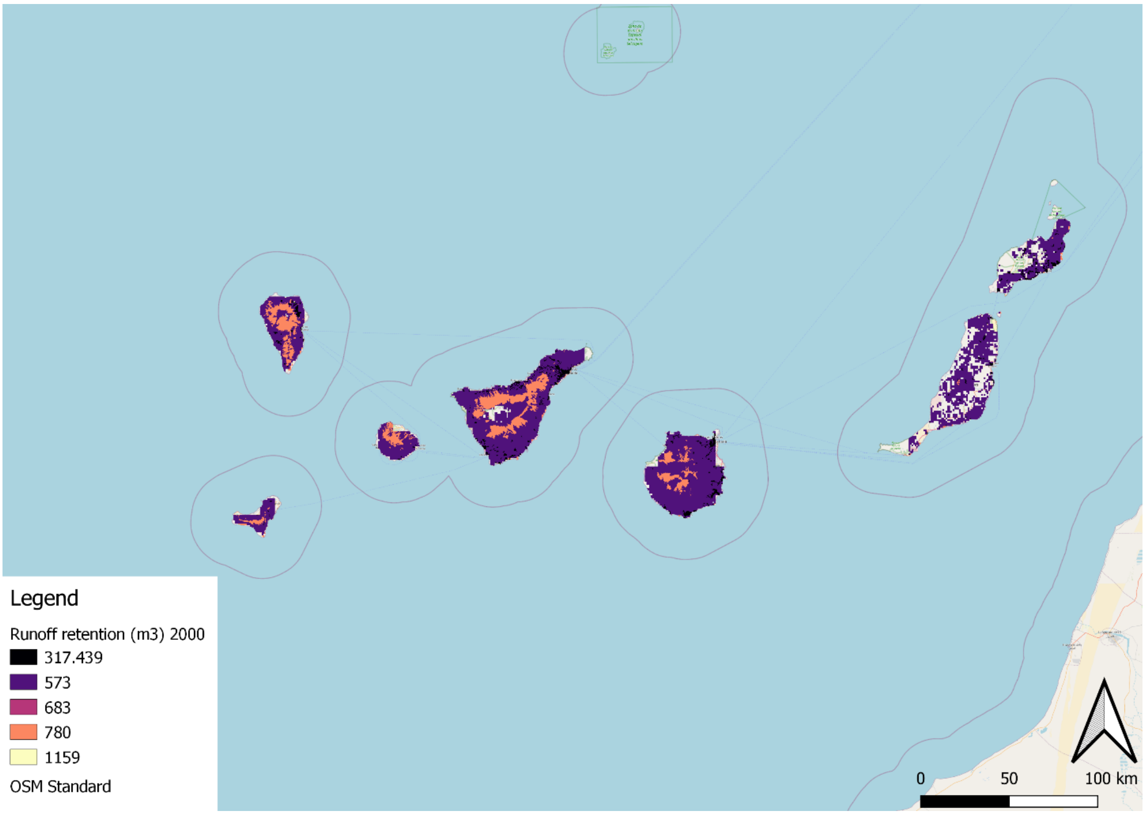

*Figure 69: Runoff retention volume (2000)*

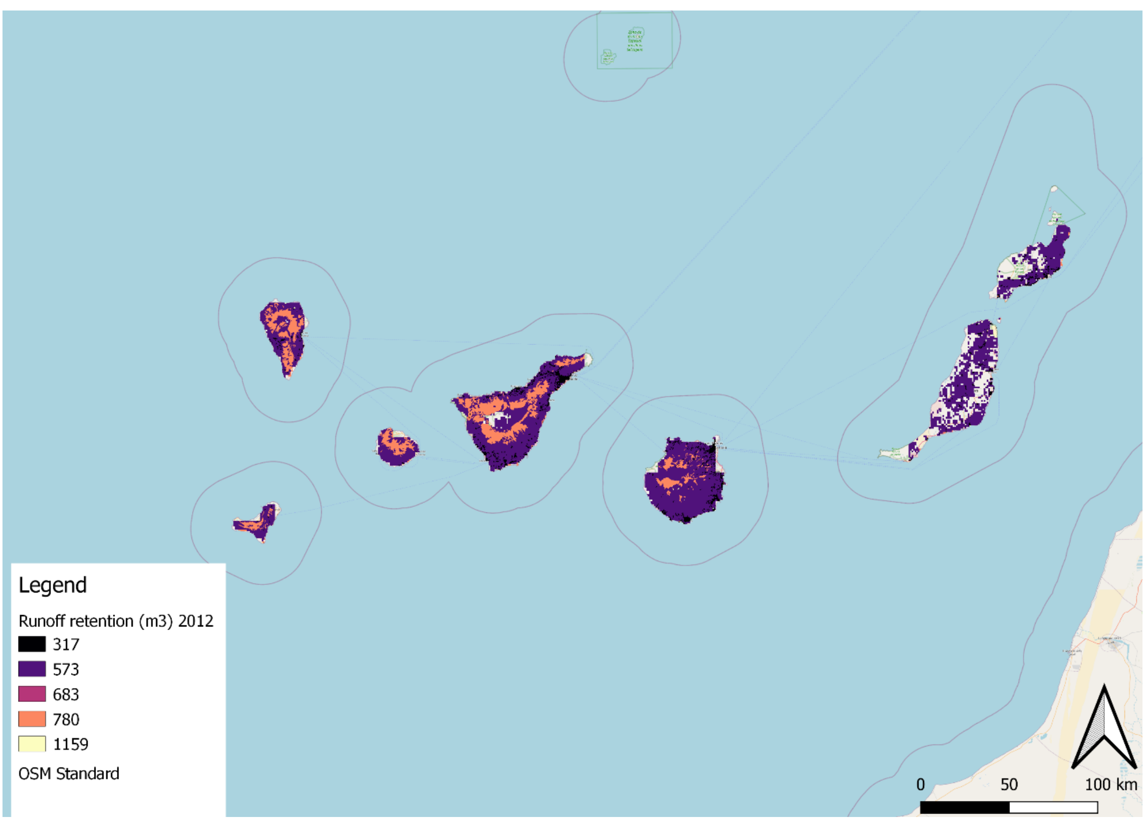

*Figure 70: Runoff retention volume (2012)*

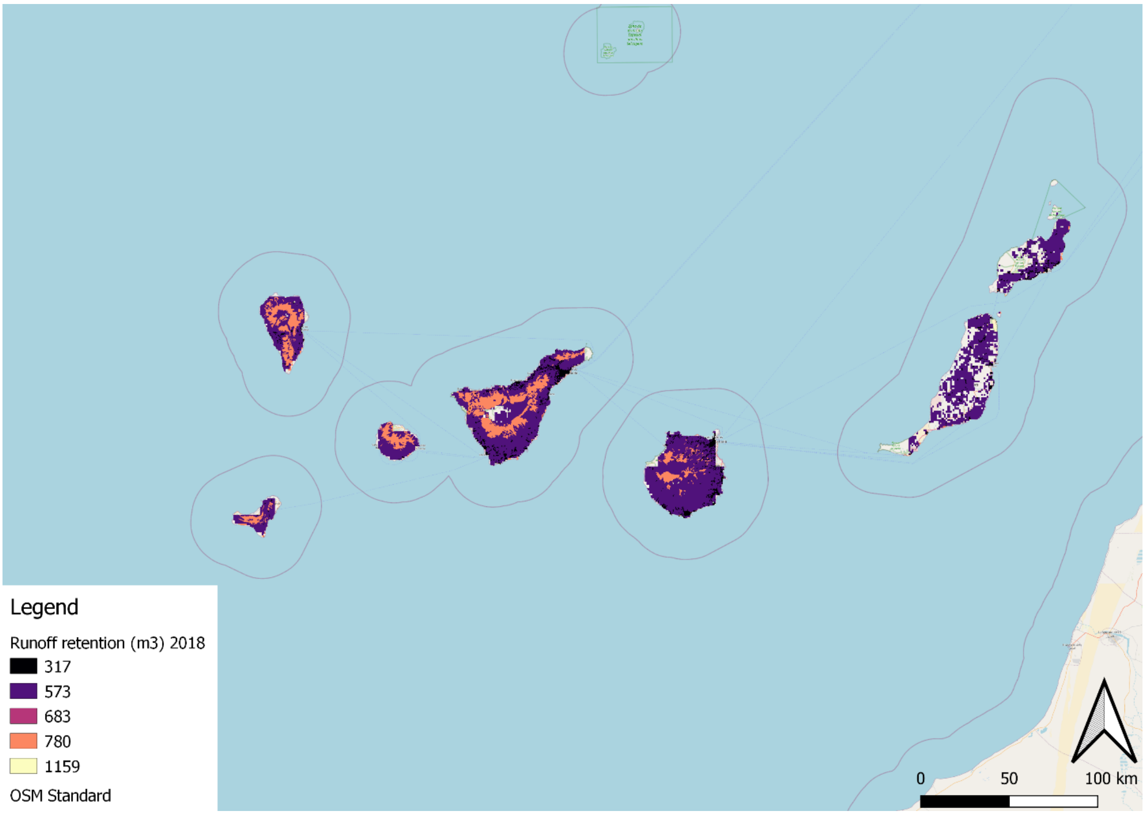


*Figure 71: Runoff retention volume (2018)*

| LULC Year | Total Runoff Retention Volume ($m^3$) | Change from 1990 (%) |
|---|---|---|
| **1990** | 396,946,901 | \| |
| **2000** | 396,237,210 | -0.18% |
| **2012** | 397,113,493 | 0.04% |
| **2018** | 397,086,530 | 0.04% |

*Table 28: Urban Flood Risk Mitigation statistics*

Table 28 summarizes the total runoff retention volume during a rainfall event of 100mm in the Canary Islands in 1990, 2000, 2012, and 2018. The results indicate that retention volume increased by only 0.04% in 2018 relative to the landscape in 1990. These changes follow the same path as the other models: the quality of the ecosystem services increases from 1990 to 2018, but it decreases from 1990 to 2000 and from 2012 to 2018. Changes in land cover, such as modification in the forest cover and different types of agriculture, can explain why the total runoff retention has increased and decreased over these years. For example, if forest cover increases, then the runoff retention is higher, because trees can retain larger volumes of water in the soil.

# 6. Results by Island

In this section we present the InVEST results by island. *Figure 72* shows the main islands that have been considered.

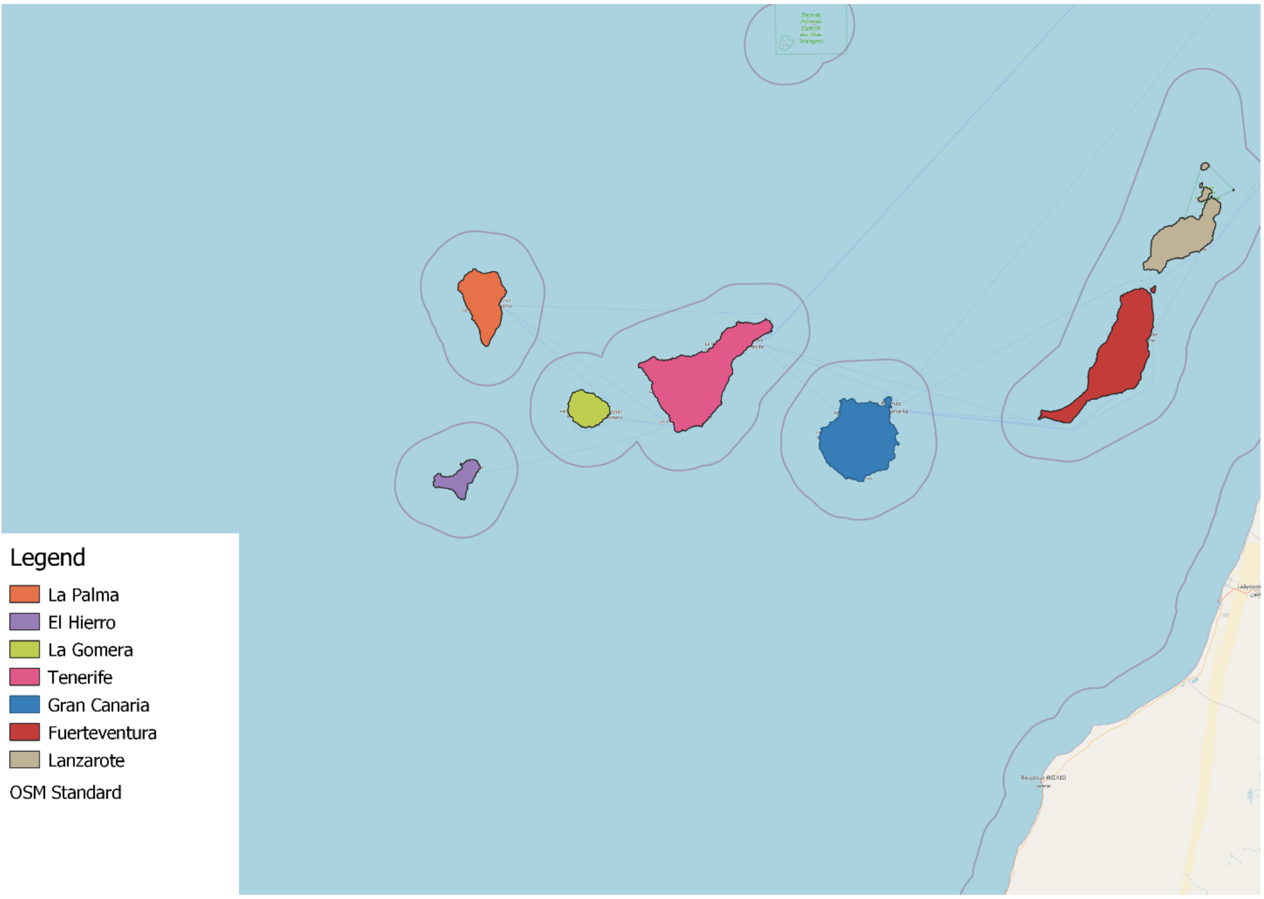


*Figure 72: main islands of the Canary Islands archipelago*

## 6.1 Results – Carbon Storage

| | | Sum (Tons) | Change from 1990 (%) |
|---|---|---|---|
| El Hierro | 1990 | 579,790 | \| |
| | 2000 | 579,498 | -0.05% |
| | 2012 | 1,049,125 | 80.95% |
| | 2018 | 1,049,125 | 80.95% |
| Fuerteventura | 1990 | 1,229,711 | \| |
| | 2000 | 1,228,542 | -0.10% |
| | 2012 | 1,264,342 | 2.82% |
| | 2018 | 1,263,235 | 2.73% |
| Gran Canaria | 1990 | 3,766,244 | \| |
| | 2000 | 3,761,855 | -0.12% |
| | 2012 | 3,563,693 | -5.38% |
| | 2018 | 3,564,362 | -5.36% |
| La Gomera | 1990 | 1,528,506 | \| |
| | 2000 | 1,536,003 | 0.49% |
| | 2012 | 1,863,763 | 21.93% |
| | 2018 | 1,863,763 | 21.93% |
| Lanzarote | 1990 | 1,112,604 | \| |
| | 2000 | 1,108,749 | -0.35% |
| | 2012 | 1,009,037 | -9.31% |
| | 2018 | 1,008,845 | -9.33% |
| La Palma | 1990 | 4,178,799 | \| |
| | 2000 | 4,180,126 | 0.03% |
| | 2012 | 4,487,594 | 7.39% |
| | 2018 | 4,487,888 | 7.40% |
| Tenerife | 1990 | 8,288,793 | \| |
| | 2000 | 8,240,448 | -0.58% |
| | 2012 | 9,875,302 | 19.14% |
| | 2018 | 9,876,184 | 19.15% |

*Table 29: results by island – carbon storage*

*Table 29* shows the carbon storage (tons) found in the main islands from 1990 to 2018. The results indicate the general trend for the whole archipelago: a small drop from 1990 to 2000 and an increase in carbon storage from 2000 to 2012, while no significant changes are found from 2012 to 2018. Some islands show a large increase in carbon storage from 2000 to 2012. For example, in El Hierro the carbon storage increased by more than 80% during those years. A possible explanation of this large increase may be linked to the fact that since the 22th of January 2000, the island has been declared a "Reserva de la Biosfera[1]" (biosphere reserve), which may have contributed to restore and preserve carbon sinks such as forests in the island.

## 6.2 Results – Habitat Quality

| | | Mean of HQ | Change from 1990 (%) |
|---|---|---|---|
| **El Hierro** | **1990** | 0.4864 | \| |
| | **2000** | 0.4861 | -0.06% |
| | **2012** | 0.5206 | 7.02% |
| | **2018** | 0.5206 | 7.02% |
| **Fuerteventura** | **1990** | 0.4447 | \| |
| | **2000** | 0.4438 | -0.21% |
| | **2012** | 0.4440 | -0.15% |
| | **2018** | 0.4433 | -0.32% |
| **Gran Canaria** | **1990** | 0.4497 | \| |
| | **2000** | 0.4476 | -0.47% |
| | **2012** | 0.4469 | -0.63% |
| | **2018** | 0.4464 | -0.73% |
| **La Gomera** | **1990** | 0.5339 | \| |
| | **2000** | 0.5318 | -0.38% |
| | **2012** | 0.6057 | 13.46% |
| | **2018** | 0.6054 | 13.39% |
| **Lanzarote** | **1990** | 0.3854 | \| |
| | **2000** | 0.3838 | -0.41% |
| | **2012** | 0.4134 | 7.27% |
| | **2018** | 0.4128 | 7.11% |
| **La Palma** | **1990** | 0.5844 | \| |
| | **2000** | 0.5839 | -0.09% |
| | **2012** | 0.6179 | 5.74% |
| | **2018** | 0.6179 | 5.73% |
| **Tenerife** | **1990** | 0.5002 | \| |
| | **2000** | 0.4966 | -0.71% |
| | **2012** | 0.5304 | 6.04% |
| | **2018** | 0.5302 | 6.00% |

*Table 30: results by island – Habitat Quality*

[1] https://www.gobiernodecanarias.org/medioambiente/materias/biodiversidad/espacios-protegidos/areas-protegidas-por-instrumentos-internacionales/reservas-de-la-biosfera/red-canaria-rb/el-hierro/

*Table 30* shows the mean of habitat quality in the main islands from 1992 to 2018. Overall, the mean of habitat quality increases in almost all islands only from 2012, while small drops are recorded from 1990 to 2000. The only exceptions are Gran Canaria and Fuerteventura, where the mean of habitat quality never increases compared to 1990. If we compare these results with the one of the Carbon Storage models, also in Gran Canaria the carbon storage increases, while it increases in Fuerteventura. Moreover, carbon storage always decreases in Lanzarote, while the mean of habitat quality increases in this island. The reason to explain these differences is the fact that not always carbon storage and habitat quality are linearly dependents. Habitat fragmentation can decrease habitat quality while carbon storage increases, or habitat quality can increase in some areas where it was already low and affect the mean in an entire island, but the overall carbon storage content can decrease anyway. Further studies are needed to assess the drivers of these changes.

## 6.3 Results – Nutrient Export (Nitrogen)

| | | Nitrogen export (Kg) | Change from 1990 (%) |
|---|---|---|---|
| El Hierro | **1990** | N/A | \| |
| | **2000** | N/A | N/A |
| | **2012** | N/A | N/A |
| | **2018** | N/A | N/A |
| Fuerteventura | **1990** | 135,561 | \| |
| | **2000** | 135,866 | 0.22% |
| | **2012** | 143,716 | 6.02% |
| | **2018** | 143,758 | 6.05% |
| Gran Canaria | **1990** | 470,081 | \| |
| | **2000** | 470,936 | 0.18% |
| | **2012** | 467,380 | -0.57% |
| | **2018** | 467,270 | -0.60% |
| La Gomera | **1990** | 84,183 | \| |
| | **2000** | 85,345 | 1.38% |
| | **2012** | 74,553 | -11.44% |
| | **2018** | 74,553 | -11.44% |
| Lanzarote | **1990** | 126,771 | \| |
| | **2000** | 126,774 | 0.00% |
| | **2012** | 108,889 | -14.11% |
| | **2018** | 108,889 | -14.11% |
| La Palma | **1990** | 211,548 | \| |
| | **2000** | 212,209 | 0.31% |
| | **2012** | 208,031 | -1.66% |
| | **2018** | 208,031 | -1.66% |
| Tenerife | **1990** | 762,306 | \| |
| | **2000** | 767,384 | 0.67% |
| | **2012** | 766,718 | 0.58% |
| | **2018** | 766,718 | 0.58% |

*Table 31: results by island – Nitrogen Export*

*Table 31* shows the Nitrogen export in the main islands from 1992 to 2018. The results for El Hierro are not available because the spatial inputs used in this model were not available for this island. Nitrogen export only increases by more than 6% in Fuerteventura and by more than 0.5% in Tenerife from 1990 to 2018.

## 6.4 Results – Nutrient Export (Phosphorus)

| | | Nitrogen export (Kg) | Change from 1990 (%) |
|---|---|---|---|
| El Hierro | **1990** | N/A | \| |
| | **2000** | N/A | N/A |
| | **2012** | N/A | N/A |
| | **2018** | N/A | N/A |
| Fuerteventura | **1990** | 13,458 | \| |
| | **2000** | 13,510 | 0.39% |
| | **2012** | 14,517 | 7.87% |
| | **2018** | 14,528 | 7.95% |
| Gran Canaria | **1990** | 44,877 | \| |
| | **2000** | 45,138 | 0.58% |
| | **2012** | 46,781 | 4.24% |
| | **2018** | 46,763 | 4.20% |
| La Gomera | **1990** | 11,987 | \| |
| | **2000** | 12,076 | 0.74% |
| | **2012** | 9,213 | -23.14% |
| | **2018** | 9,213 | -23.14% |
| Lanzarote | **1990** | 12,321 | \| |
| | **2000** | 12,341 | 0.16% |
| | **2012** | 10,623 | -13.78% |
| | **2018** | 10,623 | -13.78% |
| La Palma | **1990** | 34,115 | \| |
| | **2000** | 34,258 | 0.42% |
| | **2012** | 25,223 | -26.06% |
| | **2018** | 25,223 | -26.06% |
| Tenerife | **1990** | 76,886 | \| |
| | **2000** | 78,083 | 1.56% |
| | **2012** | 74,894 | -2.59% |
| | **2018** | 74,894 | -2.59% |

*Table 32: results by island – Phosphorus Export*

| | | Nitrogen export (Kg) | Change from 1990 (%) |
|---|---|---|---|
| El Hierro | 1990 | N/A | \| |
| | 2000 | N/A | N/A |
| | 2012 | N/A | N/A |
| | 2018 | N/A | N/A |
| Fuerteventura | 1990 | 13,458 | \| |
| | 2000 | 13,510 | 0.39% |
| | 2012 | 14,517 | 7.87% |
| | 2018 | 14,528 | 7.95% |
| Gran Canaria | 1990 | 44,877 | \| |
| | 2000 | 45,138 | 0.58% |
| | 2012 | 46,781 | 4.24% |
| | 2018 | 46,763 | 4.20% |
| La Gomera | 1990 | 11,987 | \| |
| | 2000 | 12,076 | 0.74% |
| | 2012 | 9,213 | -23.14% |
| | 2018 | 9,213 | -23.14% |
| Lanzarote | 1990 | 12,321 | \| |
| | 2000 | 12,341 | 0.16% |
| | 2012 | 10,623 | -13.78% |
| | 2018 | 10,623 | -13.78% |
| La Palma | 1990 | 34,115 | \| |
| | 2000 | 34,258 | 0.42% |
| | 2012 | 25,223 | -26.06% |
| | 2018 | 25,223 | -26.06% |
| Tenerife | 1990 | 76,886 | \| |
| | 2000 | 78,083 | 1.56% |
| | 2012 | 74,894 | -2.59% |
| | 2018 | 74,894 | -2.59% |

Table 32 shows the Phosphorus export in the main islands from 1992 to 2018. The results for El Hierro are not available because the spatial inputs used in this model were not available for this island. Nitrogen export only increases by more than 7% in Fuerteventura and by more than 4% in Gran Canaria from 1990 to 2018. These results, like the ones for Nitrogen export, may have been affected by the small areas of the islands which may not be able to compress the large spatial inputs required to run the Nutrient Export InVEST model. Nevertheless, they give a sense on where nutrient export has increased or decreased over time, but further studies are required to validate these results.

## 6.5 Results – Urban Flood Risk Mitigation

| | | Total Runoff Retention Volume (m3) | Change from 1990 (%) |
|---|---|---|---|
| **El Hierro** | **1990** | 13,998,492 | \| |
| | **2000** | 13,994,905 | -0.03% |
| | **2012** | 14,452,057 | 3.24% |
| | **2018** | 14,452,057 | 3.24% |
| **Fuerteventura** | **1990** | 57,788,110 | \| |
| | **2000** | 57,749,984 | -0.07% |
| | **2012** | 57,068,170 | -1.25% |
| | **2018** | 57,051,456 | -1.27% |
| **Gran Canaria** | **1990** | 95,213,171 | \| |
| | **2000** | 95,066,186 | -0.15% |
| | **2012** | 93,432,005 | -1.87% |
| | **2018** | 93,432,005 | -1.87% |
| **La Gomera** | **1990** | 22,188,632 | \| |
| | **2000** | 22,171,855 | -0.08% |
| | **2012** | 22,772,561 | 2.63% |
| | **2018** | 22,772,561 | 2.63% |
| **Lanzarote** | **1990** | 31,393,801 | \| |
| | **2000** | 31,340,760 | -0.17% |
| | **2012** | 31,651,623 | 0.82% |
| | **2018** | 31,644,961 | 0.80% |
| **La Palma** | **1990** | 47,818,454 | \| |
| | **2000** | 47,800,517 | -0.04% |
| | **2012** | 48,430,368 | 1.28% |
| | **2018** | 48,430,368 | 1.28% |
| **Tenerife** | **1990** | 128,543,920 | \| |
| | **2000** | 128,110,683 | -0.34% |
| | **2012** | 129,305,231 | 0.59% |
| | **2018** | 129,301,644 | 0.59% |

*Table 33: results by island – Urban Flood Risk Mitigation*

*Table 33* shows the total runoff retention volume ($m^3$) found in the main islands from 1990 to 2018. Overall, the total runoff retention volume increases in almost all islands only from 2012, while small drops are recorded from 1990 to 2000. The only exceptions are Gran Canaria and Fuerteventura, where the total runoff retention volume never increases compared to 1990. These results are similar to the ones obtained through the Habitat Quality InVEST model, proving the consistency of the results between the two models.

| Threat | Max_ Distan ce | Max_Distan ce Adopted sources | Weighte d value | Weight value Adopted sources | Decay function | Decay func. Adopted sources |
|---|---|---|---|---|---|---|
| **- Urban** | 0.4 km | (Salata, Ronchi, Arcidiacon o, & Ghirardelli , 2017) | 0.8 | (Salata, Ronchi, Arcidiacono, & Ghirardelli, 2017) | Linear | (Salata, Ronchi, Arcidiacono , & Ghirardelli, 2017) |
| **-Roads** | 1 km | (Salata, Ronchi, Arcidiacon o, & Ghirardelli , 2017) | 0.65 | (Salata, Ronchi, Arcidiacono, & Ghirardelli, 2017) | Linear | (Salata, Ronchi, Arcidiacono , & Ghirardelli, 2017) |
| **- Cropland, herbaceous cover** | 4 km | (Terrado, et al., 2016) | 0.7 | (Bhagabati, et al., 2012) | Linear | (Bhagabati, et al., 2012) |
| **- Cropland, tree cover** | 0.5 km | (Ciobotaru , et al., 2019) | 0.3 | (Ciobotaru, et al., 2019) | Linear | (Ciobotaru, et al., 2019) |

*Table 34: Habitat Quality model – references “threat table”*

| Value | Habitat | Habitat Adopted sources | Sensitivity to Agricultural sources | Sensitivity to Agri source Adopted sources | Sensitivity to Urban Areas Sources | Sensitivity to Urban Area Adopted sources | Sensitivity to Roads | Sensitivity to Paved Road Adopted sources |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 2 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 3 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 4 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 5 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 6 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 7 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 8 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 9 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 10 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 11 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 12 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 13 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 15 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 16 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 18 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 19 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 20 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 21 | 0.4 | (Terrado, et al., 2016) | 0.03 | (Terrado, et al., 2016) | 0.69 | (Terrado, et al., 2016) | 0.59 | (Terrado, et al., 2016) |
| 23 | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 24 | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 25 | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 26 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 27 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 28 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 29 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 30 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 31 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 32 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 33 | 0.5 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 38 | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 41 | 0.3 | (Sulistyawan, et al., 2017) | 0.7 | (Sulistyawan, et al., 2017) | 0.8 | (Sulistyawan, et al., 2017) | 1 | (Sulistyawan, et al., 2017) |
| 42 | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 43 | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) | 1 | (Bhagabati, et al., 2012) |
| 44 | 0.3 | (Sulistyawan, et al., 2017) | 0.7 | (Sulistyawan, et al., 2017) | 0.8 | (Sulistyawan, et al., 2017) | 1 | (Sulistyawan, et al., 2017) |
| 48 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 49 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 50 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |
| 255 | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) | 0 | (Sulistyawan, et al., 2017) |

*Table 35: Habitat Quality model – references "threat sensitivity table"*

# Annex 2 – Main Model Components

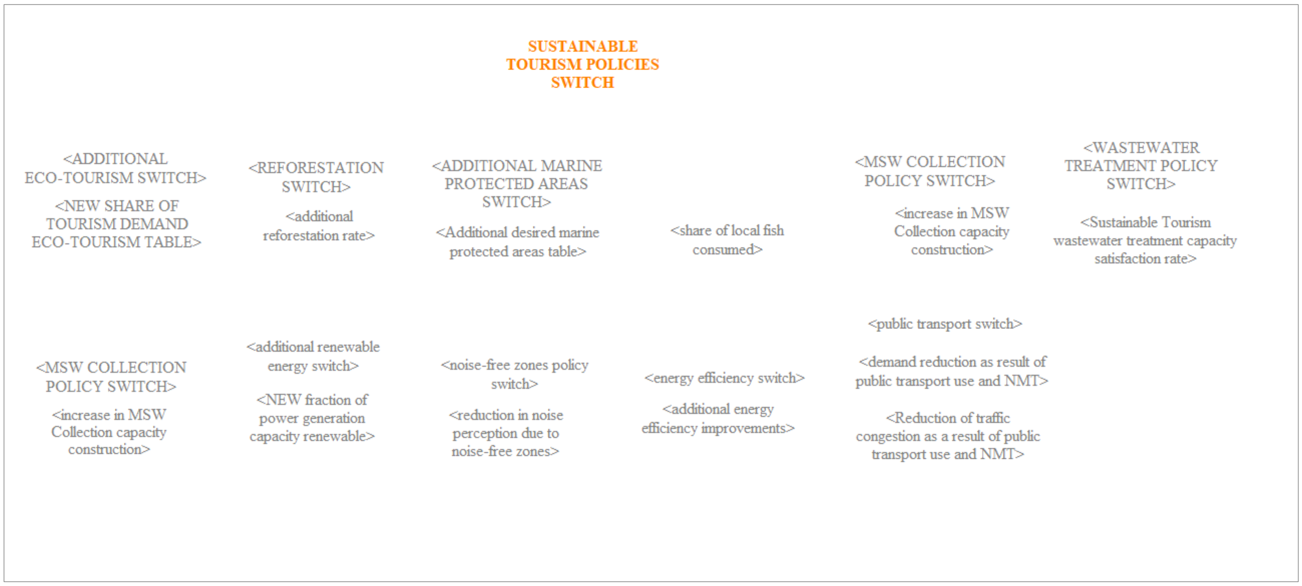


*Diagram 1: Sustainabile Tourism Policies Board module*

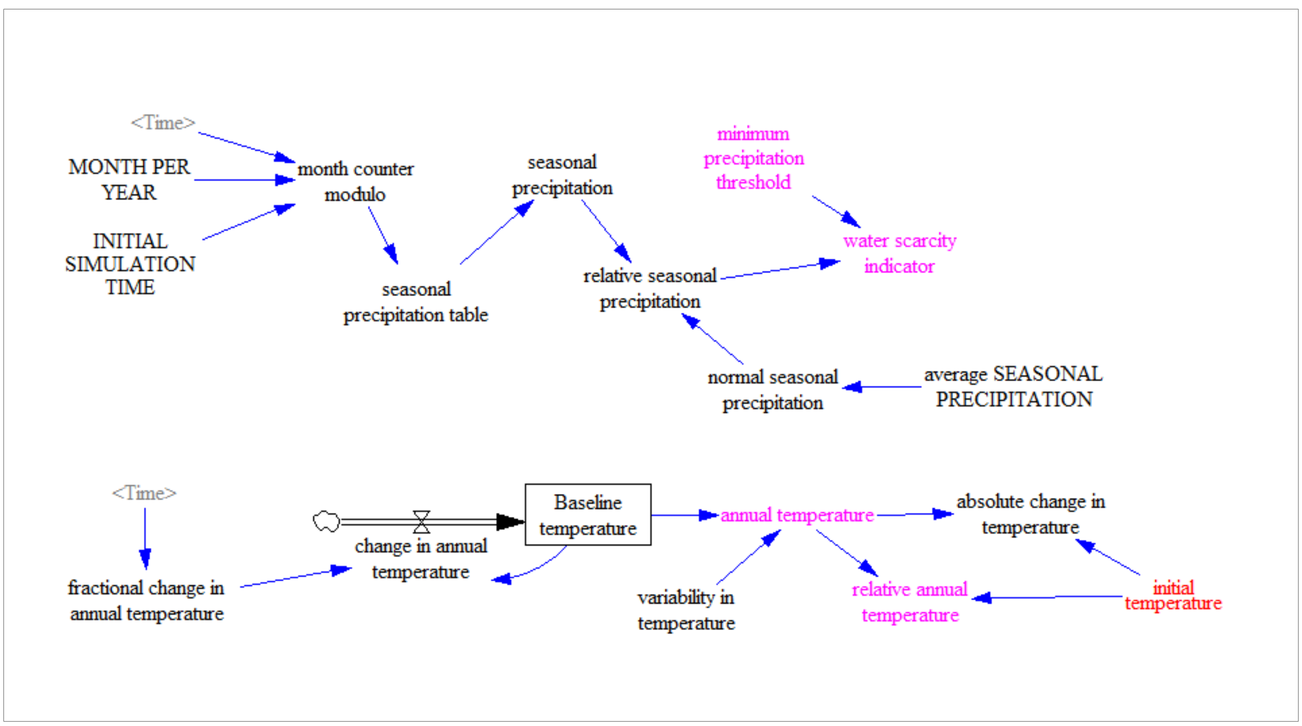


*Diagram 2: Climate module*

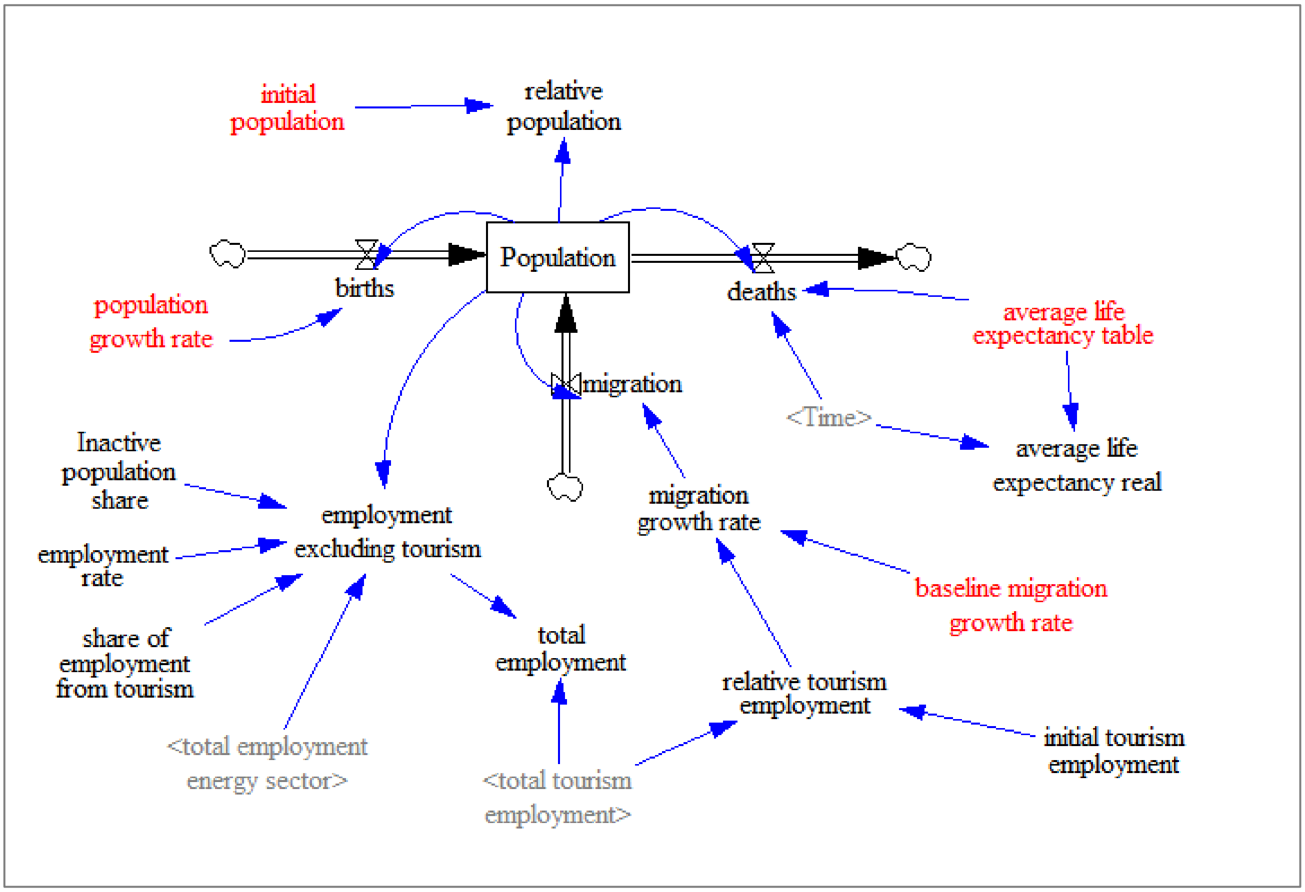


*Diagram 3: Population and employment module*

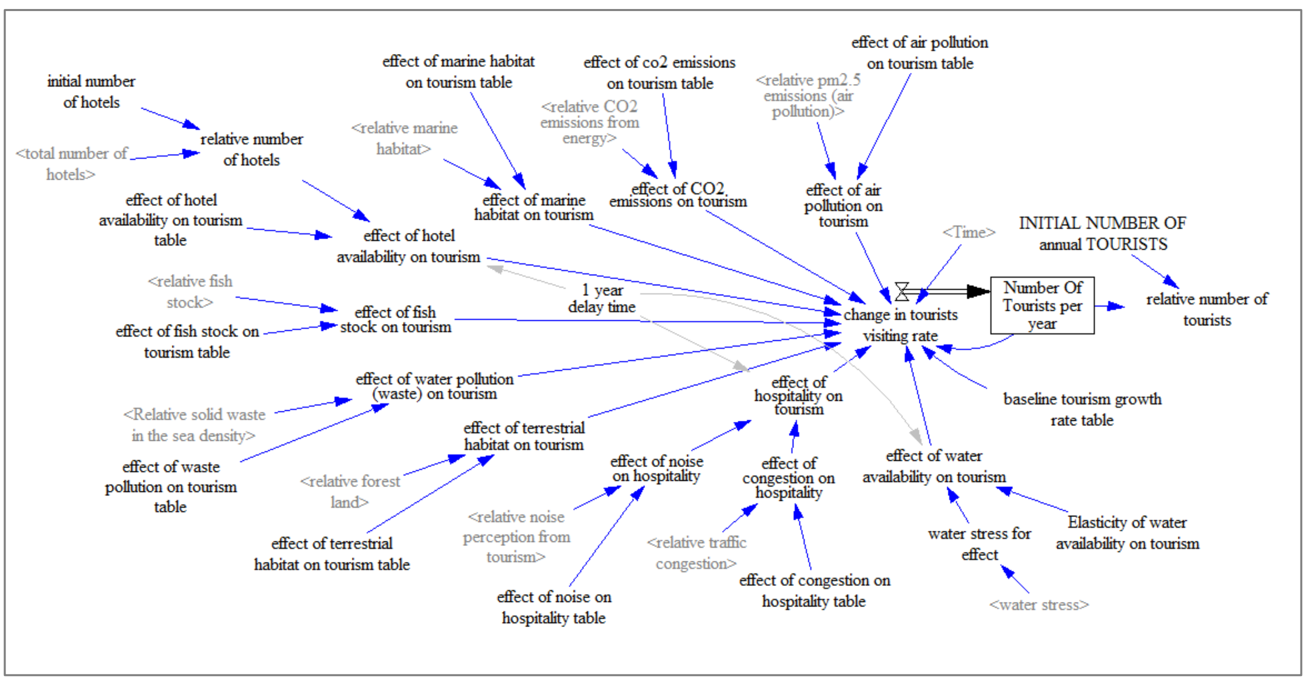


*Diagram 4: Tourism demand module*

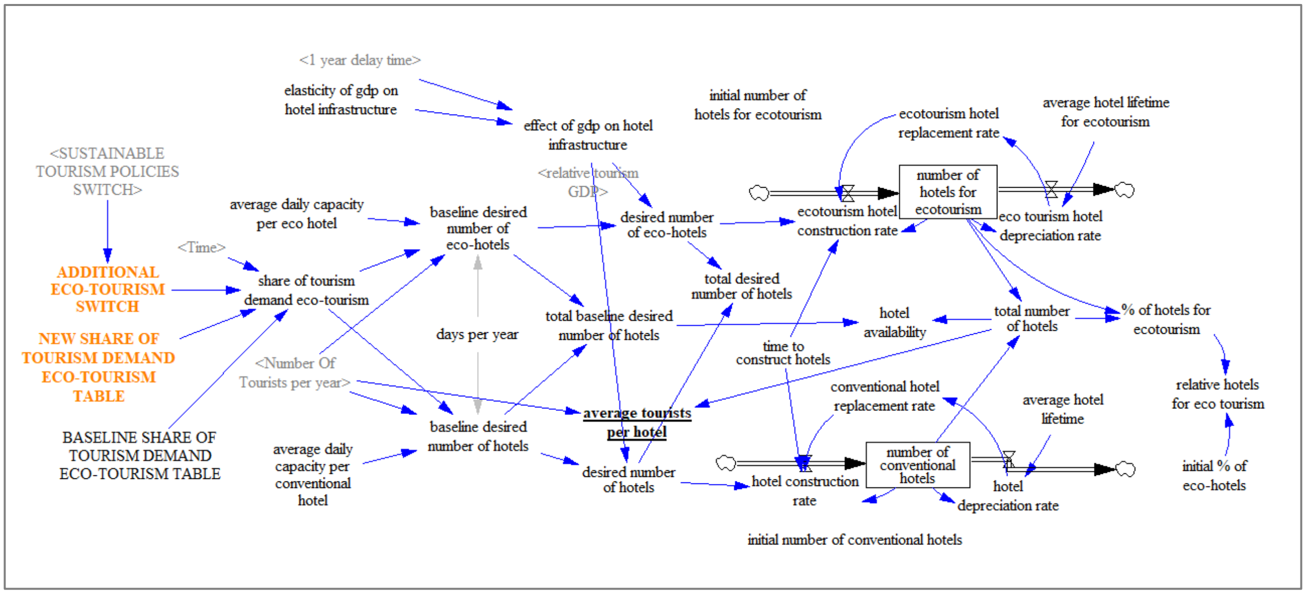


*Diagram 5: Tourism capacity module*

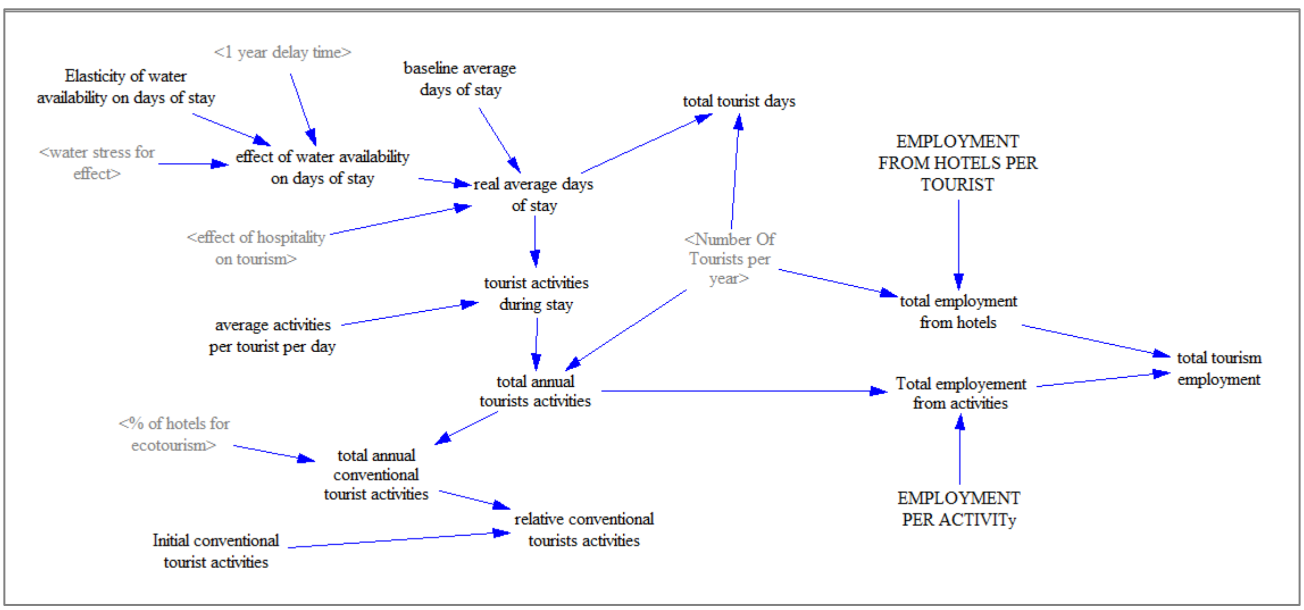


*Diagram 6: Tourism employment module*

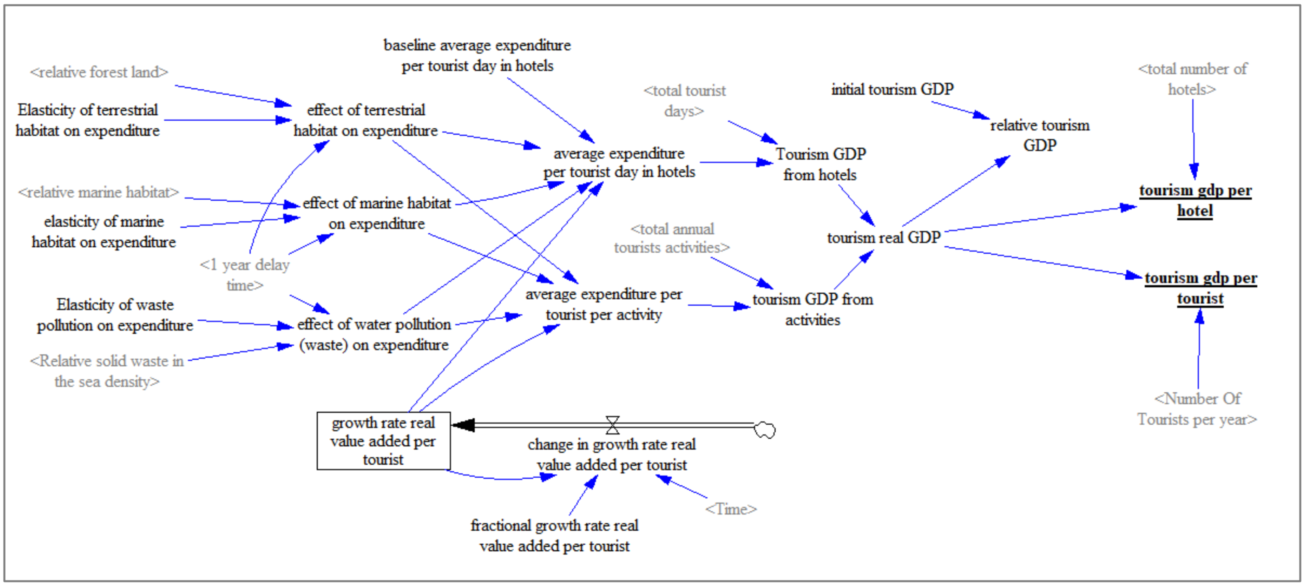


*Diagram 7: Tourism GDP module*

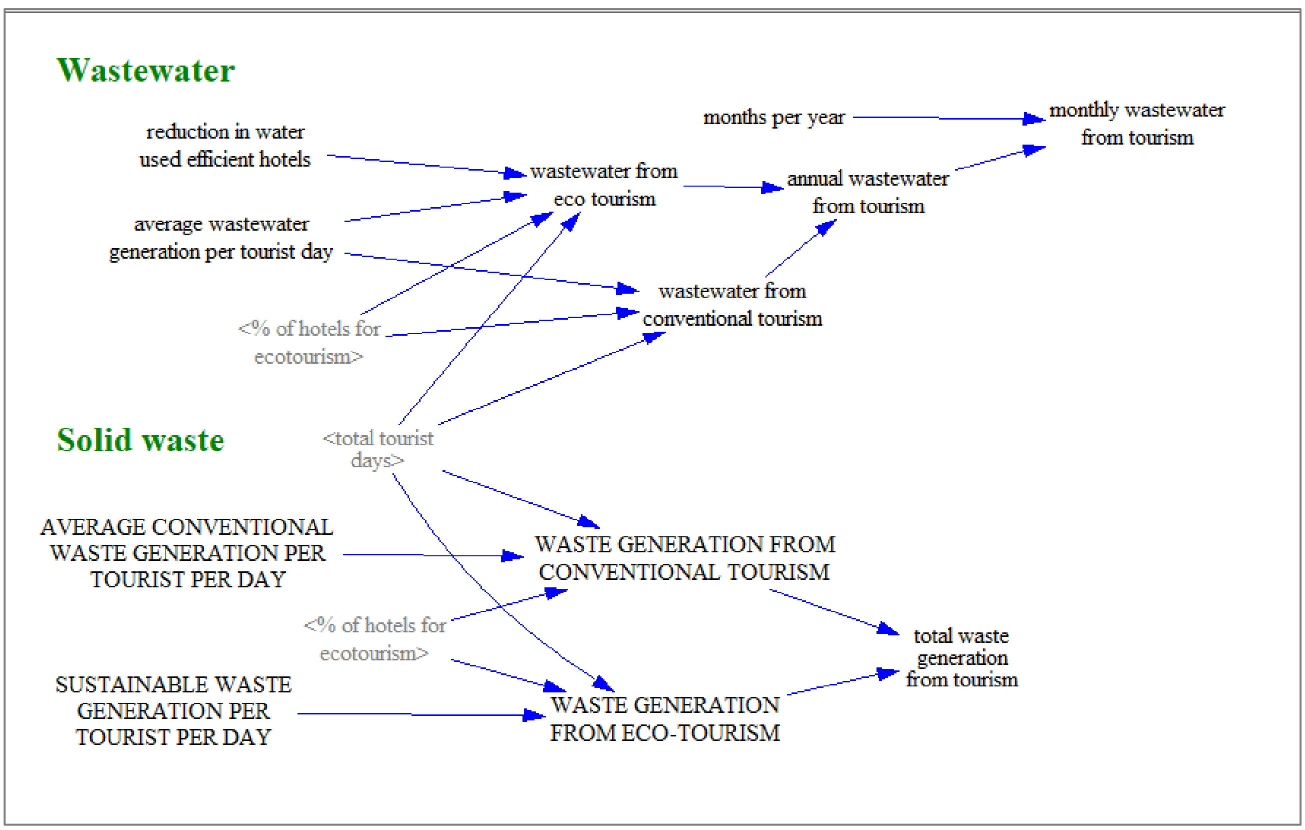


*Diagram 8: Tourism waste generation module*

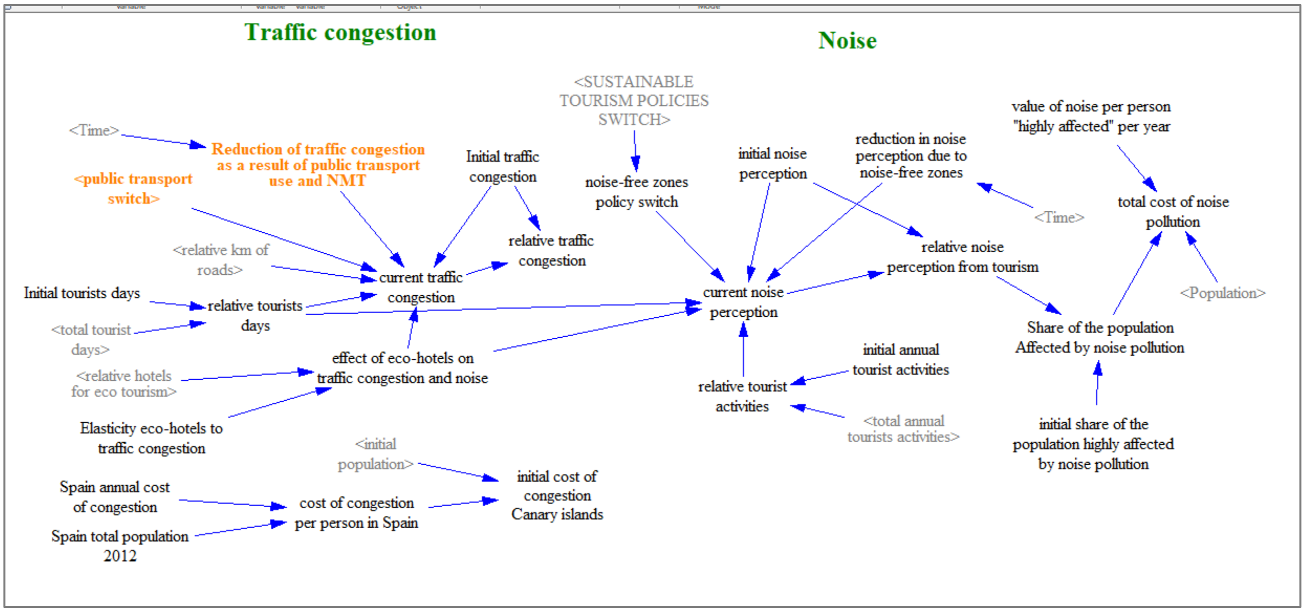


*Diagram 9: Tourism traffic congestion and noise module*

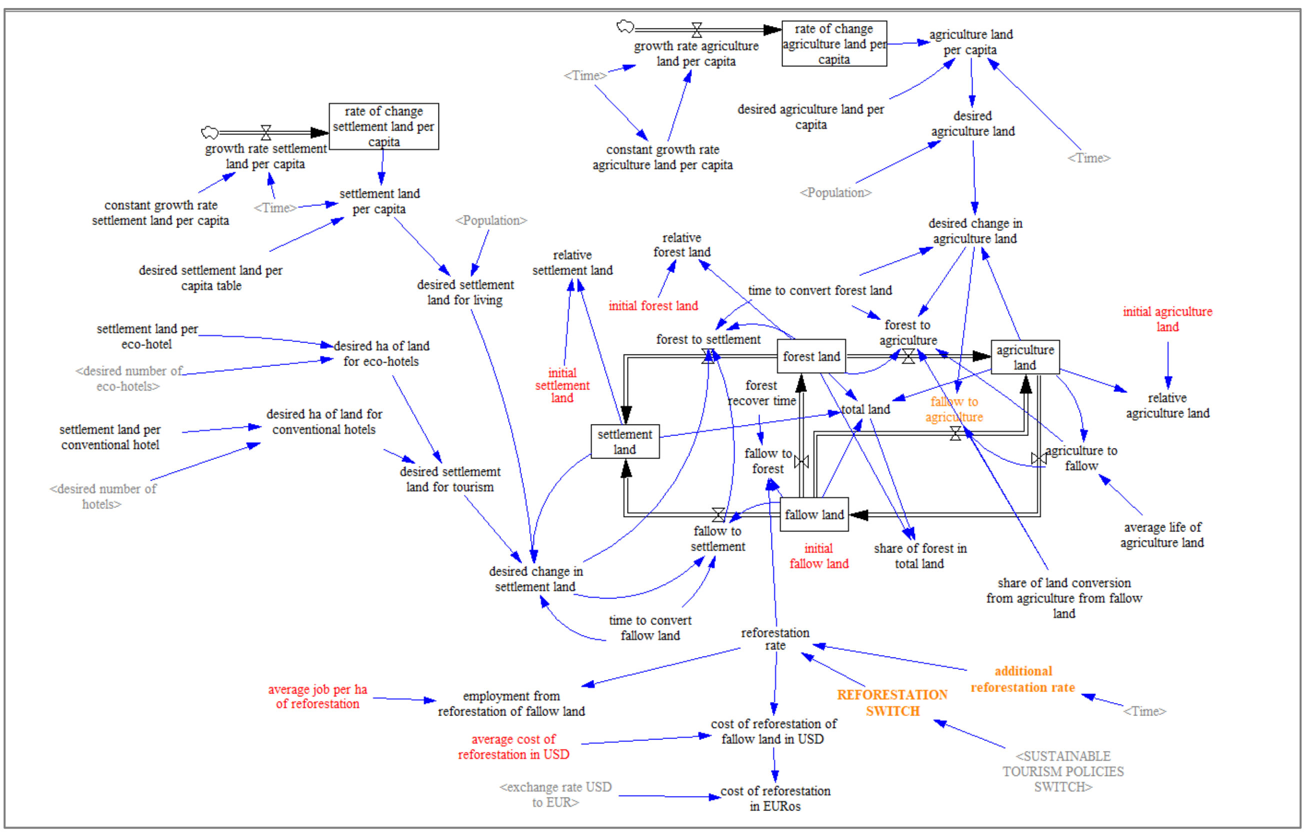


*Diagram 10: Land use module*

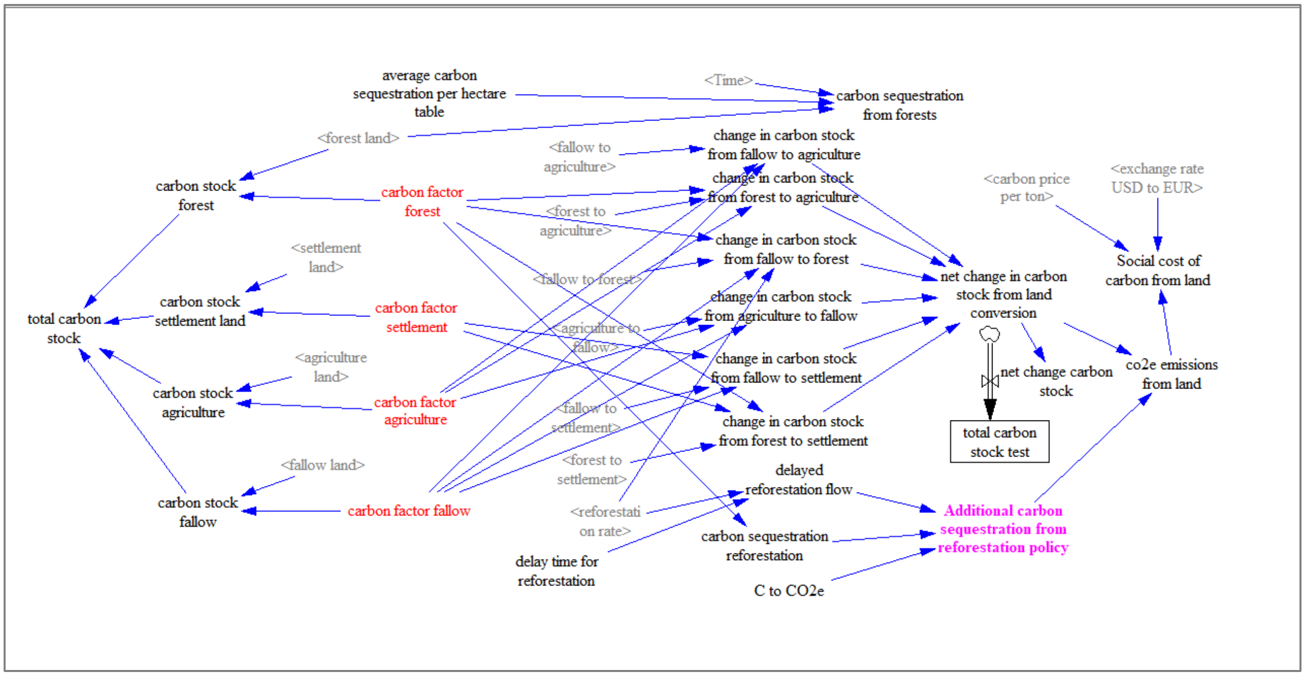


*Diagram 11: Emissions from land module*

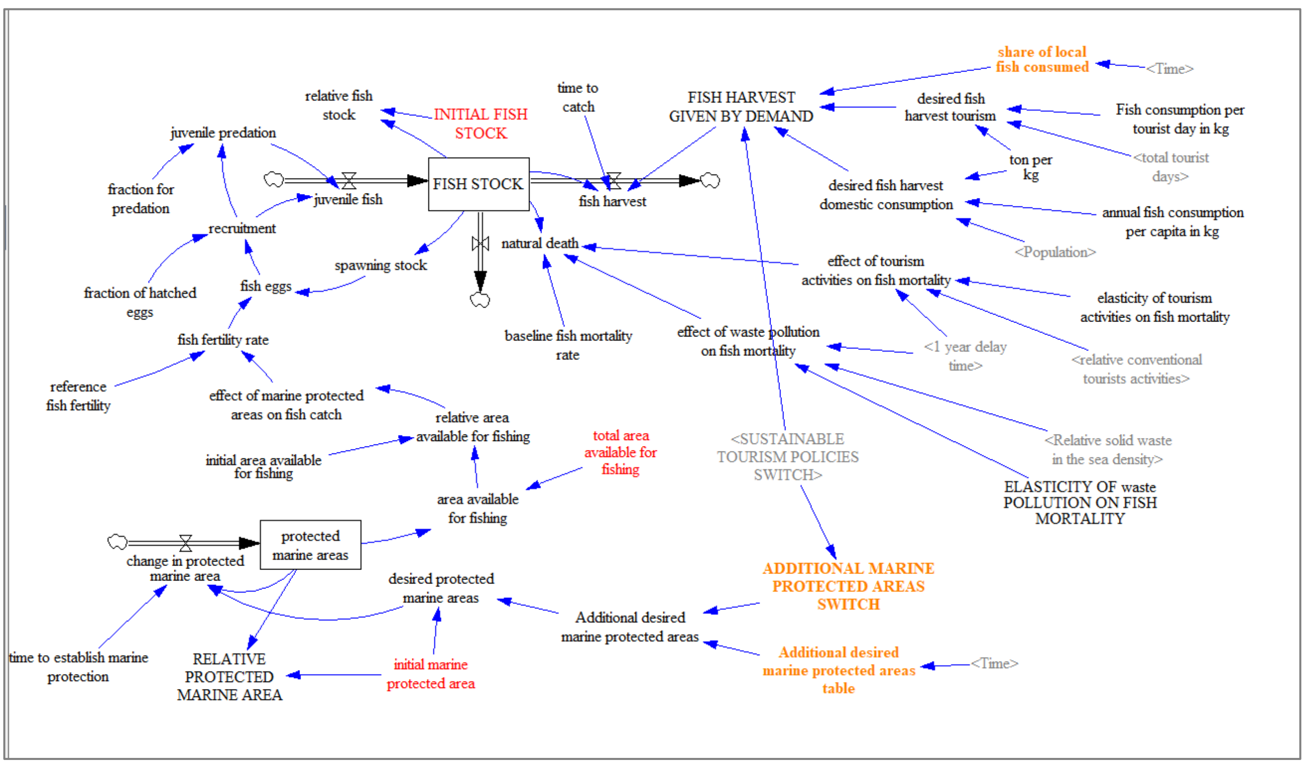


*Diagram 12: Fish stock module*

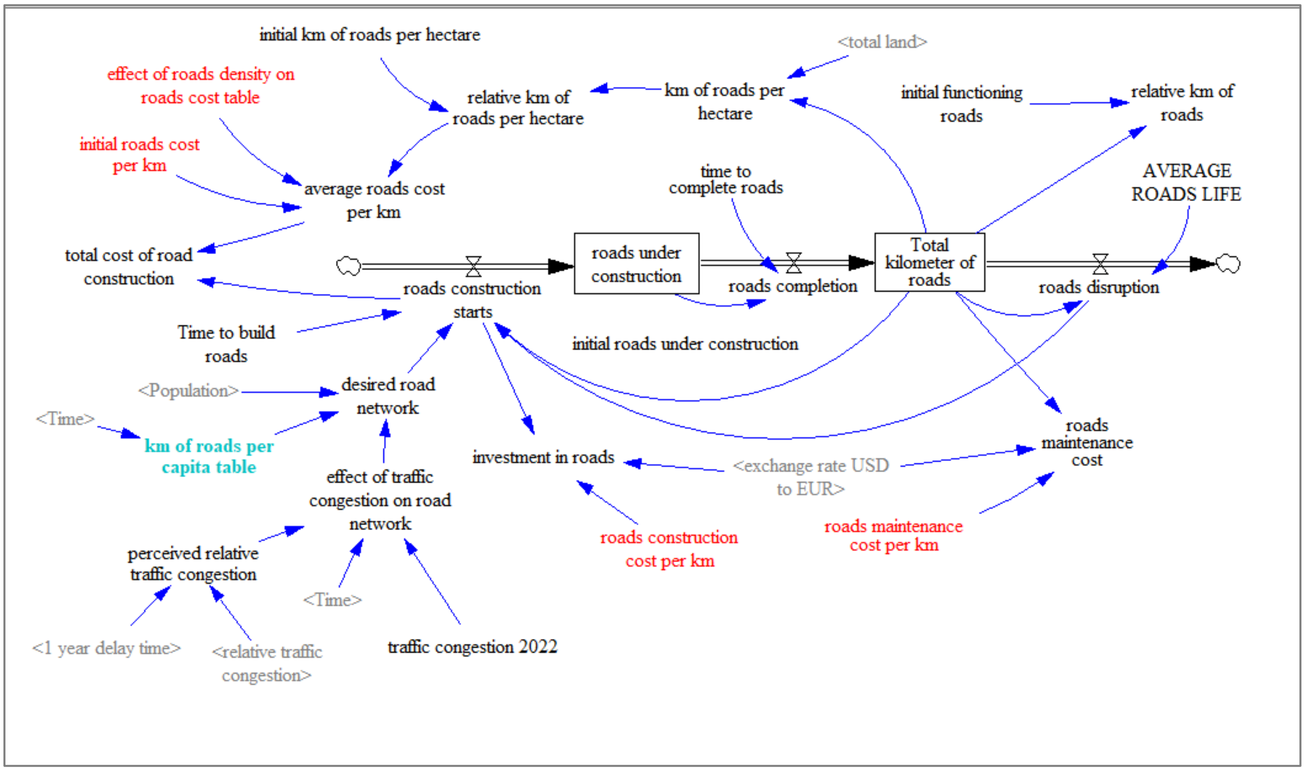


*Diagram 13: Roads module*

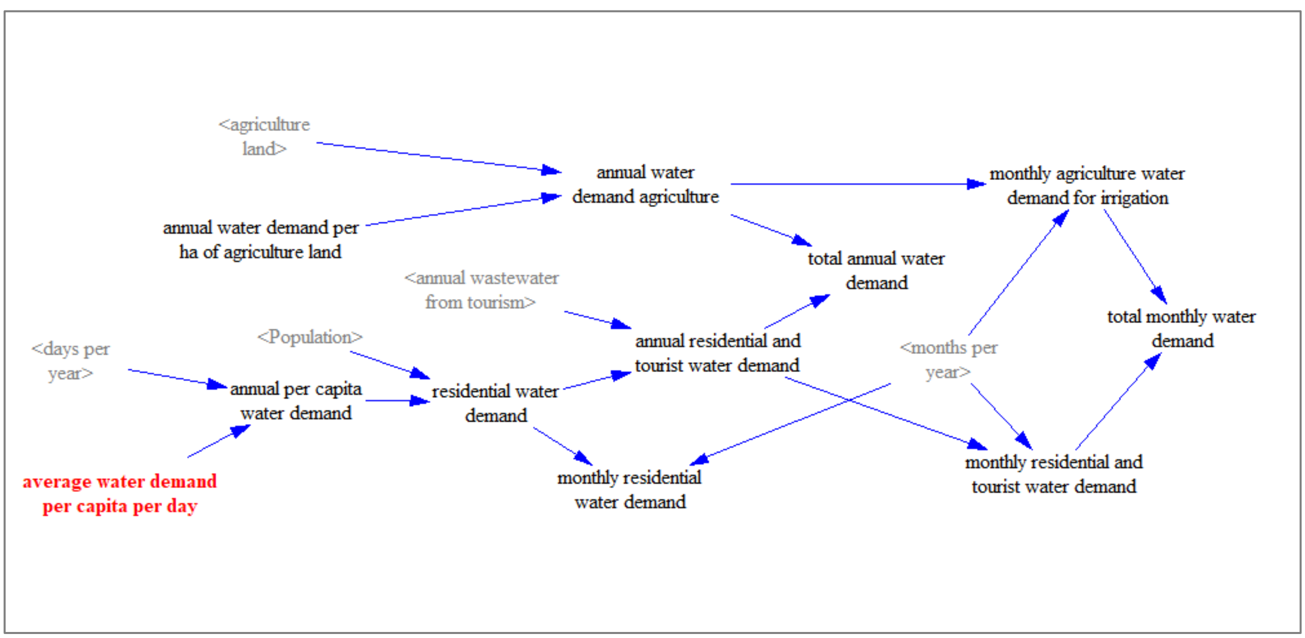


*Diagram 14: Water demand module*

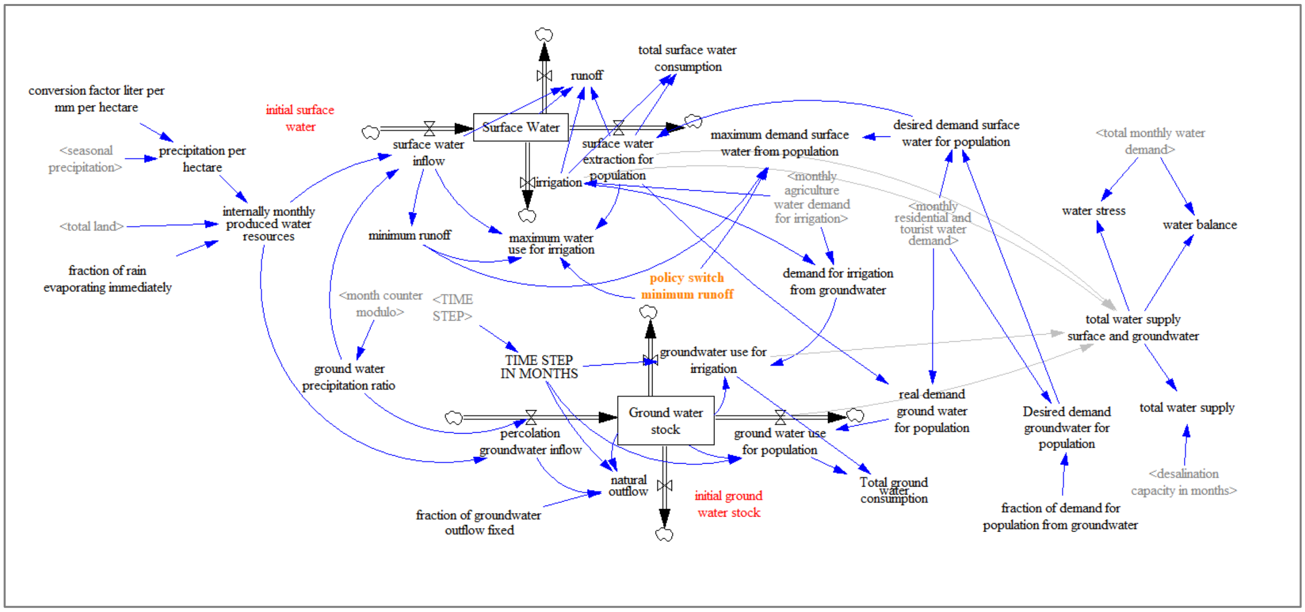


*Diagram 15: Water supply module*

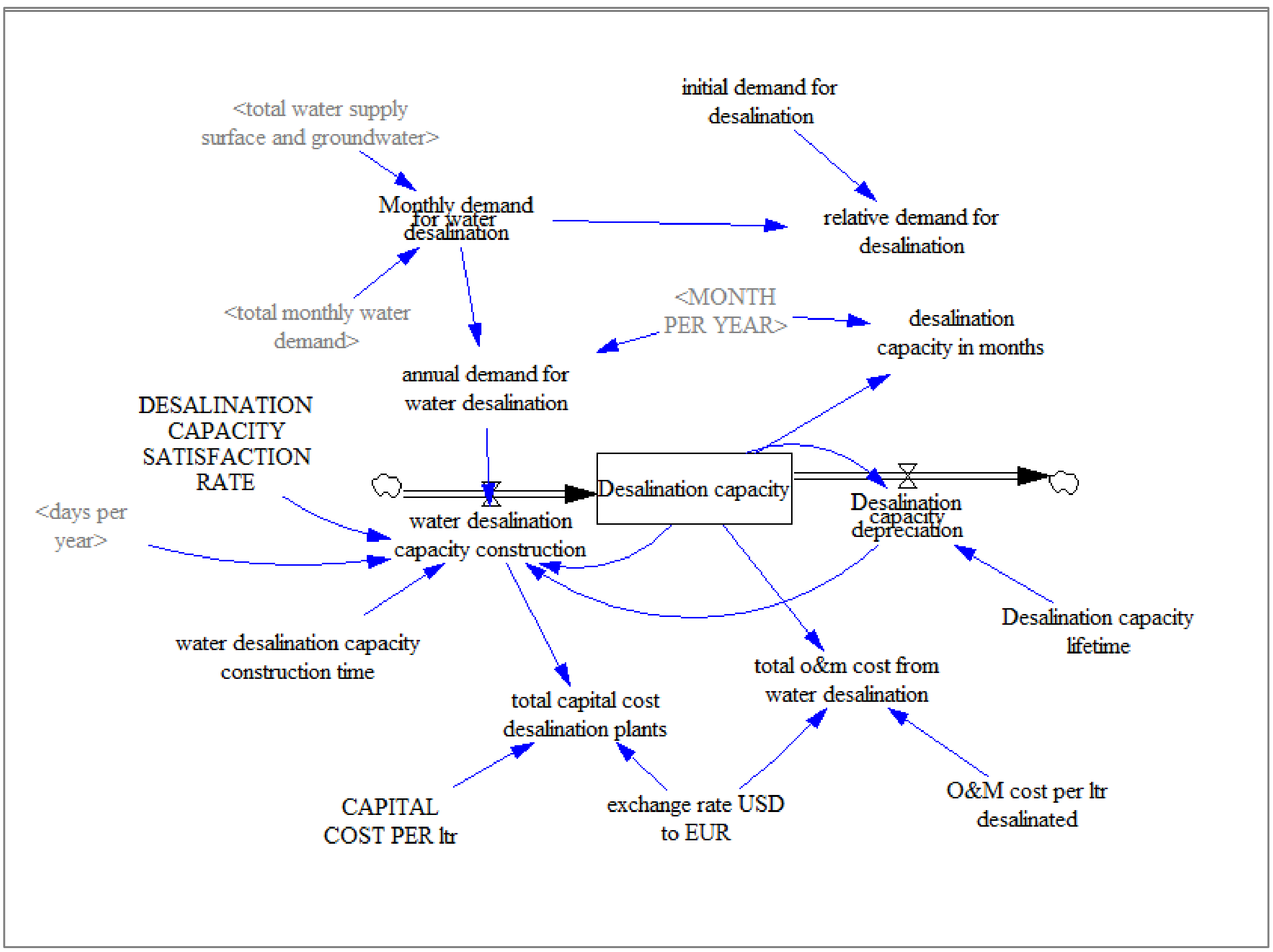


*Diagram 16: Water desalination module*

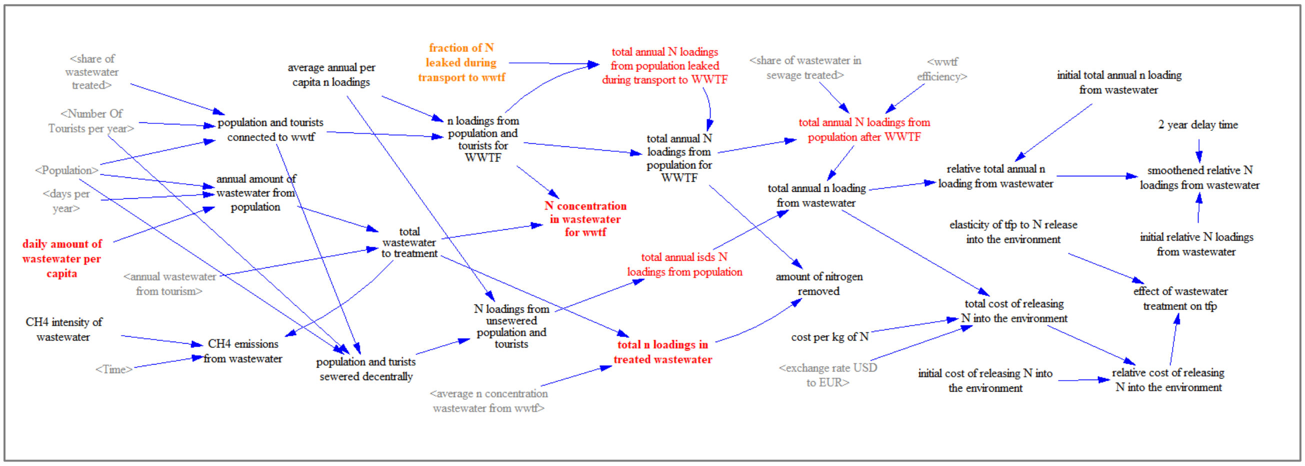

*Diagram 17: Wastewater demand module*

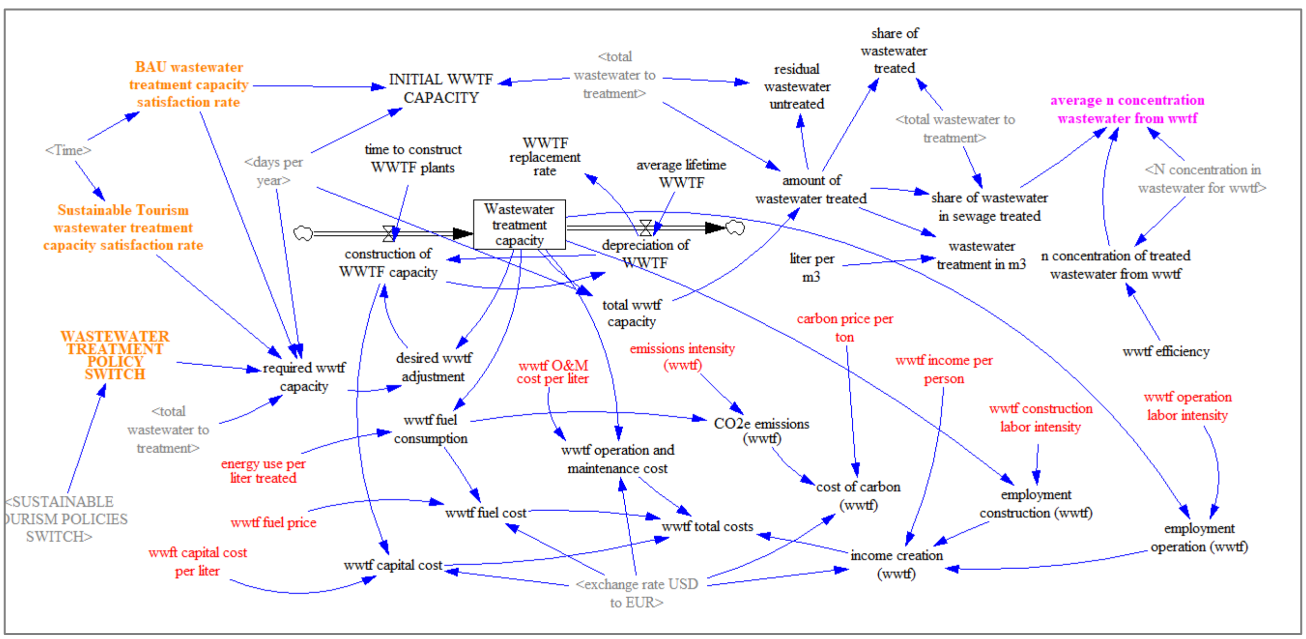

*Diagram 18: Wastewater capacity module*

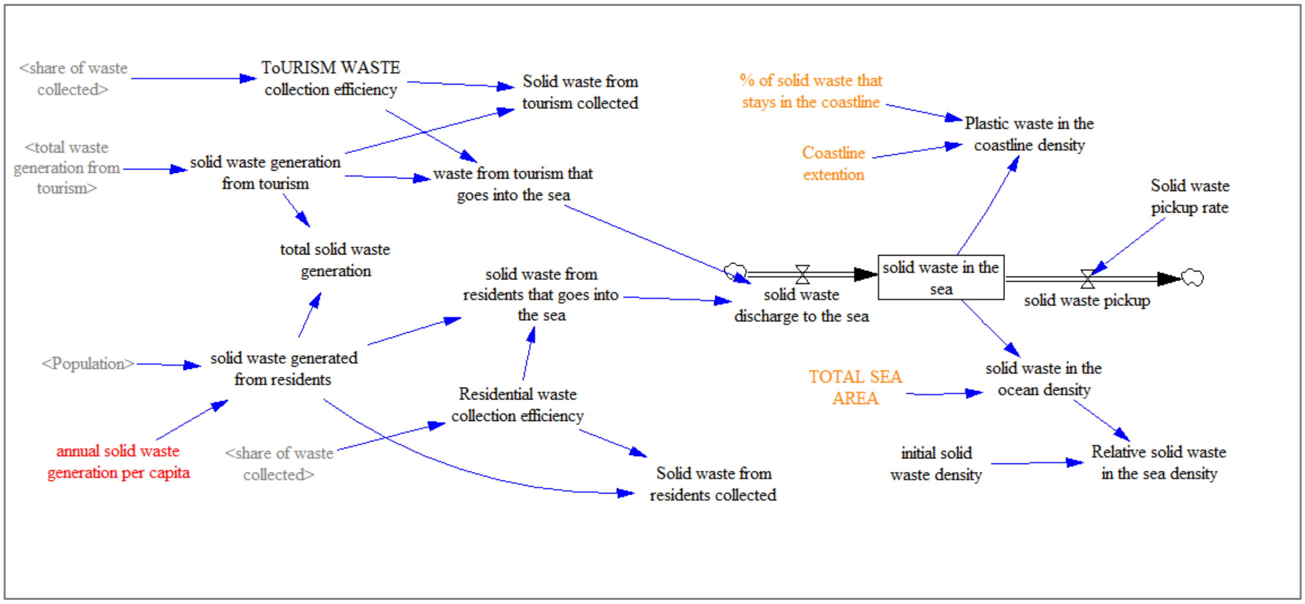


*Diagram 19: Solid waste generation module*

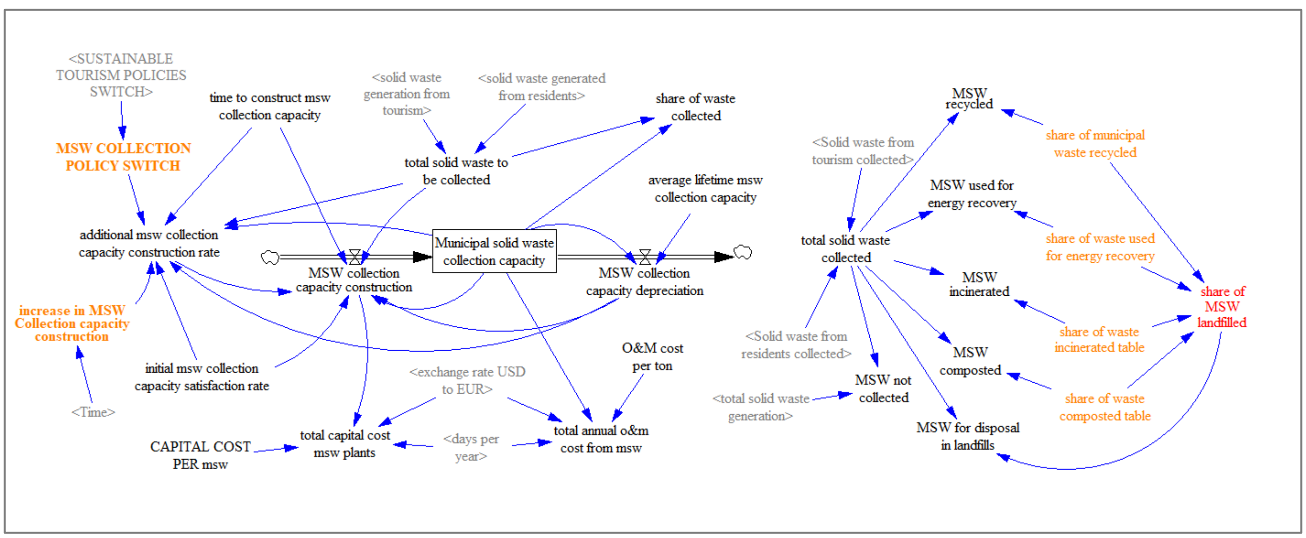


*Diagram 20: Solid waste treatment capacity module*

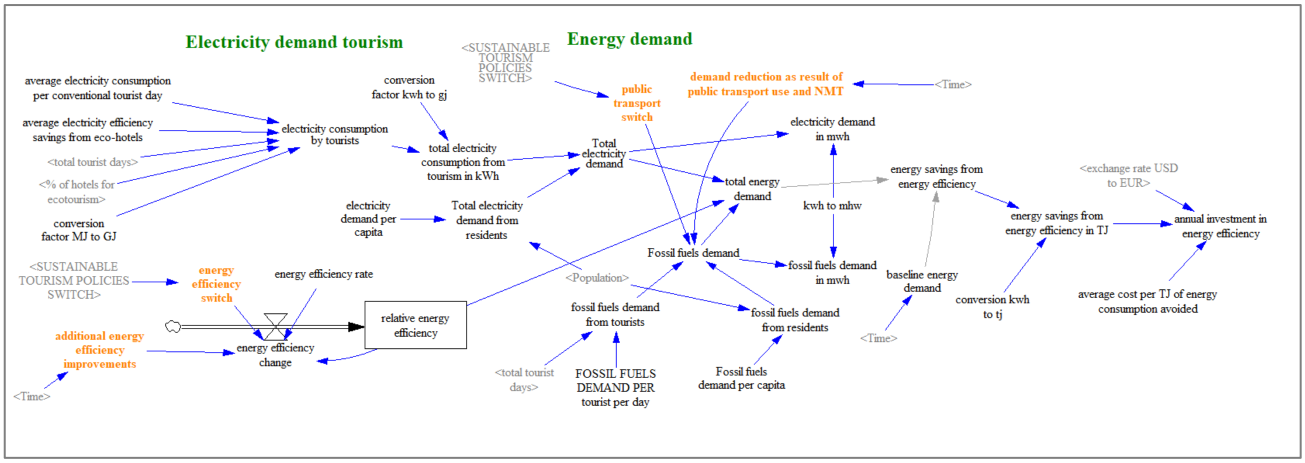

*Diagram 21: Energy demand module*

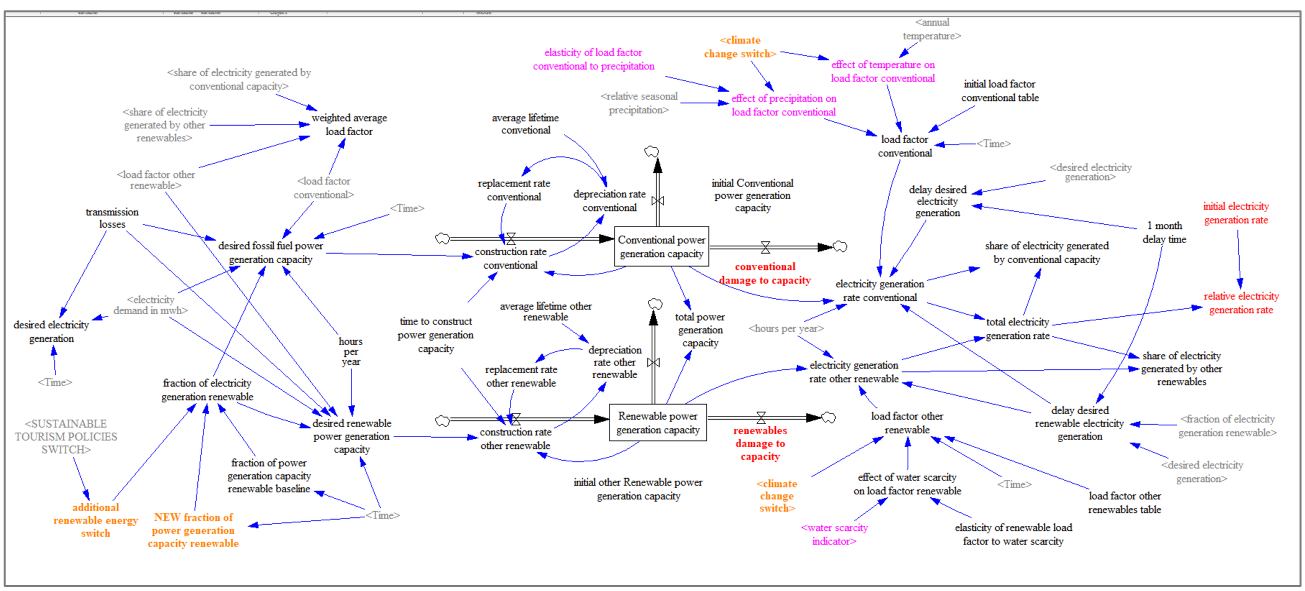

*Diagram 22: Power generation capacity module*

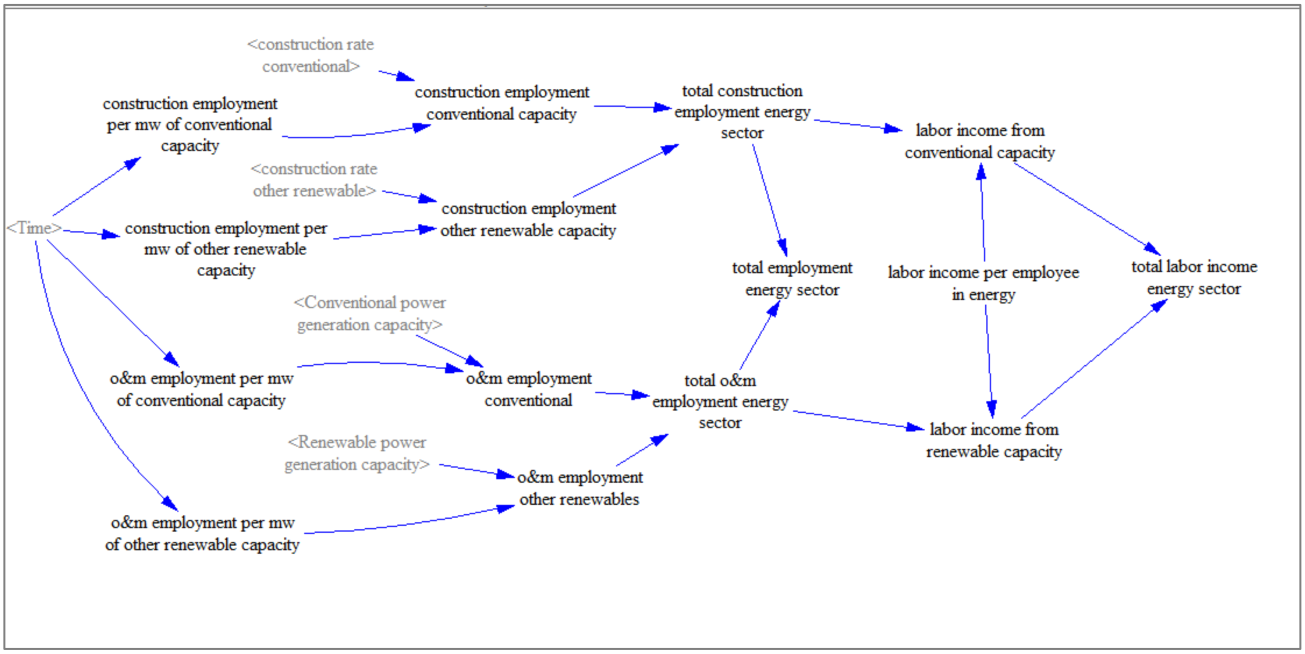


*Diagram 23: Power generation employment module*

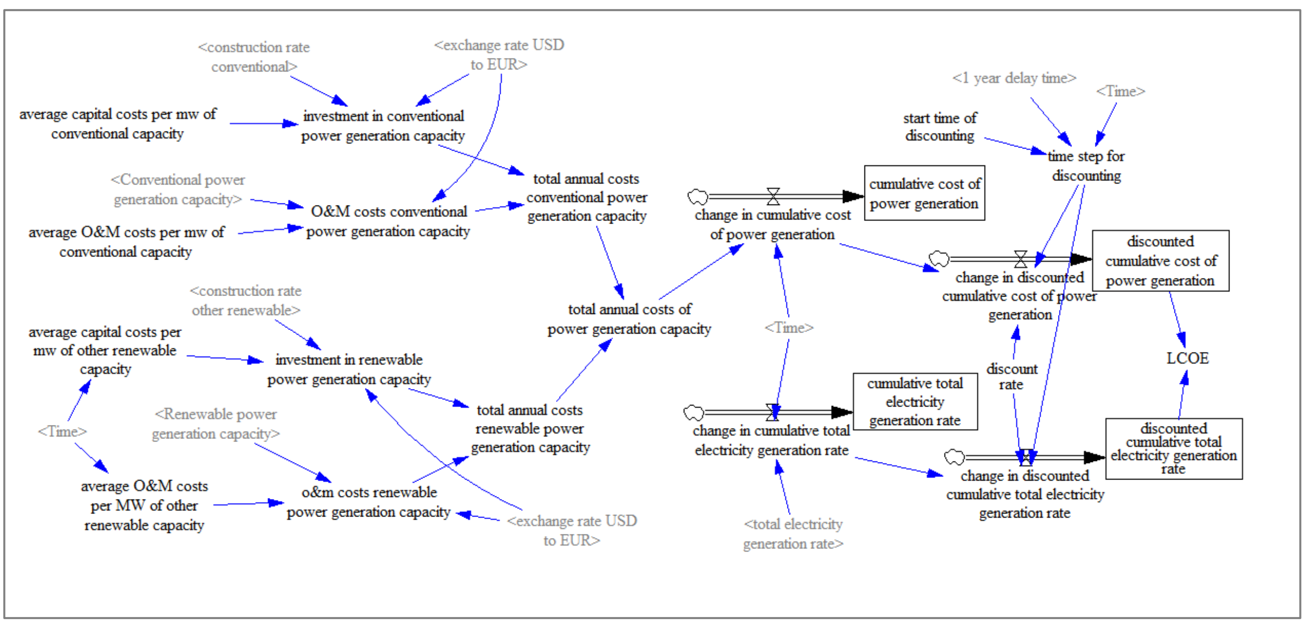


*Diagram 24: Power generation costs module*

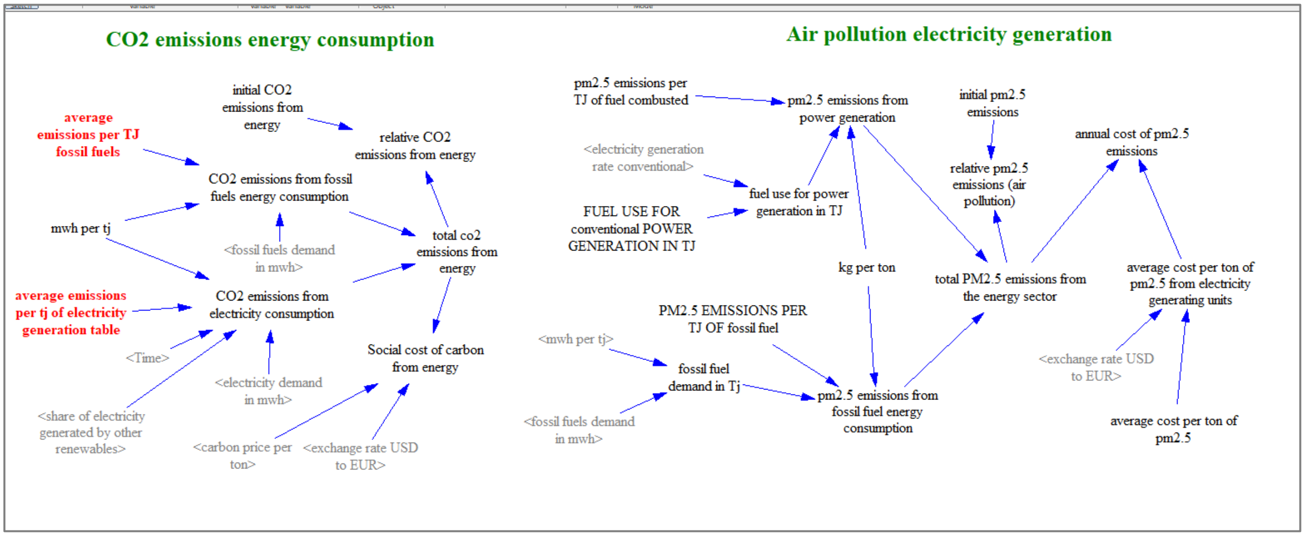


*Diagram 25: Energy emissions module*

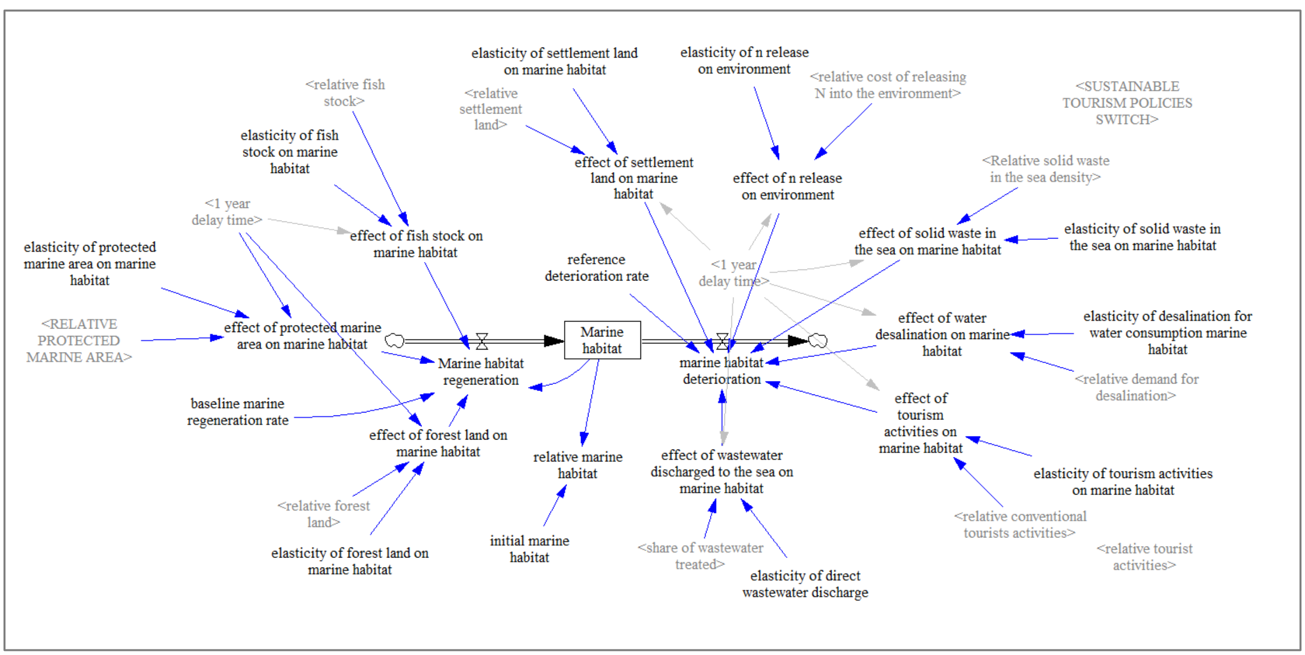


*Diagram 26: Marine habitat module*

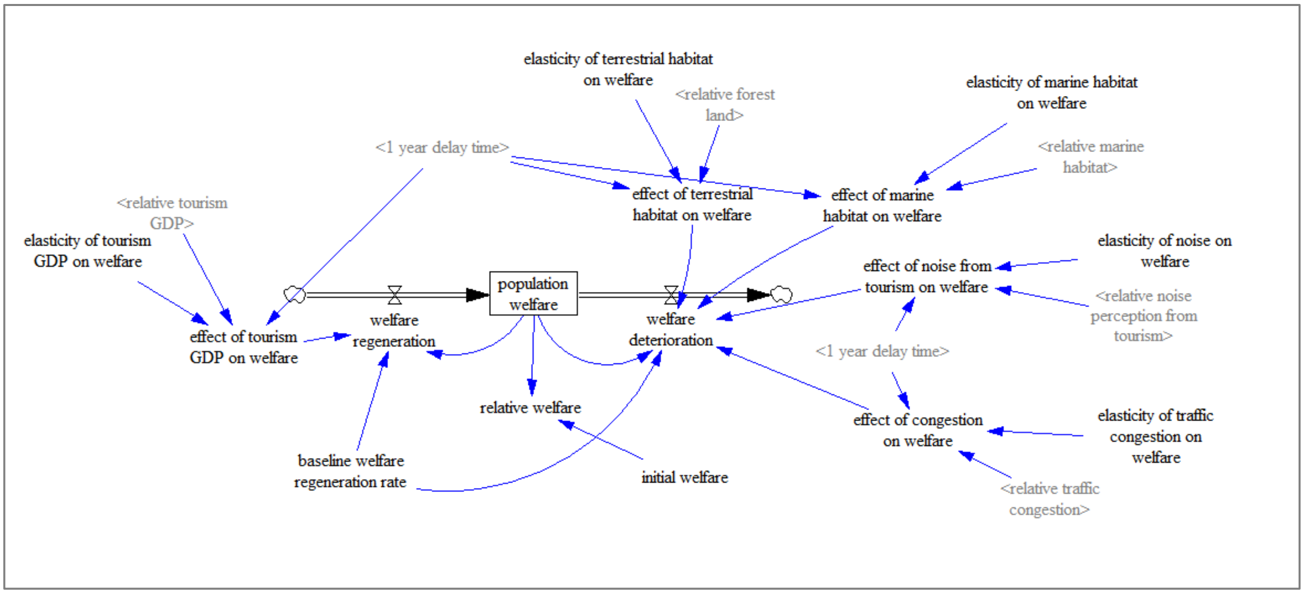


*Diagram 27: Welfare module*

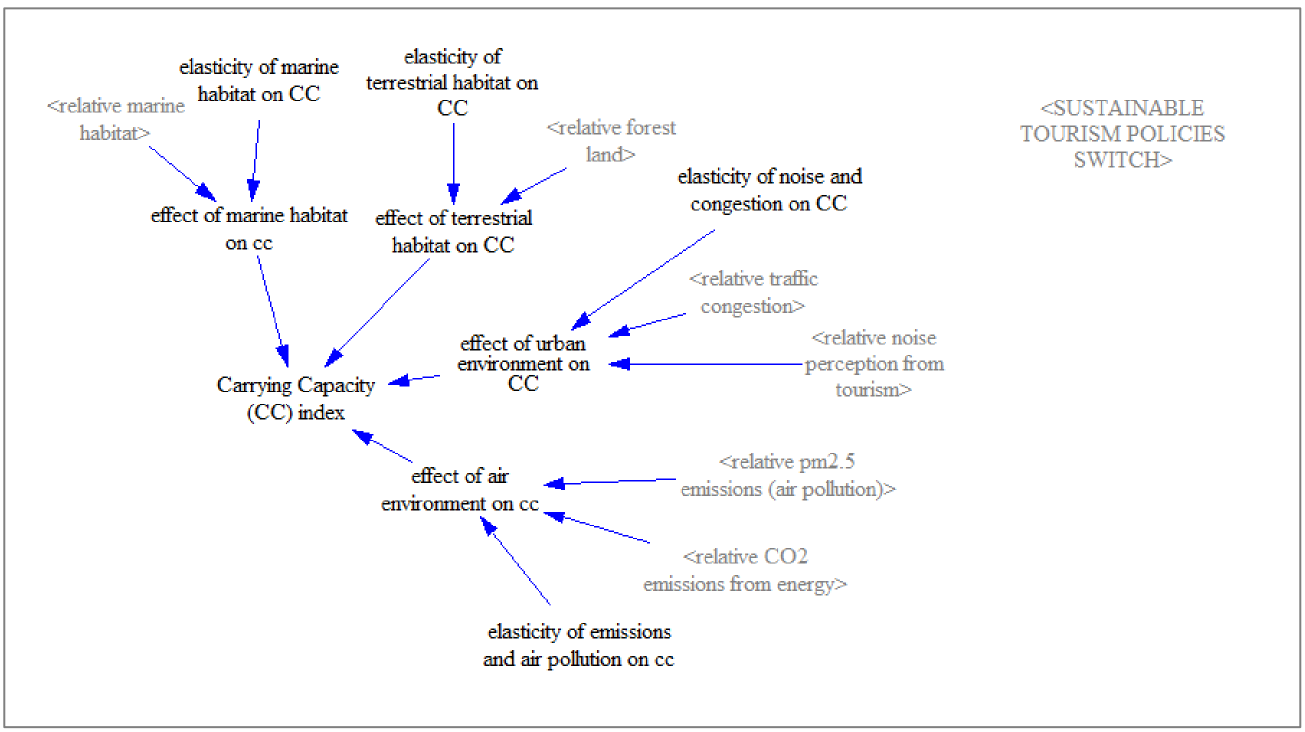


*Diagram 28: Carrying Capacity module*

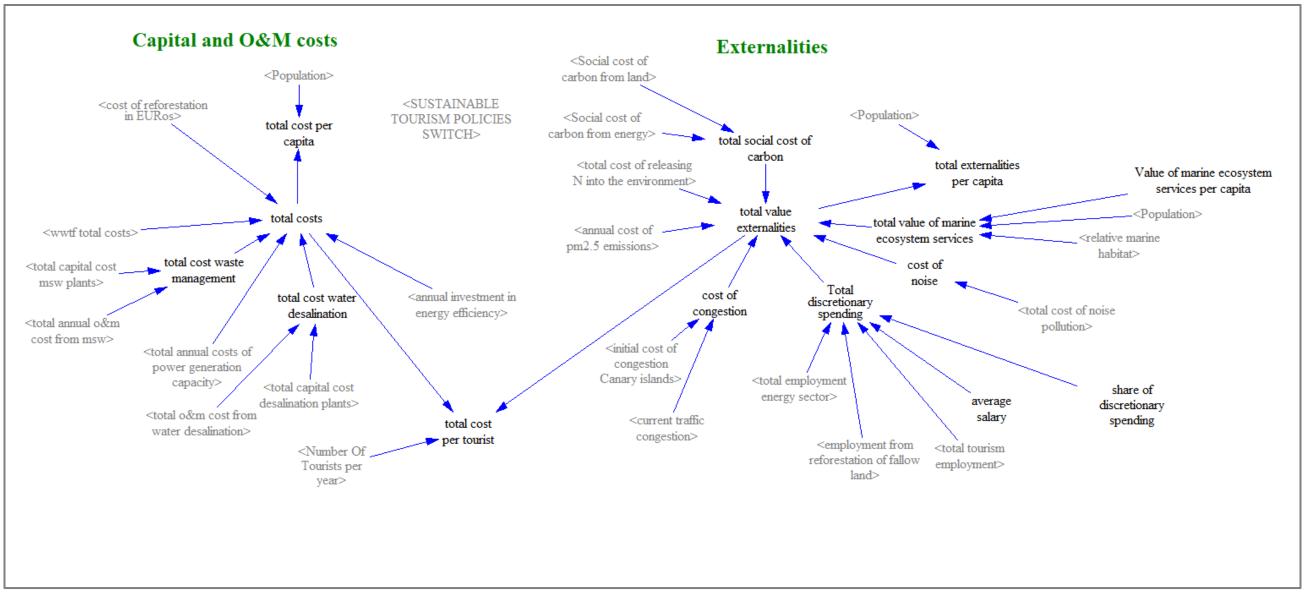

*Diagram 29: Costs module*

# Whole System Modeling of the Relationship Between Tourism Activity and Carrying Capacity in The Canary Islands

November 2023

ISBN: 978-84-09-56363-0