Climate change and adaptation efforts BES islands

Final report

Ministry of Infrastructure and Water Management

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SUMMARY

Climate change has clear effects on the BES islands (Bonaire, St. Eustatius and Saba). Among other things, these effects manifest through increasing temperatures, sea level rise and more severe hurricanes. The islands have been undertaking projects for both climate mitigation and adaptation.

This report serves 4 goals:

1 To provide more detailed insight into the climate developments that are expected to occur on the BES islands, describing the expected developments of temperature, sea level rise, precipitation, droughts and hurricanes.
2 To provide a climate change impact assessment for various sectors on the BES islands.
3 To provide an overview of past and present adaptation and mitigation efforts across the BES islands.
4 To identify any further knowledge gaps regarding climate developments and impacts.

Climate developments

In 2023, the Royal Meteorological Institute (KNMI) has developed 4 different climate change scenarios. The BES islands are included in the scenario analysis. On a coarse level, the KNMI expects the following developments resulting from climate change:

- Temperatures will continue to increase across the islands. The extent of this increase depends on the emission of greenhouse gases:
  - In the L-scenario (low emission), the increase is limited to approximately 0.8 °C.
  - In the H-scenario, the increase is projected to be much higher: up to 1.3 °C in 2050 and 3.4 °C in 2100.
- Sea level rise continues and accelerates. Sea level rise will amount to approximately 25 cm by 2050. It is projected to be between 50 cm (low emissions) and 80 cm (high emissions) in 2100. After 2050, the projections are very uncertain.
- In almost all climate scenarios, the amount of precipitation is expected to decrease or increase slightly. The extent varies strongly among climate scenarios. Bonaire records about half of the total annual precipitation as compared to Saba and St. Eustatius. This pattern remains roughly the same in the future. All precipitation predictions are highly uncertain.
- In addition to the overall drier projections, the likelihood of short and extreme precipitation will increase across the region.
- Hurricanes will not become much more frequent but will become more severe. They will also develop more rapidly and the hurricane season will become longer.

Climate impacts

In this report, the (potential) impacts of all climate hazards on various sectors (e.g. nature, water management, infrastructure) have been documented. See chapter 4 and appendix II for a full overview.

Besides sectoral impacts, climate change will have an impact on livelihoods, communities and general accessibility of the islands. The following high risk impacts were identified:

- Infrastructure may be severely damaged by floods, landslides (resulting from extreme rainfall) and hurricanes. The risk of all these impacts increases. This applies to roads, but also to harbours and ports. As a result, general accessibility is jeopardized. This affects day to day life and business.
- In terms of livelihood, tourism is an important sector on all islands. However, tourism is also vulnerable to multiple climate hazards. Potential impacts include:
  - Hurricanes may directly damage hotels and tourist attractions.
  - Income from tourism is likely to decline following hurricane events. This is due to (1) unavailability of tourist infrastructure that is still damaged, (2) regular air travel and cruise routes are disrupted and (3) tourists being scared away after hurricanes.
  - Tourism income may further decline as climate change leads to rising temperatures elsewhere. During the winter and spring, there may simply be less reason for (European) tourists to travel to places far away.
  - Coral diving is an important travel motive for many tourists on Saba and Bonaire. Coral bleaching and sedimentation of the reefs diminish their attractive value.

- Agriculture is not a major sector on either of the islands. However, it is the source of livelihood for some communities. Drought projections are very uncertain. In the worst case scenario, precipitation may decrease by up to 50 % in the long term (by 2100). This would severely affect traditional agriculture as crop cultivation may no longer be feasible. In other climate scenarios the precipitation is expected to decrease less (0 to 11 %).

Mitigation and adaptation efforts

Across the BES islands (and many small island states in general), the definitions of climate mitigation and adaptation are more ambiguous in practice. From a Caribbean perspective, most adaptation efforts are aimed at improving self-sufficiency. In this report, the classical definition from the IPCC is used:
- Mitigation aims to reduce or prevent greenhouse gas emissions to slow climate change.
- Adaptation involves adjusting systems and the environment to cope with the impacts of climate change, thereby reducing harm or exploiting beneficial opportunities.

Mitigation

All islands have undertaken several efforts for sustainable energy production through solar and wind power. By 2025, about 75 % of the energy production on the islands is projected to be sustainable. In addition, Bonaire has plans to start electrically powered aviation in the next decade, and there are plans for more sustainable transit.

Adaptation

All islands have also taken steps to improve climate adaptation. On a coarse level, their efforts focus on:
- Reforestation (also to combat erosion).
- Limitation of grazers to combat erosion.
- Coral restoration.
- Mangrove restoration.
- Grey water reuse and rainwater harvesting.
- Governance efforts that directly and indirectly include adaptation measures.

The following sectors receive relatively little attention in terms of adaptation efforts, while the climate impact is projected to be severe:
- Health: across the islands there are few efforts aimed at improving health. This sector is threatened by multiple climate hazards, such as heat, floods and hurricanes.
- Tourism: the islands' economies greatly depend on tourism and the sector is vulnerable to multiple climate hazards (e.g. damage to tourism infrastructure due to hurricanes and floods, shorter tourism season due to hurricanes). Despite the efforts in coral protection and restoration, no specific adaptation measures have been found regarding the broader tourism infrastructure.
- Agriculture: some communities across the islands rely on agriculture for their livelihoods. Efforts are being made to increase rainwater harvesting. However, for the driest climate scenarios (although highly uncertain) rainwater harvesting may not be sufficient and crop cultivation will then be severely limited. Hydroponic farming (e.g. on Saba) is a potential solution.
- Accessibility: the islands are vulnerable to disruptions of global supply lines. Despite the steps taken for self-sufficiency, infrastructure networks (e.g. roads, ports and airports) remain vulnerable to multiple climate hazards. For example because of floods and hurricane damage.

It is recommended to determine, in collaboration with local authorities, which sectors face the greatest and most urgent climate risks and prepare measures for those sectors. If insufficient knowledge is available, then further research can be conducted (see also identified knowledge gaps). For sectors with lower risks, it is still recommended to incorporate climate vulnerabilities into future efforts.

Additional knowledge gaps

Several knowledge gaps have been identified. The most important ones are listed below:
- There is a good overview of general climate effects in the Caribbean region. However, there is no island-specific information on climate effects and impacts. Such an overview is important to target specific measures and draft adaptation plans.

- Precise impacts of climate change on the sector level are partly unknown. This report provides an overview of (potential) impacts and qualitatively assesses their risk. Ideally, climate adaptation plans are also based on quantitative information to decide which measures can be (cost) effective.
- Some basic information of the physical environment is lacking, for example a detailed DEM, information on soil composition and a comprehensive overview of catchments and urban drainage. Such information is crucial to plan and design specific interventions for climate adaptation.
- The effectiveness of adaptation measures is currently not monitored and evaluated. As a result, there is no clear overview of best practices from which policy makers may benefit.

SAMENVATTING

Klimaatverandering heeft diverse effecten op de BES-eilanden (Bonaire, St. Eustatius en Saba). Deze effecten manifesteren zich onder andere door stijgende temperaturen, zeespiegelstijging en hevigere orkanen. De eilanden voeren al projecten uit voor zowel klimaatmitigatie als -adaptatie.

Dit rapport heeft 4 doelstellingen:

1 Meer inzicht bieden in de verwachte klimaatontwikkelingen op de BES-eilanden, waaronder stijgende temperatuur, zeespiegelstijging, neerslag, droogte en orkanen.
2 De (mogelijke) impact van klimaatverandering voor verschillende sectoren op de BES-eilanden kwalitatief in kaart brengen.
3 Een overzicht geven van eerdere en huidige inspanningen voor adaptatie en mitigatie op de BES-eilanden.
4 Eventuele kennisleemtes over klimaatontwikkelingen en -effecten identificeren.

Klimaatontwikkelingen

In 2023 heeft het Koninklijk Nederlands Meteorologisch Instituut (KNMI) vier verschillende klimaatscenario's ontwikkeld. Daarin zijn de BES-eilanden ook meegenomen. Op hoofdlijnen verwacht het KNMI de volgende ontwikkelingen als gevolg van klimaatverandering:

- De temperaturen blijven stijgen op de eilanden, afhankelijk van de uitstoot van broeikasgassen:
  - In het L-scenario (lage uitstoot) is de stijging beperkt tot ongeveer 0,8 °C.
  - In het H-scenario wordt een stijging tot 1,3 °C in 2050 en 3,4 °C in 2100 voorspeld.
- De zeespiegel blijft stijgen en dit proces versnelt. Tegen 2050 zal de stijging ongeveer 25 cm bedragen. In 2100 wordt een stijging tussen 50 cm (lage uitstoot) en 80 cm (hoge uitstoot) voorspeld. Na 2050 zijn de voorspellingen zeer onzeker.
- In bijna alle klimaatscenario's zal de hoeveelheid neerslag afnemen. De mate hiervan varieert sterk per scenario. Bonaire ontvangt ongeveer de helft van de jaarlijkse neerslag in vergelijking met Saba en St. Eustatius. Dit patroon blijft ongeveer gelijk. Alle voorspellingen over neerslag zijn zeer onzeker.
- Naast de overwegend drogere voorspellingen, zal de kans op korte en hevige neerslag toenemen in de regio.
- Orkanen zullen niet veel vaker voorkomen, maar ze zullen heviger worden. Ze zullen zich ook sneller ontwikkelen en het orkaanseizoen zal daardoor langer duren.

Klimaateffecten

In dit rapport zijn de (potentiële) effecten van klimaatrisico's op verschillende sectoren (bijvoorbeeld natuur, waterbeheer, infrastructuur) beschreven. Zie hoofdstuk 4 en bijlage II voor een volledig overzicht.

Naast sectorale effecten zal klimaatverandering ook een impact hebben op het levensonderhoud, lokale gemeenschappen en de algemene toegankelijkheid van de eilanden. De volgende belangrijkste en risicovolle effecten zijn geïdentificeerd:

- Infrastructuur kan ernstig beschadigd worden door overstromingen, aardverschuivingen (als gevolg van extreme regenval) en orkanen. Het risico op al deze effecten neemt toe. Dit geldt voor wegen, maar ook voor (lucht)havens. Hierdoor wordt de algemene toegankelijkheid verminderd, wat het dagelijkse leven en het bedrijfsleven beïnvloedt.
- Op het gebied van levensonderhoud is toerisme een belangrijke sector op alle eilanden. Toerisme is echter kwetsbaar voor meerdere klimaatbedreigingen. Mogelijke gevolgen zijn:
  - Orkanen kunnen hotels en toeristische attracties direct beschadigen.
  - Inkomen uit toerisme zal waarschijnlijk afnemen na orkanen door (1) beschadigde toeristische infrastructuur, (2) onderbrekingen van vlieg- en cruiseverkeer en (3) toeristen die na orkanen wegblijven.
  - Het toerisme kan verder afnemen door stijgende temperaturen elders. In de winter en het voorjaar is er mogelijk minder reden voor (Europese) toeristen om naar verre bestemmingen te reizen.
  - Koraalduiken is een belangrijke reden voor toeristen om Saba en Bonaire te bezoeken. Koraalverbleking en sedimentatie van de riffen verminderen hun aantrekkelijkheid.

- Landbouw is geen bijzonder belangrijke of omvangrijke sector op de eilanden, maar wel een bron van levensonderhoud voor sommige gemeenschappen. De droogtevoorspellingen zijn zeer onzeker. In het minst gunstige geval kan de neerslag op de lange termijn (2100) met 50 % afnemen. Dit zou traditionele landbouw ernstig aantasten omdat het verbouwen van de meeste gewassen dan wellicht niet meer mogelijk is. In de andere klimaatscenario's neemt de neerslaghoeveelheid niet of beperkter af (0 tot 11 %).

Mitigatie- en adaptatiemaatregelen

Op de BES-eilanden (en veel kleine eilandstaten in het algemeen) zijn de definities van klimaatmitigatie en -adaptatie in de praktijk vaak minder duidelijk. Vanuit een Caribisch perspectief zijn de meeste adaptatiemaatregelen gericht op het vergroten van zelfvoorziening. In dit rapport wordt echter de klassieke definitie gehanteerd van het IPCC:
- Mitigatie richt zich op het verminderen of voorkomen van de uitstoot van broeikasgassen om klimaatverandering te vertragen.
- Adaptatie omvat het aanpassen van systemen en de omgeving als reactie op de werkelijke of verwachte gevolgen van klimaatverandering, door schade waar mogelijk te beperken of kansen te benutten.

Mitigatie

Alle eilanden hebben verschillende inspanningen geleverd voor duurzame energieproductie via zonne- en windenergie. Tegen 2025 zal naar verwachting ongeveer 75 % van de energieproductie op de eilanden duurzaam zijn. Daarnaast heeft Bonaire plannen om in het komende decennium elektrisch vliegen te introduceren, en er zijn plannen voor duurzamer vervoer.

Adaptatie

Ook zijn er stappen ondernomen om de klimaatadaptatie te verbeteren. Globaal richten deze inspanningen zich op:
- Herbebossing (ook om erosie te bestrijden).
- Beperking van grote grazers om erosie te bestrijden.
- Koraalherstel.
- Mangroveherstel.
- Hergebruik van grijs water en opvang van regenwater.
- Ruimtelijke ordening.
- Beleidsontwikkelingen die zowel directe als indirecte klimaatadaptatie omvatten.

De volgende sectoren krijgen relatief weinig aandacht in termen van adaptatiemaatregelen, terwijl de impact van klimaatverandering op deze gebieden groot wordt geacht:
- Gezondheid: op de eilanden zijn tot dusver weinig maatregelen genomen om de gezondheid te verbeteren in het licht van klimaatverandering. Deze sector wordt bedreigd door meerdere klimaatrisico's, zoals hitte, overstromingen en orkanen.
- Toerisme: de economieën van de eilanden zijn sterk afhankelijk van toerisme, maar deze sector is kwetsbaar voor meerdere klimaatrisico's (zoals schade aan toeristische infrastructuur door orkanen en overstromingen, korter toeristenseizoen door orkanen). Ondanks inspanningen op het gebied van koraalbescherming en -herstel – een belangrijke toeristische trekpleister – zijn er geen specifieke adaptatiemaatregelen gevonden met betrekking tot de bredere toeristische infrastructuur.
- Landbouw: sommige gemeenschappen op de eilanden zijn afhankelijk van landbouw voor hun levensonderhoud. Er worden inspanningen getroffen om de regenwateropvang te vergroten. Voor de droogste klimaatscenario's (hoge mate van onzekerheid) zal dit niet genoeg blijken om gewasverbouwing mogelijk te houden. Hydrocultuur (zoals gestart op Saba) is een mogelijke oplossing.
- Toegankelijkheid: de eilanden zijn kwetsbaar voor verstoringen van wereldwijde bevoorradingslijnen. Ondanks de stappen naar meer zelfvoorziening blijven infrastructuurnetwerken (wegen, havens en luchthavens) kwetsbaar voor natuurrampen zoals overstromingen en orkaanschade. Door klimaatverandering zullen deze naar waarschijnlijkheid toenemen.

Er wordt aanbevolen om, in samenwerking met de lokale bevolking, te bepalen in welke sectoren de grootste en meest urgente klimaatrisico's aanwezig zijn en om voor die sectoren bestuurlijke besluitvorming over eventuele maatregelen voor te bereiden. Indien er niet voldoende of de juiste kennis beschikbaar is, dient eerst meer onderzoek worden gedaan (zie ook de kennisleemtes). Voor sectoren met een lager risico wordt alsnog aanbevolen om klimaatkwetsbaarheden mee te nemen in toekomstige inspanningen.

Aanvullende kennisleemtes

Er zijn verschillende kennisleemtes geïdentificeerd. De belangrijkste zijn hieronder opgesomd:

- Er is een goed overzicht van de algemene klimaateffecten in het Caribisch gebied, maar er is geen eiland-specifieke informatie over klimaateffecten en -gevolgen. Een dergelijk overzicht is belangrijk om gerichte maatregelen te nemen en adaptatieplannen op te stellen.
- De exacte gevolgen van klimaatverandering op sectorniveau zijn deels onbekend. Dit rapport biedt een overzicht van (potentiële) effecten en beoordeelt hun risico's kwalitatief. Idealiter zijn klimaatadaptatieplannen ook gebaseerd op kwantitatieve informatie om te bepalen welke maatregelen (kosten)effectief kunnen zijn.
- Bepaalde basisinformatie over de fysieke omgeving ontbreekt, zoals een gedetailleerd digitaal hoogtebestand, informatie over de bodemopbouw en een uitgebreid overzicht van stroomgebieden en stedelijke afwatering. Deze informatie is cruciaal voor het plannen en ontwerpen van specifieke aanpassingen voor klimaatadaptatie.
- De effectiviteit van adaptatiemaatregelen wordt momenteel niet gemonitord en geëvalueerd. Hierdoor is er geen duidelijk overzicht van goede praktijken waar beleidsmakers van kunnen profiteren.

TERMINOLOGY

Table 1.1 provides definitions and clarifications of terminology used throughout this document.

Table 1.1 Overview of terminology and definitions

Terminology	Definition/clarification
Climate development	Observed or projected changes in climate parameters, such as temperature, precipitation and sea level
Climate impact	The effects and consequences as a result of climate change
Climate hazard	Negative climate impact that threatens society and or the economy
Climate mitigation	Limiting the magnitude of long-term climate change, such as by reducing greenhouse gas emissions or reducing actions that are harmful to the environment
Climate adaptation	Changes made to minimize the present and future impacts of climate change. The focus in the BES islands is on increasing the resilience regardless of climate developments
Climate mitigation/ adaptation efforts	Measures, plans, strategies and projects that aim to improve climate mitigation and/or adaptation on the BES islands
DCNA	Dutch Caribbean Nature Alliance
OLB	Public Entity Bonaire (Openbaar Lichaam Bonaire)
OLE	Public Entity Bonaire (Openbaar Lichaam St. Eustatius)
OLS	Public Entity Saba (Openbaar Lichaam Saba)
Sector	Specific part of society or the economy that is made up of similar elements. In this report, the 10 sector definitions of the National Climate Adaptation Strategy (NAS) are used (see chapter 4)

1

INTRODUCTION

1.1 Background

Introduction
Climate change has profound effects on the islands Bonaire, St. Eustatius (Statia) and Saba (together also known as the BES islands). For example, the frequency and intensity of heat waves and dry spells increase, and the islands' drainage systems cannot cope with extreme precipitation events increasing in frequency and severity. In addition, St. Eustatius and Saba are vulnerable to hurricanes, which are also increasing in severity. While Bonaire is not located within the hurricane belt, tropical storms will become more severe as well. Despite efforts to increase resilience against climate hazards, the islands remain vulnerable to the adverse effects of climate change.

1.2 Knowledge gaps

Knowledge of climate change
In the Netherlands, the Royal Meteorological Institute (KNMI) draws from IPCC research and has developed 4 different climate change scenarios specifically for the Dutch territory including the public entities. Each scenario is a combination of (1) a low or high carbon emission scenario and (2) drier or wetter climate conditions. No probability is assigned to each scenario, and all of them are considered as possible outcomes (KNMI, 2023). The KNMI has historically focused only on the European Netherlands. The Caribbean part of the Netherlands was included in the KNMI report for the first time in 2023. Thus, the scenarios and evolution of variables are now provided for the BES islands in the same way as the Netherlands, albeit on a much coarser level. This is because there is less climate data available on the BES islands and because no detailed regional climate model is available. As the climate scenarios are recent, the most up-to-date climate insights have not yet been translated into climate (policy) plans on the islands.

On a coarse level, the expected climate developments are clear. The climate developments have various effects on sectors on the islands, such as agriculture, transportation and nature. Possible effects include reduced crop yields due to prolonged droughts, disrupted supply chains due to hurricanes and damage to nature areas. However, there is currently no analysis that encompasses all 3 BES islands and makes a detailed analysis of climate impacts on the sector level.

Availability of funding for mitigation and adaptation
Since the islands are a part of the Netherlands, they do not qualify for international assistance reserved to developing countries. However, access to European Union (EU) funds is not guaranteed either, since the islands are outside of the EU and therefore do not always meet the requirements. The BES islands do have access to national funding, but still have limited financial and human capacity and technical expertise to develop, implement and monitor the plans and measures that are necessary to adapt to climate change.

Lack of overview on adaptation and mitigation efforts
The Ministry of Infrastructure and Water Management (referred to as IenW throughout this document) shares responsibility for policy making on the BES islands with the islands themselves. This also concerns policies for climate change adaptation. The Ministry of Climate Policy and Green Growth is responsible for

climate change mitigation. To compose an integral climate adaptation plan, IenW requires a complete overview of past and current climate adaptation and mitigation efforts across the islands. Such an overview is currently lacking.

1.3 Goals of this report

This report aims to fill the 3 knowledge gaps identified in section 1.1. More specifically, the report serves the following 4 goals:

1. To provide more detailed insight into the climate developments that are expected to occur on the BES islands, describing the expected developments of temperature, sea level rise, precipitation, droughts and hurricanes.
2. To provide a climate change impact assessment for various sectors on the BES islands.
3. To provide an overview of past and present adaptation and mitigation efforts across the BES islands.
4. To identify any further knowledge gaps regarding climate developments and impacts.

1.4 Reading guide

The remainder of the report is structured as follows:

- Chapter 2 describes the climate developments projected to occur in the BES islands.
- Chapter 3 describes the climate impact assessment for 10 sectors in the BES islands, as well as the climate impact on the economy and livelihood.
- Chapter 4 describes the current adaptation and mitigation efforts in the BES islands.
- Chapter 5 analyses the current gap between the expected impacts and the current efforts and provides recommendations on how to address these gaps.
- Chapter 6 contains a list of references.

2

CLIMATE CHANGE DEVELOPMENTS

2.1 Introduction

Multiple aspects of climate change have been studied and reported on by the IPCC and the KNMI. In addition, various scientific papers have been published in which climate change developments are described. The climate change developments are outlined in this chapter.

2.2 Data acquisition and climate modelling

The IPCC gathers, assesses and summarizes large amounts of independent climate research. The Working Group 1, which focuses on the physical science of climate, largely bases its activity on the 28 global climate models (GCM) put together by the Coupled Model Intercomparison Project (CMIP), as well as regional climate models (RCM) put together by the Coordinated Regional Downscaling Experiment (CORDEX) programme. The KNMI uses the same GCMs as starting points to develop its scenarios for the European and the Caribbean Netherlands. However, the procedure is different: in Europe the KNMI uses RCMs, while for the Caribbean they apply statistical downscaling by choosing the 10 wettest and driest available models. To run these, KNMI uses data from nearby Sint Maarten and Curaçao, which is then interpolated for each specific BES island.

The low resolution of climate models, their continuous downscaling processes, as well as the small size of the islands cause many of the results obtained so far to be uncertain. This means that it is difficult to establish trends that are clear or that have a high degree of confidence, with some models often contradicting each other. This effect is amplified by the local variability (for example in microclimate) that each island has, which makes general conclusions only applicable to a certain extent or field. Moreover, the observation data gap is significant due to the historic isolation of the islands. To overcome this, the KNMI conducts continuous research such as field measurements or model refining out in specific regions and islands to understand how their unique characteristics influence climate developments.

In their latest KNMI’23 climate scenarios, the KNMI distinguish 4 main climate scenarios (KNMI, 2023):
1. High emission, dry (Hd).
2. High emission, wet (Hn).
3. Low emission, dry (Ld).
4. Low emission, wet (Ln).

This approach is similar to the KNMI ’23 scenarios of the European Netherlands. However, in the case of the BES islands the KNMI consider the wet and dry season rather than summer and winter.

Many publications make a distinction between the western, northern, eastern and southern Caribbean as many climate phenomena strongly differ across geographical locations. Saba and St. Eustatius are parts of the eastern Caribbean, while Bonaire belongs to the southern Caribbean.

2.3 Climate change per climate topic

Sections 3.3.1 through 3.3.4 discuss in detail the climate change developments in the region for 4 specific climate topics:

1 Heat and rising temperature on land and in the sea.
2 Sea level rise.
3 Precipitation and drought.
4 Extreme storm events and hurricanes.

These topics were selected because they are currently believed to be the 4 most relevant and impactful climate developments in the region. The information in this chapter is limited to factual information on climate developments. Their (potential) impacts are discussed in chapter 4.

2.3.1 Heat and rising temperature

The BES islands' average temperature is expected to rise in all of the KNMI scenarios, reaching a 0.8-1.2 °C increase against the reference temperature (1991-2020) by 2050. Figure 2.1 shows the development of air temperature for Bonaire (left) and St. Eustatius and Saba (right).

Figure 2.1 Annual averaged temperatures as compared to the 1991-2014 reference on Bonaire (left) and St. Eustatius and Saba (right). The figure shows both past observations and future projections according to the L- and H-scenarios (KNMI, 2023)

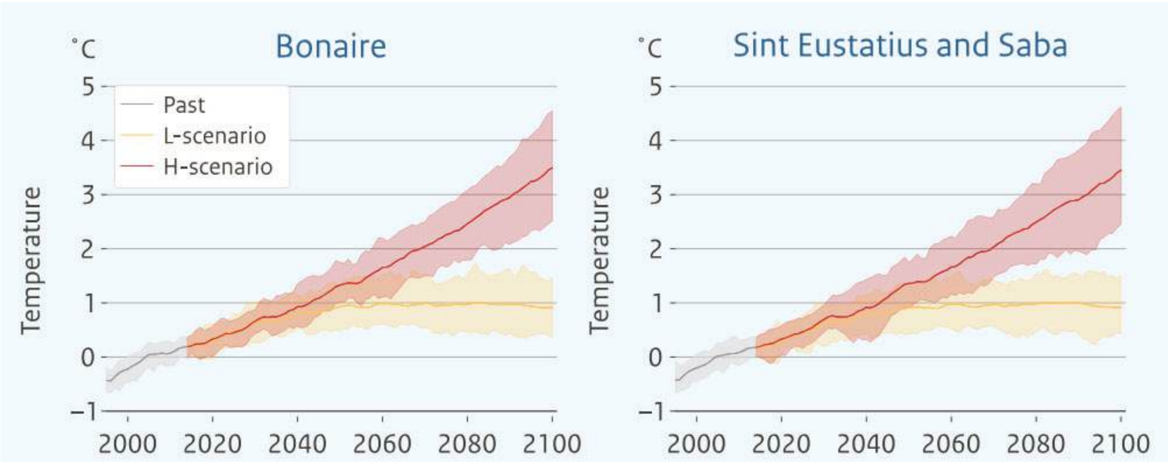


Table 2.1 Projected change in air temperature on the BES islands (annual and wet/dry season). The bandwidths of L- and H-scenarios are shown

Island	Season and reference (1991-2020)	L-scenario 2050 and 2100	H-scenario 2050 and 2100
Bonaire	Annual (28.5 °C)	+0.8 °C / +0.7 °C	+1.2 °C / +3.3 °C
	Wet (28.9 °C)	+0.8 °C / +0.7 °C	+1.3 °C / +3.4 °C
	Dry (27.8 °C)	+0.8 °C / +0.7 °C	+1.2 °C / +3.2 °C
Saba and St. Eustatius	Annual (27.8 °C)	+0.8 °C / +0.7 °C	+1.2 °C / +3.2 °C
	Wet (28.5 °C)	+0.8 °C / +0.7 °C	+1.3 °C / +3.3 °C
	Dry (26.8 °C)	+0.8 °C / +0.7 °C	+1.2 °C / +3.1 °C

Figure 2.1 and Table 2.1 show the following information:
- The annual average temperature has already been increasing since the early 2000s. This is supported by various scientific publications (e.g. Jones, 2015 and Taylor, 2018).
- The temperature is projected to increase further in both emission scenarios. However, the extent of the increase differs:
  - In the L-scenario, the increase is limited to approximately 0.8°C.
  - In the H-scenario, the increase is projected to be much higher. up to 1.3 °C in 2050 and 3.4 °C in 2100.
  - These projections are in line with IPCC projections for the entire Caribbean region (high emission scenario: +1.5 °C in 2050 and +3.0 °C in 2100.
- The extent of uncertainty is slightly larger in the long term H-scenarios than in the L-scenarios.

In addition, climate change has the following effects related to rising temperatures:
- Not only the air temperature, but also the ocean temperature is increasing due to climate change. The KNMI has not published projections specifically for ocean temperature. Taylor & Stephenson (2017) estimate an increase in sea surface temperatures (SST) of 0.9 (low emissions) to 1.8 (high emissions) °C per century.
- Maitland et al. (2024) note that increasing temperatures contribute to sea level rise in the Caribbean region through thermal expansion of ocean water.
- Additionally, higher atmospheric CO_2 concentrations will lead to higher amount of dissolved CO_2 in the oceans. In turn, this will lead to ocean acidification (decrease in pH).

2.3.2 Sea level rise

The global sea level has seen an increase since the 19th century. Since 1900, sea level has risen about 20 cm (1.7 mm/year). Sea level rise has accelerated during the past 50 years and reached a rate of about 2.3 mm/year from 1971 to 2018, and 3.7 mm/year from 2006 to 2018. Sea level rise is still accelerating. It is also one of the most universally recognised threats for low-lying and small islands across the world. Due to Bonaire's low elevation, the threat of sea level rise is greater in comparison to Saba and St. Eustatius.

The KNMI has published projections of sea level rise around the BES islands. Figure 2.2 and Figure 2.3 show the projected sea level rise on Bonaire and Saba/St. Eustatius respectively.

Figure 2.2 Past and projected (until 2100) sea level rise on Bonaire (source: KNMI)

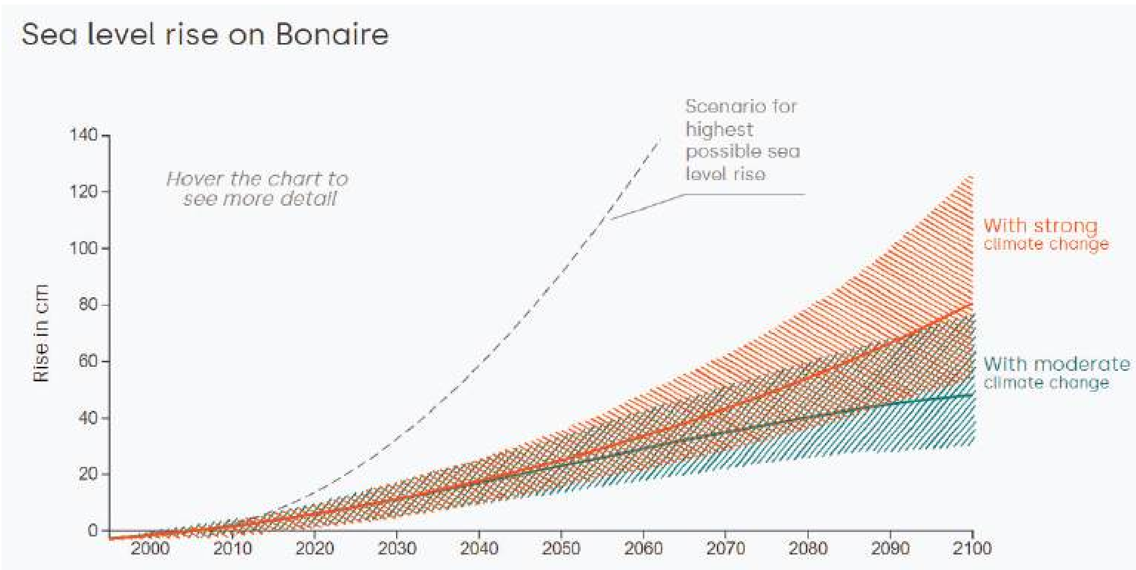


Figure 2.3 Past and projected (until 2100) sea level rise on St. Eustatius and Saba (source: KNMI)

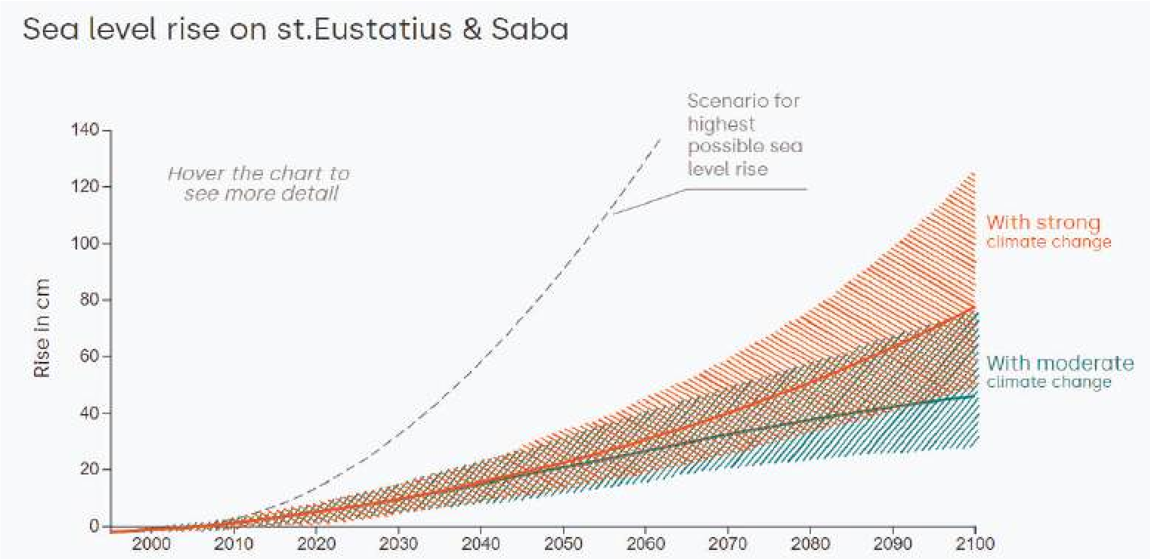
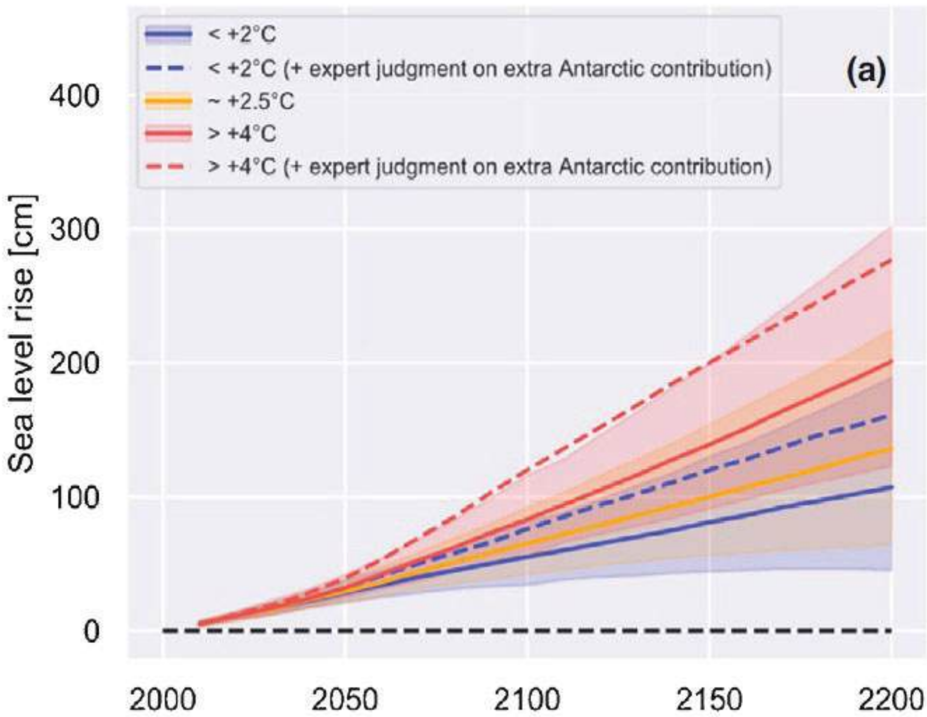


Figure 2.4 shows the projections of local rea level rise in cm according to multiple climate scenarios in the period until 2200. The figure shows sea level rise projections in the Bahamas as an indication of the possible sea level rise in the BES-islands. Exact long term predictions of sea level rise in the BES-islands have not been carried out.

Figure 2.4 Projections of local sea level rise (cm) until 2200 in the Bahamas (Martyr-Koller et al., 2021)



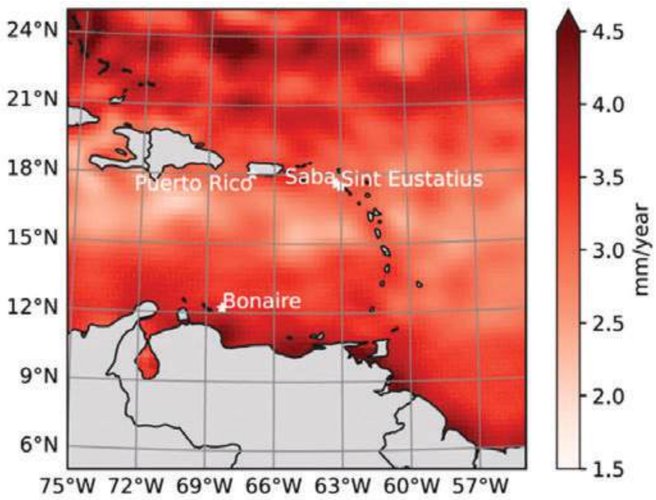
Figures 2.2 through 2.4 show the following:

- Sea level rise has already occurred and will continue to occur regardless of emissions and climate change scenario. The rate of sea level rise and the total extent do differ:

· In the scenario with moderate climate change (low emissions), the sea level rise is limited to 48 cm (Bonaire) and 46 cm (Saba and St. Eustatius) in 2100. Note that these projections are a mean sea level within a larger bandwidth of uncertainty.
· In the scenario with strong climate change (high emissions), sea level rise may amount to 81 cm (Bonaire) and 78 cm (St. Eustatius and Saba) in 2100.

- Until 2050, the projected sea level rise is similar for both climate change scenarios (approximately +25 cm compared to the reference level). Uncertainty is therefore limited. However, after 2050 the uncertainty rapidly increases.
- Sea level rise scenario's according to the Shared Socio-economic Pathways (SSPs) show a sea level rise of 20 cm by 2050. The figures also show the highest possible sea level rise (Low Likelihood, High Impact (LLHI) scenario). This is an unlikely scenario, where the sea level rise amounts to several metres by 2100 on both islands (see grey dotted line in Figure 2.2 to Figure 2.3). This scenario shows the highest possible sea level rise. These scenarios are related to processes that are not well understood yet, such as the melting of Greenlandic and Antarctic ice sheets. Recent research suggests that LLHIs may be even less likely to unfold than previously assumed (e.g. Morlighem et al, 2024).
- For the even longer term (beyond 2100), Martyr-Koller et al. (2021) have published projections for the Bahamas. Figure 2.4 shows that sea level rise may only come to a halt in a scenario with very limited climate change. In all other scenarios, the sea level will continue to increase.
- Both the rate and the total extent of projected sea level rise differ among (1) Bonaire and (2) Saba and St. Eustatius. In general, sea level rise is expected to be more rapid and extreme on Bonaire. This is because of geographical variation in sea level rise. Figure 2.5 depicts such variation within the Caribbean. It shows that the rate of sea level rise is more rapid on Bonaire than on the other 2 islands.

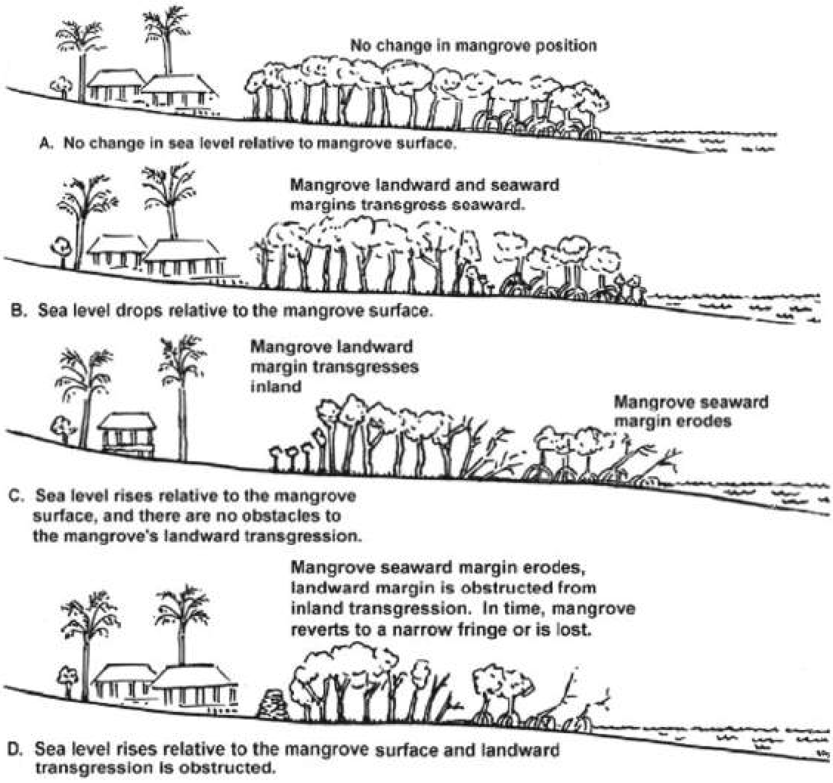
Figure 2.5 Spatial differences in sea level rise. Source: D. Le Bars (2022)



The following additional notes are made with regard to sea level rise:

- During storm surges, the sea level temporarily strongly increases. This is discussed in more detail in section 3.3.5.
- Sea level rise does not only increase the risk of flooding, but also causes salinisation. This may yield risk to freshwater resources.
- Sea level rise also increases the waves and related flood risk.
- Mangrove forests provide natural protection against high waves from storm surges and flooding. If the rate of sea level increase is large, mangroves are possibly no longer able to maintain their elevation relative to the sea level and will die (Ellison, 1993. Saintilan et al., 2020). It is difficult to provide a specific rate at which this occurs, because the health of mangroves depends on multiple factors such as the availability of nutrients and sediment. It is estimated that 6 mm/year sea level rise is a tipping point for most mangrove forests. Mangrove forests do have the ability to partly adapt to rising sea levels, as long as there are no obstacles landward. This is visualized in Figure 2.6.

Figure 2.6 Response of mangrove forests to changes in sea level and obstacles



2.3.3 Precipitation and drought

The KNMI has included the projected amount of precipitation for the BES islands, both annually and for the wet and dry seasons. These are shown in Figure 2.7 and Table 2.2.

Figure 2.7 Projected changes (relative to 1991-2014) in the annual mean precipitation on Bonaire, St. Eustatius and Saba in the low (yellow) and high (red) emission scenarios

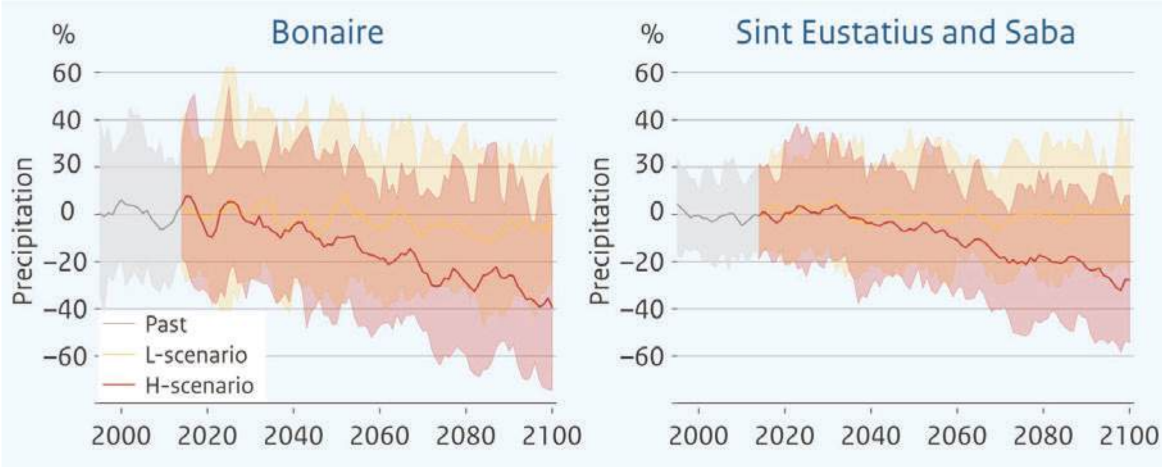


Table 2.2 Projected relative differences in precipitation in 2050 and 2100 according to all KNMI'23 scenarios. Source: KNMI

Island	Season and reference	2050 Ld	2050 Ln	2050 Hd	2050 Hn	2100 Ld	2100 Ln	2100 Hd	2100 Hn
Bonaire	Annual (514 mm)	-8 %	0 %	-15 %	-2 %	-7 %	0 %	-48 %	-11 %
	Wet (346 mm)	-6 %	+2 %	-13 %	0 %	-5 %	+2 %	-48 %	-12 %
	Dry (169 mm)	-12 %	-3 %	-20 %	-5 %	-11 %	-3 %	-48 %	-7 %
Saba and St. Eustatius	Annual (1,034 mm)	-6 %	+3 %	-12 %	+2 %	-5 %	+3 %	-44 %	-8 %
	Wet (730 mm)	-7 %	+ 5 %	-14 %	+4 %	-6 %	+4 %	-48 %	-7 %
	Dry (304 mm)	-3 %	-3 %	-8 %	-5 %	-3 %	-3 %	-34 %	-9 %

Figure 2.7 and Table 2.2 show the following:
- In almost all scenarios, the amount of precipitation is expected to decrease or increase slightly. The extent varies:
  - On Bonaire, the total annual precipitation may drop up to 15 % in 2050 and up to 48 % in 2100 in the Hd scenarios. In the wetter climate scenarios, the amount of precipitation increases only marginally.
  - On Saba and St. Eustatius, the expected development is similar, but somewhat less severe. Total annual precipitation may drop up to 12 % in 2050 (Hd) and 44 % in 2100 (Hd).
- The distribution of precipitation throughout the year will probably shift:
  - On Bonaire, both the wet and dry seasons are projected to see less precipitation. The relative decrease is roughly the same during both seasons.
  - On Saba and St. Eustatius, the decrease in precipitation is larger in the wet season than in the dry season. This is especially the case in the extreme Hd scenario (2100: -48 % during the wet season, -34 % during the dry season).
- Bonaire records about half of the total annual precipitation as compared to Saba and St. Eustatius. This pattern remains roughly the same in the future.
- The uncertainty in the projections is larger for Bonaire than for St. Eustatius and Saba. This is especially the case for the long term. The underlying reasons for this have not yet been identified.

The KNMI specifically notes that the shown projections seem to deviate from actual field observations so far. While the models predict a decrease in precipitation, observations show more precipitation (La Niña scenario). This deviation is not yet fully understood, but it may stem from natural variability. Overall, precipitation may decrease to a lesser extent than shown here, but this is not yet certain. Brotons et al. (2024) have looked at this question in more detail. They conclude that the Caribbean region is drying in the 21st century, but the effect is weaker than projected in high emission scenarios.

Apart from changes in precipitation patterns, temperatures are projected to rise (see section 3.1.1) and evapotranspiration is likely to increase. As a result, drought conditions are expected to worsen on islands all across the Caribbean. Compared to other island regions in the world, the Caribbean shows a clear increasing trend in agricultural drought conditions.

In the case of meteorological drought, related to precipitation deficits, the increases only appear in high emission scenarios. Finally, hydrological drought, which makes reference to the recharge of surface and groundwater bodies, is characterized for a generalized lack of data and is heavily dependent on local conditions. This type of drought constitutes the main knowledge gap for island regions. Overall, water stress will continue to be a reality in the entire Caribbean area as a combination of lower water availability and increased population and agricultural needs (Seneviratne et al., 2021).

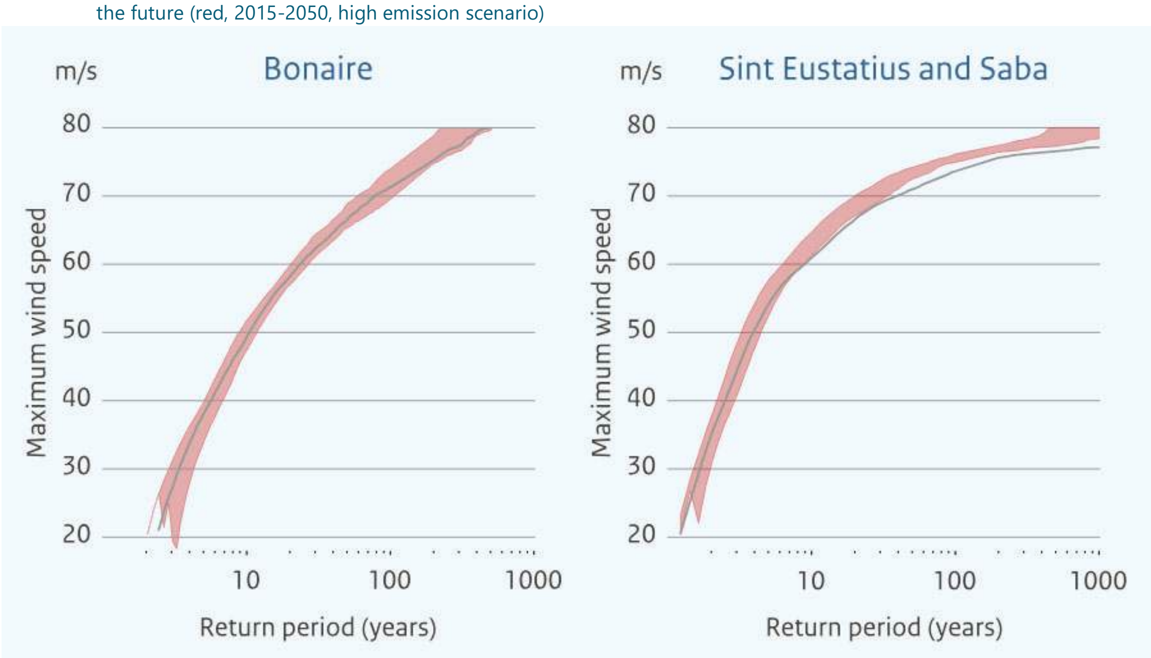
Despite the overall projected decrease in precipitation amounts, it is expected that extreme rainfall events will become even more extreme in terms of intensity (De Boer et al., 2023). This means that the annual rainfall that is expected will have less variation in time. This has 2 consequences: (1) the amount of projected rainfall falls in less time, which also means that dry spells will become longer, and (2) precipitation events become more extreme, causing more runoff and erosion. This trend can be seen across almost the entire Caribbean region (Esteban-Cantillo et al., 2004).

2.3.4 Extreme storm events and hurricanes

Hurricanes are among the most dangerous weather phenomena in the region. Hurricanes involve extremely strong winds and heavy rainfall and can also cause high waves. Extreme storm events and hurricanes are especially important in Saba and St. Eustatius, as the islands are located in the hurricane belt. Bonaire gets collateral heavy rains and winds from the nearby hurricane season but is less likely to be hit directly by hurricanes.

Figure 2.8 shows the maximum wind speed in storms and hurricanes against the return period for Bonaire (left) and St. Eustatius and Saba (right).

Figure 2.8 Wind speeds (m/s) as a function of return periods within 250 km of the BES islands, reference (grey. 1980-2017) and in the future (red, 2015-2050, high emission scenario)



For reference: at wind speeds of 18 m/s and above, a tropical storm and damage begins to occur, from 33 m/s the storm is called a hurricane, and from 50 m/s the damage is usually catastrophic. KNMI (2023) and IPCC predict the following for hurricanes:

- In the current climate, the return periods on Bonaire are roughly half of those at St. Eustatius and Saba. This is because of the geographical distance: Bonaire is not located within the so-called hurricane belt.
- The number of hurricanes has increased globally and in the Caribbean over the past decades.
- For the future, less but more intense hurricanes are expected. These hurricanes will be accompanied by much higher rain rates. The intensity of hurricanes increases due to higher sea surface temperatures.
- Only hurricanes of the most severe category are expected to occur more frequently on St. Eustatius and Saba: once every 20 to 34 years from 2015 to 2050, compared to once every 39 years from 1980 to 2017.
- Hurricanes are not only becoming more intense, but they also develop more rapidly. This is supported by recent scientific papers, such as Garner (2023). For instance, tropical cyclones used to take about 36 hours to develop in the historical era (1971-1990). In the present day, hurricanes often develop within 24 hours to comparable wind speeds. This means that the lead time for preparation and evacuation is reduced.
- As hurricanes are primarily fuelled by high sea surface temperatures, the hurricane season will probably become longer as a result of climate change. As of early July 2024, the first hurricanes have already developed (e.g. hurricane Beryl), while the hurricane season traditionally does not start until August.

The combination of sea level rise (see 3.3.2) with hurricanes can be especially impactful. Hurricanes and storms cause the sea water to surge. In turn, this causes higher waves which may propagate further land inward and cause flooding.

Moreover, climate change may affect wind reversals, especially on Bonaire. While climate models are uncertain regarding wind reversals, some models suggest that the frequency and intensity of wind reversals may increase due to climate change (Kossin, J. P., et al. (2020)). This is because climate change is likely to alter the strength and consistency of trade winds as well as jet streams. In addition, hurricanes may trigger wind reversals even in the current climate. With more and stronger hurricanes, it may be expected that wind reversals also become more common and intense.

3

IMPACTS OF CLIMATE CHANGE

3.1 Introduction and approach

In chapter 3 the climate change projections for the BES islands until 2100 are described. Climate changes will have significant impacts on the daily life of inhabitants, businesses and tourists. This chapter is dedicated to the possible impacts of climate change on the BES islands.

The results have been visualized in a graph for each sector. The graphs are based on the so-called 'bollenschema's' included in the Dutch NAS. The graphs can be found in Appendix II.

For each sector, a list of relevant physical consequences was prepared based on the climate changes of chapter 3 (heat and rising temperature, sea level rise, precipitation and droughts and hurricanes). These consequences were then translated into impacts on each respective sector.

The following notes are made with regard to this chapter:
- This chapter's content is limited to threats that stem from climate change. Climate change may also yield some benefits or opportunities, but due to the urgency and scale of the consequences of climate change, identifying the threats has been prioritised.
- The overview in this chapter is based on information from scientific sources and expert judgment to provide factual information. Therefore, only those impacts that can be objectively tied to climate change developments are included. The findings were validated during interviews with sector experts on the islands.
- In most cases, there is no quantitative information available for an impact assessment. All impacts are therefore described qualitatively. Within the sectors, the impacts for each climate hazard are ranked from highest to lowest risk.

3.2 Sectors

For the impact assessment on the BES islands, 10 NAS sectors have been selected. These 10 sectors give a wide overview of activities, businesses, people, and assets that can be affected by climate change. Table 3.1 provides an overview of the 10 sectors.

Table 3.1 Overview of 10 sectors, derived from the Dutch NAS

Sector	Clarification
Water management	All efforts related to water safety, water quality, but also availability of process water for industries for example. Groundwater is also included in the sector water management
Nature	Habitats of animals and plants, ecosystems, and shifts that can occur due to climate change
Agriculture and fisheries	Includes crop cultivation, livestock farming, and fishing activities. This sector is a part of the economy, but agriculture and fishing are also important for food security and self-sufficiency on the islands

Sector	Clarification
Health	Covers public health services, healthcare infrastructure, disease prevention, and health promotion, as well as general wellbeing and mental health
Recreation and tourism	Activities related to the tourism industry. Also domestic recreation and leisure activities on the islands
Infrastructure	Infrastructure related to all transportation modes, such as roads, paths, airports and harbours. Infrastructure for water management is covered under water management. Power supply and distribution systems and telecommunications are covered under the energy and ICT/telecom sectors respectively.
Energy	All infrastructure and resources required to generate and distribute energy across the islands. Also includes storage facilities for energy carriers, such as oil
ICT and telecom	All infrastructure and assets required to keep ICT and telecommunication systems active
Safety	Encompasses public safety, emergency response and disaster preparedness
Built environment and spatial planning	All buildings, parks and other man-made assets on the islands. Excluding infrastructure, as that is covered under various other sectors

3.3 Impact assessment

In this section, the local context of each sector is briefly described. This description is followed by the main impacts to that sector brought about by climate change.

3.3.1 Water management

Context and description

The hydrological cycle and important hydrological parameters on the BES islands are described as follows:

- Elevation: most built up areas of Saba and St. Eustatius are located at least 10 to 20 m above mean sea level. Both islands have hilly and mountainous sections. Only the coastal zone features lower elevations, but the coastal zone is generally not urban. Bonaire has much lower elevation levels (maximum several meters above sea level), especially across the southern part and in Kralendijk. Bonaire is therefore more vulnerable to coastal flooding and storm surges.
- Soil: the islands vary in terms of soil type. On Saba and St. Eustatius, the soil is mostly composed of volcanic rock types and sandy loam in lower areas. On Bonaire, the soil consists mostly of limestone and partly of volcanic rock.
- Groundwater: all groundwater resources across the islands are mostly brackish due to the proximity to the sea and porosity of the subsoil.
- Hydrologic cycle: Bonaire receives about 500 mm of rainfall on an annual basis in the current climate. On Saba and St. Eustatius, this is approximately 1,000 mm. All islands have a pronounced dry and wet season. On average, about 85 % of precipitation evaporates, 5 % infiltrates into the subsoil and groundwater and 10 % runs off toward lower areas and eventually the ocean through streams. Some of these streams feature dams to retain water. Runoff has increased over the past decades as a result of erosion and urban development.
- Wastewater: some urban areas are equipped with a sewer system. It transports wastewater to treatment plants. All islands have their own treatment plant, but many areas still use cesspools to dispose of wastewater. Grey water systems are being installed in various places, especially on Bonaire and Saba.
- Drinking water is produced through reverse osmosis (RO) installations that desalinate sea water. It is then transported to individual homes or to central distribution locations in villages. Especially remote homes remain dependent on rainwater cisterns for the provision of fresh water.

Climate change will affect the water management sector due to droughts, extreme rainfall events, sea level rise, increasing temperatures and due to hurricanes. Appendix II shows a full chart of potential effects. The most important effects of climate developments are described below. The impacts for each climate hazard are ranked from highest to lowest risk (qualitatively).

Increasing temperatures

Rising temperatures will pose the following threats for the water management sector:

- An increase in sea water temperature has an effect on the intensity of hurricanes, and the speed with which they develop. As a result, less lead time is available for preparations before a hurricane. Both the likelihood and impact of this effect are high.
- The increase in air temperature will have an effect on the sea water temperature. Prolonged exposure to warmer water leads to coral bleaching and ecological losses. For example through the loss of fish habitat.
- For other surface waters, higher water temperatures will lead to a decrease in water quality as algae blooms arise and other pathogens such as botulism thrive. As a result, the overall water quality of rainwater cisterns on the islands decreases as stored rainwater warms up and becomes more susceptible to the growth of pathogens (Wijsman & Baboe-Kalpoe, 2024).
- The increased air temperature leads to a higher demand for drinking water among inhabitants and tourists. As a result, the capacity of desalination plants may be insufficient to meet the demand. The overall risk is considered low, because the current desalination plants have some overcapacity and may be upgraded accordingly.

Sea level rise

Sea level rise will pose the following threats for the water management sector:

- Unprotected areas on Bonaire will ultimately be hit by coastal flooding more often. VU-IVM (2022) shows that some parts of the island could be permanently flooded in the future. This effect is amplified by more intense storms and the resulting storm surges. St. Eustatius and Saba also see this effect, but to a lesser extent as these islands tend to have higher elevations in built up area. All islands will experience coastal squeeze: a decrease in available land area due to the rising sea level.
- Difficulties for (urban) drainage. In locations where pipes drain excess stormwater towards the sea (e.g. Kralendijk), the difference in hydraulic head becomes smaller. Especially during storm surges, stormwater may not be able to be adequately drained to the sea. This amplifies pluvial flooding in built up areas, especially during hurricanes and storms. Both the likelihood and impact are considered high.
- Coastal areas will ultimately suffer from more erosion and mangrove forests will become submerged and perish. This weakens the natural coastal defence against wave overtopping and has a further negative effect on coastal protection. The likelihood is high in the future due to sea level rise. the impact is medium because mangroves have only a limited role in coastal protection.
- Salinization will increase. This applies both to water in open connection with the sea (saliñas) and to groundwater resources close to the sea. Current brackish groundwater will become more saline.
- In low-lying coastal areas, sea level rise may cause tidal flooding (sunny-day floods). So far there have been no reported instances of this in the BES islands, but along low-lying areas along the coast of Bonaire this can occur. Overall the risk of tidal flooding is deemed low.

Droughts

Many climate scenarios indicate a decrease of precipitation during both the wet and dry seasons, combined with an increase of evaporation due to increasing temperature. This may lead to the following impacts:

- Due to droughts, it also becomes more difficult to harvest rainwater and reuse it. As a result, there is less access to fresh water and an increased strain on desalinated water. Some households are not connected to a water grid. Droughts may become particularly difficult for these households as they can no longer provide for their domestic water demand. Droughts may also cause over-abstraction of groundwater resources. Overall the risk of this effect is high, as the most extreme drought projections are likely to bring about serious water scarcity.
- Prolonged drought could even change the ecosystem and cause species to shift. There has been no applied research to identify which other species will be affected by this. The overall risk is considered medium and is also uncertain.
- Droughts negatively affect the water quality. Both surface water and groundwater become more saline. Especially surface water becomes more vulnerable to contaminations and pollution as there is less natural flushing and dilution. Deteriorated water quality may amplify algae growth. Furthermore the increasing temperature results in lower oxygen levels in surface temperature.

- For the water management sector, increasing droughts have a negative effect on groundwater levels and will further increase the groundwater's salinity. This also has an effect on nature and agriculture, as groundwater is abstracted in some locations to irrigate crops. The overall risk is low, because the impact would be limited.
- Furthermore, the increasing temperature results in lower oxygen levels in surface water. The water quality deteriorates as a result.

Precipitation

- Apart from drier dry seasons, precipitation extremes are projected to increase in both frequency and intensity. As a result, drainage systems on the islands may become overwhelmed and pluvial floods and waterlogging likely occur. This can cause deterioration of surface water quality due to spilling of contaminated areas and sewer overflows. This is especially the case in urban areas because of the high degree of pavement. Pavement strongly increases runoff. Problems are especially expected on Bonaire where the drainage system already cannot cope with extreme precipitation. Pluvial floods cause damages and have an impact on multiple sectors. The risk is high.
- Heavy precipitation causes additional erosion, despite efforts to reforest natural areas and mitigate erosion. Erosion will cause increased deposition of sediment and debris in downstream areas, such as the saliñas. This causes the saliñas to have less storage capacity, reducing their drainage function and exacerbating pluvial flooding in urban areas. Erosion also potentially causes dangerous landslides. This effect's likelihood and impact are considered high.
- Erosion and sedimentation also have a negative impact on the health of coral reefs and mangroves. These may ultimately perish under the additional stress, reducing the natural level of coastal protection against waves. The risk is medium as reefs and mangrove play only a limited role in coastal defence.

Case: Pluvial flooding and erosion around Saliña di Vlijt

Erosion and resulting landslides and the deposition of sediment is a major problem across all BES islands. Especially in hilly areas where vegetation is scarce, intense rainfall events erode soil material upstream and transport it downstream. This has multiple adverse effects:

1 Fertile top soils are washed away. Agricultural yields decrease.
2 Soil and rock formations may become unstable, causing dangerous landslides. These pose a safety hazard, especially in built up areas.
3 Mud and debris are transported downstream. The sediment is deposited in the saliñas. If these lakes are not dredged, their storage capacity decreases dramatically. During subsequent rainfall events, there is insufficient storage in the saliña. This causes floods and the deposition of sediment in harbours, villages and coral reefs and mangrove forests in the ocean.

Rainfall events are projected to become more intense, making erosion and pluvial flooding more likely. One of the problem sites is Saliña di Vlijt, near Kralendijk, Bonaire. In November 2022, extreme precipitation caused major erosion and sedimentation as well as flooding. Figures 3.1 through 3.3 give an impression of the sedimentation and floods.

Figure 3.1 Sediment entering the sea from Saliñas di Vlijt after heavy rainfall. Source: Public Entity Bonaire. © Directie R&O

Figure 3.2 Overflow of the saliñas following intense rainfall. Flooding causes sedimentation in the built environment

Figure 3.3 Suspended sediments in the ocean near Kralendijk, resulting from erosion upstream. Source: Nature Today (Casper Douma)

Heavy rainfall also caused water quality problems in 2022. During the floods, it appeared that the installed vacuum sewer system was not fully watertight. This resulted in backflow in toilets and an uncontrolled flow of untreated wastewater. Moreover, cesspools are still common on Bonaire. During floods they may overflow, contaminating the flood waters. This poses a health hazard and contaminants eventually end up in the groundwater and in the ocean.

Hurricanes

- Hurricanes often go hand in hand with extreme winds and precipitation. Therefore, flooding from rainwater is a possibility and all related impacts apply. Added to that is the combination of extreme winds and the tide that will combine into a storm surge, with higher waves and tides than usual. This will increase the risk of flooding for the low-lying parts of the islands.
- Hurricanes may also damage vital water management infrastructure on the island. They can cause erosion or break off large pieces of rocks (on Saba and St. Eustatius). For example:
  - If dams are damaged or destroyed by hurricanes, this could lead to uncontrolled runoff and erosion. Water is no longer retained upstream and will flow downstream, causing flooding and sedimentation.
  - If the wastewater treatment plant and/or sewerage is damaged or destroyed, it may no longer be possible to treat and sanitize wastewater. Wastewater will flow into the soil and water system uncontrolled, causing contamination and pollution.
  - If the desalination plant and/or distribution network of fresh water is destroyed, freshwater and tap water may become scarce or non-existent.

3.3.2 Nature

Context and description

The BES islands form part of the Caribbean Islands Biodiversity Hotspots, which is an area with high biodiversity as well as high pressure from human activity. Across the islands, the significance of protecting and conserving nature extends beyond the inherent value of the natural environment. Nature provides important services such as natural resources (for small-scale farming and fishing), coastal protection and income (for example through tourism). The islands' rich biodiversity and pristine ecosystems are some of their major attractions, making nature a key economic driver. In 2013, the economic value of the ecosystems was 31 %, 63 %, and 24 % of the Gross Domestic Product (GDP) for Bonaire, Saba and St. Eustatius respectively (Wageningen University, 2017).

Bonaire's natural landscape includes dry tropical forests, often degraded, and saliñas. Mangrove forests are concentrated around Lac Bay, and extensive coral reefs fringe the coastline. These ecosystems support threatened species like turtles and the yellow-shouldered Amazon parrot.

St. Eustatius has a rocky landscape, with much of the surface covered in dry tropical forests and some rainforests (on the Quill). The coastal areas of the islands feature coral reefs and seagrass beds that are vital for marine life, including endangered sea turtles.

Saba is guarded by steep cliffs on all sides, with no permanent beaches. The greatest part of the island is covered with rain forests and dry tropical forests. Saba Bank lies about 4.3 km southwest of the island of Saba and covers around 2,600 km^2, holding home to some of the richest biodiversity of the Caribbean Sea. The bank is an important area for coral reefs in the region, acting as a source of coral and fish larvae that spread throughout the region. (Saba Conservation Foundation, 2024).

Common challenges across all islands include overgrazing by free-roaming animals, invasive species, and coral reef degradation due to diseases and bleaching events (DCNA). The loss of forests on the islands has led to increased erosion, further damaging the reefs due to deposition of sediments. The nature on the islands is locally important as well as regionally, as migratory (and local) bird species are dependent on the coastal ecosystem, the beaches provide nesting habitats for turtles (especially Bonaire and St. Eustatius) and the coral reefs provide food for the entire Caribbean region.

While nature conservation benefits extend beyond environmental impacts, the following impacts focus on the direct implications for nature.

Increasing temperatures

Rising temperatures will lead to higher terrestrial temperatures and higher sea temperatures. The following (potential) effects on nature are noted:

- The increase in temperature will have a warming effect on both sea water temperature and surface water temperature. The rise in sea water temperatures will ultimately result in coral bleaching and habitat loss of fish species. This negatively affects marine ecosystems. This effect’s likelihood is high (already happening), and its impact is medium.
- Increased sea surface temperatures alongside ocean acidification (due to increased CO_2 levels in the atmosphere) are expected to trigger mass coral bleaching. Ocean acidification will also impact the formation of coral reefs and reduce coral growth. (IPCC, 2015).
- In addition, due to the increasing temperature, evaporation will increase which will then result into droughts and a decrease in water availability. The infiltration and natural groundwater recharge will therefore also decrease. Prolonged increases in temperatures could therefore alter ecosystems and cause migrating species to change or alternate migration routes for example. The future impact of droughts is considered high. the likelihood strongly depends on the uncertain drought projections.
- The increased water temperature of surface waters could provide harmful algae blooms (especially sargassum in Bonaire) and botulism a perfect habitat to grow in, deteriorating the water quality and clear water state. This could change the current clear water ecosystems towards more turbid water ecosystems. This change is difficult to reverse.
- Increasing temperatures and other climate effects may lead to a mismatch in the food chain of species on the BES islands. Species especially at risk are turtles (Bonaire, St. Eustatius), red-billed tropicbird (Saba), bridal quail dove (Saba) and Amazon Parrots (Bonaire). For example, threatened and endangered turtle species depend on the coasts of Bonaire and St. Eustatius for nesting habitats. Sand temperatures determine the sex of newborn turtles, and rising temperatures may lead to more females. This causes an imbalance the ratio of female to male turtles. (Sea Turtle Conservation Bonaire, 2023).

Sea level rise

- Sea level rise will have a direct effect on natural areas that are just above the sea level, such as the mangrove forests on Bonaire. These forests will eventually erode and be flooded which will kill most

- mangrove trees. These mangrove forests not only contribute to coastal protection, but also contribute to habitats for various species such as crabs and shrimps. Due to sea level rise, these habitats shrink, leading to stress among species in the mangrove forests. This effect's likelihood is high, the impact is medium.
- Due to salinization, more surface water will become brackish or saline. This forms an opportunity for species that are native to brackish environments as they may flourish.
- The sea level rise will also have an effect on the ground water levels, which will rise near the coast and will result in more saline groundwater. This change could both pose a threat to existing nature that is not accustomed to saline groundwater but can as well pose an opportunity to create new saline and wet nature. The overall physical space for nature on land will however decrease due to the coastal squeeze.

Droughts
- Due to increased temperatures and longer periods of droughts, the natural areas become more susceptible to forest fires. Over the last 25 years, all islands together already lost approximately 9 ha of tree cover from fires, not accounting for the year 2024 yet (GFW, 2024). This impacts likelihood strongly depends on uncertain drought projections. The impact is high.
- Prolonged drought could also change the ecosystem and cause species to shift. As previously mentioned, it is unknown which species will be affected but certain species (such as corals, or land-dwelling birds) are vulnerable to such changes (Hassell - Knijff, 2024).
- Due to prolonged drought, there is less freshwater available to nature on the BES islands. This applies to both natural areas and irrigated (urban) parks and greenery. This results in deterioration of natural areas.

Extreme precipitation
- The scenarios for precipitation show a possible increase in rainfall during the rainy season. The overall impacts of more extreme rainfall events are negative, as some green areas might get flooded or damaged due to an excessive amount of water. The extreme rainfall causes runoff which transports debris and mud towards sea. This will negatively impact the coral reefs of the coast of the islands.
- Increased precipitation extremes can also destroy major habitats (breeding and nesting spots) for bird species and land-dwelling animals. However, this effect's overall risk is deemed limited.

Hurricanes
- Hurricanes will affect nature in both direct and indirect ways. The direct effects of the extreme winds during a hurricane can cause damages to trees, vegetation, and the overall destruction of habitats for different species. Other direct effects can be extreme waves and current due to storm surges, which can damage coral reefs, or the flooding of natural areas due to extreme rainfall. The overall risk is considered medium, as more severe hurricanes increase the likelihood of more severe damages.
- Hurricanes may have a lasting effect on animal species. For example if their habitat is destroyed and they lose access to shelter and food.
- The indirect effects come from possible storm water runoff that is transported into the sea or surface waters. This water can then transport debris and other pollutants into the water which could potentially have negative effects on the water quality and marine ecosystems. This risk already exists. The additional effect from climate change is expected to be limited.

3.3.3 Agriculture and fisheries

Context and description

Agriculture in the BES islands generally comprises only small-scale agriculture. Their climate conditions and limited availability of arable land do not allow for large-scale agriculture. Local agriculture provides only a small part of the market's food and vegetables. The livestock sector provides some additional eggs and meat (Wageningen University, 2019). On Saba, the hydroponic farm provides additional food.

None of the BES islands have large scale or industrial fisheries, but especially on Saba fishers have high yields. In Bonaire, fishers mainly use line fisheries to target reef fish while in Saba the fishery consists of fishery with traps. St. Eustatius uses a mix of these methods, including diving for lobsters and conches (Rijksdienst Caribisch Nederland, 2023).

As a result, the islands are not fully self-sufficient in terms of food provision. They thus rely heavily on food imports for food security. In Bonaire, 99 % of consumed food is imported (van der Geest & Slijkerman, 2019). Exact import values for Saba and St. Eustatius are unknown, the majority of the food is also imported (gathered from interviews and articles from Wageningen University (2021). Although there are no large-scale agriculture or fisheries in the islands, people who are reliant on these resources may face direct consequences. The effects on the agriculture and fisheries sector are described below.

Increasing temperatures

Rising temperatures will have the following (potential) effects on agriculture, horticulture and fisheries:

- Increased temperatures (resulting in increased evaporation) and changing rainfall patterns may lead to crop failures and lower crop yields. Changing climatic conditions may not be favourable for cultivation of specific crops. Due to this it could be necessary to switch to other crops that are more resistant to higher temperatures. It is currently unknown which crop types will suffer the most under higher temperatures.
- The surface water temperature will also increase under climate change. Higher temperatures may lead to increased sargassum blooms that lead to die-offs (fish, seagrass) and damage (mangroves) (DCNA, 2019). These die-offs and damages are already being experienced (especially in Bonaire) and are therefore expected to become more frequent with higher temperatures. This may result in a reduction of the availability of fish for the coastal fisheries.
- Warmer temperatures may lead to higher vulnerability of livestock due to heat stress.
- The increase in multi-day warm periods and warmer dry seasons can lead to an increase in pests. Changes in temperature may increase the vulnerability of agrosystems to pests and introduced species (USDA, 2024).
- Increased surface water temperatures may increase the occurrence of waterborne diseases that affect livestock.

Sea level rise

- Sea level rise may lead to changes in surface water quality and increased groundwater salinity. This leads to shifting freshwater ecosystems and species, failure of crops/lower yields due to saline conditions. This may provide opportunities for more brackish habitats or saline agriculture but will come at the cost of existing habitats and agriculture.
- Irrigation systems may become unusable due to saltwater contamination.
- Rising sea levels may result in coastal squeeze. In low-lying areas this may result in loss of agricultural areas. This is less relevant for St. Eustatius and Saba as there are less areas prone to flooding due to sea level rise.

Droughts

- Lower groundwater levels and drier soils in dry periods will have negative consequences for crop production. This can result in reduced yields and damage existing crops.
- Groundwater is often used for drinking water for livestock (Timber & Kitson-Walters, 2024). If this reduces in quality and becomes more saline, farmers may have to switch to other means of providing water for livestock.
- Surface water quality may change due to droughts. This may result in lower water usability for irrigation due to increased pollution of surface water.
- Droughts will lead to an increase in coastal groundwater salinity and river estuary salinity. This may lead to reduced yields for existing agriculture. In Bonaire groundwater is mostly used for construction, watering private gardens and agriculture. Government-managed wells are already brackish or saline, making many of them unsuitable for agriculture (WUR, 2022). Water from desalination plants is more expensive and therefore can also lead to increased costs for farmers.

Extreme precipitation

- The increased precipitation will lead to increased erosion in hilly and mountainous areas. This can damage small-scale agricultural practices in these areas due to erosion.
- Increased extreme peak precipitation leads to waterlogging of agricultural lands. This can lead to crop failures and reduced habitat for livestock.

- The increased erosion as a consequence of increased extreme precipitation will lead to more frequent overaccumulation of sediments in coral reefs. This will impact the coastal ecosystem and consequently the fisheries as fish habitat is lost (Hassell - Knijff, 2024).
- Increased multi-day wet periods can lead to changes and an increase in pests. This will have negative consequences for agriculture and livestock.

Hurricanes

- Hurricanes can lead to poor surface water quality as fresh water sources become contaminated. For example, because of sewer spills. As hurricanes become more intense, this can lead to reduced crop yields.
- Hurricanes may directly damage crops, reducing yields and increasing the vulnerability of agricultural practices.
- During hurricanes no fishing activity can take place. More intense hurricanes and longer hurricane seasons in and around the BES islands will lead to worse conditions for fishing and therefore reduced fisheries. Moreover, fishing infrastructure in the harbour may be damaged. This also directly impacts the fishermen's livelihoods.
- Hurricanes also lead to increased erosion and waterlogging due to increased extreme precipitation. See consequences under extreme precipitation.
- Hurricanes interrupt supply lines and may damage harbours. This causes disruption of the distribution of goods, among which are agricultural products. This includes, for example, food for livestock, pesticides and herbicides. This eventually negatively impacts the farmers' livelihoods and food security.

Case study: Increased droughts and the dependency of the BES islands on global food supply

The current food production on the islands of Bonaire, St. Eustatius and Saba is limited and the majority of the food on the islands is imported. The secondary impacts of climate change worldwide are therefore expected to affect the BES islands greatly. Increased drought will lead to crop failures and it is expected that food insecurity will become a major challenge globally (Wageningen University, 2021).

Given their remote location, the BES islands may be among the last to receive necessary supplies during shortages after droughts. The islands are therefore focussing great measures on reducing their dependency on imported foods. The BES islands are therefore focussing on improving their domestic agriculture production and fishing to reduce the dependence on imported food (see plans in NEPP-CN).

3.3.4 Health

Context and description

Of the 3 BES islands, healthcare is most extensive and accessible on Bonaire. Bonaire's hospital (Fundashon Mariadal) provides various medical services, such as emergency care, surgery and maternity care. In addition, Bonaire hosts various general practitioners and dentists. For highly specialized care, patients do need to travel abroad (e.g. Sint Maarten or the United States). On Saba and St. Eustatius, basic healthcare services are provided. However, these islands rely more heavily on the healthcare services provided on Sint Maarten. For highly complex procedures, patients need to travel elsewhere, such as Latin America or the U.S.

Overall, all 3 islands face challenges such as limited access to specialized medical care, reliance on off-island medical facilities for advanced treatments, and logistical issues due to their remote locations.

Increasing temperatures

- Increase in extreme temperatures may lead to more heat stress, decreased quality of nights rest, and work productivity loss. This is likely to lead to higher sickness rates, more hospital admissions and deaths (PAHO, 2024). This primarily threatens those who have a fragile health. There is currently no data on climate change-related health risks in the BES islands. The likelihood and impact are both considered high.

- A warmer climate will increase the reproduction rate, resilience and distribution of vector-borne diseases (PAHO, 2024). Diseases such as chikungunya, dengue, and zika are likely to increase (IVM, 2022). The overall risk is high. Once vector-borne diseases are prevalent on an island, it is very difficult to eradicate them.
- Increased frequency and intensity of heat waves will lead to increased heat-related mortality (heart attacks) and heat exhaustion (heat strokes, physical exhaustion) (PAHO, 2024). This effect strikes mostly those who are already in poor health.
- Higher temperatures (along with more frequent extreme weather events and air pollution) can exacerbate the symptoms people experience from non-communicable diseases such as diabetes, heart and lung diseases, and kidney disease (IVM, 2022).
- Higher temperatures are expected to lead to less outdoor recreation from locals, however it can also lead to more outdoor activities from tourists (such as sunbathing). It is not known exactly which way this will go, as this is context-specific[1]. Therefore, more frequent outdoor activity due to higher average temperatures can lead to higher exposure to UV radiation because of more outdoor recreation. This will lead to an increase in cases of associated diseases, such as skin cancer and cataracts. The local population is already partly used to these hazards, but immigrants and tourists may be more susceptible to these changes (Wijsman & Baboe-Kalpoe, 2024).
- Higher temperatures will likely lead to increased water recreation. This leads to an increase in exposure to waterborne diseases through water recreation.
- All the above-mentioned effects can lead to more pressure on first aid services (Wijsman & Baboe-Kalpoe, 2024). This effect is likely to occur year-round, but especially during the tourist season and during heatwaves. This is because tourists are not always used to high temperatures and their hazards.

Drought

- While the climate projections for drought are uncertain, drier climates can lead to a lower air humidity. This is especially the case in the landward areas of the islands. This effect may lead to increase in particulate matter (dust) and changes in airborne diseases (PAHO, 2024). This is a threat to the vulnerable population, such as children, the elderly or people suffering from asthma.
- Drier soils in the summer may lead to higher instances of wildfires, which reduce air quality and can pose a threat to health.
- Increased instances of drought will also lead to changing surface water quality. Surface water is generally used for hygienic purposes in the BES islands (Wijsman & Baboe-Kalpoe, 2024). If the water quality deteriorates this can lead to higher exposure to waterborne diseases.

Extreme precipitation

- Extreme precipitation events may cause the deterioration of surface water quality due to flooding and spilling of contaminated areas, sewer overflows and stagnant water. This can contaminate drinking water with fecal-oral pathogens and spread waterborne diseases (Rise, Oura, & Drewry (2022), IVM (2022)).
- Increased multi-day wet periods and changes in the dry/wet seasons changes seasonal patterns that affect mosquito breeding and biting (Macpherson & Akpinar-Elci, 2015). This can contribute to more vector-borne and water-borne diseases.
- Increased multi-day wet periods and increased extreme precipitation may lead to flooding and water damage to houses. This increases the risk of flooded/damp houses. Living in damp houses introduces the exposure to mould and fungi, which bear health hazards.
- Increased pluvial flooding may lead to physical injuries as a result from landslides.
- Pluvial flooding may lead to mental stress and trauma among inhabitants and tourists.

Hurricanes

- More intense hurricanes increase the vulnerability of the islands. During hurricanes there can be no import of medical supplies and patients requiring more complex healthcare cannot be transported to

[1] A study conducted in Grenada and Trinidad & Tobago shows differences in expected climate change-related health issues. In Grenada an increase of hospitalization from dehydration and sunburn was perceived, while this was not seen in Trinidad & Tobago. Both islands experienced increased heat strokes and heart attacks tied to hotter temperatures. (Macpherson & Akpinar-Elci, 2015).

hospitals in other islands (Wijsman & Baboe-Kalpoe, 2024). Damage of supply chains or harbours can have long-term consequences for the healthcare systems of the islands.
- Damage to supply chains from hurricanes also has a direct impact on health as no food can be imported (Wijsman & Baboe-Kalpoe, 2024). This is a great risk for the general well-being of the islanders.
- Higher intensity hurricanes may lead to higher frequency and intensity of wind. This may lead to increased damage to buildings, houses and trees (PAHO, 2024). Moreover, there is also an increase in risk of electricity supply failure.
- Physical injuries from hurricanes. More intense hurricanes may lead to more victims due to direct physical damage.
- Extreme weather events such as hurricanes can lead to mental health issues such as anxiety, depression due to forced displacements and sense of loss (PAHO, 2024).
- Damage to access roads to the health centres or hospitals may temporarily make them inaccessible and limit healthcare during that period.
- Health problems during/after flooding due to exposure to waterborne diseases.
- More intense hurricanes bring more extreme precipitation. See overlapping effects ‘extreme precipitation’.

3.3.5 Recreation and tourism

Context and description

Tourism is an important sector as the BES islands are predominantly tourism-based economies. The main attractions for tourism do differ:
- Bonaire is renowned for its marine life and is a premier destination for diving enthusiasts. The island boasts protected coral reefs and is famous for its excellent underwater visibility. On Bonaire, tourism accounts for almost 40 % of the GDP (Bonaire Chamber, 2024). This underlines the importance of tourism for the economy.
- St. Eustatius is more known for its rich history and cultural tourism, as well as hiking and diving activities.
- Saba tourism is mostly geared towards outdoor recreation, like hiking and diving. It is also noteworthy that business trips of Dutch civil servants are an important contributor to tourism on the island. Next to daily visits, the students at the medical school at Saba, make up approximately 25 % of the island’s inhabitants. The medical school is therefore an important factor for the local economy and tourism sector. The island is smaller than Bonaire and St. Eustatius, and therefore a larger part of the tourism is made up from these short-term visitors.

Increasing temperatures
- Higher sea temperatures lead to coral bleaching (DNCA, 2018), which will greatly impact diving tourism. The risk is high, especially on Bonaire and Saba.
- Less attraction as a tourist destination due to high temperatures worldwide (Layne, 2017). Research has shown that tourism in Europe may face a south to north shift, as tourists will avoid the hot southern coastal regions (European Comission, 2023). Such a shift may also be seen in the Caribbean as tourists may decide to spend their holidays in cooler areas closer to home (e.g. Northern Europe and North America). The extent of this effect is unknown, but the impact may be large seeing as tourism is an important sector.
- Shifting climate zones can affect the natural attraction of the islands, for example if certain species go extinct in the islands. This may lead to a reduction in tourism as nature is one of the main tourism features. The precise impact is unknown.
- Higher temperatures and increased multi-day warm periods can impact the water quality and occurrence of infectious diseases, which may also reduce tourism (Layne, 2017). However, the impact is considered small.
- Higher temperatures and more frequent heat waves may lead to less interest for outdoor activities and recreation during heat waves and reduction of tourism.

Precipitation

- More extreme precipitation events will increase instances of sedimentation, which is damaging for the coral reefs that are important for tourism.
- If bad water quality becomes severe or frequent (e.g. due to runoff, erosion and sewage overflow), this will negatively affect the attraction value of the islands for tourism. However, this is considered a minor risk.
- Increase in extremes (frequency and intensity of wind, lightning, precipitation) can have negative effects on tourism and business climates for companies.

Sea level rise

- Rising sea levels will lead to beach erosion and reduction. This can damage coastal tourism infrastructure (e.g. resorts) and lead to less coastal activities (e.g. beach recreation, scuba diving). Increased coastal erosion can also lead to more sedimentation on the coral reefs, which accelerates the deterioration of the reefs that are important for recreation and tourism.
- Decrease of physical space for coastal nature due to coastal squeeze. This can lead to a decline in coastal ecosystems and therefore a decrease of the natural attraction, which is important for tourism.
- Extreme sea level rise can lead to mangrove destruction, which will reduce the recreational and tourism activities possible in the mangroves.
- Higher sea levels may increase the incidence of flooding and create an unsafe environment for recreation and tourism.

Droughts

- Drier soils and lower groundwater levels can lead to damaged nature from the droughts. Ultimately this could reduce the attraction of natural areas, reducing tourism.
- Droughts may lead to higher chances of wildfires and therefore closure of natural areas that are important for tourism and recreation. If wildfires become common on the islands, their attractive value to tourists will decrease.

Hurricanes

Hurricanes are projected to become more extreme and bring about more severe rains and storm surges. They will also develop more rapidly than in the past. Possible consequences of these developments for tourism are:

- Direct damages to tourism infrastructure (such as hotels, resorts). The impact on the tourism sector as a whole is large, as this would severely limit the number of tourists.
- Much less direct income from tourists because they will avoid hurricanes and hurricane seasons. This especially applies when the hurricane season becomes longer. The overall risk is considered high because of the tourism sector's importance.
- Disruption of accessibility, such as from cruises and air travel. This not only reduces tourism but can increase the risk of tourists getting trapped during a storm.
- Damage to natural and manmade sites and attractions. Hurricanes may physically damage coral reefs and mangroves. This decreases the attractive value to tourists, but the risk is deemed low.

Case: Coral bleaching and tourism
The economies of the Caribbean Netherlands islands are highly dependent on tourism, and therefore also on the natural environment. The islands consist of 2 coral reef areas (Bonaire and Saba Bank) and 2 areas with a rich diversity of coral communities (Saba and St. Eustatius). The largest coral reef in Bonaire covers about 5 km^2 and the Saba Bank covers about 2,000 km^2. In St. Eustatius and Saba, the coral areas cover about 30 and 8 km^2 respectively (Wageningen Universtiy, 2018).

These coral reefs are a main attraction for tourists. It is estimated that 70 % and 60 % of Bonaire and St. Eustatius' tourists come for diving. The Saba Bank is the largest area of coral reefs in the Caribbean Netherlands, supporting fisheries and tourism (NEPP-CN, 2020).

The coral reefs in the islands have been experiencing degradation due to a range of factors. Erosion and runoff of water with high nutrients (and polluted water in general) have been threats to the coral reef health. Heat stress in coral reefs has led to large-scale bleaching, diseases outbreaks and eventually mortality (Muñiz-Castillo, 2019). The years 1998, 2005, 2010–2011, 2015 and 2017 have been identified as severe and widespread heat-stress years in the Caribbean. The reefs of Bonaire have been experiencing near-annual bleaching events. In Saba and St. Eustatius large-scale bleaching events (such as in 2005) have increased the vulnerability of the reefs. (DNCA, 2018).

Coral reef degradation will be exacerbated by rising temperatures due to climate change. The reefs can bounce back, but it is important to reduce other threats to increase the resilience of the reefs. The loss of coral reefs will greatly affect the tourism sector, as this is one of the main attractions of the Caribbean Netherlands.

Figure 3.4 Bleached corals (DCNA, 2024)

3.3.6 Infrastructure

Context and description
All BES islands feature a road network of paved and gravel roads. These allow for general accessibility on the islands. The role of public transport is limited and there are no railroads. Additionally, all islands feature a seaport and an airport for regional and worldwide connections. All islands rely heavily on these outside connections for the import of essential goods and services. Disruption of these supply lines causes many cascade effects and leads to scarcity of food medical supplies, and other (essential) goods.

Climate change will impact the infrastructure on the islands by direct disruptions due to extreme events such as hurricanes or extreme rainfall, or long-term effects, such as humidity and corrosion or inaccessibility of the port due to sea level rise. The infrastructure sector in this report is only focused on transport infrastructure.

Increasing temperatures

- More frequent extreme temperatures will increase the wear and tear of infrastructure due to thermal expansion. For example, the study by (Padmini P. Gudipudi, 2017) showed an increase of 2-9 % fatigue cracking of roads. This could apply more to materials that have more thermal expansion, such as the repeated cycle of heating of steel (during high temperatures/heatwaves). Maintenance efforts therefore increase with increased fatigue, depending on the material. The likelihood is medium to high, and the impacts are medium.
- High temperatures could affect the quality of asphalt and concrete roads, causing asphalt to melt and concrete to crack due to fatigue, making the roads inaccessible. In the study by Padmini (Padmini P. Gudipudi, 2017) the researchers focused on how climate change may impact the transportation infrastructure in the United States for example. The findings showed an increase of 2-9 % fatigue cracking and an increase of 9-40 % for AC(Asphalt-Concrete) due to climate change rutting after a 20 year time frame. The likelihood is low to medium, and the impacts are medium.
- A higher air temperature will reduce lift capacity of airplane wings. Either by increasing the runway length or decreasing the weight, the airplane will be able to lift off the same as at a lower temperature. There is a medium likelihood of the lift capacity being insufficient, although the impacts are small, as the carrying capacity can easily be reduced.

Sea level rise

- Existing coastal protection infrastructure is no longer sufficiently high and/or stable in the future. This infrastructure requires additional maintenance and upgrading costs to ensure flood protection in the future. The likelihood is medium but the impacts of a flood are high.
- Sea level rise will increase the risk of flooding from the sea, and therefore the risk of flooded roads. This decreases general accessibility on the island and affects multiple other sectors. For example, essential goods can no longer be distributed from the port and tourists are no longer able to move to their destination. The likelihood is low to medium but the impacts of a flood are high.
- Sea level rise may lead to difficulties to operate existing ports for the loading, unloading and docking. The time window in which operations are possible, is reduced. This makes supplying the islands with (essential) goods more difficult. The likelihood is low but will increase over time, the impacts for the islands are medium, as the ports will be available but during a smaller time frame.

Precipitation

- Extreme rainfall events could increase the risk of pluvial flooding, impacting accessibility and infrastructure in multiple ways:
  - Damage to control and monitoring systems used to manage infrastructure. For example at the airport and ports. This causes the infrastructure to be inaccessible due to system failure.
  - Reduced accessibility to transportation hubs (harbour and airport), due to flooded roads leading towards the transportation hubs.
  - Decreased availability of infrastructure due to direct damages from flooding. All of these 3 effects have a low likelihood but the impacts are high.
- Due to extreme rainfall events, water will runoff from steep areas causing erosion of land and sediment deposition. The deposited sediments could make the roads inaccessible. For example, roads may be blocked as a result of landslides. The likelihood of runoff is quite high as the erosion is already ongoing. It will result in medium impacts as steps have already been taken to reduce erosion.
- Due to more rainfall, the humidity level will increase as well, causing more corrosion at the islands. This negatively affects infrastructure in the harbours of the islands. The likelihood of increased corrosion is low as the overall increase in yearly rainfall is limited.
- More precipitation can cause traffic safety problems, as roads tend to get more slippery and visibility might decrease during rainfall events. A study, performed on both Boston (US) and Santo Domingo (Dominican Republic), showed the correlation with extreme rainfall and traffic accidents. An increase of approximately 25 % in traffic injuries and a 42 % in property damages. (Nazif-Munoz, 2021) Although the likelihood of more rainfall is high, the impacts for the islands will be low as there are less crowded intersections and chances of traffic injuries.

Drought

- Drought can be the cause of wildfires, which in turn could lead to damage of roads and road closures due to safety issues. Chances of wildfires due to droughts are medium, as indicated previously, the overall evaporation exceeds rainfall at times causing droughts. The number of wildfires on the islands however has not been that high. The impact so far also does not indicate any damages to infrastructure. The impacts are therefore low.

Hurricanes

- Due to hurricanes, transportation networks could be disrupted in multiple ways, either runways or roads could be damaged due to extreme wind and debris, but the harbours could also be affected by storm surges. The likelihood is medium, but impacts are high.
- Supply lines could be down for longer time, as the critical infrastructure is damaged, such as the airfield and harbour. The likelihood remains low as both supplies should be affected at the same time, the impact is very high however.

Case study: Hurricane Irma

Hurricane Irma, one of the most powerful Atlantic hurricanes on record, had varying levels of impact on the infrastructure of the BES islands in September 2017. While Bonaire was largely spared from the worst effects, St. Eustatius and Saba experienced more significant damages and problems.

Bonaire was on the periphery of Hurricane Irma's path and experienced less severe impacts compared to other islands. However, the following impacts were observed:

1. Damage to buildings and homes: minor structural damage occurred, particularly to older buildings and less sturdy constructions. Some roofs were damaged, and there were reports of broken windows.
2. Utility disruptions: there were temporary disruptions in power and water supply due to precautionary shutdowns and minor infrastructure damage.
3. Transportation and communications: roads experienced minor flooding and debris, but major transportation routes remained functional. Communication networks saw brief interruptions.

St. Eustatius, though not in the direct path, faced more severe challenges:

1. Structural damage: several homes and buildings experienced roof damage and waterlogging. Public buildings, including schools, sustained major damage.
2. Utility Services: power outages were widespread and prolonged due to downed power lines. Water supply systems faced interruptions. This underlined that the island is vulnerable to interruptions of vital services.
3. Transportation: roads were blocked by debris, and the port facilities sustained damage, affecting supply chains and transportation. As a result, emergency supplies could not be distributed freely across the island. This is an important cascade effect of the hurricane event itself.

Saba, closer to Irma's path, experienced more pronounced infrastructural impacts:

1. Building damage: many homes and buildings, including schools and government structures, sustained significant damage. Roofs were blown off, and structural integrity was compromised in several cases. An example is shown in Figure 3.5.

Figure 3.5 A shed with collapsed roof on Saba after hurricane Irma (photo by Aron Hoogendoorn)

2 Utility disruptions: Water supply systems faced significant interruptions. Inhabitants therefore lost access to basic needs such as clean drinking water. In addition, there were serious concerns about telecommunications infrastructure being severely damaged. Irma struck particularly hard in the area where submarine internet cables make landfall. In the end, the cable landing point appeared not to be damaged beyond repair, but there were outages of telecommunications. The electrical grid was shut down beforehand and was up and running within 24 hours. Most of the electrical infrastructure was located underground, causing only little damages to the functioning of the grid.

3 Transportation: landslides and debris blocked roads, complicating transportation and emergency response. An impression is shown in figure 3.6. The small airport and port facilities were temporarily non-operational due to damage and were not available for urgent humanitarian aid and military transports.

Figure 3.6 Landslides and debris blocked road towards Saba’s Fort Bay Harbor, photo by Hazel Durand

While Bonaire faced relatively minor impacts, St. Eustatius and Saba experienced more severe infrastructural damage due to their closer proximity to Hurricane Irma’s path. The storm underscored the need for improved disaster preparedness and resilient infrastructure in the BES islands to mitigate the effects of future hurricanes. Recovery efforts involved repairing damaged structures, restoring utility services, and rebuilding critical transportation and communication networks, with a focus on enhancing resilience against future storms.

3.3.7 Energy

Context and description

All 3 islands have taken big steps on the implementation of solar and wind power. These power sources are not only more sustainable, but also enhance self-sufficiency. However, sustainable energy sources are still being supplemented by diesel-powered generators. Each island has its own electricity and utility company that manages the power supply and distribution through an electricity grid.

The average yearly wind speed in the area of Bonaire is expected to increase, based on the KNMI'23 scenarios. Saba and St Eustatius show hardly any differences in the climate scenarios compared to the current base line. This increase in wind speed can be relevant as it can increase energy yield from wind parks on Bonaire.

In addition, both St. Eustatius and Bonaire feature major oil storage and reserve locations (e.g. GTI). While these sites do not process or refine oil products, they are important in the storage and distribution of oil products across the world.

Increasing temperatures

- Overheating of energy systems themselves, causing energy blackouts to happen (Mathaios Panteli, 2015). This impact has many secondary cascade effects that overlap with multiple other sectors. For instance, transportation, health care and tourism will be severely hampered by blackouts. This is not likely to happen but can have very high impacts on the energy sector.
- Increase in air temperature will also cause the water temperature to rise. Increased water temperature causes a reduced amount of cooling water for energy facilities, hence reducing energy production. The likelihood for cooling water to warm up is medium, the impacts could be high however, as without cooling the power systems cannot function properly.
- Higher temperatures overall will increase the energy demands, due to cooling for either tourists or inhabitants of the islands. This is very likely to happen and will have a low to medium impact on the energy sector.
- An increase in air temperature could lead to a decreasing energy yield from solar panels. Above 25 °C, the energy production of solar panels starts to decrease with increasing temperature (Sauer D., 2007) (Jehad Adeeb, 2019). This is very likely to happen but will only pose a small impact on the energy sector.
- Due to increased heat waves, power cuts and increased water demand, there will be less time to fill up the RO installations as preparation for droughts and heat events. The likelihood is medium, as multiple heat events should follow up in rapid succession, the impacts on the energy sector is low.

Precipitation

- Due to more extreme discharges, energy plants, and other energy infrastructure, could get flooded causing a failure of energy supply. This effect has a low likelihood but a high impact.
- More extreme discharges could damage the electricity grid, for example through landslides damaging utility poles. This effect has a low likelihood but a high impact.

Hurricanes

- Due to storm surges, vital and vulnerable infrastructure (solar parks, GTI plant) can become flooded, causing a big part of energy supply to fail. This effect has a medium likelihood for low lying areas and low likelihood for higher locations, but a high impact.
- Direct damages to the energy infrastructure, caused by heavy winds and debris (e.g. utility poles, solar and wind parks), leading to blackouts of the power supply. This has a medium likelihood a medium impact, as much of the power supply is now being built for category 5 hurricanes. Category 5 hurricanes have no upper limit, however.
- If supply lines are also cut, the distribution of alternative energy carriers such as oil is also hampered. This event has a low likelihood and medium impacts on the energy sector.

3.3.8 ICT and telecom

Context and description

The ICT and Telecom sector comprises all infrastructure and assets required to keep ICT and telecommunication systems active. From the interviews with the islands, it became clear that there is an increasing awareness of the vulnerability of communication and telecom lines during extreme events. On Saba and St. Eustatius, most of the new power lines and communication lines are created underground. On average, there are 2 telecom providers per island. During an extreme calamity, efforts are controlled via a WhatsApp group on Saba. There is also an old back-up system between Saba and Statia that makes it possible to communicate between islands if one of the islands has lost communications with the outside world. However, it is uncertain if this system is still operable.

Increasing temperatures

- Extreme heat waves could cause overheating of ICT-equipment, leading to communication outages and increased maintenance costs. (Wu, 2022) This is not likely to happen, but can have very high impacts on the energy and ICT/telecom sector.

Sea level rise

- On Saba, a major sea cable makes landfall, as indicated by a Saba representative during the interview. This area is very prone to erosion. During big storms, this location is vulnerable. It may cause unrepairable damage to the cable, causing major hurdles in communications. The likelihood is low, but the impacts are high.
- Due to sea level rise coastal flooding could occur, making disruptions more likely to happen to coastal communications. The likelihood is low, as is the impact on the overall ICT and telecom sector on the islands.

Precipitation

- Extreme pluvial flooding causes a greater likelihood of failure of electrical supply systems. This also impacts telecommunications as a secondary effect This effect has a low likelihood but a high impact.
- In addition, infrastructure management systems in the harbours and airports may be struck by pluvial flooding. As a result, operations of this vital infrastructure have to be ceased. This effect has a low likelihood but a high impact.

Hurricanes

- Damages at power supply can cause blackouts or IT system failures. This is effect has a low likelihood and has a medium impact on the ICT and telecom.
- More and intense hurricanes will cause disruptions in power lines that are above ground and will disrupt communication possibilities. This effect has a medium likelihood but a low impact as an increasing amount of telecom and power lines is put underground.

3.3.9 Safety

Context and description

This sector encompasses public safety, emergency response and disaster preparedness. As mentioned, the KNMI monitors the weather for the Caribbean Netherlands. In the event of expected extreme weather, they inform and alert the Public Entities and the Ministry of IenW. This also applies to earthquakes and tsunamis.

On the islands of Saba and Statia, there is an evacuation protocol for medical emergencies for example. When the port and airfield are inactive, there is a helicopter service to St. Maarten.

Increasing temperatures

- Increasing heat waves will also increase the health care demand on the island and exceed the health care capacities of the islands themselves. This is very likely to happen and will have a medium impact on the safety.
- Due to higher overall temperatures, monitoring systems of the airport or harbour could get disrupted, causing more accidents to happen. This has a low likelihood but has a medium impact on the safety.
- Overall higher temperatures will decrease road safety, as drivers are fatigued earlier and show delayed responses (Wyon, 1996). The likelihood of this is medium and the impacts are considered low, as the roads and intersections on the islands are not that crowded.

Sea level rise

- An increased risk of flooding and severe damages to buildings and people. This effect has a medium likelihood for low lying areas and low likelihood for higher locations, but a high impact.
- An increase of coastal erosion, resulting in unstable cliffs. These may collapse and form a potential safety hazard. This effect has a medium likelihood and a high impact on safety.
- A decrease of harbour safety, as the water level will rise to higher levels during storms in combination with sea level rise. This effect has a medium likelihood and a medium impact on safety.

Precipitation

- Extreme precipitation effects can cause more road accidents due to decreased visibility and slippery roads. (Nazif-Munoz, 2021). The likelihood is medium as is the impact.
- Due to more extreme rainfall, erosion and sedimentation may cause disrupted roads and decrease road safety. An example of a landslide striking a major road on Saba is shown in Figure 3.7. The likelihood of runoff is quite high as the erosion is already ongoing. It will result in low impacts for safety.

Figure 3.7 Landslide striking a major road on Saba

Drought

- Due to droughts, green areas are more vulnerable to wildfires, causing a safety risk for inhabitants. Chances of wildfires due to droughts are medium, as indicated previously, the overall evaporation exceeds rainfall at times causing droughts. The number of wildfires on the islands however has not been that high. The impacts are medium.

Hurricanes

- Hurricanes are expected to develop faster than in the current situation, which will cause the response time to decrease. This could pose a safety risk, as evacuation plans and preparations could be too late. The likelihood is medium (due to uncertainty) but impacts are high.
- Due to severe hurricanes supply lines could get cut off and food security, as well as other daily essentials, on the islands is compromised. The likelihood is low as both supplies should be affected at the same time, the impact is very high, however.
- Due to inaccessible roads, healthcare service could become inaccessible.

- As extreme winds could transfer debris, the general safety of people inside and outside of buildings is affected. The likelihood is low as measures have been taken on Saba and Statia to prevent debris, the impact can be high, however.

3.3.10 Built environment and spatial planning

Context and description

Built environment and spatial planning include all buildings, parks and other man-made assets on the islands. Infrastructure is excluded, as that is covered under various other sectors.

Increasing temperatures

- Higher temperatures will increase the need for heat prevention and cooling spaces in buildings and houses. The use of ACs may cause even warmer temperatures in outdoor environments (such as more closely built urban spaces) The likelihood is high, as are the impacts on the outdoor environment.
- Higher temperatures can lead to increased need for outdoor cooling spaces, such as parks. The likelihood is high and the impacts for spatial planning will be medium.
- Extreme temperatures will damage infrastructure, such as asphalt. (Padmini P. Gudipudi, 2017). The likelihood is high, although the impacts are low to medium over time. The life expectancy of the infrastructure is expected to decrease.

Sea level rise

- A rising sea level will increase costs for flood defences and increase maintenance costs. The likelihood is high as are the impacts.
- Due to sea level rise, coastal floods are more likely to happen. In the event of a flood, buildings in low lying areas could get damaged or completely destroyed. The likelihood is medium for low lying areas but impacts are very high.
- An increase in sea level will decrease the available space on an island to build due to the coastal squeeze. The likelihood is high, although the impacts are low.

Precipitation

- Due to more year-round precipitation, the humidity will increase causing damage to wooden parts of buildings (mainly in the historical centres) (René K.W.M. Klaassen, 2012). The likelihood of increased groundwater levels is low as the overall increase in yearly rainfall is limited. The impacts are in the medium range for infrastructure though.
- Extreme rainfall events will create erosion and sedimentation across the islands. This could induce landslides that devastate everything in its path, such as buildings and roads. The likelihood of runoff is quite high as the erosion is already ongoing. It will result in medium impacts, as preventive measures against erosion are actively maintained.

Drought

- Drier soils in the summer and lower groundwater levels will cause water shortages for urban green spaces. The likelihood is high, as are the impacts for greenery.
- Drought will lead to higher chances of wildfires, which can spread to the built environment. Chances of wildfires due to droughts are medium, as indicated previously, the overall evaporation exceeds rainfall at times causing droughts. The number of wildfires on the islands however has not been that high. The impacts are medium.

Hurricanes

- Increased hurricane intensity will lead to physical damage to buildings, houses and trees. Subsequently this will lead to increased stress on the available infrastructure. The likelihood is medium and the impact is high.
- Damage from hurricanes will in worst cases lead to displacement of inhabitants. This will cause additional stress on the built environment. The likelihood is medium and the impact is medium.

3.4 Impact on accessibility and livelihood

Being small island states, the BES islands are relatively remote and dependent on imports for many essential goods and services. Moreover, many local inhabitants rely on global supply lines and tourism for their livelihoods. Impacts across various sectors impact both accessibility and livelihoods. This chapter addresses the combined effects of climate hazards to accessibility and livelihood.

Accessibility

Especially Saba and St. Eustatius are greatly reliant on imports for the provision of food, medical supplies and other goods. This dependency also applies for Bonaire, but the vulnerability to climate impacts is lower because it is better connected to the outside world and has more import options.

All islands have taken steps to reduce their dependency on imports. Hurricane Irma has been a trigger in accelerating these efforts, as it exposed the adverse effects of being a small island state. However, climate change poses several additional challenges. These are listed below:

- Rising temperatures are likely to affect infrastructure. Both in terms of damage to the infrastructure itself (e.g. melting asphalt), and in terms of damage to control and management systems (e.g. on airports and harbours).
- Sea level rise may cause more frequent flooding of important roads on Bonaire, especially during hurricanes (storm surge). This is less of a problem on Saba and St. Eustatius because most urban areas are located on higher grounds. Sea level rise does affect port operations across all 3 islands as docking and mooring may become more difficult. It is conceivable that the time window in which operations are possible, is limited. Sea level rise should be accounted for in regard to operations when designing new ports (e.g. on Saba).
- The main threat that stems from precipitation is erosion and landslides. Landslides may render roads unusable for a while and even pose a safety hazard. It is recommended that erosion hotspots in the vicinity of major roads and power lines are assessed, and appropriate measures are taken to reduce the risk of landslides.
- Hurricanes can have devastating effects on infrastructure. This is not new and most new infrastructure is designed to withstand extreme weather. However, as hurricanes develop more rapidly and the hurricane season becomes longer, the likelihood of supply lines being interrupted grows. It therefore becomes more uncertain if and when the islands can be supplied with necessary goods. One way to further reduce dependency on weather-dependent supply lines is to stockpile food and medical supplies, or to produce more food on the islands.

It is noted that the BES islands have limited options to increase resilience in the supply lines on the islands themselves. Extreme weather events in the region may severely hamper supply lines. For example, a major hurricane that strikes Florida or Sint Maarten is bound to disrupt the flow of supplies, goods and tourists to and from the BES islands. Such events will become more common as hurricanes' severity increases and the hurricane season becomes longer.

The following actions can be taken to reduce the effects of climate hazards on accessibility:

- Making infrastructure on the islands more resilient against climate hazards. This includes roads, harbours and airports as well as energy infrastructure, telecommunications and water management infrastructure.
- Further decreasing the islands' dependency on other islands and countries as they have already been doing. This includes stockpiling food and emergency supplies.

Livelihood

Tourism is by far the most important source of income and livelihood on all islands. The tourism sector is likely to be affected by climate change in the following ways:

- Tourism infrastructure such as hotels and resorts are damaged by hurricanes. Across the entire Caribbean, hurricane Irma caused some USD 65 billion in damages.
- Income from tourism declines following hurricane events. This is due to (1) unavailability of tourist infrastructure that is still damaged, (2) regular air travel and cruise routes are disrupted and (3) tourists being scared away after hurricanes.

- Tourism income may further decline as climate change leads to rising temperatures elsewhere. During the winter and spring, there may simply be less reason for (European) tourists to travel to places far away. Locations in southern Europe and northern Africa are much closer by and will have more comfortable temperatures during the winter than they have now.
- Tourists may also be scared away by more severe hurricanes.
- Coral diving is an important travel motive for many tourists on Saba and Bonaire. Coral bleaching and sedimentation of the reefs diminish their attractive value. Eventually the islands may lose coral diving tourism. However, this may partly be compensated through accommodating different types of tourism (e.g. beach resorts, hiking in nature).
- Other natural attractions are also at risk of damage. For instance, forest fires and erosion increase and damage forests.
- Rising temperatures may bring about a shift in the preferred type of tourism. Some tourists may find the heat uncomfortable and stay away. On the other hand, some tourists may enjoy the heat. In general, water recreation may become more popular, but this cannot be proven.

Next to tourism, some inhabitants rely on agriculture and fisheries for their livelihoods. Agriculture is threatened by more frequent and severe droughts and more saline groundwater resources (caused by sea level rise and droughts) and probably by the increase of pests and diseases. As a result, crop yields may become smaller or crop failure may occur. One way to adapt to this threat is by changing to crops that are more resistant to drought and saline water. Agricultural productivity may further be hampered by extreme rainfall and soil erosion. Indoor hydroponic farms, such as the one on Saba, are a possible way to make agriculture resilient against climate change.

Like agriculture, fisheries make up a small portion of livelihoods. As a result of coral bleaching and sedimentation of coastal zones, fish species will likely lose habitat. This makes it more difficult for fishermen to make a living. One way to adapt is to fish in the open sea (already done on Saba), but this does require different equipment. Implementing aquaculture can also provide a new type of fishery on the islands. Fisheries are further hampered by longer hurricane seasons during which fishing operations frequently have to be ceased. By continuing the coral restoration projects and reducing erosion, the ecosystems that the fisheries are dependent on will be better protected.

4

OVERVIEW - PAST AND PRESENT ADAPTATION AND MITIGATION EFFORTS

4.1 Introduction and approach

This chapter presents the overview of past and present adaptation and mitigation efforts on the BES islands. Sections 2.2 and 2.3 contain the key efforts in the region and on the islands respectively and are thus a selection of the overview. The full overview of efforts can be found in Appendix I.

The overview was derived from literature reviews. Literature sources were retrieved from 4 different sources:
1 Search queries for climate mitigation and adaptation in about 40 scientific journals.
2 Government reports received from Infrastructuur en Waterstaat (IenW), Klimaat en Groene Groei (KGG) IenW, and the public entities of the BES islands.
3 Google search for media articles and publications on climate mitigation and adaptation efforts, including measures for self-sufficiency.
4 The chapter on the Caribbean in the latest IPCC report (AR6).

Chapter 6 contains a list of references and documents that were used for the review. The findings from the literature review were verified and discussed during digital interviews with experts on specific topics.

Distinction between adaptation and mitigation on the BES islands
Throughout this report, a classic definition of climate adaptation and mitigation is used (as described by the IPCC):
- Adaptation involves adjusting systems and the environment to cope with the impacts of climate change, thereby reducing harm or exploiting beneficial opportunities.
- Mitigation aims to reduce or prevent greenhouse gas emissions to slow climate change.

However, it is emphasized that on the BES islands (and many small island states in general), these definitions are more ambiguous in practice. From a Caribbean perspective, most adaptation efforts are aimed at improving self-sufficiency. There are 2 main reasons for this: (1) the islands rely on imports and global supply lines, making self-sufficiency a priority (2) the islands' role in greenhouse gas emissions is minimal. As a result, some measures that would be considered mitigation efforts under the classical definition, are considered adaptation measures on the islands. An example is solar energy: its primary goal on the BES is to reduce energy dependency.

4.2 Key mitigation and adaptation efforts in the region

This section describes key mitigation and adaptation efforts in the region. This comprises the 3 BES islands as well as some overarching, regional efforts which have an effect on the BES islands.

Summary 'It is never too late' by Ed Nijpels
In May 2022, Bonaire's Executive Council informed the Minister for Climate and Energy Policy that it intended to set up a climate table on Bonaire. The Executive Council therefore asked the Dutch Government to provide a quartermaster to develop the climate table concept. In November 2022, Ed Nijpels was appointed

the quartermaster for the investigation of the climate table Bonaire. He was tasked with investigating in which form a climate table could be set up on Bonaire, and if these findings would also be applicable on Saba and St. Eustatius. He has also identified key gaps in knowledge and governance efforts.

The report contains various findings on different topics. While Nijpels primarily considered Bonaire, Saba and St. Eustatius are also included in his final report. The following bullets show several key findings that are also relevant to this report:
- The BES islands have large responsibilities with a variety of tasks as compared to their size. Also, the available resources in terms of capacity and knowledge are limited.
- There is no integrated or central vision on climate adaptation and mitigation. The task division between the central government and the island has been ill-defined since the 2010 change in constitutional relationships.
- Inhabitants are worried about climate change and its effects on the islands. This has become a hot topic among inhabitants, amplified by the report for Greenpeace by the Institute for Environmental Studies (IVM)
- Many intended policies were not implemented or only partly implemented.
- Information on climate change developments and impacts on the BES islands is limited. For example, there are no (complete) data on greenhouse gas emissions, elevation and island-specific climate risks.

4.2.1 Mitigation efforts in the region

Several notable mitigation efforts that entail all BES islands (or even the Caribbean as a whole) are the following:
- The National Government has made EUR 33.6 million available from the Stimulation Sustainable Energy Production and Climate Transition regulation (SDE++) to support the development of sustainable energy in the BES islands. This funding is being used to implement projects in the energy transition. This is already being used to implement customized projects to make energy generation more sustainable and to reduce the dependency on fossil fuels. In Bonaire, a solar park has been built with more than 10,000 solar panels, providing for 5,000 households (Rijksoverheid, 2023). Further projects per island are described in chapter 4.3.
- The National Government has allocated funds to alleviate energy poverty. This initiative includes efforts to install solar panels on social homes to reduce people's energy costs. Plans are detailed in the Social Housing and Physical Development Policy Agenda and are being executed from 2023 onwards.
- Bonaire, Saba and Sint-Eustatius, together with the Dutch government, are working on their own climate plans in 2024. These plans include mitigation as well as adaptation plans.
- All BES islands undertake knowledge sharing initiatives with other small island states, both on the topic of mitigation and adaptation.
- The Dutch Caribbean Nature Alliance (DCNA) published a Climate Action Plan in 2022. It stresses the importance of quick action for both mitigation and adaptation. The document does not contain specific or detailed goals.

4.2.2 Adaptation efforts in the region

The following adaptation efforts for all BES islands are highlighted here:
- The Spatial Development Programme Caribbean Netherlands was published in June 2024. The document is primarily aimed at public entities. All public entities must use the guiding principles from the Programme and incorporate them in the spatial development plans specific to the islands. While its scope is broad (economical activities, nature, recreation, etc.), it explicitly takes into account climate adaptation and mitigation. For example, through stipulating the need for rainwater buffers.
- The Nature and Environment Policy Plan Caribbean Netherlands 2020-2030 (NEPP) was published in 2020. This document outlines plans and goals for nature and environmental policies on each of the BES islands. It briefly describes the current state of nature in the Caribbean Netherlands and provides long term strategies and goals. The targets entail multiple disciplines, such as waste management, coral reef

restoration, the conservation of important habitats and developing the local economy by sustainable use of land and water. The targets are specific to each island.

- Bonaire, Saba and Sint-Eustatius are currently developing climate plans. The Dutch government has made EUR 1 million available for this. This is part of the response of the Dutch government to the report 'It is never too late' by Ed Nijpels. (Rijksdienst Caribisch Nederland, 2023). The following documents and studies will be input of the climate plans:
  - The KNMI (Royal Netherlands Meteorological Institute) provided climate impact scenarios (KNMI'23) and will continue this research in the coming years.
  - A climate impact atlas has been created, this will be further developed in the coming years. The climate impact atlas shows the expected climate developments and some of their impacts on a series of interactive maps (Stichting CAS).
  - IenW has commissioned a climate impact analysis (this report) which will take multiple policy domains (e.g. tourism, nature, infrastructure) into account.
  - The BES islands will be included in the 2026 revision of the National Adaptation Strategy (NAS). The NAS provides a long term and national strategy for climate adaptation.
  - In 2016 IenW commissioned research to assess the risks of flooding, conducted by HKV lijn in water. An update of this research building on the new climate scenarios will be published in Q3 2024 (HKV, 2024).
- KNMI monitors the weather for the Caribbean Netherlands. In the event of expected extreme weather, they inform and alert the Public Entities and the Ministry of IenW. This also applies to earthquakes and tsunamis (DCC-IenW, 2018).
- An operational early warning system for coastal floods and cyclones has been developed on the island of Hispaniola (Dominican Republic and Haiti). The system produces and disseminates new early warning information on coastal flooding, which will help save lives and protect property in low-lying, populated coastal areas. The article explicitly mentions the potential to enhance this early warning platform in the future and to extend it to other Caribbean nations.
- Smart hospitals initiative: this initiative comes from the Pan American Health Organization (PAHO) and focuses on enhancing the resilience and energy efficiency of hospitals in the Caribbean. The goal is to have hospitals with energy autonomy that allow them to run during emergencies and disasters.
- (PAHO, 2024).
- Following the 2012 Rio+20 conference, the notion of a 'blue economy' was raised. This concept focuses on using the ocean's resources for economic growth, improved livelihoods and jobs and maintenance of the ocean ecosystem health. Many Caribbean islands have been implementing this notion, through regional projects such the Caribbean Large Marine Ecosystem (CLME), Caribbean Challenge Initiative (CCI), Eastern Caribbean Regional Oceans Policy and Action Plan (ECROP) funded by governments and development partners. At a national level, many islands have introduced policies to transition to a blue economy (World Bank Group, 2016). Bonaire has also embraced this notion of a blue economy in its tourism development plans (OLB, 2021).
- The Caribbean Community Climate Change Centre (CCCCC) co-ordinates the region's response to climate change. The CCCCC is a repository and clearing house for regional climate change information and data and provides climate change-related policy advice and guidelines to the Caribbean Community (CARICOM) Member States. Various projects have been carried out by the CCCC, such as adaptation projects, educational projects, resilience development plans that cover the whole Caribbean region (CCCCC, 2024).
- Island(er)s at the Helm contributes to equipping Dutch Caribbean societies (ABCSSS islands) with tools for confronting climate change through, amongst other methods, participation with community stakeholders, research and trans-Atlantic academic platforms. (KITLV, 2023).

4.3 Key adaptation and mitigation efforts on each island

In the following sub-chapters the key adaptation and mitigation efforts per island are described. The classic distinction between adaptation and mitigation is used. Some efforts are considered to be both adaptation and mitigation efforts. These are classified according to their primary objectives.

4.3.1 Bonaire

The efforts on Bonaire generally aim to mitigate environmental impacts (such as coral reef degradation) and to adapt to climate change to ensure a resilient future for Bonaire. Many efforts therefore tackle challenges in various sectors. The main efforts revolve around improving (waste)water management, restoring and conserving ecology and nature, developing renewable energy and improving socio-economic well-being.

Mitigation

The following mitigation efforts on Bonaire are highlighted:

- Bonaire aims to have 80 % sustainable energy production in 2025. This is accomplished through a solar park and wind turbines. The national government has provided a subsidy of EUR 10 million to Bonaire Bon Transition (BBT) so that they can be co-owners of the production (additional to the EUR 10 million the government allocated to improving the sustainability for the BTT). Part of this subsidy comes from the SDE++ regulation. (Minister voor Klimaat en Energie, 2022). The project details are as follows:
  - Bonaire solar park: solar park on Bonaire is still in development. Currently, 1 MW is in use, while a total capacity of 10 MW is planned. This saves CO_2 emissions and decreases the dependency on fossil fuels. The solar park is shown in Figure 4.1.
  - Bonaire currently has 13 wind turbines: 12 at the wind farm at Morotin and 1 at Sorobon, near Lac Bay. Currently wind energy meets 22 % of the energy demand and the objective is to increase this rate to 60 %. This will be realised by the expansion of a wind farm and central solar park at Karpata (WEB, 2024).
- The National Government has made EUR 990,000 available to – among other things – install solar panels and battery storage on 118 new social homes of the Bonaire Housing Foundation (FCB) (Social Housing and Physical Development Policy Agenda for the Caribbean Netherlands).
- Wind parks Bonaire. Wind energy meets around 22 % of the energy demand on Bonaire. The electricity producer ContourGlobal and 'Water- en Energiebedrijf Bonaire' (WEB) will realize expansion of the wind farm and a central solar park at Karpata to contribute to sustainable energy production goals.
- Vision on mobility and accessibility Bonaire. The public entity of Bonaire (Openbaar Lichaam Bonaire (OLB)) has been working on a new vision for more sustainable mobility. The primary objective is to reduce the ecological impact of mobility on Bonaire. For instance through promoting the use of public transport and bicycles.
- By 2026 the first commercial passenger flights with electric aircraft, between Aruba, Curacao and Bonaire, are expected to be conducted. The ambition is to have 50 % of the flights to be carried out by electric aircraft. Ultimately, in 2035 all the air movements between the islands will be electric (NACO, 2021).
- Bonaire has set a priority to respond quickly and effectively to the sargassum inflow, including prevention of the sargassum inflow. In 2018 a draft Civil Service Checklist (Ambtelijk Bestuurlijke Checklist (ABC Card)) was developed for emergency services (fire department, police, Area Health Authority and Public Entity) including a detailed work plan on how to assist STINAPA (Bonaire National Parks Foundation) during a sargassum disaster. The report 'The Prevention and Clean-up of Sargassum in the Dutch Caribbean' by the DCNA provides guidelines for effectively collecting and utilising the sargassum (DCNA, 2019) (see Figure 4.2).
- The public body of Bonaire (OLB. 'Openbaar Lichaam Bonaire') commissioned the report 'Integrated Wastewater Vision Bonaire 2023-2030' to describe specific targets for wastewater management for the period until 2030. The goal of this document is to create measures to ensure there will be no more environmental pollution caused by wastewater. There has been no formal reaction regarding the report's contents and targets.
- Over a period of 5 years, USD 10 million have been invested in the modernization of solid waste management and processing on Bonaire. In collaboration with the Ministry of IenW, the OLB has commissioned over 21 related projects. Proper solid waste management helps both mitigation (e.g. less emissions from landfills, less pollution) and adaptation (e.g. less clogs in urban drainage system).

Figure 4.1 Bonaire solar park. Source: The Green World Company

Figure 4.2 Sargassum on the coast of Bonaire (Source: DCNA, 2019)

Adaptation

Bonaire has been undertaking the following key adaptation efforts:

- Nature Plan Bonaire 2020-2024 (draft). This plan formulates objectives for nature conservation and environmental protection in a wide sense. It contains restoration of coral reefs and unique habitats, sustainable use of land and water resources and local conditions for successful environmental policymaking. The OLB aims to finalise the draft plan in 2024.
- Update of the spatial development plan of Bonaire (ROB2022). In the update, new information about population, tourism and housing corporation details have been added. The updated plan also includes plans for the protection of coastal communities and nature reserves.
- Bonaire has been actively combating erosion for several years, alongside a programme for nature restoration. Erosion may be caused by roaming grazers, for example. During heavy precipitation events, the water runoff is increased and soil and debris are washed away downstream. This causes damage to the built environment and to coral reefs and mangrove forests. Figure 4.3 shows sediments entering the sea from Saliña di Vlijt after heavy rainfall. The saliña (salt pan) is being restored to reduce runoff.
- There are various ongoing projects for coral reef restoration (see https://www.reefrenewalbonaire.org/map for a map and details). A part of the efforts is experimenting with different types of coral and marine climates so they are able to withstand rising sea temperatures.
- The OLB has a disaster management team that combats the consequences of crisis or disaster, such as flooding, tropical storms and hurricanes. The Crisis Management Centre of the Ministry of Infrastructure

- The OLB has a disaster management team that combats the consequences of crisis or disaster, such as flooding, tropical storms and hurricanes. The Crisis Management Centre of the Ministry of Infrastructure and Water Management (DCC-IenW) works together with the OLB to integrate the disaster management with the processes and information systems of IenW (DCC-IenW, 2018).
- The Lac Bay mangrove forest was restored from 2015 onwards. Overgrazing caused erosion, and excess sedimentation reached the mangrove forests. This led to drying and death of the forest. Through clearing up channels, trapping excess sediment and reducing runoff, the mangrove forest is being restored. The mangroves act as natural coastal protection, mitigating the effects of high waves.
- Reforestation projects have been carried out by Echo. These projects have resulted in the creation of exclusion areas to keep away invasive free-roaming animals. Additionally, Echo has planted 15,000 native trees between 2015 and 2020.
- Sustainable drinking water supply: in 2015 the reverse osmosis (RO) plant was put into operation at Hato by WEB. The RO plan produces 5,600 m^3 of drinking water per day. The increased production has led to a more sustainable (due to the RO technique) and independent production of drinking water. WEB has also invested in water distribution and storage capacities by building new pipelines for distribution and tanks for storage (Water- en Energiebedrijf Bonaire (WEB), 2024).

Figure 4.3 Sediments entering the sea from Saliñas di Vlijt after heavy rainfall. Photo by: © Directie R&O

4.3.2 St. Eustatius

Mitigation

In St. Eustatius, 2 key mitigation efforts are noted. These are:
- The public entity of St. Eustatius (OLE) has developed a waste management plan to improve waste management (period 2023 - 2030). Plans have been made closely following the NEPP agenda. These plans include, amongst others, investing in a plastic and glass recycling facility, buying more waste containers and implementing a circular economy by reusing waste materials (OLE, 2022).
- St. Eustatius Utility Company (STUCO) and OLE have installed a solar park. The solar park has a capacity of about 4.15 MW and is equipped with invertors and storage batteries. Together, the complex can supply about 45 % of the total energy demand on the island. STUCO is aiming for 80 % sustainable energy production with a third phase of investments (Minister voor Klimaat en Energie, 2022). These cuts CO_2 emissions and contribute to climate change mitigation. The project was financially supported by the ministry of Climate and Green Growth (KGG).

Adaptation

The following adaptation efforts on St. Eustatius are highlighted:

- The installation of the solar park (by STUCO and OLE, see mitigation) has reduced the dependency on energy supply from outside the island.
- The OLE is developing a water management plan with IenW to identify strategies for rainwater retention and controlling rainwater runoff (Royal HaskoningDHV, 2019). This project is complemented by erosion control measures carried out by OLE, supported by Rijkswaterstaat.
- Since 2019, multiple water retention and infiltration ponds have been constructed and restored. Their primary aim is to combat erosion due to surface runoff, water scarcity and drought problems. An overall plan is in place to collect as much surface runoff as possible to minimize the quantity that enters into the sea which has detrimental impacts on coral reef communities. In a separate project, the solar park was connected to a retention pond to collect runoff from the solar panels. This retention pond is shown in Figure 4.4.
- As on the other islands, roaming grazers have been a problem on St. Eustatius. Vegetation suffers from excessive grazing, effectively leaving the landscape barren. This harms nature and causes more rainwater runoff and erosion. Various projects have been undertaken to stop excess grazing.
- In 2021, the OLE has placed waterpipes which draw water from wells in the Zeelandia area. The primary goal of the project is to provide farmers with a sustainable (non-depletable) water supply. This helps agriculture become less susceptible to droughts.
- In 2020, STUCO has placed 50 tanks to households that do not have access to cisterns. These households relied on STUCO's water supply. During dry seasons, the water demand exceeds STUCO's production capacity. Through the provision of tanks, these 50 households can harvest rainwater.
- Reforestation efforts have been implemented on the island since 2019, initially funded by the Ministry of Agriculture, Nature and Food Quality and subsequently by the EU-RESEMBID Programme in 2023. The project has planted over 2,000 trees with a further 289 being adopted by the local community. The 18-month project aims to plant a minimum of 3,000 trees. Trees are planted in areas that are vulnerable to erosion.

Figure 4.4 Water retention pond under construction near the St. Eustatius solar park. Source: St. Eustatius government

4.3.3 Saba

Like St. Eustatius, Saba is highly dependent on external supply chains for essential goods and services. As a result, the island is vulnerable to disruptions, especially from extreme weather events like hurricanes. Saba is therefore also vulnerable to climate hazards that occur in other countries. For instance, damage to ports in St. Maarten or Miami from hurricanes or shortages in supply directly impacts Saba's access to essential resources. While direct climate impacts on Saba may be limited, the indirect effects are significant due to this vulnerability.

Mitigation

In Saba the key mitigation efforts are:

- Saba Electric Company (SEC) has commissioned 2 solar parks (2.1 MW). Together with a battery storage system (2.6 MWh), these solar parks allow the island to run on solar energy for 8 – 10 hours a day on days with optimal sunshine (IPDC, 2024). With the development of a third solar park, Saba aims to reach 90 % renewable energy. These parks were financed by the European Development Fund (EDF) and the Dutch Ministry of Economic Affairs and Climate Policy (SDE++ fund) (SEC, 2024).

Adaptation

Measures taken to improve sustainability and management of natural resources are considered to be adaptation measures. The following efforts have been identified:

- OLS (Public Entity of Saba) started a goat control project in 2020 to address the island's widespread erosion and runoff issues through the removal of roaming goats that eat away at the native vegetation, which ultimately impact the health of the coral reefs that surround Saba during periods of heavy rainfall (IPDC, 2024). The stray goat population has been reduced by around 70 %. The results are evident in an increase in greenery and hence erosion control. Continuation of the policy is necessary and sharing knowledge and resources with islands (including St. Eustatius) in the region is recommended (Advice table Bonaire).
- Initiation of the coral nursery. The Saba Conservation Foundation has initiated several coral-nursery and out-planting projects in the past years. The Saba Coral Nursery was established in 2015. One of the main goals of this project is to help create and grow new coral reefs. The restoration of coral reefs helps remove carbon dioxide from the environment and improves the resilience of the reefs.
- Construction of greenhouses by OLS (Public Entity of Saba) for hydroponic agriculture is ongoing. The farm currently provides 5 main crops. These provide a part of the total food demand. With the further expansion of the farm, the variety of crops and production volumes are expected to increase. The expansion is scheduled for the next year. Hydroponic agriculture is less susceptible to crop failures due to droughts, as the greenhouse protects crops against climate extremes. Hydroponic agriculture is therefore more drought resistant. In addition, hydroponic agriculture contributes to self-sufficient food provision. This makes Saba less dependent on food imports, especially during storms and hurricanes when supply lines are sometimes cut off. The farm has put provisions in place to store the hydroponics system indoors and continue production during hurricanes. The hydroponic farm is shown in Figure 4.5.
- In 2021 OLS developed a water bottling plant to provide the island's residents with quality drinking water. This has significantly reduced plastic waste and the import of bottled water. This has improved the islands self-sufficiency on water.
- The OLS has installed a water grid from Fort Bay harbour (RO water plant) to central locations in the villages on the island. Alongside the water grid, trucks distributing water are subsidised by the local and national government to ensure affordability. This ensures water is provided to individual homes and businesses when cisterns run dry in periods of drought (IPDC, 2024).
- Saba's residents and local governments have over the years taken measures to collect, store and conserve rainwater. Each house is equipped with a cistern to store rainwater. The local government has built special catchments at strategic locations along the island's road to collect rainwater runoff in grey water cisterns. This water is used for horticultural purposes (IPDC, 2024).
- Reforestation projects have been implemented to reduce erosion, landslides and sedimentation into the sea and reefs. They also help retain fertile soil and water. Currently 2 efforts are taking place: ReLeaf Saba (Saba Conservation Foundation) and a reforestation project from the OLS. The OLS plans to plant some 5,000 trees (including fruit trees) to also increase local food production. These efforts take place across multiple locations. Reforestation yields multiple benefits to climate adaptation.
- The coral nursery from the Saba Conservation Foundation aims to help existing reefs recover from physical damage and climate change damage (e.g. coral bleaching due to rising sea water temperatures).

Figure 4.5 Hydroponic farm on Saba. Source: Antilliaans Dagblad.

4.4 Synthesis

Table 4.1 provides an overview of the main efforts, grouped according to the main sector that the effort applies to and the island in which the effort is located.

Table 4.1 Overview of main efforts in the BES islands. A full overview is given in the fact statement overview in appendix I.

Sector	Effort	Island
Multiple sectors	Island(er)s at the helm	All
Agriculture, horticulture, fisheries	Policy vision for agriculture, husbandry and fisheries	Bonaire
	Hydroponic agriculture	Saba
	Long term strategy for sustainable agriculture	St. Eustatius
	Sustainable water supply for farmers	St. Eustatius
Energy	Alleviating energy poverty	All
	Solar parks	All
	Electric flying between ABC islands	Bonaire
	Wind parks	Bonaire
Nature	Coral reef restoration and nurseries	All
	Nature and environment policy plan (NEPP)	All
	Reforestation efforts	All
	Removal of free-roaming grazers	All
	State of the nature of Caribbean Netherlands 2017	All
	Mangrove restoration	Bonaire
	Nature plan Bonaire (2020-2024)	Bonaire
	Prevention and clean-up of sargassum	Bonaire
	Salina and bay restorations	Bonaire
	Waste management plan	St. Eustatius

Sector	Effort	Island
Nature, health, tourism	Circular economy plans	St. Eustatius
Spatial planning and infrastructure	Spatial development programme	All
	Update spatial development plan (ROB2022)	Bonaire
	Vision on mobility and accessibility	Bonaire
Water management	Integrated wastewater vision Bonaire (2023-2030)	Bonaire
	Integrated water management plan	Bonaire
	Rainwater collection	Saba
	Water bottling plant	Saba
	Water grid from RO to villages	Saba
	Development of water management plan	St. Eustatius
	Improvement of water supply	St. Eustatius
	Rainwater harvesting tanks	St. Eustatius
	Water retention & infiltration ponds	St. Eustatius
Water management, nature	Modernization of waste management	Bonaire

Table 4.1 shows that the majority of the efforts revolve around nature and water management. These efforts are generally tied to improving the state of nature and water resources that increase the resilience of the islands in the face of climate change. The efforts in the energy sector (solar and wind parks) also reflect that the islands undertake efforts to reduce their greenhouse gas emissions and dependency on energy imports. Since the energy demand on the islands is small, a single project already has a large impact on climate mitigation.

Governance efforts are generally specific to Bonaire or encompass all 3 islands. There are fewer public plans for Saba and St. Eustatius, partly due to their smaller size. The sections below discuss the findings in more detail. Section 4.4.1 describes efforts across all islands. sections 4.4.2 through 4.4.4 are island specific.

4.4.1 General (all islands)

From the literature review and interviews, the following is deducted regardless of adaptation and mitigation on the 3 islands:

- **All islands have implemented some key mitigation measures:**
  - All islands have greatly improved **their production capacity of sustainable energy through solar and wind power**. This reduces greenhouse gas emissions and energy security. Because of the limited energy demand, single projects have a large impact. In 2025, around 75 % of the energy production is targeted to be sustainable.
  - In addition to energy production, sustainable practices for transport are also being investigated, mainly on Bonaire. For example electrically powered aircraft and sustainable transit.
  - Other mitigation efforts focus on limiting environmental pollution and reforestation.
  - Mitigation efforts are **typically undertaken at the level of the individual islands**, and not overarching. There is some knowledge sharing between the islands, but this may be optimized.
- **All islands have implemented various key adaptation efforts**:
  - Adaptation has a slightly different connotation than in the European Netherlands. Because of their remoteness and dependency on imports, adaptation on the BES islands is much **more about self-sufficiency**. Most climate adaptation measures therefore primarily aim to improve self-sufficiency in terms of energy provision and food and water security.

- The following **adaptation measures have been implemented on all islands**, albeit to different extents:
  - Reforestation: aimed at both restoring natural areas and reducing erosion in upstream areas. This helps reduce runoff and retain rainwater upstream. Forests also help provide shade and cool spots, reducing heat stress. Moreover, forests take up CO_2.
  - Limitation of grazers subsequent erosion. All islands have experienced problems with excess grazing. This has resulted in the uncontrolled runoff of rainwater and subsequent erosion. Soil and debris that is washed away, flows downstream and causes clogs in the drainage system. Sediment is also deposited in coral reefs and mangrove forests, jeopardizing their health.
  - Coral restoration. The amount of coral has diminished quickly over the past few decades. Climate change and rising sea water temperatures are partly responsible for this. The efforts are aimed at finding coral types that are more resistant to warm sea water.
  - Mangrove restoration: aimed at rehabilitating natural mangrove forests that play a role in coastal defence. Mangroves are endangered by excess sedimentation that results from runoff and by rising sea levels.
  - Grey water reuse and rainwater harvesting aimed at freshwater provision for remote households and limiting the use of groundwater resources. Many homes are equipped with systems to reuse domestic wastewater as grey water. The water can be used to flush toilets and for watering plants, for instance. This effort has not yet been implemented on St. Eustatius, but it is an ambition.
- **However, multiple sectors remain vulnerable to climate change and require adaptation measures**. The following sectors are important to the islands' societies and economies, but have received no or few adaptation efforts as compared to the expected impacts:
  - Health: across the islands there are no targeted efforts aimed at implementing adaptation measures in the health sector. This health sector is expected to be threatened by multiple climate hazards, such as heat, floods and hurricanes.
  - Tourism: the islands' economies greatly depend on tourism and the sector is vulnerable to multiple climate hazards (e.g. damage to tourism infrastructure due to hurricanes and floods, shorter tourism season due to hurricanes). In spite of the vulnerabilities, no specific adaptation efforts were found.
  - Agriculture: some communities across the islands rely on agriculture for their livelihoods. While various measures are being taken across the islands for rainwater harvesting, the impact of droughts could be devastating in case of a pessimistic climate scenario. If the amount of precipitation does decrease by 50 %, current efforts will be insufficient to support the current agriculture sector.
  - Accessibility: the islands are vulnerable to disruptions of global supply lines. They have all been working on self-sufficiency over the past years. However, infrastructure networks (e.g. roads, ports and airports) remain vulnerable to multiple climate hazards. For example because of floods and hurricane damage.

- **(Scientific) data on climate developments and efforts are scarce** relative to the European Netherlands and other small island states in the vicinity:
  - While the KNMI has included a section on the BES islands in their latest report, the output is less extensive and certain than for the European Netherlands. One of the reasons is the limited number of climate observations across the islands and the use of a coarser scale in modelling studies.
  - One reason may be that the BES islands are part of the Netherlands, but not always incorporated in national research, which usually focusses on the mainland only. The islands lack capacity and budget to execute the research themselves.
  - The literature review shows that more information is available for larger and autonomous islands in the region, such as Curacao, Aruba and St. Maarten. Much of the information for surrounding islands is also applicable to the BES islands because of similar characteristics in terms of climate and remoteness.
  - Not all research results and data are published or made easily accessible. The Dutch Caribbean Biodiversity Database makes much information accessible, but only for nature related topics.
  - Also, a number of university groups have visited the islands to conduct research, for instance as part of student theses. These reports may not be part of larger ongoing research and are not made easily

accessible to the islands. The Dutch Caribbean Biodiversity Database helps with this, but it is only aimed at nature-related topics.

- Across the islands, **some elementary data on the living environment and water system are lacking**. This makes it more difficult to assess the effects of climate change and to draft suitable mitigation and adaptation measures:
  - Examples include elevation data and a complete overview of the functioning of the water system including groundwater resources.
  - See also the section on knowledge gaps.
- In terms of **governance, not all islands have up-to-date plans and strategies for all fields of expertise**.
  - This issue is described in detail in the report by Ed Nijpels. The islands are currently lacking a clear framework in which governance plans are made, executed, evaluated and adapted where necessary.
  - Governmental bodies across the islands indicate that they struggle to deploy sufficient capacity. The general lack of financial means at the local governments has forced them to prioritize heavily and allocate resources accordingly.
  - In the plans and strategies that do exist, climate adaptation is often considered a co-benefit and not the primary focus.
  - The overall feeling of the interviewees is that **governance efforts have been improving recently**. Especially on Bonaire this has led to recent plans, for example on wastewater, mobility and nature conservation. The Ed Nijpels report and pressure groups have successfully managed to put nature, water and climate governance on the agenda.
- **Going forward, adaptation has the highest priority** on the islands, partly for reasons of self-sufficiency. However, many of the adaptation projects also contribute to climate change mitigation. The following type of projects are conducted and/or planned across the BES islands:
  - Limitation of grazing. There are many initiatives across the islands to limit the presence and negative effects of freely roaming grazers. This limits the loss of vegetation and aids reforestation efforts. In some locations, simply removing or limiting grazers is sufficient for autonomous reforestation. These projects are aimed at reducing erosion, but they also contribute to mitigation as more vegetation means more CO_2 uptake.
  - Grey water reuse. Many homes are equipped with systems to reuse domestic wastewater as grey water. For instance, the water can be used to flush toilets and for watering plants.
  - Development of renewable energy, such as solar or wind parks.
  - Hydroponic farms. Farming efforts have seen some shift from traditional farming towards indoor hydroponic farms and horticulture. This provides multiple benefits, such as conserving water, protecting crops against heat, drought and diseases brought about by climate change and promoting self-sufficiency.
- There is a **strong connection between nature restoration and water management**. Combating erosion, run-off and flooding results in improvement of the state of natural environments, such as the coral reefs.

4.4.2 Bonaire

The following is deduced specifically for Bonaire:

- Bonaire has been drafting and updating governance reports (e.g. plans and strategies). These plans are starting points for various adaptation efforts (such as nature restoration, waste management). Some of these plans have already been officially adopted, others require more work for finalisation.
- Physical efforts are primarily aimed at the restoration of coral reefs, mangroves and saliñas, as well as combating erosion.
- Compared to Saba and St. Eustatius, efforts are less geared towards self-sufficiency. This is likely due to the multiple supply routes to the island, the main one being through Curacao, where food comes from the US, the Netherlands and countries in Latin America (van der Geest & Slijkerman, 2019). Furthermore, because Bonaire is not directly in the hurricane belt, it is also less vulnerable to destructions of the supply chain as food and goods can still be delivered through Curacao.
- Parts of Bonaire are susceptible to coastal flooding. Traditionally, wind and waves have arrived on Bonaire from the northwest. This region of Bonaire is not very developed. The wind and wave direction may change under the influence of climate change. This also means the vulnerability to coastal floods

will be exacerbated due to climate change and this is identified in multiple reports. One relevant effort is the restoration of mangrove forests and restoration of coral reefs, which act as natural coastal defences against waves. Note that these efforts offer only very little protection against sea level rise. Due to the low current threat, there are no large-scale efforts being undertaken that address the vulnerability to coastal flooding. With sea level rise it is expected that such efforts will be required.
- There are no or limited efforts aimed at the health, tourism and infrastructure sectors. These sectors are threatened by multiple climate impacts and are important for the island's society and economy.

4.4.3 St. Eustatius

The following is deducted specifically for St. Eustatius:
- Many of the efforts on St. Eustatius have focused on water retention ponds and the installation of rainwater harvesting tanks. This reduces remote households' dependence on fresh water provided by the RO installations.
- In addition, some governance efforts have been undertaken. St. Eustatius has prepared several plans and strategies that aim to make their water management system, agriculture and waste management future proof.

4.4.4 Saba

The following is deducted specifically for Saba:
- Most of Saba's mitigation and adaptation efforts aim to reduce the island's dependency on imports and global supply lines. Past disasters and the COVID-19 epidemic have shown that the island is not fully self-sufficient. The efforts increase the availability of essential goods and services, such as electricity, drinking water and food.
- Like the other islands, Saba has been suffering from a loss of coral. Coral restoration projects are therefore being undertaken.

4.4.5 Knowledge gaps

The following knowledge gaps were identified:
- Island-specific climate risks have not been identified. There is research available on the general effects of climate change in the Caribbean region, but not per island. Therefore, targeted adaptation measures have also not been implemented. Many adaptation measures follow from improving the self-sufficiency of the islands and are not results of targeted climate adaptation projects.
- The effectiveness of the different adaptation measures is unknown. Research into the effectiveness of these measures can assist in policy making in the islands.
- There is a lack of some elementary environmental and water management data. Such data is important to fully understand the system of water and natural resources. The data is also very helpful in detailing climate adaptation plans and measures. The following information is (partly) lacking:
  - A detailed digital elevation model (DEM) and bathymetry.
  - Ground water levels and influence of the ocean.
  - Soil composition.
  - Bearing capacity of the soil/susceptibility of the soil towards erosion or landslides.
  - Permeability of the soil.
  - Urban drainage assessment to indicate weak spots during potential extreme rainfall events.
  - Complete overview of streams and water bodies on the islands. Including any structures such as culverts, weirs and dams.
  - Flood simulations (under development/review for Bonaire).
  - Heat stress test for infrastructure, dwellings and public spaces.
  - Susceptibility of surface water to heat up during hot periods having adverse effects on water quality and therefore water availability.

5

CONCLUSIONS AND RECOMMENDATIONS TO ADDRESS CLIMATE CHANGE IMPACTS

This concluding chapter is structured as follows:
- Section 5.1 draws conclusions of the current state of affairs in terms of climate adaptation across the BES islands.
- Section 5.2 identifies the ‘adaptation gaps’: sectors or climate impacts that are not yet sufficiently addressed by adaptation measures.
- Section 5.3 identifies the most relevant knowledge gaps that remain.

5.1 Current state of adaptation efforts

From the literature and various interviews with local experts, the following is concluded regarding current efforts for climate adaptation.

Availability of data and information
Despite the KNMI report on model projections for the BES islands, scientific data on climate developments and efforts across the BES island remain scarce. One reason may be that the BES islands are part of the Netherlands and thus not automatically included in scientific studies that are undertaken by other countries in the region. However, more information is available on a regional scale (greater Caribbean). Many of the small island states are similar to the BES in terms of climate conditions and remoteness. Climate information can thus be translated to the context of the BES islands. There are some knowledge sharing initiatives, but most efforts are undertaken at the level of individual islands.

In addition, it is difficult to obtain a full system understanding of the islands’ management of water and natural resources. This is mainly because some essential data is lacking or not widely available (see also section 4.4.5). As a result, it is difficult to assess or quantify the effects of some climate hazards.

Focus of efforts on self-sufficiency
On the BES islands, many measures that could be considered adaptation or mitigation efforts are meant as solutions to improve self-sufficiency. The islands are very dependent on imports and rely heavily on global and regional supply lines. Especially Saba and St. Eustatius tend to be the last ones in line to receive essential goods because of their modest size. Examples of measures include local sustainable energy production (also mitigation), rainwater harvesting (also adaptation) and taking climate into account in the design of the new port on Saba (also adaptation). Overall, climate adaptation and mitigation are often considered a co-benefit of other measures. The primary reasons for this are (1) the importance of self-sufficiency and (2) the limited capacity and expertise on the islands.

Common physical efforts
The following adaptation measures find a common denominator on each island, although there are differences in focus and extent of the efforts:
- Reforestation (also to combat erosion).
- Limitation of grazers to combat erosion.
- Coral restoration.
- Mangrove restoration.
- Grey water reuse and rainwater harvesting.

Governance
Not all islands have up-to-date plans and strategies for all fields of expertise. This issue is described in detail in the report by Ed Nijpels. Mentioned causes for this problem include (1) the lack of a framework in which governance plans are made, executed, evaluated and adapted, (2) difficulties in deploying sufficient capacity, budget, and expertise across the islands and (3) difficulties in prioritizing issues and effectively addressing these.

The overall attitude across the islands is that governance efforts are ramping up and improving. In this regard it is mentioned that the Ed Nijpels report and pressure groups have successfully managed to put nature, water and climate governance on the agenda.

5.2 Adaptation gaps and recommendations

Climate change affects all sectors. However, some sectors are especially at risk due to their vulnerability to climate change and/or importance to the livelihoods of local communities. Also, the efforts mentioned in chapter 4 and section 5.1 do not address all identified climate impacts. Based on the information gathered from interviews and research on existing projects, gaps in adaptation efforts per sector have been identified. This section describes the sectors with the largest adaptation gaps.

It is recommended that further efforts are aimed at closing the adaptation gaps and enhance adaptation in the most important sectors. This is based on expert judgment and supported by local expertise. This document is not an adaptation plan, but some guidelines to improved resilience are provided below.

Health
Many climate hazards have a relationship with health. Direct impacts include heat stress and destruction of homes by floods and hurricanes. More indirect impacts include worse water quality, the introduction of certain pathogens and diseases and hampered supply of medical goods by as a result of hurricanes. Current efforts are not directly aimed at improving health on the islands. However, steps have been taken in the safety sector, as crisis management plans and disaster response plans exist on the islands. These plans are generally aimed at existing threats and do not account for possible future threats under climate change.

The following actions are recommended:
- Preparation of health care facilities to treat larger number of patients. The nature of required care differs strongly across impacts.
- Health care facilities could consider stockpiling medical essentials whose supply chains may be interrupted by hurricanes.
- Identification of surface waters vulnerable to deteriorating water quality. At these locations, specific measures may be considered to ensure an acceptable water quality (e.g. flushing, reduction of pollution).
- Incorporating increased frequency and intensity of hazards, and new possible threats due to climate change in crisis management and disaster response plans.

Tourism
The islands are greatly dependent on tourism, which is under threat due to climate change. Any harmful effects to tourism therefore also have an effect on the livelihood of local communities. Heat, hurricanes and flooding all have strong negative effects on tourism. At the same time, current adaptation efforts contribute little to resilience or adaptation within the tourism sector.

The following actions are recommended:
- The climate impacts can only be controlled to a certain extent. Developing alternative revenue models helps protect local livelihoods. Such alternative revenue models may be found within or outside of the tourism sector.
- Investigation into other types of tourism on the islands, as tourism from coral diving and other outdoor activities may no longer be fully possible.

- Improving the resilience of existing tourism infrastructure on the islands to climate hazards. Especially floods and hurricanes can have devastating effects that lead to large direct damages, as well as secondary damages because hotels and attractions are not available.

Agriculture
Agriculture is not a particularly large sector on either of the islands. However, it is an important source of income for some communities. In addition, agriculture may be struck particularly hard by the effects of future droughts. The drought projections are very uncertain, but precipitation may decrease by almost 50 %. In that scenario, crop cultivation will become very difficult due to the lack of fresh water. The current efforts on rainwater harvesting will then likely be insufficient.

The following actions are recommended:
- Current farmers could consider switching to a crop type that is less dependent on freshwater availability or reconsider their source of income altogether. In either case it is advised that governmental bodies help the farmers find alternative revenue sources.
- Current farmers could also increase their capacity to harvest and store rainwater.
- Switching to hydroponic farming is a good way to reduce the dependence on freshwater availability.

Accessibility and supply lines
The BES islands are already vulnerable to disruptions to global networks and supply lines. Climate change will exacerbate this problem, most notably due to longer hurricane seasons. All islands have already taken steps to improve self-sufficiency. However, infrastructure on the islands remains vulnerable.

The following actions are recommended:
- Making vital transportation infrastructure more resilient against floods and hurricanes. This includes harbours, airports and main roads as the backbone of transportation. Without good and continuous transportation options, many other sectors will suffer from inaccessibility.
- In addition to transportation infrastructure, it is recommended that the islands continue to invest in making water management and energy infrastructure more resilient to floods and hurricanes. This infrastructure is vital to provide basic (health) services during calamities.
- Stimulation of local food production and other essential goods. This requires a sound agriculture and fisheries plan that includes coping with climate change. Stimulating the use/development of local resources reduces their dependency on other islands and countries. It also limits the likelihood that the islands lack important supplies during emergencies.
- Not all essential supplies can be produced on the islands. It is recommended that these supplies are stockpiled in strategic locations across the island. This will help alleviate emergencies without lacking essential goods.

5.3 Remaining knowledge gaps

In this report the following remaining knowledge gaps have been identified.
- Island-specific climate effects have not been researched. There is research available on the general effects of climate change in the Caribbean region, but not per island. Although there is a general idea of which effects may be seen in the different islands, targeted adaptation measures require more specific research. Many adaptation measures follow from improving the self-sufficiency of the islands and are not results of specific climate adaptation projects. This is considered a good approach but may leave out adaptation to risks that have not been identified yet. This is a critical knowledge gap as future adaptation efforts need to be based on good impact research.
- Some basic information of the physical environment is lacking, for example a detailed DEM, information on soil composition and a comprehensive overview of catchments and urban drainage. Such information is crucial to plan and design specific interventions for climate adaptation.
- More information is required to make a better assessment of heat stress and its effects. For example: a map of tree and vegetation cover on the islands, an overview of housing characteristics (e.g. sunscreens, air conditioning) and measurements of physical equivalent temperatures in built-up areas.

- The effectiveness of the different adaptation measures is unknown thus far. The effectiveness of current and past efforts has not been monitored and evaluated. As a result, there is no clear overview of best practices from which policy makers may benefit. It is recommended that the effectiveness of future measures is monitored and reported.
- It is not sufficiently clear what the exact impacts will be on tourism in the future. It is assumed less recreation from locals will take place if temperatures increase. however, warmer weather does not necessarily mean less tourists will visit the islands. It is expected that more frequent hurricanes will reduce the number of visitors around hurricane seasons, but the tourism during these seasons is already limited.
- There is limited research available about the effects of climate change on human health and the health sector in the BES islands (and the Caribbean region as a whole (Rise, Oura, & Drewry, 2022)). Identifying these impacts allows for a better understanding of which measures should be taken to ensure good public health on the islands.
- There is a lack of historical climate data on the islands, making the determination of trends and impacts climate change of the extent of climate change more difficult. The extent of the impacts is therefore assessed indirectly, such as by looking at coastal loss or coral reef degradation. However, these changes are also influenced by external factors. By looking at regional historic data and comparing this to more recent data, trends can be identified.
- Certain species are expected to be more affected by climate change than others. Such applied research has not been conducted but is important to carry out in order to identify species that require additional protection (such as by protecting their habitats).
- The effect of climate change on current and future agricultural practices is unknown. One of the NEPP targets is investing in sustainable food production, which requires increasing food security and agricultural production. However, this requires knowledge of which crops will become increasingly difficult to cultivate or which crops may have better yields (e.g. under higher temperatures or more saline groundwater). This will help identify targeted strategies that contribute to sustainable food production, such as hydroponics or more saline agriculture.
- The economic impact of climate change on the island has currently not been investigated quantitatively. Due to the dependency of the islands on global supply chains for the resources needed to sustain daily life, the economic impact of being cut off from these supply chains is expected to be substantial.
- In addition, there is no research available on the societal and socio-economic effects of climate change in the Caribbean context. In many other parts of the world, vulnerable groups are often struck harder by climate change, for example because their livelihoods are threatened or because they are located in more vulnerable areas. Such research does not exist for the BES islands but may help in the future to take more targeted action.

6

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Appendices

APPENDIX: FULL OVERVIEW OF MITIGATION AND ADAPTATION EFFORTS

Project	Date	Responsible party	Type of effort (adaptation, mitigation, both)	Type of measures (physical or governance)	Island	Summary	Goal(s)	Climate topics (Heat and rising temperature, sea level rise, drought, precipitation, extreme storm events and hurricanes)	Sectors (water management, nature, agrilculture/horticulture/fisheries, health, recreation and tourism, intrastructure, energy, ICT and telecom, safety, built environment and spatial planning)	Water management	Nature	Agrilculture/fisheries/horticulture	Health	Recreation and tourism	Infrastructure	Energy	ICT and telecom	Safety	Built environment and spatial planning
Climate Adaptation in Deltas, Coasts and Islands: Introducing the IPDC Guidance Framework and the Climate Adaptation Context of the IPDC Members	2024	International Panel on Deltas and Coastal Areas – IPDC	Adaptation	Governance	All	Overview of adaptation efforts that have taken place per island. Includes goat control projects, catchments to collect rainwater for agriculture and reduce runoff, reforestation proejcts, solar parks (Saba), hydroponics farm, coral restoration projects.	To introduce the IPDC framework by applying a demand-driven approach and identiy adaptation gaps, describe adaptation efforts and stratefies and give recommendatios regarding future direction of the IPDC	Heat and rising temperature, drought, precipitation, extreme storm events and hurricanes	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism, Infrastructure, Energy, Safety, Built environment and spatial planning	1	1	1		1	1	1		1	1
Nature and Environment Policy Plan Caribbean Netherlands 2020 - 2030 (NEPP-CN)	2020	Ministry of Agriculture, Fisheries, Food Security and Nature; Ministry of Infrastructure and Water Management; Ministry of the Interior and Kingdom Relations	Adaptation + mitigation	Governance	All	Contains plans and goals for nature and environment policies per island	Main goal is the conservation and restoration of the unique and important nature of Caribbean Netherlands	Drought, precipitation, extreme storm events and hurricanes	Water management, Nature, Agrilculture/fisheries/horticulture, Health, Recreation and tourism	1	1	1	1	1					
Spatial Development Programme Caribbean Netherlands (draft)	2023	Public entities Bonaire (OLB), St. Eustatius and Saba	Adaptation	Governance	All	Contains policy tasks that have implications for the living environment.	To create a sustainable and safe environmental plan for the islands and to contribute to sustainable economic development, healthy living environment, protecting the cultural and natural aspects per island	Heat and rising temperature, sea level rise, drought, precipitation, extreme storm events and hurricanes	Water management, Nature, Infrastructure, Built environment and spatial planning	1	1				1				1
State of the nature in the Caribbean Netherlands 2017 [Staat van de natuur van Caribisch Nederland 2017]	2017	Wageningen University (for the Ministry of Economic Affairs NL)	Adaptation	Governance	All	Review of the state, threats and management implications of the habitats and habitat types in Caribbean Netherlands		Heat and rising temperature, sea level rise, drought, precipitation, extreme storm events and hurricanes	Nature		1								
Climate Agenda for the BES islands	2024 (ong	Public entities Bonaire, St. Eustatius and Saba	Adaptation + mitig	Governance and physical	All	Bonaire, Saba and Sint-Eustatius, together with the Dutch government, in 2024 will work on their own climate plans. The Dutch government will make 1 million euro available for this. This is stated in the response of the Dutch government to the report 'It is never too late'.	The goals is to fight against climate change and create plans for climate adaptation and mitigation	N/A	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism, Energy	1	1	1		1		1			
Update Spatial Development Plan Bonaire (ROB2022) [NL: Actualisatie Ruimtelijke Ontwikkelingsplan Bonaire (ROB2022)]	2023	Public entity Bonaire (OLB)	Adaptation	Governance	Bonaire	Protection of coral reefs by management of the coastal areas, protection of nature reserves, development of policy for possible effects of	Actualisation of the spatial development plan based on new information such as population, tourism and housing corporation deal	Sea level rise	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism, Infrastructure, Safety, Built environment	1	1	1		1	1			1	1
Advisory Report on Bonaire Climate Table "It is never too late"[Advies Klimaattafel Bonaire 'Het is nooit te laat"]	2023	Ed Nijpels (for the Ministry of Climate and Energy)	Adaptation + mitigation	Governance	Bonaire	Advice for the mitigation and adaptation agenda. Sectors and goverments are identified that can contruibute to the climate change tables.	Formulate a tight agenda and a proposal for the organization of the Bonaire Climate Table.	Heat and rising temperature, sea level rise, drought, precipitation, extreme storm events	Water management, Nature, Agrilculture/fisheries/horticulture, Health, Recreation and tourism, Safety	1	1	1	1	1				1	
Erosion control & Nature restoration [NL: Erosiebestrijding & Natuurherstel]	2019	OLB, Bonaire Agri, Aqua Business BV	Adaptation	Physical	Bonaire	Due to the eroded soils and urbanization, more water containing sediments now flows towards the sea, which is bad for the coral reefs. Water can be collected in dams and saliñas, so that the coral reefs are protected. The following activities have been carried out for this project: improving water storage dams, saliña restoration, mangrove restoration, restoration of water wells and water mills, reserach of possible catchment areas	Reduce erosion of coral reefs, reduce flooding, increase biodiversity, improve nature for tourists, make water available for agriculture.	Drought, precipitation, sea level rise, extreme strom events	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism	1	1	1		1					
Policy Vision for Agriculture, Husbandry and Fisheries 2014-2029 [NL: Beleidsvisie Landbouw Veeteelt Visserij Bonaire 2014-2029]	2014	OLB	Adaptation	Governance	Bonaire	Policy vision offers opportunities for the economy, such as sustainable and multifunctional agriculture, livestock farming and fishing and a liveable and attractive countryside.	Goal is to identify policies that improve the conditions for food production that can lead to projects	N/A (not directly applicable, but unreliable precipitation, bad groundwater quality and erosion are challenges/threats)	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism	1	1	1		1					
Salina di Vlijt ecological restoration project	2018	OLB & Wildconsciece B.V.	Adaptation	Physical	Bonaire	The areas around Salina di Vlijt are beind developed. Aspects of the proposed interventions have been reviewed by Wildconscience.	Project will provide a significant quality increase to the environment in this part of Bonaire, improving not only the natural environment itself, but also the recreational possibilities, including touristic activities	N/A	Water management, Nature	1	1								
Cycling plan Bonaire [NL: Fietsplan Bonaire]	2011	Rijksdienst caribisch Nederland	Mitigation	Physical	Bonaire	Cycling plan for Bonaire to focus on sustainable development. The increase in cars causes more traffic on roads, parking problems and environmental pollution. Cycling offers a green and healthy alternative: it can lead to less car traffic, attracts nature tourism and contributes to more exercise and therefore a healthier lifestyle.	Less CO2 emissions, contribution to sustainable policy (Bonaire's strategic development master plan)	N/A	Nature, Health, Recreation and tourism, Infrastructure, Built environment and spatial planning		1		1	1	1				1
Nature plan Bonaire 2020-2024 [NL: Natuurplan Bonaire 2020-2024]	2020	OLB	Adaptation + mitigation	Governance	Bonaire	Describes in broad terms the policy for safeguarding, protecting and improving nature on Bonaire.	Develop concrete policy visions to create measures for protecting nature and species and nature management outside of protected natural areas of Bonaire	Heat and rising temperature (rising temp. of ocean and ocean acidification), extreme storm events	Nature, Health, Recreation and tourism		1		1	1					
Nature policy plan 1999 - 2004 [NL: Natuurbeleidsplan 1999 - 2004]	1999	OLB	Adaptation + mitigation	Governance	Bonaire	Contains policies and measures per "area zone" of Bonaire.	Objective is aimed at achieving sustainable development within one generation. Planning horizon 20 years with measures to be implemented between 1999 - 20004	Extreme storm events	Nature, Health, Recreation and tourism		1		1	1					
Development vision Hato	2022	Muiltiple, plans indicated in ROB2022 (carried by OLB)	Adaptation + mitigation	Physical	Bonaire	The development vision contains visions for the Hato area development and tackling water and nature threats. Important themes are "building with nature and preventing flooding. The latter is important to ensure less damage to coral reefs.	Providing direction for future developments and properly coordinate current initiatives	Precipitation, drought	Water management, Nature, Built environment and spatial planning	1	1								1

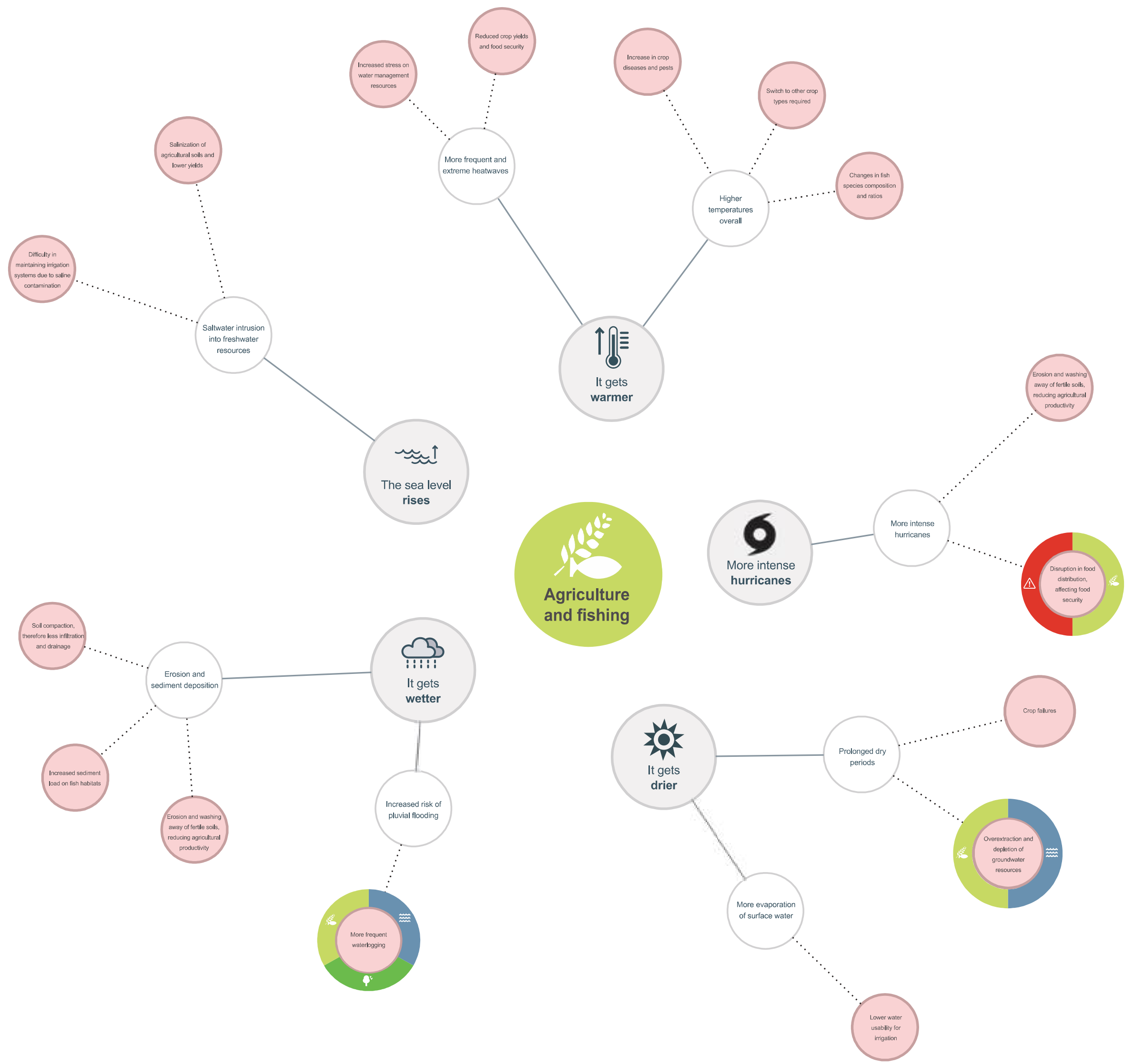
A nature inclusive vision for Bonaire in 2050	2020	WUR	Adaptation + mitigation	Governance	Bonaire	Summary of nature-inclusive visions for Bonaire. Includes summaries per landscape type in Bonaire. Includes visions on forest and coral restoration, low-impact recreation, sustainable energy (solar + wind).	Looks into policy context to create a nature-inclusive vision for the future of Bonaire	Heat and rising temperature, sea level rise, drought, precipitation, extreme storm events and hurricanes	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism, Infrastructure, Energy, Built environment and spatial planning	1	1	1		1	1	1			1
Integrated water management on Bonaire	2023	Waterschap Rijn en Ijssel	Adaptation	Governance	Bonaire	This document contains solutions and actions for water management. Focuses on the collection capacity of the saliñas, the wastewater system and sea level rise.	Contains actions based on goals of the NMBP-CN: (Goal 1) 'Reverse coral reef degradation to enhance wellbeing in the CN' and (goal 4) 'Create the local conditions to ensure sustainable results of nature policy in the CN' are important. More specifically, 1.1 'Control erosion and runoff', 1.2 'Effective waste and wastewater management' and 4.1 'Create awareness through education and training'.	Not directly mentioned. Focus on reversing coral reef degradation, controlling erosion and runoff	Water management, Nature, Agrilculture/fisheries/horticulture, Recreation and tourism	1	1	1		1					
Tourism recovery plan	2020	OLB	Adaptation	Governance and physical	Bonaire	Contains short term and long term goals for the sustainability og Bonaire's tourism sector, such as less cruise tourism, subsiding sustainability initiatives	Main objective is for Bonaire to thrive as a destination that enhances people's quality of life considering its core attributes of ocean, nature and heritage	N/A (only coral reef degradation mentioned, cruise ships will have to meet sustainability goals	Nature, Recreation and tourism		1			1					
Lac Bay mangrove restoration	2015	STINAPA	Adaptation	Physical	Bonaire	Overgrazing in the surrounding areas of Lac Bay have led to erosion and ultimately an excess in sedimentation in the mangrove forests, leading to their drying and death. To combat this, the channels in the Bay are being cleared up, which allows seawater to reach the forest again, and excess sediment is caught in culverts just upstream. This ecosystem is a critical barrier towards sea level rise and storm surges, while helping in carbon storage.	Improve health of mangrove forests	Sea level rise, extreme storm events and hurricanes	Nature		1								
Workshop Bonaire Climate Impact diagrams	2023	TERRAMAR	Adaptation + mitigation	Governance and physical	Bonaire	Workshop to promote knowledge and awareness of climate change. Climate impact diagrams were discussed and feedback per theme was gathered, including defiining prioirities and how to use input to continue knowdledge intrastructure and research	Promote knowledge and awareness of climate challenges through courses, lectures and workshops	Drought, precipitation, extreme storm events, warming and acidification of ocean, sea level rise	Nature, Health, Recreation and tourism, Infrastructure		1		1	1	1				
Coral reef restoration	Ongoing	Reef Renewal Bonaire	Adaptation	Physical	Bonaire	With the help of partner diveshops, the Bonaire governement and STINAPA the project aims to outplant corals back to the reef.	Aims to restore and protect coral reefs in Bonaire	Heat and rising temperature (ocean acidification)	Nature		1								
Reforestation projects	2020	Echo	Adaptation	Physical	Bonaire	Echo has established exlusion ares (81.5 acres) to keep away invasive free-roaming animals. 15,000 native species have been planted betwee 2015 and 2020.	Forest restoration efforts aimed at improving the biomass and biodiversity in order to rehabilitate the degraded vegetation.	Heat and rising temperature, drought	Nature		1								
Prevention and clean-up of sargassum in the Dutch Caribbean	2019	Dutch Caribbean Nature Alliance (DCNA), STINAPA	Mitigation	Physical	All	Sargassum has caused die-offs (fish, seagrass) and damage (mangroves). The recent and likely recurring seaweed influxes have given rise to a number of socio-ecological and economic concerns (in the hospitality and fisheries sectors) as well as threatening already fragile and often endangered coastal ecosystems such as mangroves and seagrass beds. STINAPA has organised massive clean-ups with volunteers. DCNA has presented a range of removal measures, measures to assist and engage stakeholders, propose mitigation strategies	Mitigate the effects of sargassum. With rising temperatures the growth of sargassum (in warmer waters) is stimulated.		Nature, Health, Recreation and tourism		1		1	1					
Customised waste management ("Afval Beheer op Maat")	2016	Ministry of Infrastructure and Water management	Mitigation	Physical	Bonaire	In a period of 5 years $10mln has been invested in modernising the waste management and processing on Bonaire. The OLB has comissioned over 21 projects.	Implementation of strategies to reduce waste (ban of single use plastics), promote re-use of waste by educational campaigns and recycling by implmenting waste separation	N/A	Water management, Nature, Agrilculture/fisheries/horticulture, Health, Recreation and tourism	1	1	1	1	1					
Ban of single use plastics	2021	OLB	Mitigation	Physical	Bonaire	The OLB started a campaign in 2019, together with local companies, to reduce the use of single-use plastics. Since 20121 there is a ban on these plastics.	Reduce the impacts of single-use plastic on nature and use non-toxic alternatives.	N/A	Nature		1								
Saba reforestation projects	2023	OLE	Adaptation	Physical	Saba	The OLE will intensifty reforestation efforts by planting some 5000 trees, inclusing a large number of fruit trees	Boost recovery process and expansion of island's forested areas. Reduce erosion, increase local food production.	Heat and rising temperature, drought, hurricanes			1								
Dutch Caribbean Climate Action Plan	2022	Dutch Caribbean Nature Alliance (DCNA)	Adaptation + mitigation	Governance	All	The document stresses urgency of countering and adapting to climate change. It outlines 4 governance actions	Identify specific mitigation and adaptation governance plans	All											
Island(er)s at the Helm	2021	NWOCA, KITV-KNAW	Adaptation	Governance and physical	All	Co-creation and knowledge exchange platform between researchers, universities and stakeholders in all Caribbean Islands.	Co-develop efficient tools to face societal challenges due to climate change in the islands	Drought, precipitation, extreme storm events, warming and acidification of ocean, sea level rise											
Water system Salinja di Vlijt (2022)	2022 (ongoing)	Multiple (plans from OLB)	Adaptation + mitigation	Physical	Bonaire	Plans to redirect/reduce runoff after heavy rainfall. Project not directly related to the impact of climate change but the plans will reduce sedimentation, which impacts the coral reefs.	Aim to reduce the impact of flooding due to heavy rainfall	Precipitation, extreme storm events	Water management, Agrilculture/fisheries/horticulture, Recreation and tourism	1		1		1					

Integrated Wastewater Vision Bonaire 2023-2030 [Integrale Visie A	2023	OLB (carried out by Royal HaskoningDHV)	Adaptation + mitigation	Governance	Bonaire	Contains long-term ambitions that the OLB wants to achieve in the field of wastewater management by 2030.	Ensure there will be no more environmental pollution caused by waste water	N/A (focuses on reducing the threats faced by coral reefs and improving public health)	Water management, Health	1			1						
Saba solar parks	2019	Saba Electric Company	Mitigation	Physical	Saba	Installation and connection of two solar parks (2.1MW) with energy storing facilities (2.6MWh) and inverters, allowing the island to run on renewable energy for 8-10h a day	Increase energetic self-sufficiency of the island	n/A	Energy							1			
Reverse Osmosis water plant and bottling station	2021	Saba Splash	Adaptation	Physical	Saba	Installing of a water grid from Fort Bay harbour to the island villages to provide affordable water and ease the transportation and bottling process	Reduce water stress, increase availability	N/A	Water management	1									
"Saba Grows" Hydroponic Farm	2023	Gezondheid Farms and OLS	Adaptation	Physical	Saba	Greenhouses for hydroponic agriculture are able to provide 20+ varieties of fruits and vegetables. This allows the creation of jobs, enhance the food security and provide food for people below the poverty line	Increase food security and independence	N/A	Agrilculture/fisheries/horticulture			1							
ReLeaf Saba	2022	Saba Conservation Foundation	Adaptation	Physical	Saba	Reforesting areas of the island helps reduce the erosion of sediments into the sea and specifically the reefs. Moreover, it retains fertile soil and water, improving overall ecosystem health and water availability. This also helps prevent landslides in the event of strong storms or hurricanes.	Minimize erosion on the island and retain water, reef conservation, improve food security	Precipitation, extreme storm events and hurricanes	Water management, Nature	1	1								
Limitation of grazing animals (especially goats)	2021	OLS	Adaptation	Physical	Saba	Removal of goats especially from areas surrounding the National Land Park. This helps the greenery to recover, contributing to the ReLeaf forestation efforts and bringing additional benefits like soil conservation, water storage or erosion reduction.	Help in the regreening of the island and combat erosion	Precipitation	Nature		1								
Coral reef restoration collaboration	2024	Carried by OLE	Adaptation	Physical	Saba	Two research plans (NEPP Saba Coral Restoration plan and ReefGrazers project) will be conducted to improve the health of coral reefs.	Identify novel species of native inverterbrate grazers with purpose of reef restoration and fisheries diversitification. The coral restoration plan aims to increase the health of the coral reefs.	Drought, extreme storm events	Nature		1								
Social Housing and Physical Development Policy Agenda for the C	2024	National government	adaptation	Physical	Saba	Letter of intent involves developing 50 afforable rental and private homes, and the accelerated construction of 18 social homes. Additionally, the National Government has allocated 360,000 euros to reduce housing costs, which will be used to disburse energy-saving appliances such as fridges, freezers and stoves to people with the lowest incomes.	Project aims to provide afforable housing and increase the standard of living for Saba, while also protecting the islands uniqueness and beauty.	Heat and rising temperature, drought, precipitation	Health, Energy, Built environment and spatial planning				1			1			1
Public health on Bonaire 2020-2023 [NL: Publieke gezondheid op Bonaire 2020-2023]	2020	OLB (Public Health sector)	Mitigation	Governance	Bonaire	Climate change (changes in precipitation patterns and rising temperatures) can provide more favorable conditions for vectors (mosquitoes, etc.).	Identify running projects and successes in the field of health to set goals for the future	Rising temperatues, precipitation	Health				1						
Social Housing and Physical Development Policy Agenda for the C	2024	National government	adaptation	Physical	St Eustatius	Constsruction and renovation of social homes. National Government has made 450,000 eu available to tackle energy poverty by reducing energy costs. Solar panels will be installed on every social home.			Energy							1			
Rainwater conservation using grey water cisterns	2024	EU	Mitigation	Physical	Saba	Special catchments have been strategically built along the island's road to collect runoff in grey water cisterns. This water is used for agricultural purposes.	Improve rainwater management and provide water for agriculture	Precipitation, drought	Water management, Agrilculture/fisheries/horticulture	1		1							
Roads that increase rainwater retention and reduce erosion	2021	OLE	Adaptation	Physical	Sint Eustatius	Road repairs are being completed with an integrated approach. Space under the roads allows for electricy, internet and water infrastructure to pass, while the shape and materials ensure rainwater collection and reduce the soil erosion that ultimately accumulates in the reefs	Reduce water runoff to reefs	Drought and precipitation	Water management, Nature, Infrastructure, ICT and telecom	1	1				1		1		
Sint Eustatius solar park	2016	OLE, STUCO	MItigation	Physical	Sint Eustatius	The Statia Solar plant is equipped with panels (4.15MW), invertors and storage batteries (5.9MWh) that allow solar energy to reach 46% of the island's total electricity supply	Increase energetic self-sufficiency of the island	N/A	Energy							1			
Sint Eustatius water retention ponds	2019	OLE, STUCO	Adaptation	Physical	Sint Eustatius	Water retention ponds are being built and restored throughout the island to combat the water scarcity as an effect of drought.	Minimize erosion on the island, retain rainwater and reduce water stress	Drought, precipitation	Water management	1									
Sint Eustatius connection between water retention ponds and solar park	2021	OLE, STUCO	Adaptation	Physical	Sint Eustatius	Connection between solar park and water retention pond. Water is collected from solar panels and flows to the retention ponds. The water is then pumped to farmers with the use of a solar pump.	Ensure that there is adequate water quality and supply for the agriculture sector	Drought, precipiation	Water management, Agrilculture/fisheries/horticulture, Energy	1		1				1			
RefoреSTATIA	2022	St. Eustatius National Parks Foundation	Adaptation	Physical	Sint Eustatius	Reforesting areas of the island helps reduce the erosion of sediments into the sea and specifically the reefs. Moreover, it retains fertile soil and water, improving overall ecosystem health and water availability. This also helps prevent landslides in the event of strong storms or hurricanes.	Minimize erosion on the island and retain water, reef conservation	Precipitation, extreme storm events and hurricanes	Water management, Nature	1	1								
Removal of roaming animals	2021	OLE	Adaptation	Physical	Sint Eustatius	Efforts to remove free roaming animals from public spaces and nature areas	Remove free roaming animals as they case major damage through erosion leading to sediment runoff and subsequent coral damage	Precipitation, extreme storm events	Nature, Agrilculture/fisheries/horticulture, Recreation and tourism		1	1		1					

Placement of waterlines at Zeelandia	2021	OLE, Directorate of Economy, Nature and Infrastructure (ENI)	Adaptation	Physical	Sint Eustatius	Placement of waterlines which draw water from wells in the Zeelandia area to supply farmers with sustainable water	Implementation of short term structural solutions for the water shortage. The goal is to increase availability and quality of water	Drought	Water management, Agrilculture/fisheries/horticulture	1		1							
Long term strategy for sustainable agriculture	2020	OLE	Adaptation	Physical	Sint Eustatius	Introduction of an integrated approach for the removal of loose roaming livestock in combination with the development of sustainable livestock farming	Reduce the number of loose roaming livestock and simultaneously support the animal keepers/farmers to develop and implement a sustainable way of livestock farming which creates opportunities for economic development and people development	N/A	Agrilculture/fisheries/horticulture			1							
Supply of black tanks from STUCO	2020	STUCO	Adaptation	Physical	Sint Eustatius	In dry seasons, demand for water exceeds the production capacity. STUCO distributed 50 black tanks to users who are fully dependent on the water company and do not have a cistern	Improve water supply especially for households without a cistern	Drought, precipitation	Health				1						
STUCO improvement of water supply		STUCO	Adaptation	Physical	Sint Eustatius	STUCO is working on improving the water production and distribution on Statia. Projects include building of a new water tank, installing a new water plant and expanding production capacity to replace current water transport pipelines	Improve water supplly in Statia	Drought, precipitation	Water management, Health	1			1						
Renovation Oranje Bay road	2023 (ong	Government St. Eustatius	Adaptation	Physical	Sint Eustatius	The economic Oranje Bay road that connects the harbour to the rest of the island is located along the coastline and is under threat of being eroded. This road will be renovated startig from 2023.	Improve the connection between the port and the airport in accordance with the "showcase model" decision of the Dutch Ministry of Infrastructure and Water Management	N/A	Infrastructure, Built environment and spatial planning						1				1
Strategic tourism plan 2017-2027	2017	Tourism Bonaire, University of Florida	Adaptation + mitigation	Governance	Bonaire	Plan to convert the tourism industry to a high-end destination product. This requires an integrated vision of the tourism business. Plans for a "blue Caribbean destination" (ocean driving force)	Enhance the destination's competitive position, develop an integrated destination management approach	Not specified. Any climate effects affectig the ocean	Recreation and tourism					1					
Vision on mobility and accessibility Bonaire	2023	OLB	Adaptation + mitigation	Governance	Bonaire	Plans to make Bonaire sustainably accessible, for example new residential areas, cycling plans	Goal is to create a vision to keeping the island livable and sustainable, which requires a change in mobility.	Heat and rising temperature	Built environment and spatial planning										1
Bonaire Solar Park	2023	The Green World Company	Mitigation	Physical	Bonaire	Solar park on Bonaire. Total possible capacity is about 10 MW. Currently 1 MW is in use	Reduce GHG emissions and fossil fuel dependency	N/A	Energy							1			
Wind parks Bonaire	2021	ContourGlobal and WEB	Mitigation	Physical	Bonaire	Wind energy meets around 22% of the energy need on Bonaire. The objective is to increase the rate of sustainable energy to 60% in 2025. Therefore the electricity producer ContourGlobal and WEB will realize expansion of the wind farm and a central solar park at Karpata.	Reduce GHG emissions and fossil fuel dependency	N/A	Energy							1			
Social Housing and Physical Development Policy Agenda for the C	2024	National government	adaptation	Physical	Bonaire	The National Government makes 990,000 euros available to, among other things, install solar panels and battery storage on 118 new social homes of the Bonaire Housing Foundation FCB.			Energy							1			
Waste management plan	2023	OLE	Mitigation	Physical	St Eustatius														
Electric flying	2021	NACO, NLR	Mitigation	Physical	Bonaire	From 2026 commercial passenger flights between Aruba, Curacao and Bonaire are expected to be started with electric aircrafts. The ambition is to have 50% of the flights to be carried out by electric aircraft. Ultimately, in 2035 all the air movements between the islands will be electric.	Reduce CO2 emissions from the aviation sector	Heat and rising temperature	Recreation and tourism, Energy					1		1			

II

APPENDIX: IMPACT OF CLIMATE CHANGE ON EACH SECTOR (BOLLENSCHEMA'S)



Legend

NAS adaptation tool for climate risk analysis

Trends
- It gets warmer
- It gets drier
- It gets wetter
- The sea level rises
- More intense hurricanes

Sectors
- Water management
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- Agriculture, horticulture and fishing
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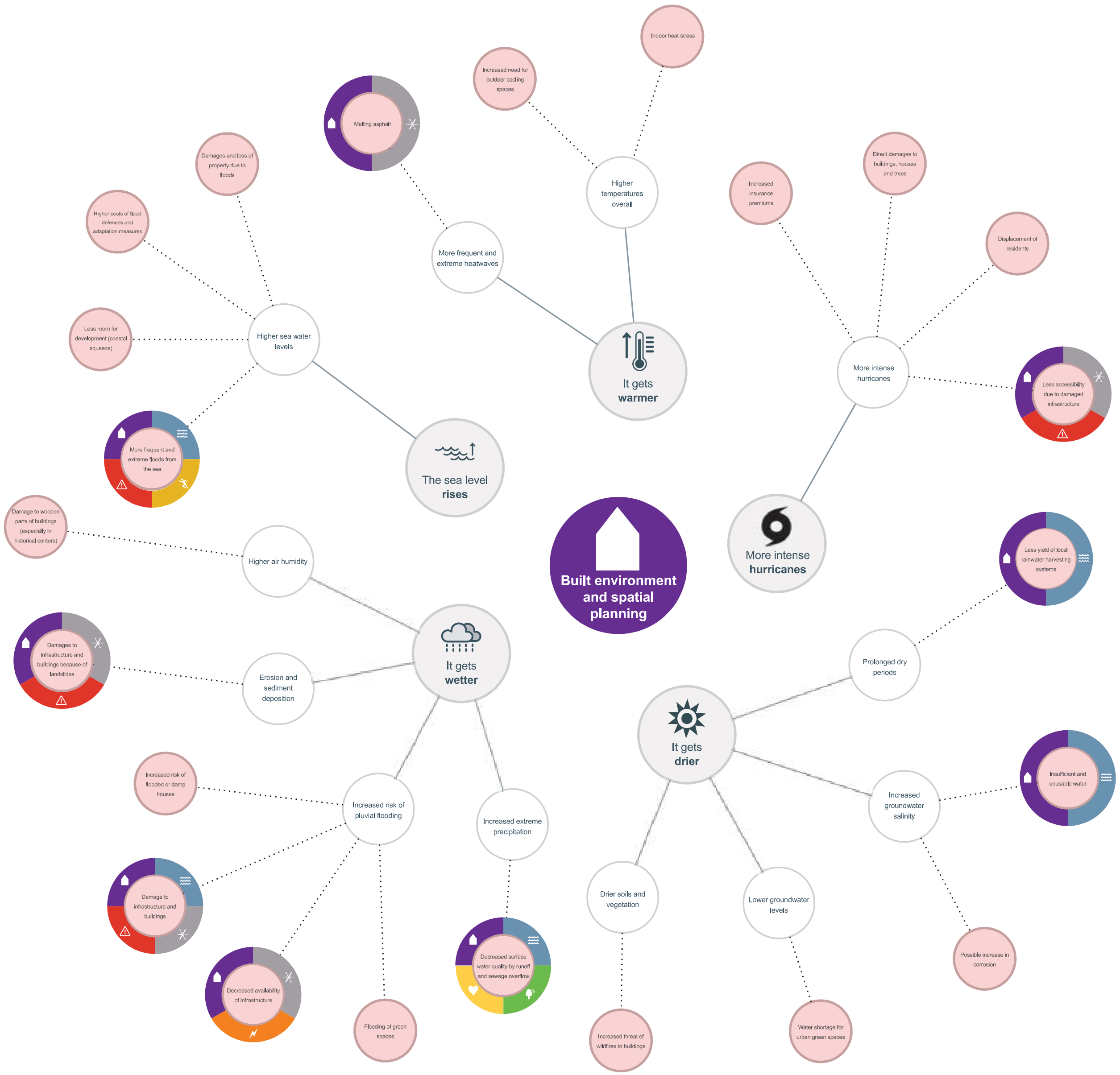

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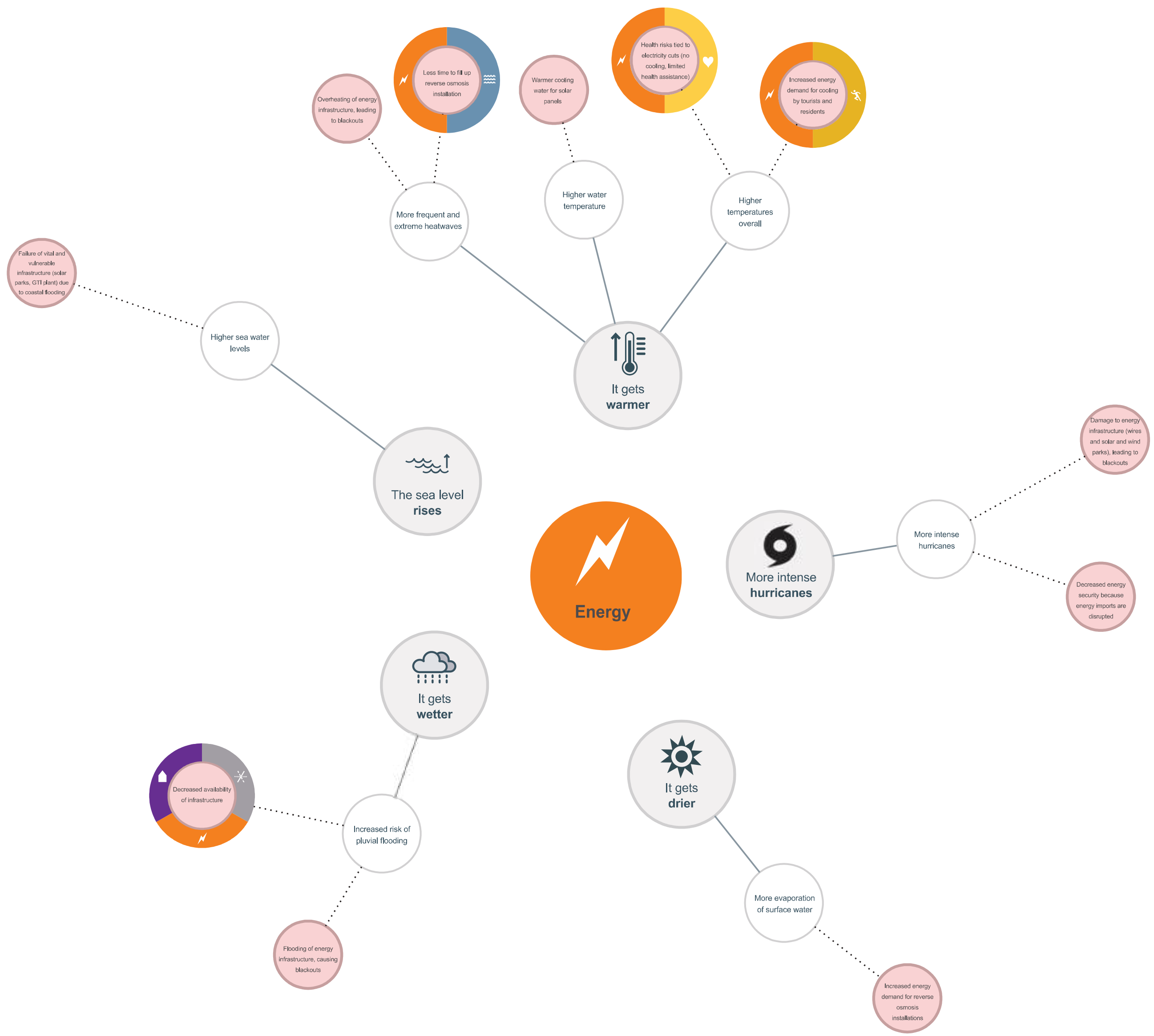

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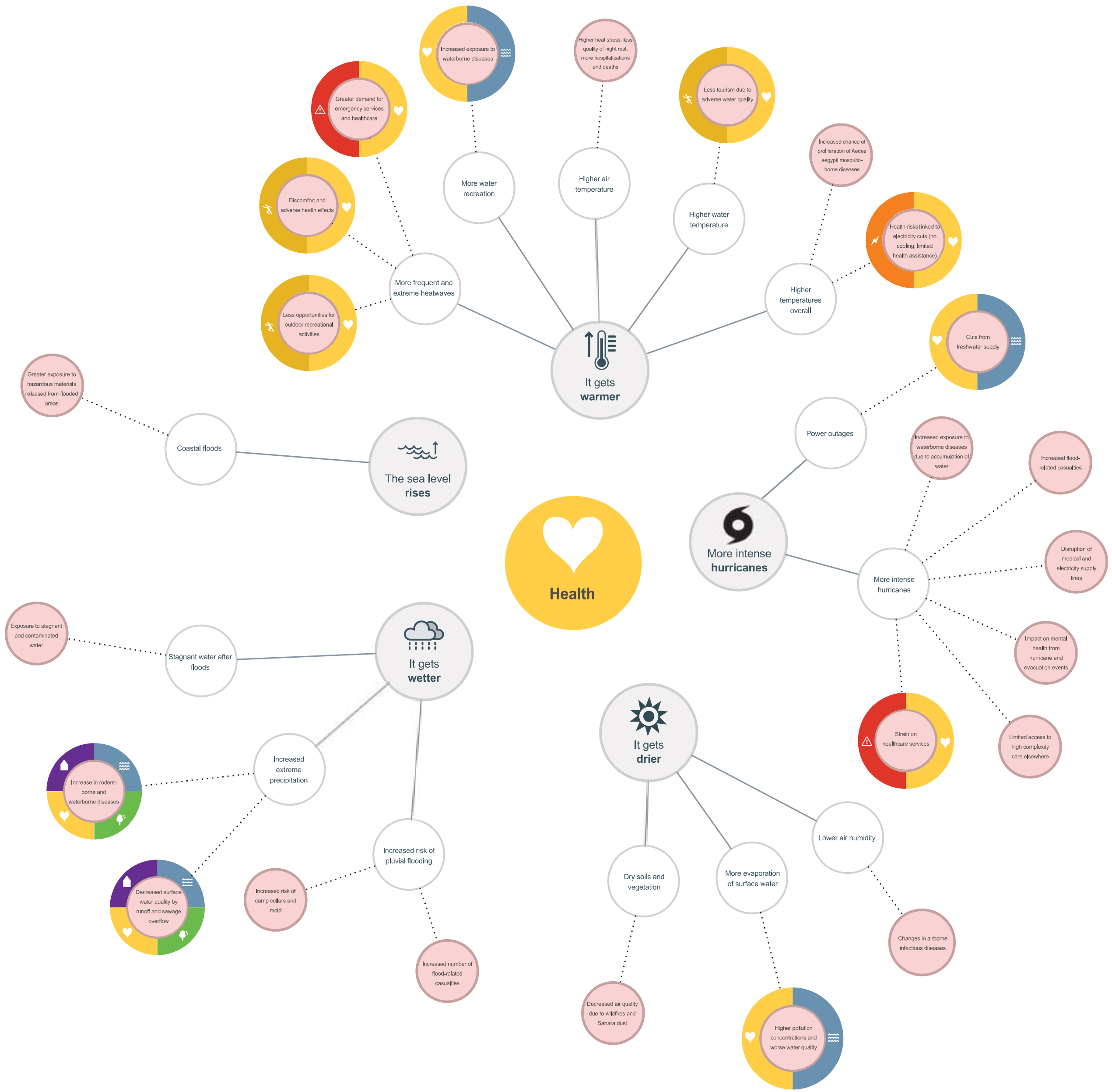

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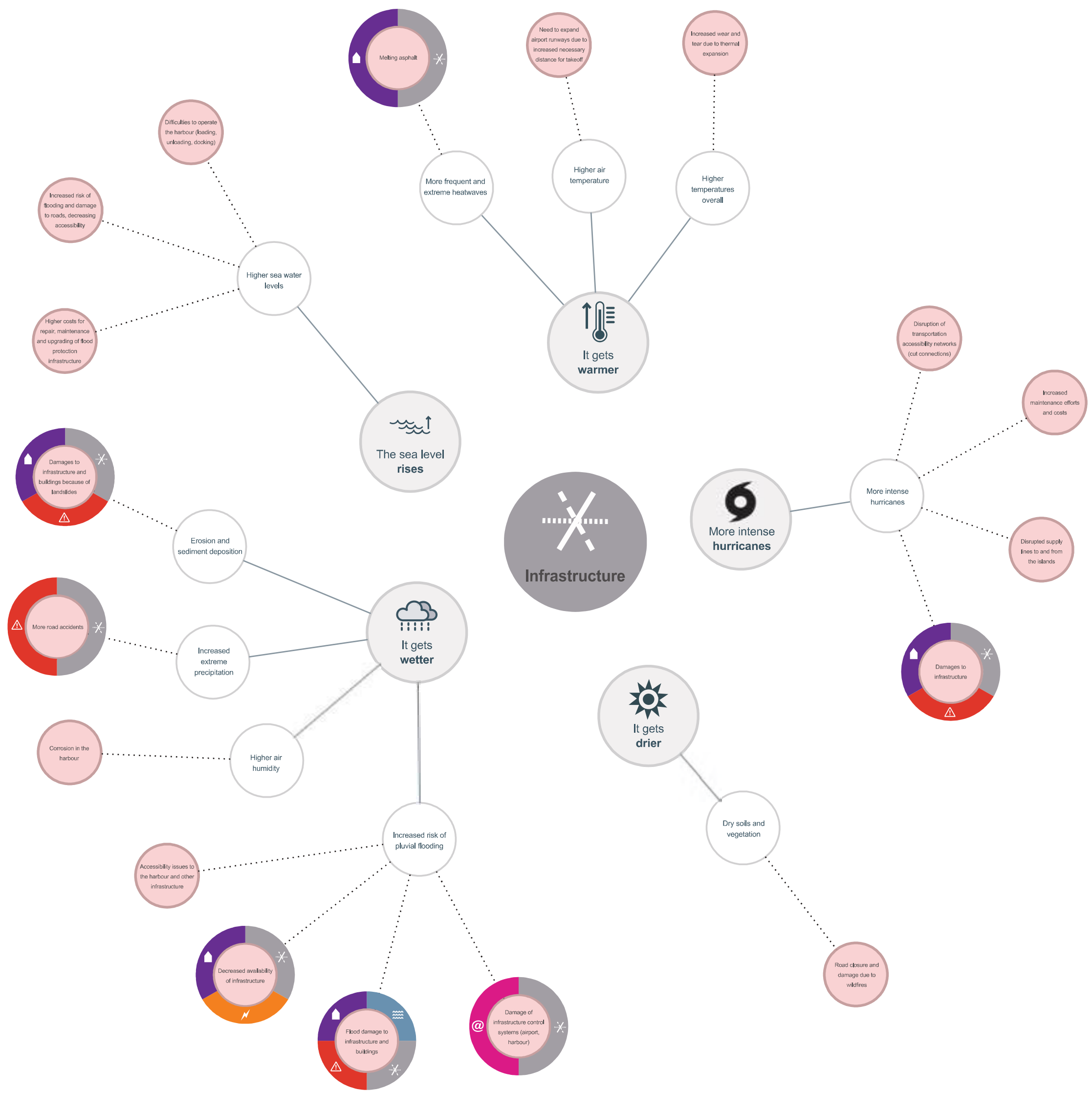

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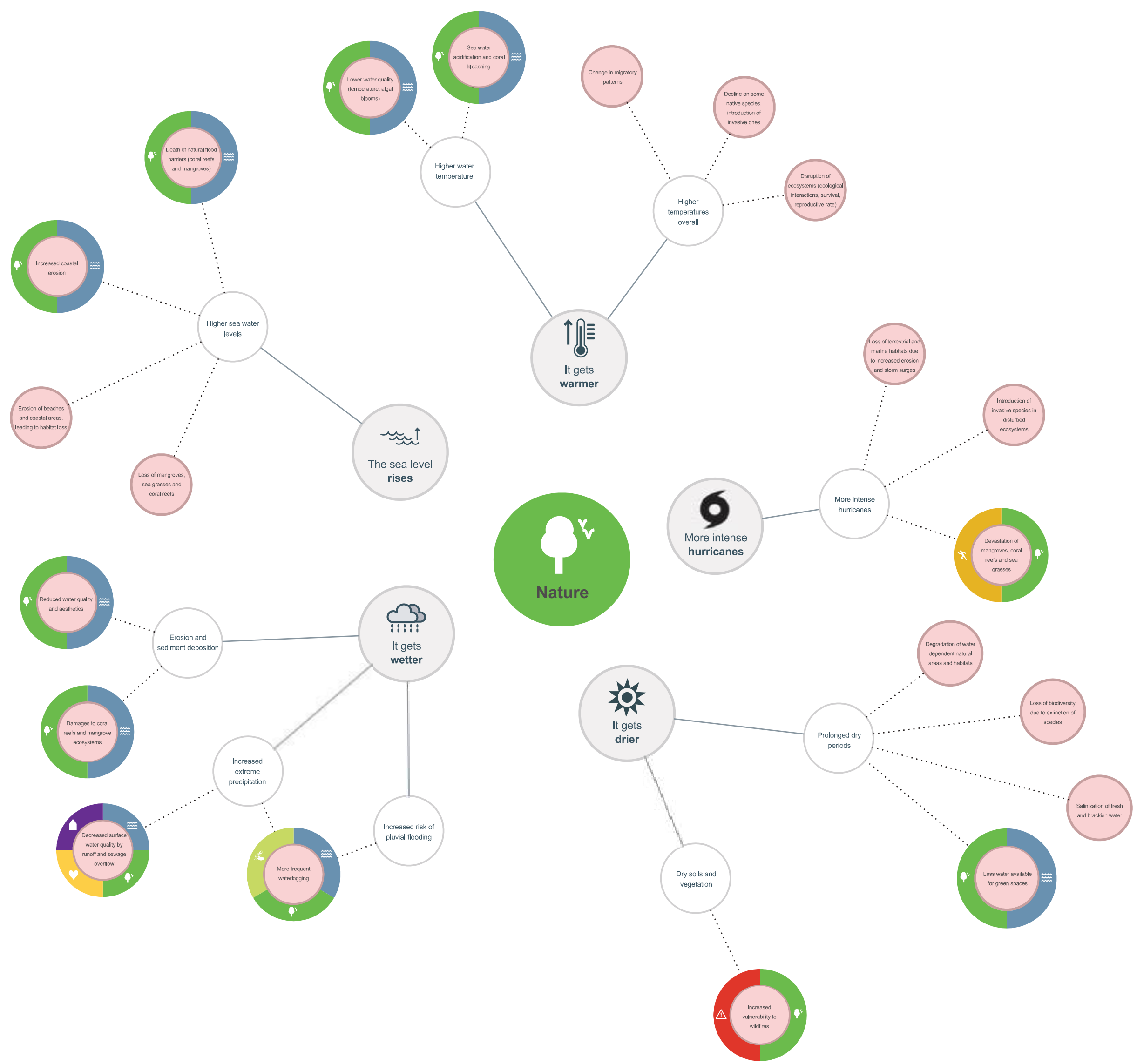

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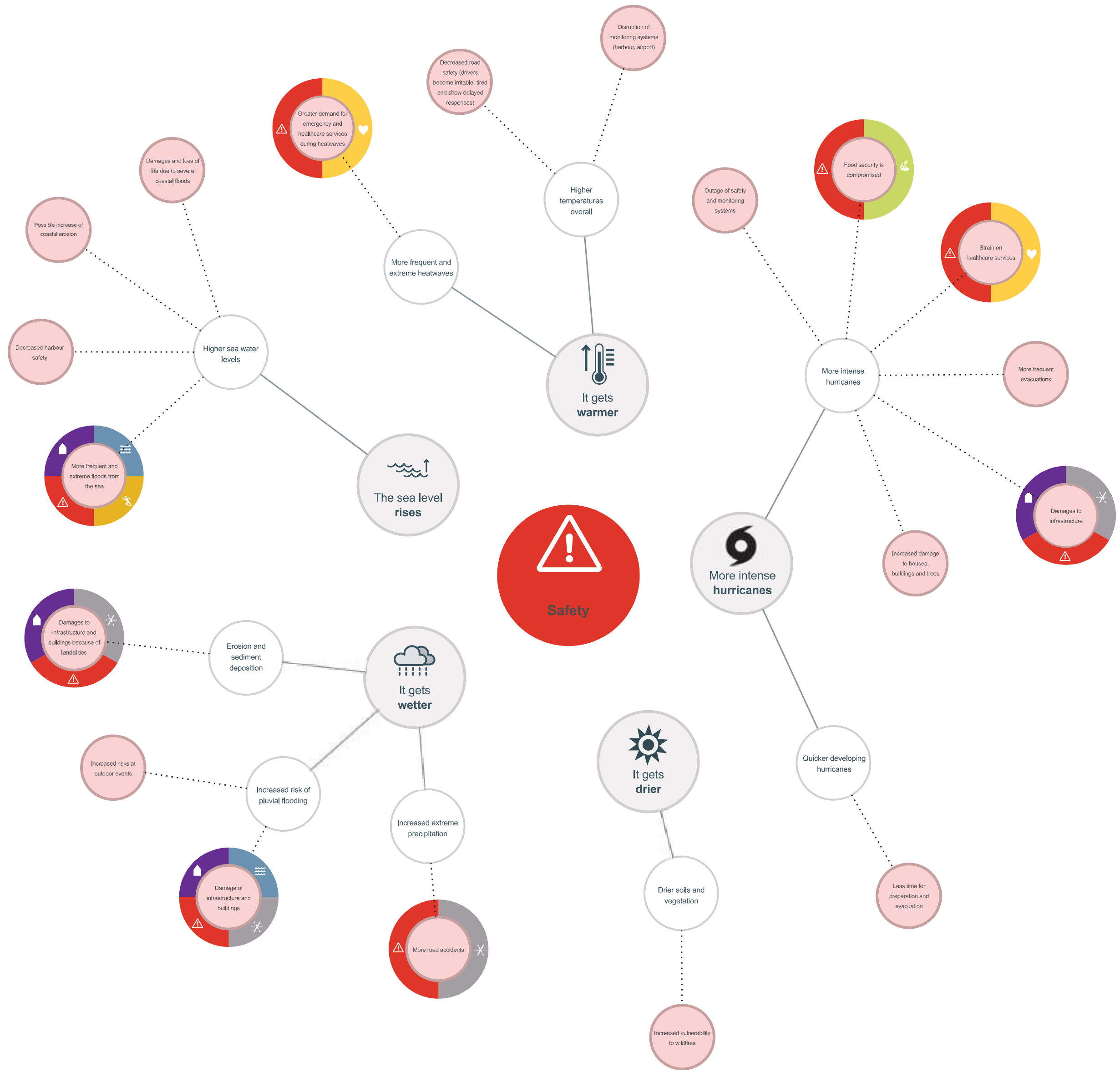

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Type of consequence
- Threat
- Opportunity
- Unclear

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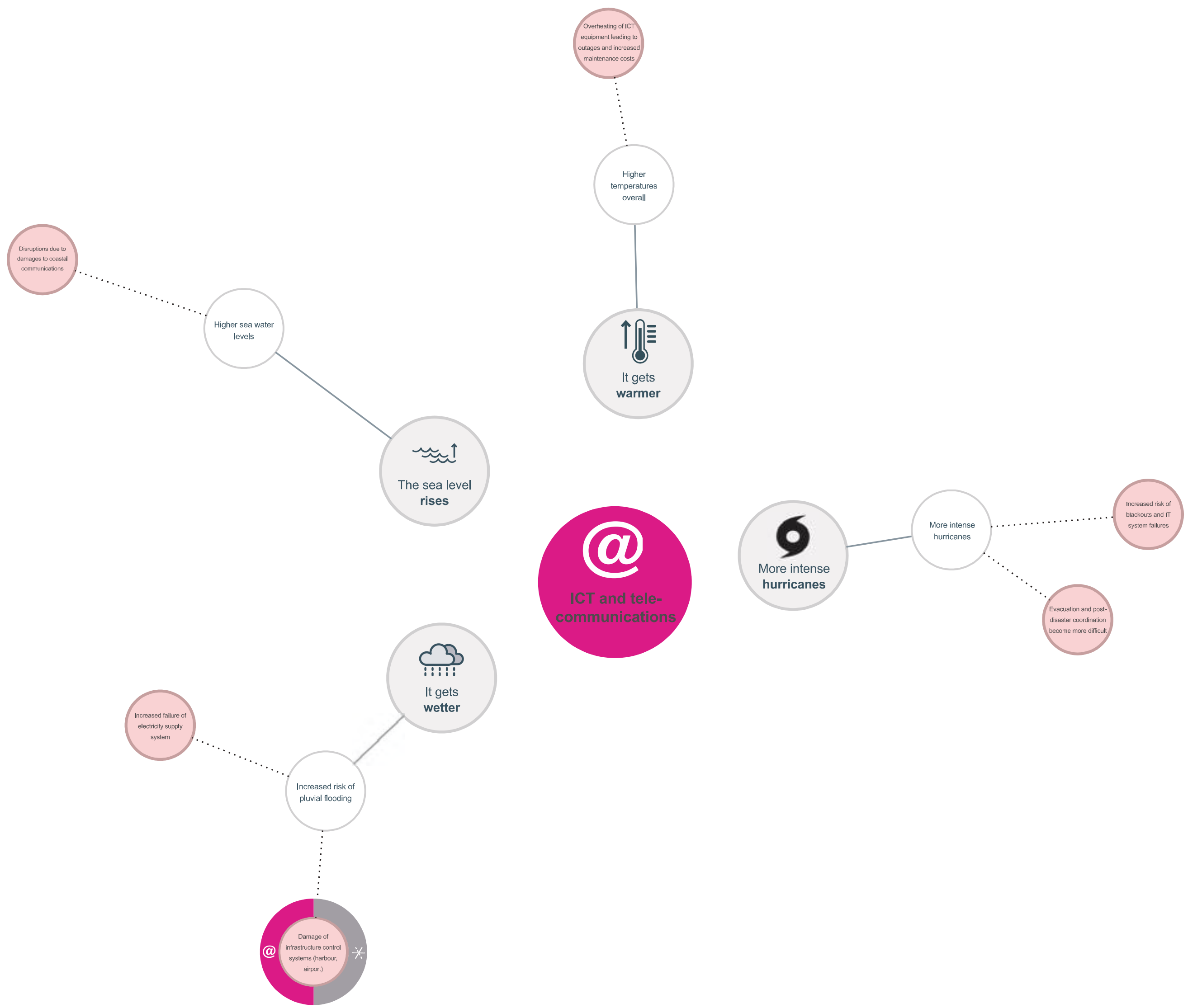

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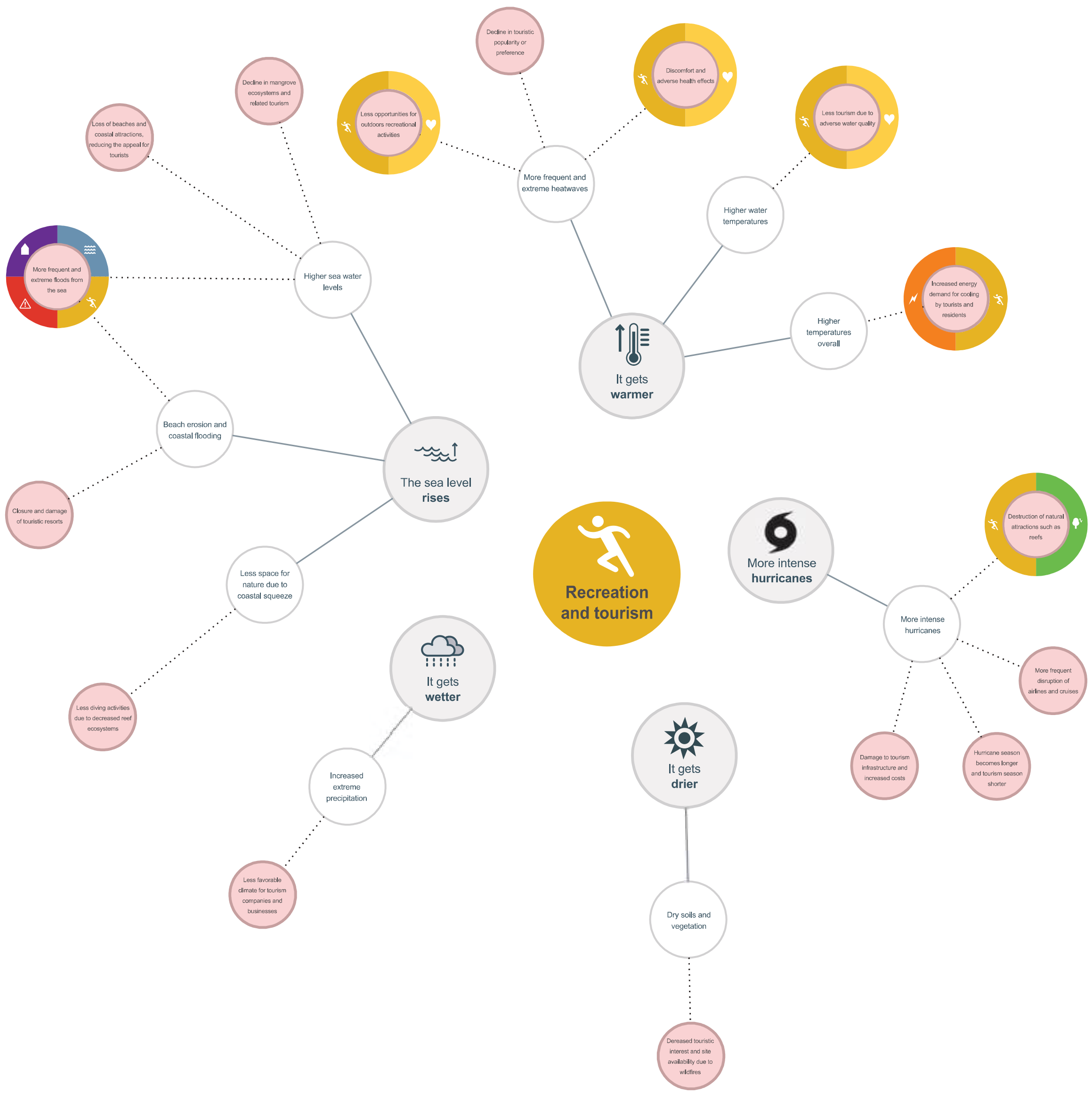

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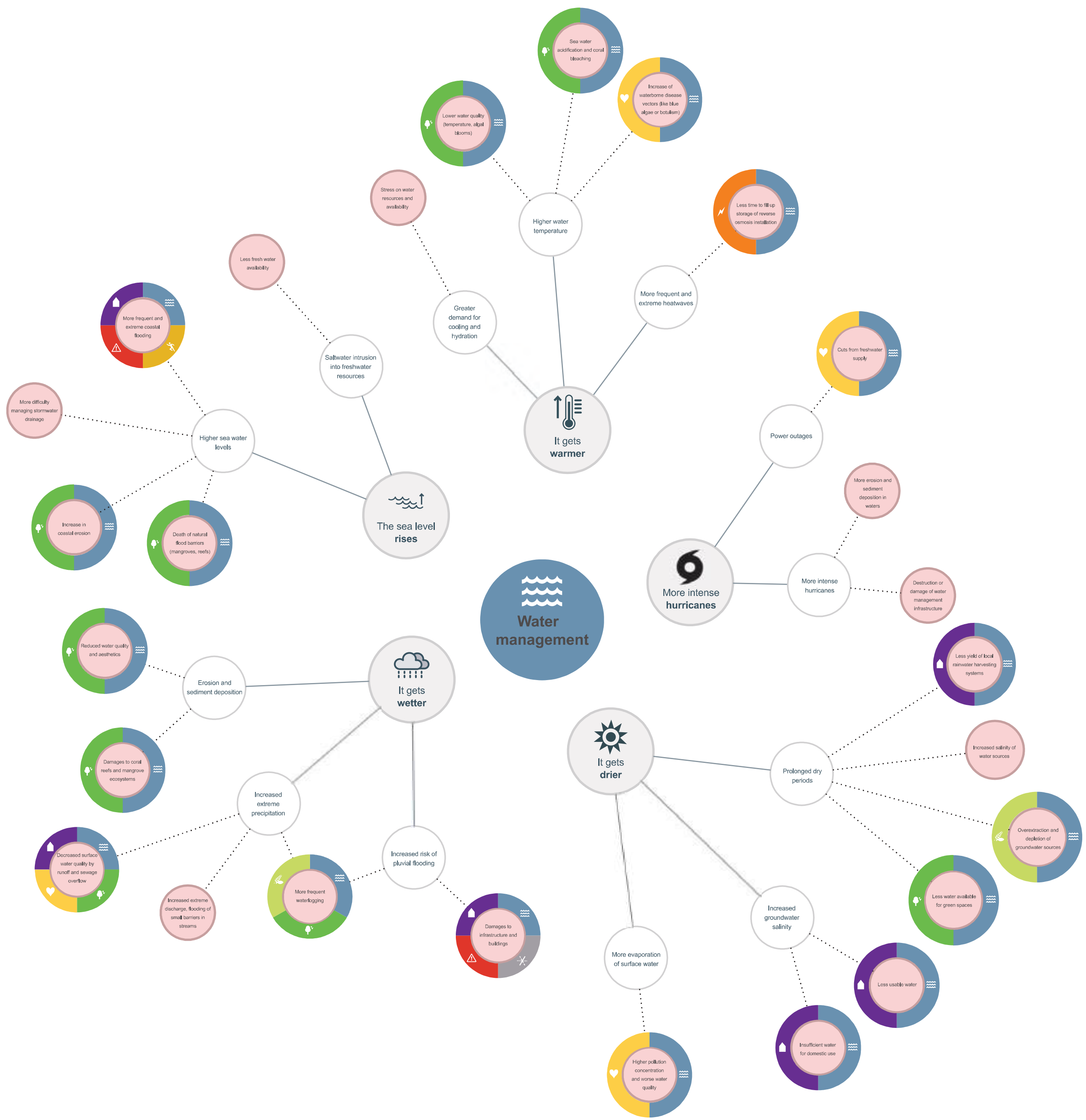

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