EVIDENCE-BASED INFRASTRUCTURE: CURACAO

NATIONAL INFRASTRUCTURE SYSTEMS MODELLING TO SUPPORT SUSTAINABLE AND RESILIENT INFRASTRUCTURE DEVELOPMENT

May 2018, Curacao

Ministry of Traffic, Transport and Urban Planning

UNOPS

University of Oxford

ITRC mistral
multi-scale infrastructure systems analytics

PREAMBLE

This report establishes the first milestone in a partnership between the Government of Curacao, the United Nations Office for Project Services (UNOPS) and the University of Oxford-led Infrastructure Transitions Research Consortium (ITRC). Through extensive data collection and cross-sectoral analysis, it estimates Curacao's future infrastructure needs for energy, water, solid waste and wastewater services and delivers recommendations for how those needs can be met. Additionally, climate-change driven flood risks to roads, social infrastructures and development projects are assessed for the purpose of prioritising risk reduction activities. In doing so, it provides new and important evidence to support infrastructure decision-making to ensure long-term sustainable and resilient development.

Ms. Zita Jesus-Leito

Minister of Traffic, Transportation and Urban Planning

Government of Curacao

"Like many islands in the Caribbean, Curacao's geography has played a significant role in the development of our infrastructure to date, as well as the challenges we face in the future. To address these challenges, Curacao has embarked on a journey of sustainable and resilient infrastructure planning using the Evidence-Based Infrastructure Framework and the National Infrastructure Systems Model. With the help of the United Nations Office for Project Services and the UK Infrastructure Transitions Research Consortium we deepen the understanding of the opportunities and challenges facing our young nation, and how evidence for decision-making can be used to best position resilient infrastructure as a driver of sustainable socio-economic development.

National infrastructure systems form the backbone of Curacao's society, distributing goods and services which are essential for social, economic and environmental well being. These infrastructure systems affect everyone every day, without us always realizing it. We have the objective of adapting the management of infrastructure in a way that will be resilient to different changes that our country will face in the future, from the effects of climate change to an economy that is less reliant on fossil fuels.

Our infrastructure is vital for the functioning of society today and its future success. Therefore, it should be efficient and resilient. In that context, cross-sectoral long-term planning is essential for maximizing the full potential of our island for the benefit of all its people. By sharing our journey of sustainable and resilient infrastructure planning we want to show leadership both on Curacao as well as in the Caribbean.

Mr. Nicholas O'Regan

Director, Infrastructure and Project Management Group

United Nations Office for Project Services (UNOPS)

"The rapidly growing global population is creating unprecedented demands for utilities and services, this, coupled with the threats to development from a changing climate. Governments are therefore facing fantastic challenges to protect socio-economic development gains that have been achieved whilst safeguarding the environment that we all depend on. Small Island Nations are amongst the first to be affected and most vulnerable and exposed in this uncertain future. Curacao is therefore to be commended in adopting an evidence-based approach to infrastructure investments, which will underpin an informed decision-making process. Which in turn will help to ensure limited resources are applied to maximize socio-economic development, and that informed infrastructure investment will lock in patterns of sustainable and resilient development for decades to come.

This report is an important building block towards this vision and target. Working with our partners, such as the Universities of Oxford and Southampton, UNOPS is proud to be of assistance and make available cutting-edge technology, world class thought leadership and technical expertise to help Curacao plan their sustainable future, as part of our commitment to our Partners in helping people build better lives and for countries to achieve resilient and sustainable development.

Professor Jim Hall FREng

Director, Environmental Change Institute

University of Oxford

"I'm delighted that the research teams from the Universities of Oxford and Southampton, who form part of the UK Infrastructure Transitions Rearch Consortium, have been able to contribute to the evidence-based infrastructure assessment for the Government of Curacao. Our team has been developing state-of-the-art infrastructure systems models and assessment methodologies for the last seven years. Over that time we have developed unique capability to understand interdependencies between infrastructure networks and to explore the implications of an uncertain future.

Though we are based in world-leading universities, we are not only motivated by excellent research – we want to see the fruits of our research making a difference around the world. That is why we have committed to a partnership with UNOPS and have used our tools and technologies to inform infrastructure decision making in Curacao, which is the latest in what I hope will be a growing number of applications that are helping to shape sustainable infrastructure worldwide.

1 EVIDENCE-BASED INFRASTRUCTURE FRAMEWORK

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What is Evidence-Based Infrastructure?

Developed by UNOPS, the Evidence-Based Infrastructure (EBI) Framework is an integrated approach to the planning, implementation and management of national infrastructure. It encompasses the processes and tools for successful implementation, considering a diverse range of social, environmental and economic contexts. EBI addresses the need to move away from a traditional silo-based planning approach, to one that recognizes the interdependence of infrastructure systems – across cities, islands, countries, and regions. Evidence-based planning supports governments and decision-makers in achieving national development plans with better knowledge of demographic, economic, and climate change risks.

The National Infrastructure Systems Model (NISMOD)

Central to EBI and to the following analysis is the National Infrastructure Systems Model (NISMOD) developed by the Infrastructure Transitions Research Consortium (ITRC), a UK-based research consortium led by the University of Oxford. NISMOD includes a process, composed of a series of steps of analysis, that has been designed to estimate a country's current and future infrastructure needs and provide recommendations for how those needs can be met. Appendix A provides an in-depth description of each step of the NISMOD process.

Integral to this model is the incorporation of datasets from a range of sources, including big data from remote sensing satellites and mobile devices, with country-specific engineering insights and on-the-ground assessments. These datasets represent the size, usage, location and interconnectivity of current and planned infrastructures from the energy, transport, water, wastewater, solid waste and digital communications sectors. Social Infrastructure, including schools, hospitals and governmental buildings are also represented, as well as forecasts for the main drivers of infrastructure demand. NISMOD integrates this complex range of data to provide state-of-the-art analysis to underpin infrastructure investment decisions and policies. In doing so, NISMOD enables evidence to be incorporated at the heart of long-term infrastructure planning – reducing future risks and providing confidence to investors.

Figure 1 illustrates how each step of the NISMOD process underpins one of three main components of evidence-based infrastructure development:

(1) Accumulation of comprehensive datasets on existing infrastructure and demand drivers, including spatial data, from in-country sources;

(2) Modelling and analysis of the infrastructure system, taking into consideration how the system meets demands in alignment with pre-defined performance targets;

(3) Results and outputs to provide the basis for decisions and recommendations on specific infrastructure investments or policies. The modelling process incorporates explicit interdependencies between sectors, discussed in Section 8 of this report, that adds a new layer of complexity beyond the usual sectoral approach.

NISMOD has been applied successfully in the United Kingdom and is used by the UK National Infrastructure Commission to undertake integrated national infrastructure planning of public and private investment totalling over 800 billion US dollars. A similar assessment has already been carried out in Palestine, and additional elements of the NISMOD methodology have been applied to infrastructure resilience planning in China and New Zealand. Curacao is the first country to use the model in the Caribbean region; applications to other small island states in the Caribbean are being explored.

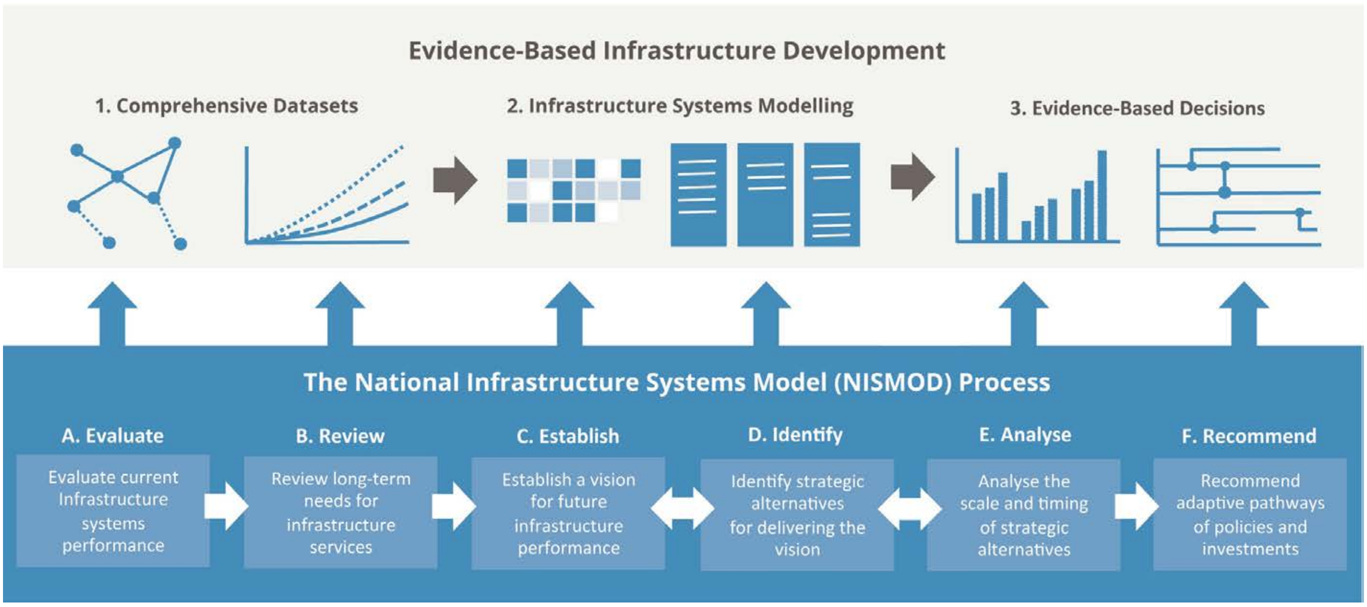

Figure 1
THE NATIONAL INFRASTRUCTURE SYSTEMS MODEL (NISMOD) PROCESS UNDERPINNING EVIDENCE-BASED INFRASTRUCTURE DEVELOPMENT

2
CURACAO: A REGIONAL PIONEER IN SUSTAINABLE AND RESILIENT INFRASTRUCTURE PLANNING

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The findings and recommendations in this report are the result of a collaborative partnership between the Government of Curacao, the United Nations Office for Project Services (UNOPS), and the Infrastructure Transitions Research Consortium at the University of Oxford

National infrastructure systems form the backbone of Curacao's society, distributing goods and services which are essential for social, economic and environmental well being. These infrastructure systems consist of a complex array of physical assets, operational organizations and regulatory authorities. Like many other Small Island Nations, Curacao has specific vulnerabilities and characteristics. These include: Its small size, remoteness, narrow resource and export base, exposure to external economic shocks and to a large range of impacts from climate change, including potentially more frequent and intense natural hazards.

To address these challenges, the Government of Curacao has embarked on a journey of sustainable and resilient infrastructure planning using the Evidence-Based Infrastructure Framework and the National Infrastructure Systems Model.

As Curacao looks to pursue a development agenda that is sustainable, resilient, adapted to climate change and prosperous for the nation, the role that infrastructure investments play in driving this agenda forward is critical

The task for decision-makers in Curacao, as it relates to infrastructure, is to deepen understanding of the opportunities and challenges facing the nation, and how evidence for decision-making can be achieved to best position infrastructure as a driver of sustainable development. For example, to counter fossil fuel dependency, modelling of the energy and water sectors can demonstrate a path to achieving high levels of renewable generation and overall energy demand reductions. The protection of ecosystems can be addressed through proposing means of reducing the production and release of unmanaged or untreated waste and wastewater. Effective flood risk management uses a range of available spatial data on flooding and infrastructure assets to prioritise risk reduction initiatives and inform the building of new development projects.

The journey of collaborative infrastructure assessment, shown in **Figure 2**, began in 2016 with the formation of a formal partnership between the Curacao Ministry of Traffic, Transport and Urban Planning (Ministerie van Verkeer, Vervoer en Ruimtelijke Planning, VVRP) and UNOPS. In July 2017, data collection for NISMOD was initiated with a kick-off meeting and workshops involving more than 60 key infrastructure stakeholders in government, civil society and industry. In February and March 2018, further consultations were held with various departments of VVRP including Public Works and the Meteorological Department, the Ministry for Health, Environment and Nature (Ministerie van Gezond, Milieu en Natuur, GMN), the Ministry for Economic Development (Ministerie van Economische Ontwikkeling, MEO), the Curacao Central Bureau of Statistics, the local utility company, and the University of Curacao. Using findings from this initial assessment, interim results were presented to the Council of Ministers.

This report concludes the first step of the analysis coordinated by UNOPS and the ITRC and is accompanied by (1) a detailed spatial infrastructure asset database for Curacao and (2) a cross-sectoral long-term infrastructure planning model. It is anticipated that the transfer of this infrastructure assessment capacity to infrastructure stakeholders in Curacao will provide a foundation for further interaction, data collection and detailed analysis. Such analysis can be used to provide evidence for decision-makers on emerging areas of interest and allow Curacao to lead the Caribbean region in sustainable and resilient infrastructure assessment and planning.

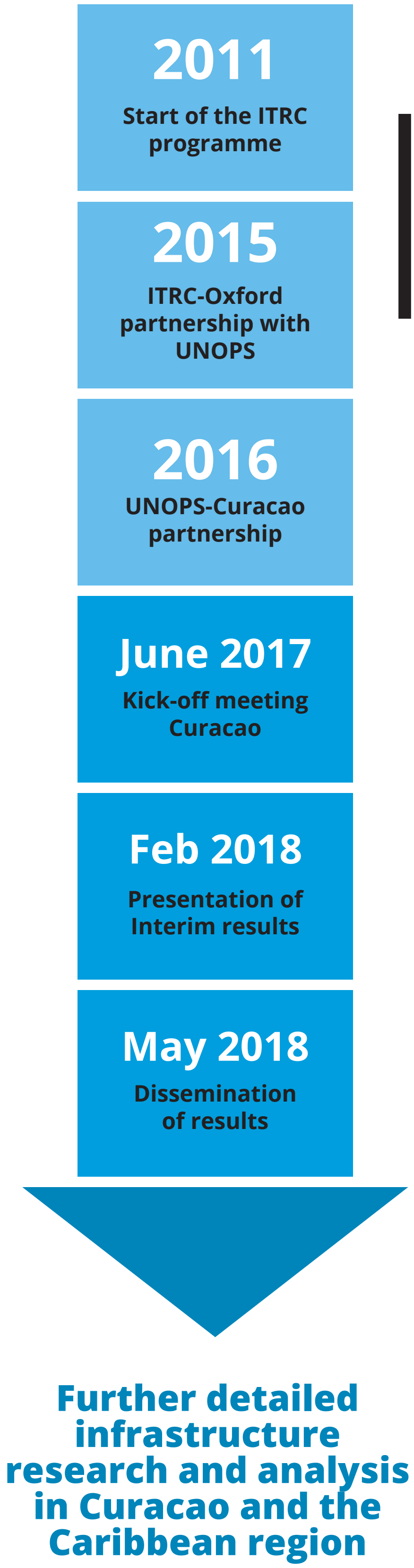
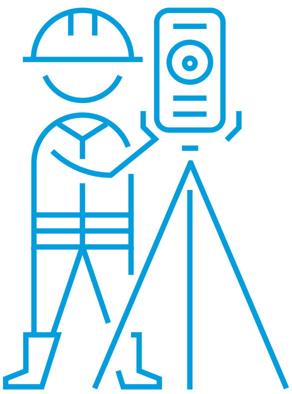


Figure 2
TIMELINE OF THE UNOPS-ITRC EVIDENCE-BASED INFRASTRUCTURE PROCESS IN CURACAO



3 THE CURACAO INFRASTRUCTURE ASSESSMENT

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Addressing future challenges through infrastructure planning

Curacao faces a number of key challenges over the coming decades, including: a continued dependence on fossil fuels that will lead to increasing vulnerability to international fuel prices and contributions to emissions levels and air pollution; growing pressures on the supply and affordability of the island's potable water; degradation of marine and terrestrial environments by disposal of untreated sewage and wastewater; a looming waste disposal crisis; and climate change related hazards such as sea-level rise, flash flooding and storm surges that threaten Curacao's residents, infrastructure systems, and potential for economic growth.

These challenges have formed the basis for an infrastructure assessment for Curacao. Using the NISMOD process, as described in Section 1, the assessment provides recommendations resulting in an analysis of long-term strategic planning of the energy, water, wastewater and solid waste sectors and the risk and resilience planning of transportation and social infrastructure, including their interconnectivity and interdependence, as outlined in **Figure 3**.

The first part of this report, comprising Sections 4 to 8, assesses each of the key challenges for Curacao's infrastructure outlined above, with a particular focus on the following sectors: energy, water, waste, and wastewater.

Each of these sectors is addressed using the long-term infrastructure planning model that accounts for the current state of infrastructure service provision in Curacao and responds to future infrastructure demands. For this assessment, these demands are estimated using forecast demand drivers of residential population (using population projections from the Central Bureau of Statistics Curacao[1]) and of stay-over and cruise ship tourists (using extrapolated trends from the Curacao Tourist Board[2,3], and capacity expansion plans of Curacao's airport[4] and cruise ship terminals[5,6].) A detailed explanation of these scenarios can be found in Appendix B. **Figure 4** shows the peak population in 2016 alongside 2050 forecasts for the combined residential and tourist scenarios using underlying low, moderate, and high growth assumptions. For the remainder of this report, results are presented using data from the moderate growth scenario. To represent the uncertainty in modelled outcomes due to uncertainties in future growth rate, Appendix C shows additional results for the low and high growth scenarios.

Figure 3
INTEGRATED METHODOLOGY FOR CURACAO'S INFRASTRUCTURE ASSESSMENT BASED ON THE NISMOD PROCESS

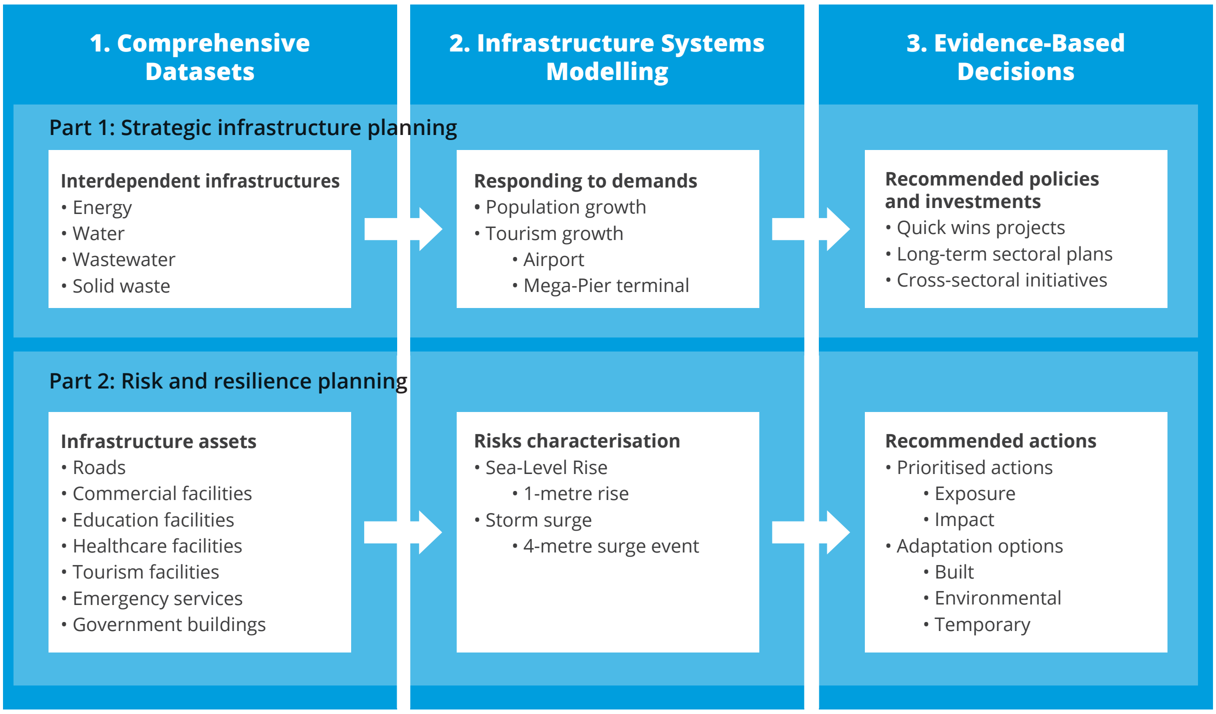
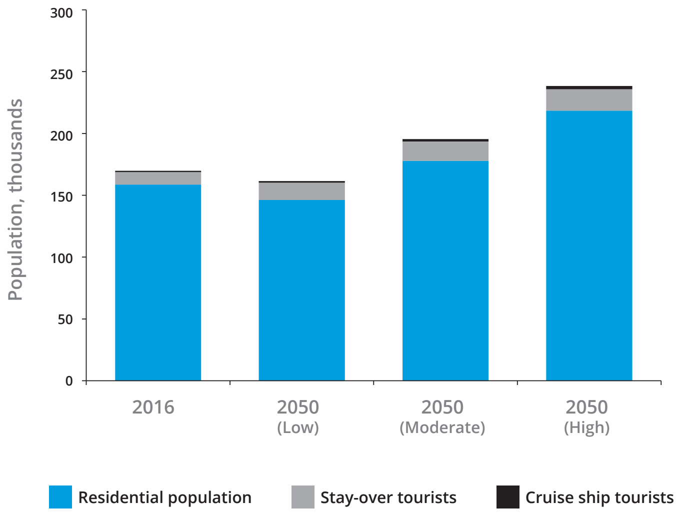
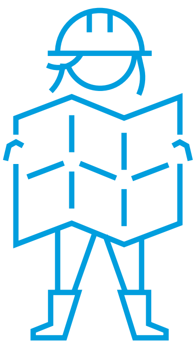


Figure 4
TOTAL PEAK POPULATION IN 2016 SHOWN WITH 2050 FORECASTS FOR RESIDENTIAL, STAY-OVER TOURISTS AND CRUISE SHIP TOURISTS (FOR LOW, MODERATE AND HIGH SCENARIO)

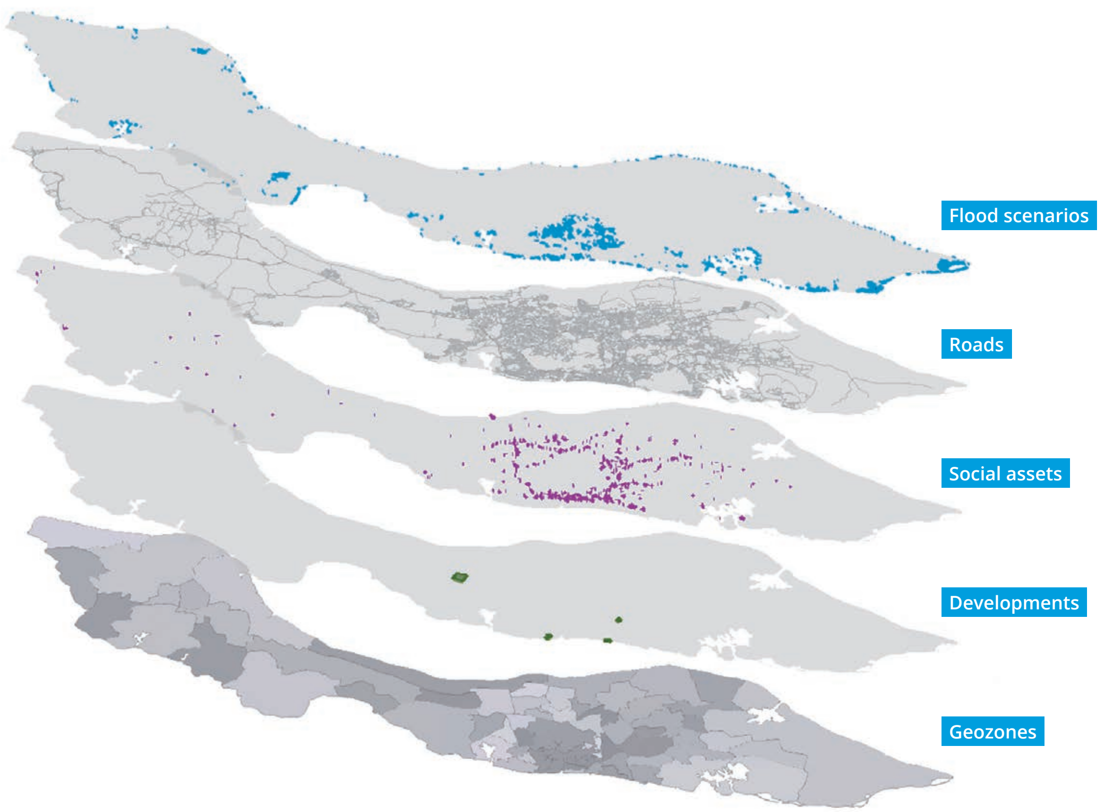




The assessment provides a means of supporting evidence-based decisions by identifying a number of infrastructure policies and projects that can be implemented over the coming years to meet infrastructure needs. This includes a selection of 'quick win' options that can be implemented in the short-term, at reduced costs, to realise significant performance gains. Further options are also presented to form the basis for evidence-based long-term plans that align with visions for broader societal development in Curacao. A full list of these policies and projects are outlined by sector in Appendix B, including relevant sources and any assumptions included in the calculations.

The second part of the report, comprising Sections 9 and 10, looks at the risk and resilience of Curacao's infrastructure assets, which is inclusive of the transportation network, social infrastructure such as educational, healthcare and emergency facilities, and a series of planned residential, commercial, and recreational developments. This aspect of the analysis characterizes two types of flood risk faced in Curacao, from sea-level rise and storm surge inundation. Sea-level rise is represented at horizon for the year 2100 with a 1-metre rise (chosen as the upper-end estimate from the Intergovernmental Panel on Climate Change (IPCC)[7], which is regarded as applicable for the Caribbean region[8,9]). Storm surge is represented by a 4-metre inundation scenario (chosen as an average value for Caribbean countries for a 1 in 100-year storm event[9]). Using digital elevation data from NASA[10], the risk of exposure of the infrastructures to these different hazard event types is estimated. Recommendations are provided for implementing prioritised risk reduction measures and with respect to the integration of adaptation and disaster preparedness measures into national infrastructure planning. **Figure 5** summarizes key spatial data that has been obtained from existing infrastructure maps and databases – as well as through interactions and collaboration with infrastructure stakeholders – which informs this component of the analysis. The combination of these datasets, for the purposes of assessing infrastructure risk, is a novel approach to infrastructure decision-making in Curacao.

Figure 5
SPATIAL REPRESENTATION OF THE INFRASTRUCTURE AND HAZARD DATA USED IN THE RISK ASSESSMENT



4 ENERGY

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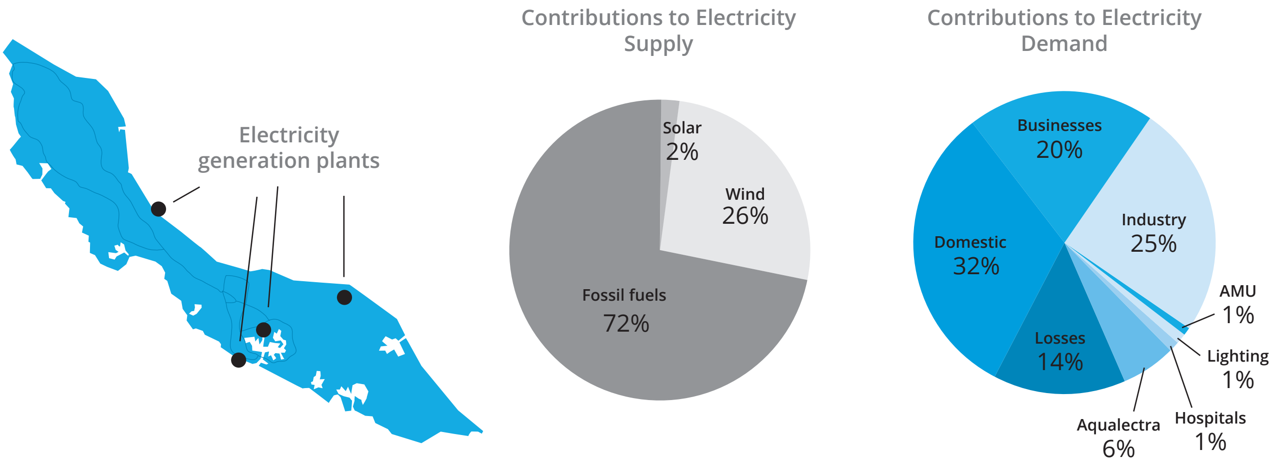
Curacao's energy sector is fossil fuel-dependent, making the country vulnerable to fluctuations in global fuel prices, reducing economic autonomy.

Curacao's energy sector has historically been defined by a heavy dependence on imported fossil fuels (**Figure 6**). According to the Ministry of Economic Development and Aqualectra, 72% of the electricity currently generated is from fossil fuels and the remaining 28% from renewables. Given Curacao's lack of fossil fuel resources, the production of energy is tightly correlated with international oil prices. Additionally, at an international scale, the use of fossil fuels exacerbates climate change, the effects of which disproportionately affect islands like Curacao, particularly in terms of the threat from sea-level rise and the potential for more extreme severe weather events.

Aqualectra is the government-owned utilities company responsible for the production and distribution of power. The diesel engines in the Dokweg area supply power to the electricity grid, playing an important role in meeting current national demands. The distributed and flexible nature of this form of generation provides a means to meet the dynamic demands of the local market, a function that will become even more necessary in the future with a larger proportion of intermittent renewables in the electricity generation mix. A gradual transition from diesel to gas as a fuel for generation will help reduce environmental and economic costs, whilst ensuring reliability and security of supply. The generation portfolio of Curacao is supplemented with a further 20-30% of electricity contracted from the Curacao Utilities Company (CUC), associated with the Isla refinery. For average domestic customers, a typical monthly bill is in the range of 28.59 US dollars, similar to regional counterparts in the Virgin Islands (31.62 US dollars) and Bonaire (34.90 US dollars)[11].

Figure 6
CURACAO SECTOR SNAPSHOT (ENERGY), SHOWING THE SPATIAL DISTRIBUTION OF ENERGY ASSETS AND CURRENT ELECTRICITY SUPPLY AND DEMAND BREAKDOWN



Small-scale development of renewable generation and implementation of demand-side efficiencies can sustain electricity needs in the short run

In the short-term, a number of low-cost, low-regret interventions can be implemented to maintain the security of Curacao's energy supply, most corresponding to key strategies identified in the National Energy Policy[11]. The development of solar parks which has the potential of more than double the current solar generation capacity is set as a key energy objective of Curacao. Further renewables development aims to increase the total solar capacity to 55 Megawatts (MW), which will pay dividends once installed. To address demand-side management, an end-use efficiency campaign amounting to a minimum of 15% reduction in consumption of domestic electricity has been proposed in Curacao's National Energy Policy. This, in combination with another 10% demand reduction focused on air conditioning optimisation in the service sector, could feasibly be envisaged by 2020; together, these reductions can reduce installed capacity needs by around 19%. The optimisation of cooling, which accounts for a large portion of electricity use, relies heavily on the implementation of performance standards for appliances or the implementation of possible future techniques like water cooling, an action which has been committed to by the Government (**Figure 7**). These interventions can lead to greater reductions on the demand side over the longer-term: the National Energy Policy envisages a 25% per capita energy reduction by 2040. Additional small-scale, targeted technical improvements to reduce losses in the grid can also be feasibly implemented in the next two years.

An ambitious future energy strategy can capitalize on Curacao's opportune access to wind, sun, and the sea

Curacao's current buffer between installed capacity and energy demanded (peak capacity margin), is above the level internationally recommended by the International Energy Agency. This buffer is internationally recommended to ensure a reliable supply of energy. Expected growth in tourism and residential population (moderate and high scenarios) will cause an increase in demand. Pursuing a renewable energy portfolio in line with the Government's objective of 50% renewable electricity production by 2035 will allow this demand to be met, maintaining the recommended capacity margin into the future. Curacao's location in the Caribbean provides it with favourable conditions to develop large-scale solar and onshore wind installations (with load factors 50 and 100% greater than in North America and Europe, respectively), and to explore the potential of sea water air conditioning (SWAC) and ocean thermal energy conversion (OTEC) as part of a long-term energy strategy. Future improvements in energy storage will provide adaptability to address intermittencies in solar and wind generation, with installed capacity in the latter aiming to expand by 37% by 2025 according to National Energy Policy objectives. While the initial investment costs of SWAC and OTEC are relatively high, the large concentration of hotels and resorts along the coasts and the high (>90%) capacity factor of ocean thermal energy conversion, suggest these options could supply a proportion of Curacao's future demand for electricity services. **Figure 7** shows the gradual phasing out of fossil fuels as renewable generation increases, reaching 50% of electricity supply before the 2035 target.

In addition to supply-side renewables growth, the impact of demand management interventions is outlined in **Figure 8**, with the implications for cumulative CO_2 emissions of the overall decarbonisation strategy shown on the right-hand axis.

ENERGY: 'QUICK WINS'

2020: THE DEVELOPMENT OF SOLAR PARKS with installed capacity of 12 to 15 MW, amounting to an additional 27 Gigawatt hours (GWh) of energy supplied by 2020, which are currently in preparation by Aqualectra. This would more than double current solar microgeneration capacity, which is currently produced from small-scale, individual installations. A downward trend in pricing will make solar conversion increasingly attractive in the near future.

2020: REDUCTIONS IN PEAK DEMAND FOR ELECTRICITY in households (15%) and the service sector (10%) are feasible in the short-term through two strategies: (1) the introduction of performance standards for cooling, lighting, water heating and appliances in households; and (2) the optimization of air conditioning through temperature settings, maintenance and ventilation, with a focus on the service sector. Overall, cooling accounts for up to 50% of electricity use. Based on current demand projections, this combination of demand-side reductions could provide an additional saving of 87 GWh of electricity supply by 2020.

2021: THE CONSTRUCTION OF A WASTE-TO-ENERGY FACILITY provides a partial solution to the waste management challenge while providing additional energy security for Curacao, and is included as a key pillar of Curacao's energy policy. Given current waste availability, Aqualectra has estimated feasible short-term generation capacity for this facility of 7 MW, amounting to an extra 80 GWh for the electricity grid from 2021.

See Appendix B for full list of interventions and relevant methodology.

Figure 7
LONG-TERM ELECTRICITY CAPACITY AND DEMAND

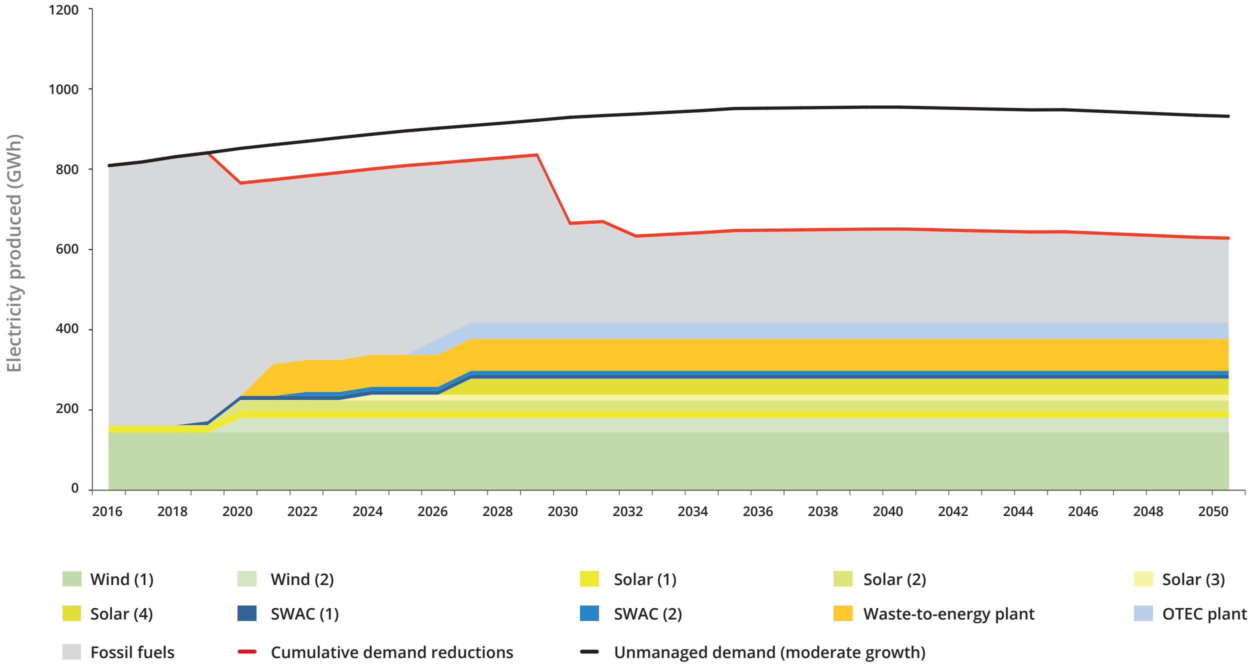
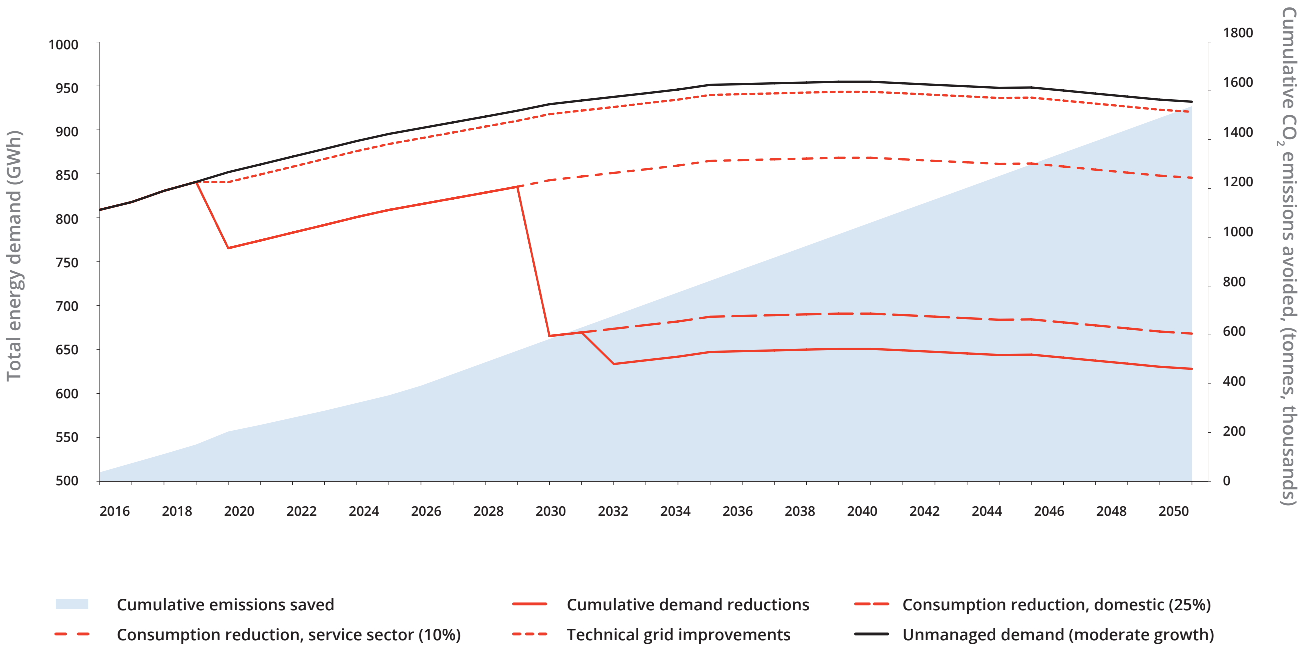


Figure 8
CUMULATIVE ELECTRICITY DEMAND REDUCTIONS AND CO_2 EMISSIONS AVOIDED



5 WATER

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Curacao's reliance on energy-intensive desalination makes potable water a costly commodity

Potable water on the island is largely provided by seawater reverse osmosis technology (**Figure 9**). Costs associated with desalination are relatively high, with domestic water tariffs applied at approximately 10 Antillian Guilders (NAf)* per cubic metre (approximately three times more expensive than the United Kingdom). The two desalination plants, located in Willemstad and Santa Barbara with a combined capacity of more than 50,000 cubic metres per day, account for approximately 9% of the island's total electricity use – this amounted to 74 GWh in 2017. The relocated Mundo Nobo plant to Dokweg will provide an additional surplus when it begins operation in 2025. To support transmission and distribution, there are a further 15 reservoir parks and 5 pumping stations installed[12]. Available surface water from lakes and rivers is scarce and groundwater abstraction is widely practiced for agriculture[13]. Aqualectra, the primary water provider in Curacao, has announced its intentions to reduce this cost by restructuring transmission and distribution systems, building new water transmission mains, and investing in mechanisms to reduce leakage across the system. Such non-revenue water accounts for 24-28% of total water production[14].

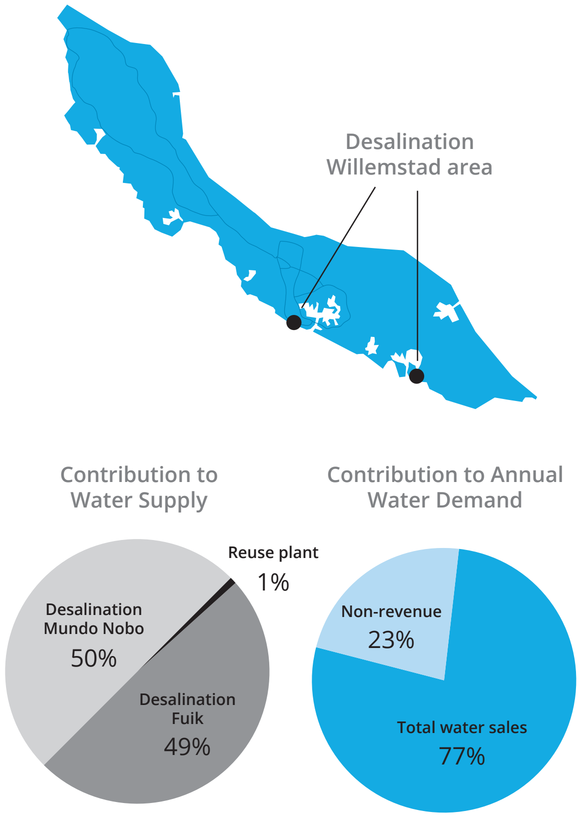
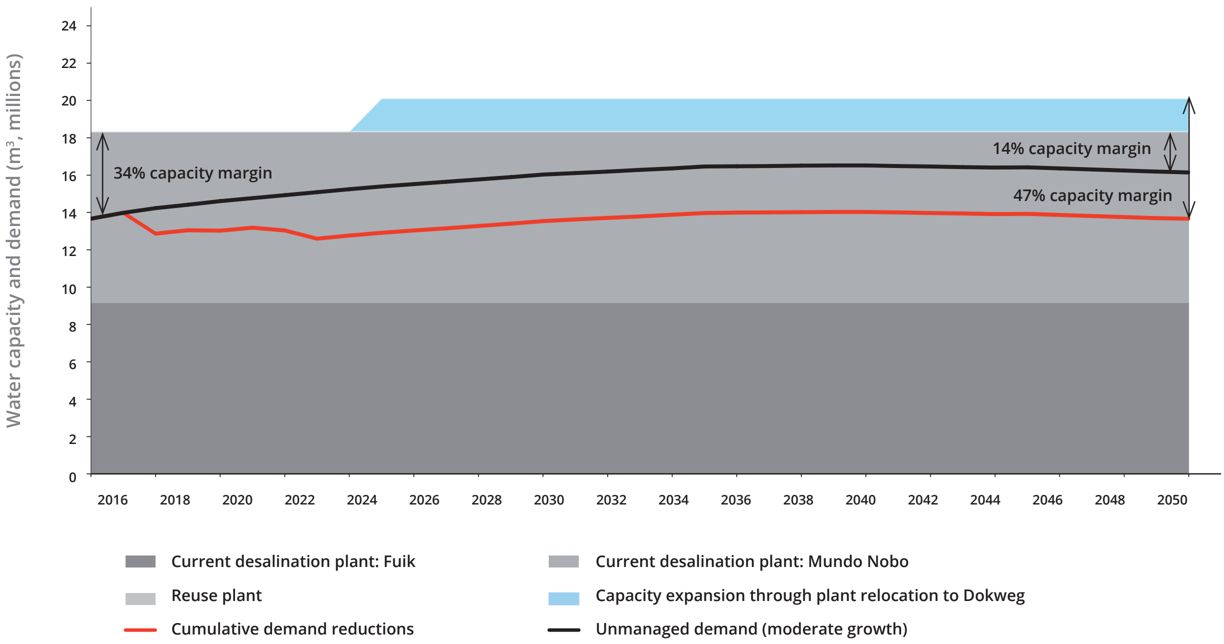


Figure 9
CURACAO SECTOR SNAPSHOT (WATER), SHOWING THE SPATIAL DISTRIBUTION OF WATER ASSETS AND CURRENT WATER SUPPLY AND DEMAND BREAKDOWN

*Aqualectra, average rate as of 1 May 2018

Figure 10
LONG-TERM WATER CAPACITY AND DEMAND



The growing tourism sector will put stress on Curacao's water supply

Potable water in Curacao is currently provided in adequate quantities for Curacao's residents and visitors. This is shown in **Figure 10**, where current and future forecast water supply is expected to exceed demand. However, uncertainty around these future demands, particularly those linked to tourism, necessitates actions to maintain this water security in the long-term. The capacity margin is expected to decline as the residential population increases and tourist numbers grow, incorporating the needs of water-intensive activities and facilities such as swimming pools, golf courses, and irrigated gardens.

A focus on water use reductions will maintain a sustainable supply in years to come

Meeting future water needs in Curacao can incorporate the challenge of decreasing levels of costly, energy-intensive desalination in favour of low-cost, demand-side interventions and policies to reduce water use or to increase the efficiency of the water supply network. Potential 'quick win' actions are identified for implementation within the next five years.

WATER: 'QUICK WINS'

2018: WATER NETWORK MAINTENANCE involving the replacement of 140 kilometres of water pipelines has been proposed by Aqualectra as a means to improve water distribution efficiency by 10%.

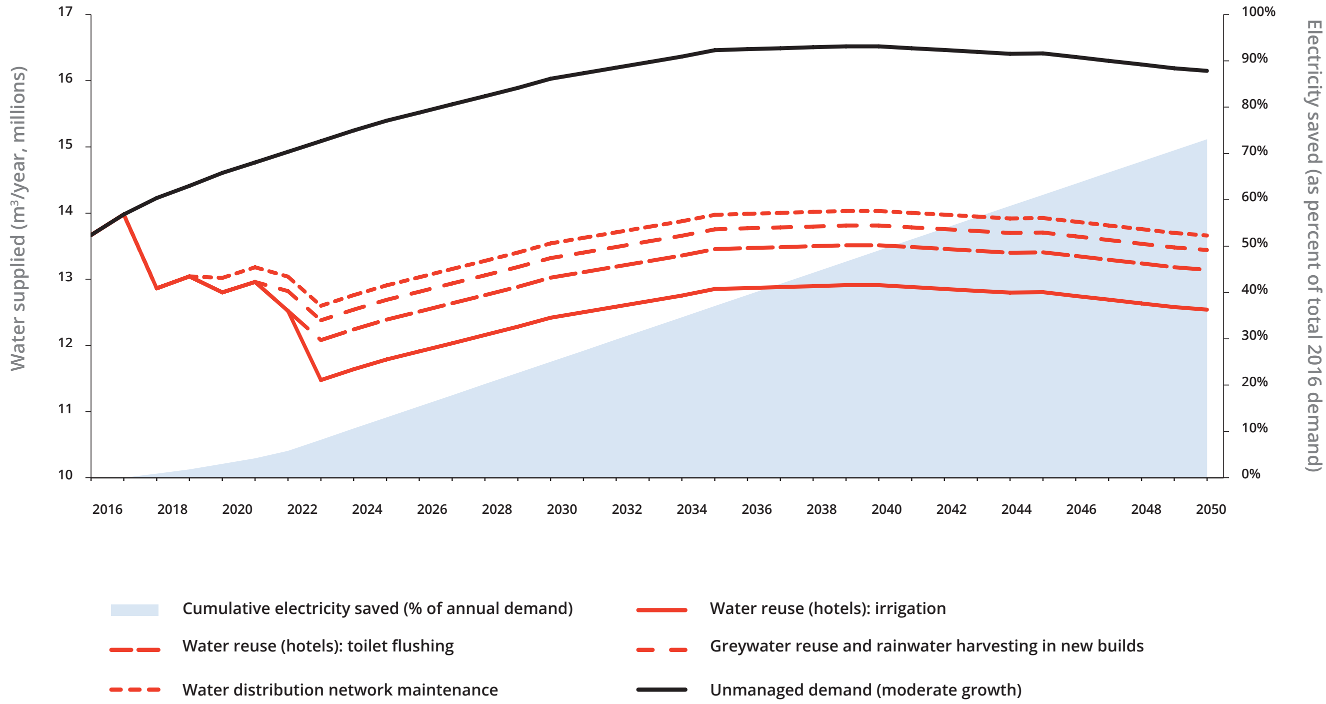
2020: STANDARDS ON THE USE OF RECYCLED RAIN OR GREYWATER in flush toilets can be applied and enforced immediately on new builds, reducing water use by 1.5%. This is based on regional evidence suggesting 50% of residential water needs can be met through rainwater and greywater reuse[15]. Using an estimation of the average number of new residents per year and the percentage of water consumed by residents, the maximum potential impact of the reuse strategy can be calculated. Incorporating greywater use in existing buildings could have an even greater impact, although the retrofitting of pipes would entail a higher cost and be more difficult to implement.

2022 & 2023: INTRODUCE WATER REDUCTION MEASURES IN THE HOTEL SECTOR assuming a tourist water demand of 16% of the total, water savings can be achieved through the enforcement of hotel water reuse for toilet flushing (2% of total demand) and irrigation (4% of total demand)[16]. A study from the Caribbean region shows that up to 38% of total hotel water needs can be reduced through these two mechanisms. Internationally, studies show this amount rising to 50%[17].

See Appendix B for full list of interventions and relevant methodology.

The impact of each of these demand management strategies is shown in **Figure 11**. Combined, the cumulative energy saved from the resulting decrease in desalination requirements amounts to nearly three-quarters (73%) of total electricity demand in 2016.

Figure 11
CUMULATIVE WATER DEMAND REDUCTIONS AND ENERGY SAVINGS



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6
SOLID WASTE

Landfill capacity in Curacao is fast running out and will be depleted within 8 years

The management of solid waste has been identified as a critical and urgent priority in the National Development Plan and the National Report of Curacao that were recently presented at the Third International Conference on Small Island Developing States[18]. Increasing volumes of solid waste, particularly in light of the growing number of tourists, are exerting unsustainable demands on the current solid waste infrastructure in place on the island. In Curacao, the major waste flows include commercial waste (approximately 66%), municipal solid waste (31%), bulky waste (2%) and sanitation waste (1%) (**Figure 12**). The public waste company Selikor collects, transports and further manages these waste streams. The main infrastructure asset for solid waste management in Curacao is the 45-hectare sanitary landfill at Malpais with a remaining lifetime estimated at 8 years.

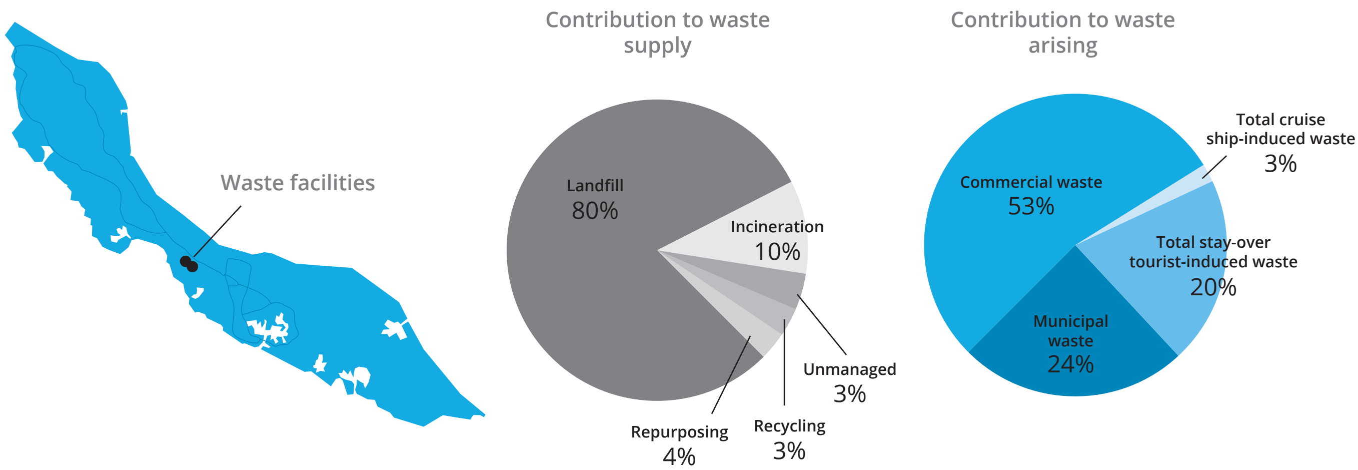


Figure 12
CURACAO SECTOR SNAPSHOT (SOLID WASTE), SHOWING THE SPATIAL DISTRIBUTION OF SOLID WASTE ASSETS AND CURRENT BREAKDOWN OF ARISINGS AND TREATMENT OPTIONS

Curacao's Ministry of Health, Environment and Nature notes that landfilling is no longer an environmentally sustainable option; solid waste management necessarily needs to include measures such as prevention, awareness, and recycling[18]. The extent to which such waste minimisation strategies are being employed effectively is limited. While a small-scale waste drop-off centre for separating wastes exists at the Malpais Landfill site, it is currently used sparingly. A notable challenge above and beyond that of sustainable solid waste management is the management of toxic substances such as pesticides, waste oil and heavy metals. Curacao currently has limited capacity to manage or dispose toxic waste substances, which results in significant risks to terrestrial and marine environments.

Prevention campaigns provide the lowest-cost means of dealing with the waste problem

A lack of public awareness of the impending waste problem resulting from the Malpais landfill's depleted capacity remains a serious challenge to successful waste management in Curacao. While some public awareness programs on waste prevention have been established, most are small-scale and their effectiveness is often not tracked[18]. However, studies of campaigns in other countries have demonstrated successful results, with the potential to prevent up to 12.5% of total waste arisings in some cases. In Curacao, this 'high prevention' scenario is projected to be lower – around 1.6% of total waste according to a recent assessment[19] – but can serve as a starting point for the projected impact of awareness campaigns. Additionally, these types of strategies are relatively low-cost to implement and can easily be integrated into educational curriculums, consumer habits, and local and community initiatives. **Figure 13** shows the current and future landfill capacity to manage waste, which will soon become unsustainable. The immediate implementation of waste interventions – including prevention campaigns – brings waste production down to a manageable level before the landfill capacity runs out.

Recycling remains underdeveloped on the island, although proposed incentives can put Curacao on a path toward meeting ambitious recycling targets

Large-scale expansion of recycling activities has the potential to solve Curacao's waste problem by directing large quantities of material away from the landfill. However, commercial recyclers have noted financial barriers to the expansion of recycling capacity at the scale required to meet long-term waste management needs. Two low-cost solutions are proposed. First, with a large portion of Curacao's recyclable waste being exported for treatment abroad, the harbour tax serves as a major disincentive for commercial recycling companies to expand their operations on the island. Currently, Greenforce is the largest commercial recycler in Curacao by volume and plans to increase its capacity by 100% in 2018, while a new plastics recycler is envisaged to begin operations in 2018. A reduction or elimination of the harbour tax would encourage further growth of the sector in the long-term, while simultaneously providing new employment opportunities. Second, a small financial incentive such as a per-unit rebate for sorted recyclable wastes would encourage use of the existing recycling facilities at the Malpais landfill and the other drop-off centres. Currently, users of the landfill who are under their maximum allowance have little motivation to sort their recyclables at the drop-off centre before depositing the remainder in the landfill. Providing an incentive to do so could increase recycling processing by an estimated thousands of tonnes per year.

In addition to recycling and prevention campaigns, the construction of a waste-to-energy plant as outlined in Curacao's National Energy Policy (2018) forms the third main component of a sustainable waste strategy and will initially have the capacity to treat 45% of waste produced, as shown in **Figure 14**. This facility, as well as a smaller-scale hazardous waste incinerator on the landfill site, highlight the potential cross-sectoral benefits of pursuing interdependent infrastructure solutions.

Figure 13
CURRENT AND FUTURE WASTE PRODUCTION AND LANDFILL CAPACITY (UNMANAGED DEMAND, MODERATE GROWTH)

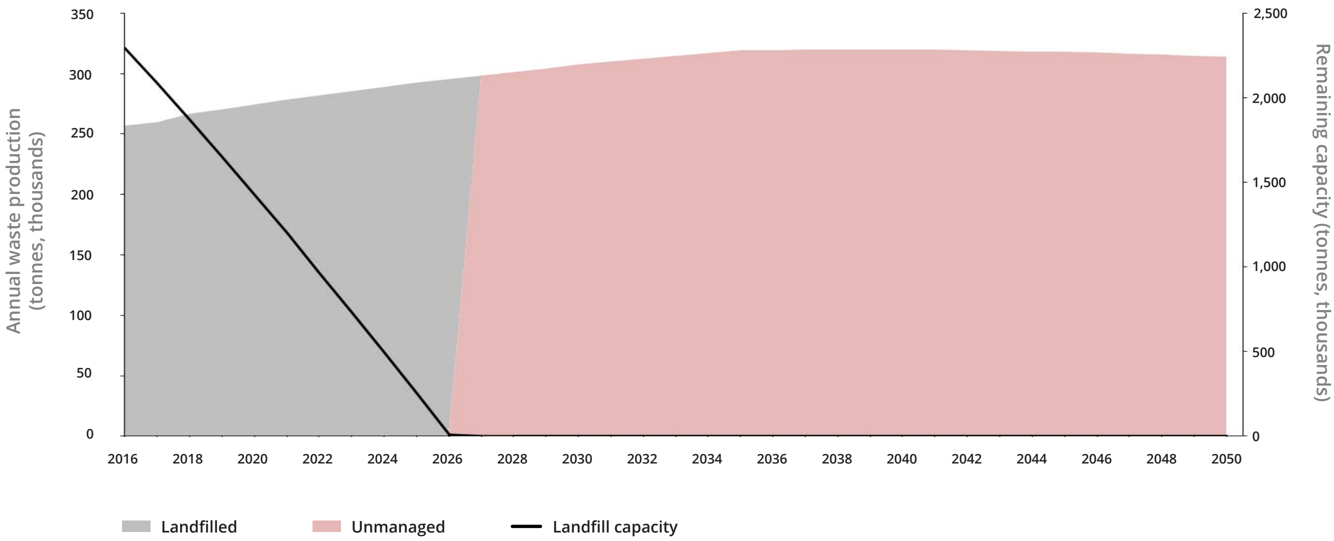
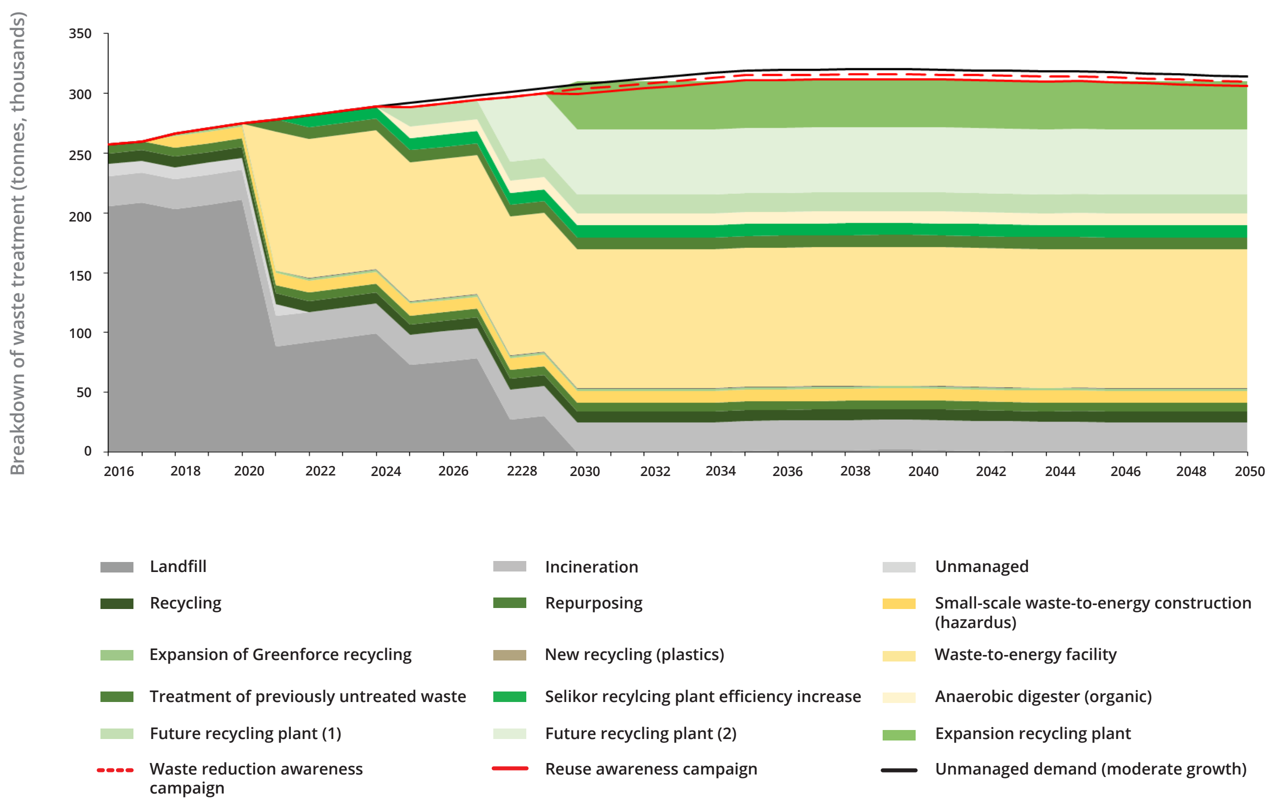


Figure 14
CUMULATIVE IMPACT OF WASTE TREATMENT INTERVENTIONS



SOLID WASTE: 'QUICK WINS'

2018-2020: BY 2030, MORE THAN A THIRD OF CURACAO'S SOLID WASTE SHOULD BE RECYCLED as part of an ambitious waste strategy. Expanding recycling on the island will require indirect although short-term measures to be taken in order to build recycling capacity and to encourage consumer behaviour. For example, the current harbour tax on exports, including recyclable wastes, acts as a disincentive to the development of the recycling sector. A reduction or elimination of this tax specifically on the export of wastes destined for recycling abroad is likely to encourage the rapid growth of commercial recycling companies on the island.

Another policy could be developed to introduce a per-unit rebate on recycling at the existing Malpais plant, similar to bottle deposit schemes in other countries. With users of the landfill more incentivised to use the recycling drop-off centre, this intervention could increase the volume of recycled waste at a low financial cost.

2020: THROUGH EDUCATION AND PUBLIC AWARENESS of the island's waste situation, a low-cost prevention campaign could achieve a prevention potential of 1.6% of total waste. This is based on a reasonable estimate of prevention potential highlighted in the Curacao waste-to-energy feasibility study[19] using findings from studies in Europe.

Additional prevention of landfill waste would result from stricter measures requiring the separation of collected waste as well as legislation banning plastic bags, cups, straws and foam in food packaging.

See Appendix B for full list of interventions and relevant methodology.

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7 WASTEWATER

©Bea Moedt

Currently, around 16% of the wastewater produced in Curacao is treated, while the remaining 84% goes untreated and is discharged into the terrestrial and marine environment

The country's deficiency in sewage treatment facilities means that high rates of partially treated or untreated effluent are discharged into the natural environment[20], both terrestrial and marine. There are four sewage treatment plants in Curacao (**Figure 15**), the majority of which exceed their designed capacity limits. The treated water from these plant is primarily used for irrigation (agriculture, horticulture). Currently, 33% of the island's properties are connected to the sewage system[21]. In areas without a centralized sewerage system, underground septic systems are used as an alternative. There is no regulated inspection of these septic tanks; trucks collect the accumulated sludge (septage) from the tanks and transport it to sludge treatment facilities. The liquid component from those facilities is typically used for irrigation, while the sludge is transported to the landfill sites or the sea.

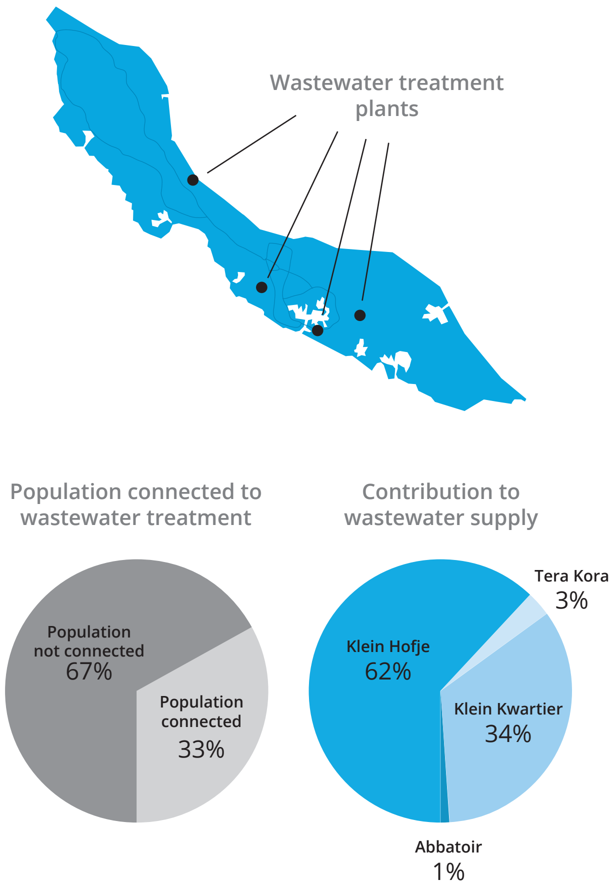


Figure 15
CURACAO SECTOR SNAPSHOT (WASTEWATER), SHOWING THE SPATIAL DISTRIBUTION OF WASTEWATER ASSETS AND CURRENT WASTEWATER SUPPLY AND TREATMENT BREAKDOWN

Significant progress can be achieved in the short-term with low-cost capacity- and demand-side interventions

There is great potential within the wastewater sector to implement projects that reduce contamination of Curacao's unique terrestrial and marine environments, and which contribute economic value to the island in the form of new jobs and increased tourism revenue. Recent marine scientific assessment has shown that seawater quality, especially in the populated Willemstad area, is very poor[22]. These findings further reinforce the need for action to reduce the current treatment deficit. Poor sewage treatment facilities, ineffective regulation and enforcement capabilities add to the threats posed to terrestrial and marine habitats and ecosystems[18].

Although agriculture currently plays a small role in Curacao's economy, treated wastewater provides a key input to expanding this sector by developing small-scale farms and community gardens, which can in turn provide employment opportunities for Curacao's residents. This water for irrigation contains more nutrients than the desalinated water currently used and can be produced at a much lower cost. Furthermore, the use of treated (recycled) water conserves groundwater and the ecosystem.

Meeting demand for wastewater treatment will require substantial capacity (and thus capital) investment in the long-term. Significant progress can be initiated by upgrading Curacao's existing treatment plants according to existing government plans, which can be carried out over the next five years. Current plans in preparation mainly concern updating the plants and sewage transport system to increase reliability. For instance, optimization of the treatment plant at Klein Hofje, which will add 14 cubic metres per day treatment capacity, has been proposed. Longer-term planning for additional treatment plant construction should take place over this period, with stakeholders noting a particular need for treatment capacity in the east of the island. In total, approximately two plants with scalable capacity would need to be built.

Substantial investment in wastewater treatment plant capacity will be needed to meet the long-term demand for wastewater treatment

A series of investments in new treatment plants and expansions over the next 30 years can eliminate Curacao's wastewater treatment deficit and significantly reduce the contamination of Curacao's terrestrial and marine environments. Given the long planning horizon, these investments are yet to be specified in Government plans but might involve the building of two new treatment plants at five-year intervals with an annual capacity of approximately 2 million cubic metres each (5,500 cubic metres per day), as well as sequenced modular capacity expansions to all plants, including existing facilities. This would require considerable planning for the lead-in times necessary for each plant to become operational.

The added capacity associated with this strategy would more than halve the proportion of untreated wastewater by 2030, and the large current wastewater treatment deficit means that all capacity added in this sector would be used. **Figure 16** shows total demand for wastewater treatment (i.e. wastewater produced) in cubic metres per year (black line), with the cumulative effect of demand reductions over time (red line). Cumulative capacity additions are stacked up from the bottom. Between the two, the wastewater treatment deficit is eliminated by 2050. A closer examination of demand-side impacts, including those resulting from interventions in the water supply sector, is shown in **Figure 17**. This figure also shows that by 2050, the disposal of over 32 million cubic metres of untreated wastewater can be avoided solely through demand management measures. This is nearly equal to the total amount of wastewater produced over three years at current rates of production.

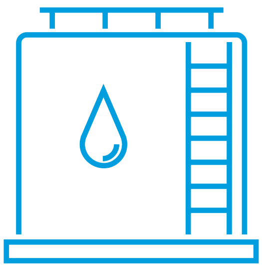


Figure 16
LONG-TERM WASTEWATER CAPACITY AND DEMAND

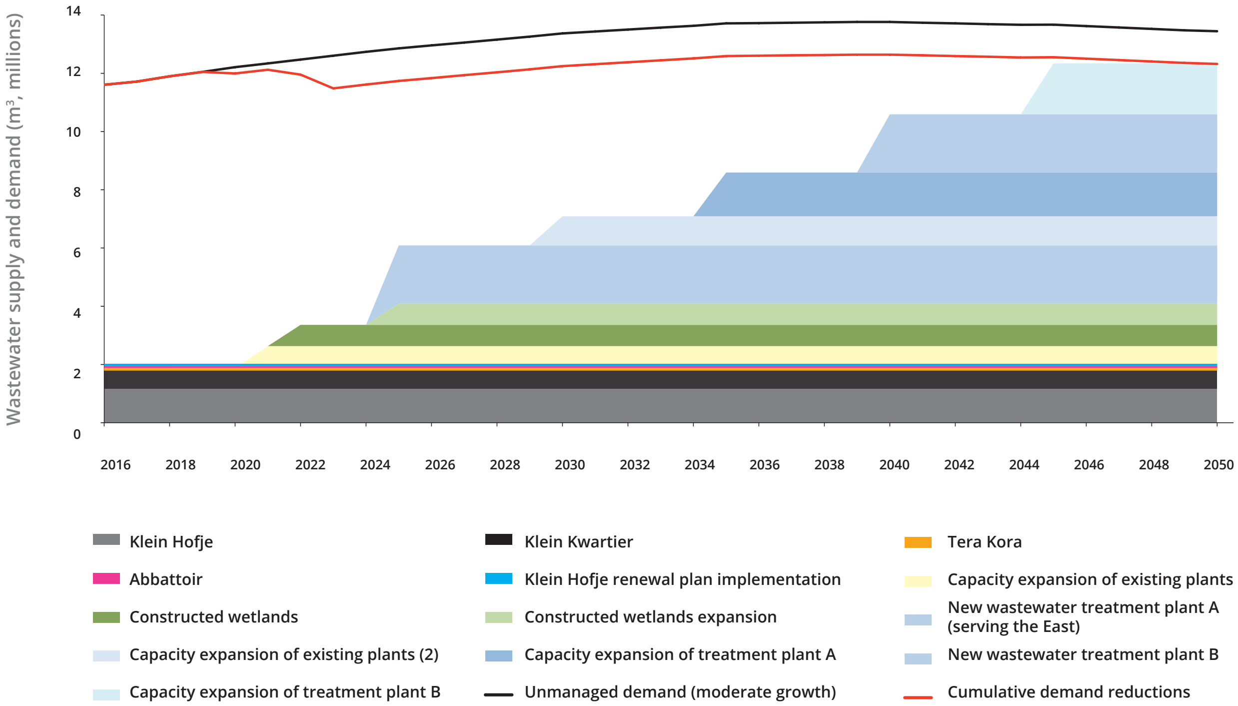
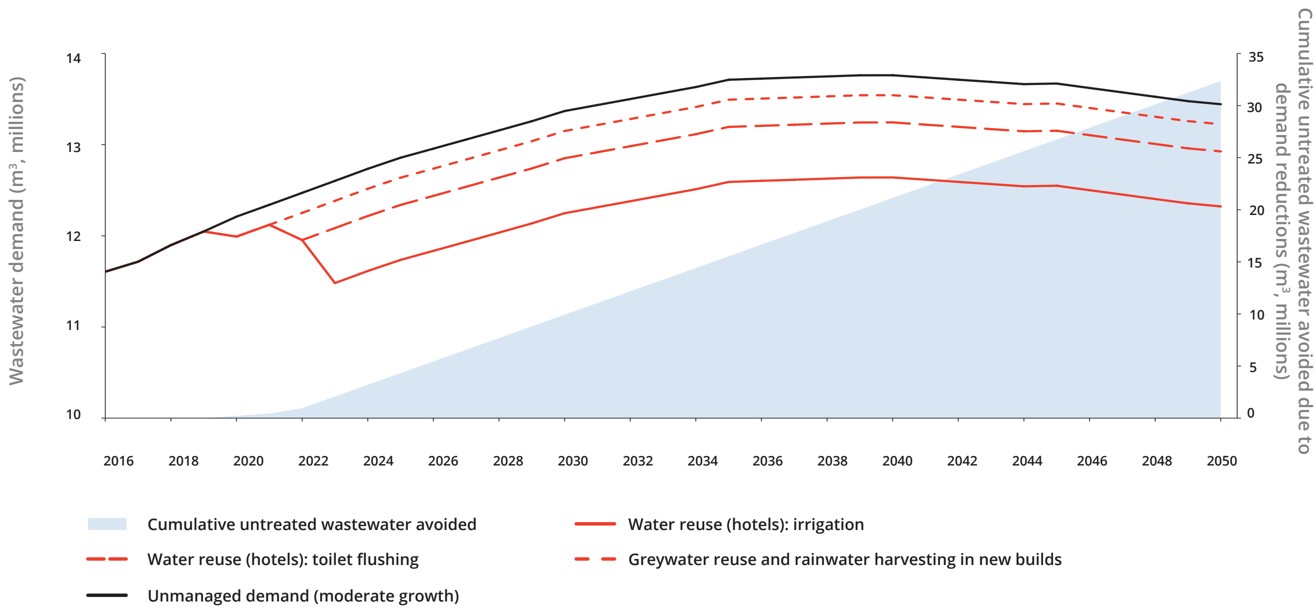


Figure 17
CUMULATIVE WASTEWATER DEMAND REDUCTIONS AND WASTEWATER AVOIDED



WASTEWATER: 'QUICK WINS'

2019-23: OPTIMISE DESIGN AND UPGRADE CAPACITY of existing plants: for instance, optimising Klein Hofje and expand the capacity of other existing wastewater treatments plants. This will provide Curacao with the means to treat an additional 6% of wastewater produced.

2022-23: AN INTEGRATED DEMAND REDUCTION STRATEGY with the water sector could decrease current wastewater production by approximately 9%. This is achieved through (1) a policy on greywater reuse and rainwater harvesting in new buildings; (2) water reuse for toilet flushing in hotels; and (3) repurposing of water for irrigation in hotels (discussed in the water sector results, Section 5).

2022 & 2025: A PLAN FOR CONSTRUCTED WETLANDS in Buskabaai has been proposed to treat up to 730,000 annual cubic metres of wastewater produced by industrial buildings and surrounding neighbourhoods (such as Emmastad) near the Asphalt Lake, with a further 730,000 added in a subsequent upscale. The cost of the plan would be 5,800,000 US dollars for the capital cost of the treatment facility, with an additional 679,000 US dollars for tourism and education-related infrastructure on the wetlands site.

See Appendix B for full list of interventions and relevant methodology.

The case for constructed wetlands: highlighting a proposed project in Buskabaai

A private initiative presented to the Public Works Department and other government representatives in 2017 to convert parts of the Asphalt Lake into constructed wetlands to treat wastewater discharge from adjacent neighbourhoods provides an environmentally-focused wastewater solution that can have added benefits for local ecosystems as well as the aesthetic of the land.

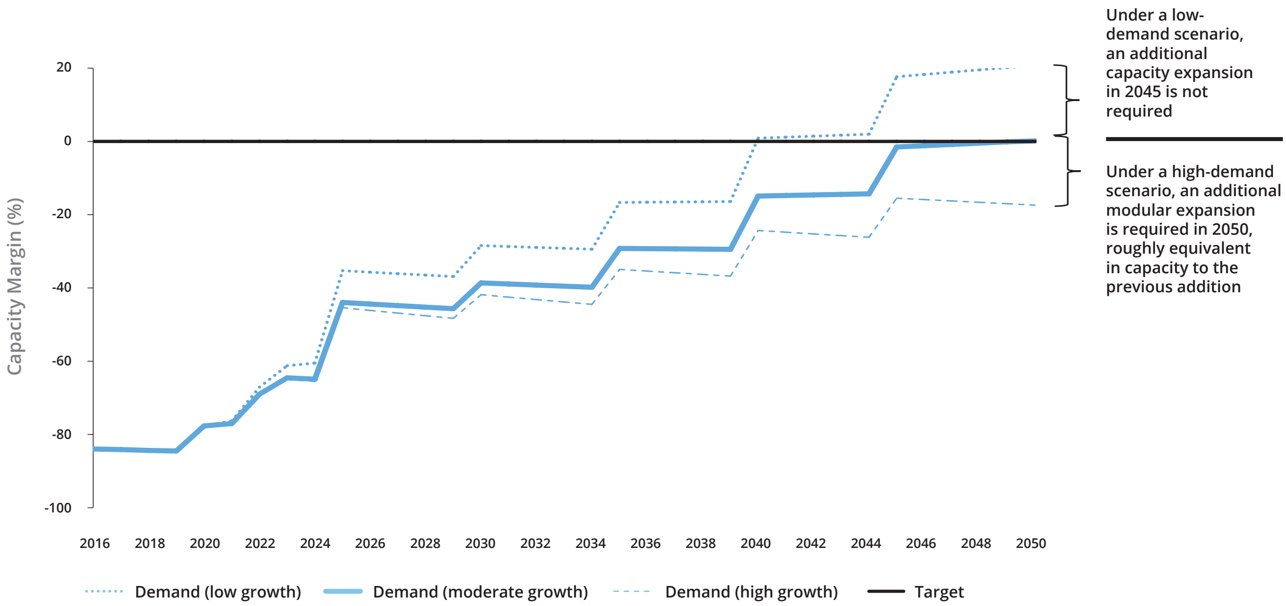
A constructed wetland environment provides wastewater treatment through a more natural and less capital-intensive process, while simultaneously fostering ecosystem health and biodiversity in the surrounding area. The wetland would provide the capacity to filter discharge from the adjoining industrial area as well as the neighbourhood of Emmastad, which includes several schools. The wetland would also be built with scalable capacity, meaning that the treatment area, and thus the amount of wastewater treated, could be expanded relatively easily in the near future – current plans are for a two-phase construction aligned with the development of the industrial park. A facility providing primary treatment for incoming wastewater would have a capacity of 4,000 cubic metres per day, greater than the largest existing plant at Klein Hofje, before discharging it into the wetland to undergo a natural treatment process. A constructed wetlands project would provide a host of benefits beyond the treatment of additional wastewater, such as economic, research, or educational opportunities.

Incorporating flexibility into wastewater treatment facility design

There is a large opportunity to invest in Curacao's wastewater system as there is very little pre-existing infrastructure to limit (or 'lock-in') options for the future. Therefore, there is an opportunity to build in modularity and flexibility in wastewater capacity design. An analysis of Curacao's forecast capacity margin in the wastewater sector under a range of future demand scenarios (low, moderate and high growth) illustrates the means by which this can be integrated in long-term planning in the sector (**Figure 18**).

In the short-term, all additional capacity added to Curacao's wastewater treatment system is welcomed; therefore, large capacity expansions should be encouraged. However, in the long-term, uncertainties around wastewater production will be greater, and the building of large new facilities will carry inevitable financial costs for the Government of Curacao. **Figure 18** shows that this band of uncertainty regarding capacity needs grows from approximately 10% in 2025 to nearly 40% in 2050. Implementing new facilities will

Figure 18
FLEXIBLE WASTEWATER TREATMENT FACILITY DESIGN
TO MEET LONG-TERM CAPACITY NEEDS



also need to take account of the long lead-in times before each plant can become operational. A solution to both problems is to incorporate flexibility into facility design through modularity. This will allow for adaptability should water demand trends change in the future and add efficiency to the process of supplying new wastewater treatment capacity when needed. Should long-term demand be lower than expected (dotted line), the final capacity investment in 2045 may not need to be implemented. Similarly, a high demand (dashed line) might require expanding modular capacity to meet final demand. As a rule, future capacity projects should account for the following:

1. The use of a modular engineering design to embed this flexibility in the project from the outset;

2. Consideration of the spatial aspects and dimensions of the project – ensuring that the building site incorporates the physical space necessary to expand the facility or add new buildings; and

3. Planned extension potential from the beginning of the project.

Internationally, flexible engineering has been used in UNOPS wastewater and sanitation infrastructure projects in small island states, allowing the facilities in these countries to cope with large increases in wastewater volume as whole towns and settlements connect to the network.

A TREATMENT PLANT IN TARRAFAL, CABO VERDE, PART OF A UNOPS INTEGRATED WATER RESOURCES MANAGEMENT INITIATIVE

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8 INFRASTRUCTURE INTERDEPENDENCIES

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Considering infrastructure interdependencies at the stage of strategic planning, design and operation will be critical to efficient and equitable service delivery particularly in light of the scarcity of resources on Curacao

Due to the system-of-systems nature of infrastructure, interdependence plays a major role in the analysis of Curacao's infrastructure, yet these crucial interdependencies are too often overlooked. Interdependence has relevance both in terms of long-term planning of infrastructure systems and in minimizing the risks of system failure posed by climate hazards affecting one or more interconnected assets.

Figure 19 outlines the key linkages between infrastructure sectors on the island. Interdependencies can both increase demand for additional infrastructure and provide efficiencies in terms of the multiple functions that single infrastructure interventions may fulfil.

This is illustrated in **Figure 20** using the example of capacity expansions to Curacao's major transport assets, namely the recently-completed Mega Cruise Pier II and the ongoing expansion of Hato International Airport, to show projected increases in infrastructure demand. The response to these projected infrastructure needs should be to incorporate cross-sectoral coordination for maximum efficiency and impact. For example, a waste-to-energy plant may have the capacity to treat 45% of total solid waste once installed, diverting it away from landfill while contributing an additional 9% to the electricity grid. On the demand side, a 16% water reduction, corresponding to the combined impact of the three identified demand reduction strategies and the network maintenance intervention, will reduce wastewater production by 9% and decrease levels of energy-intensive desalination, amounting to savings of 2% of Curacao's total electricity demand.

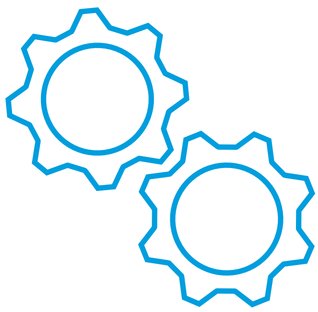
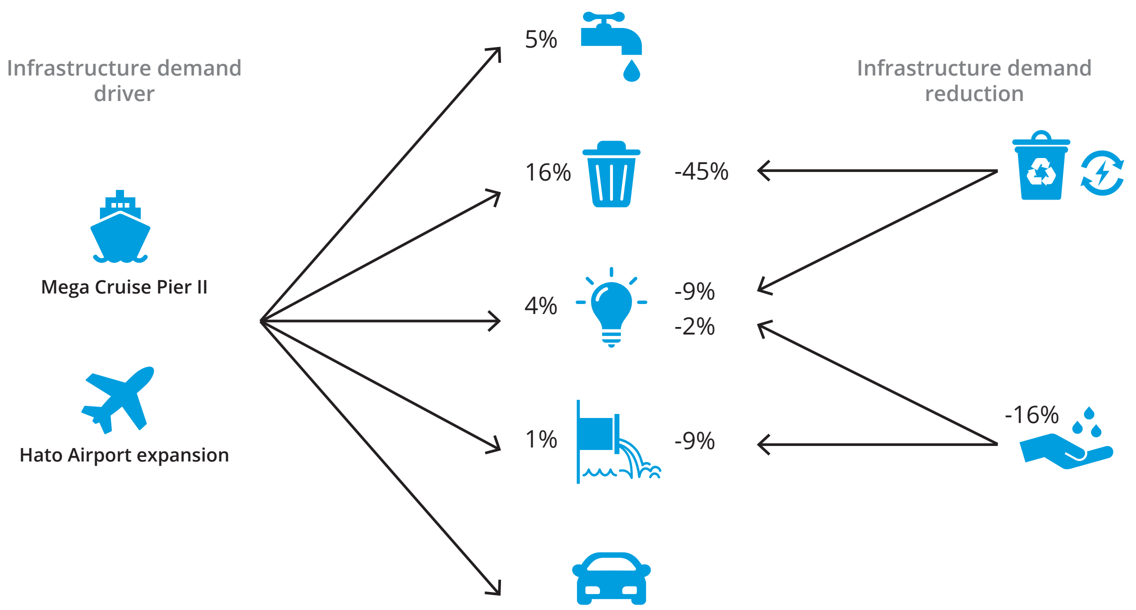


Figure 19
CROSS-SECTORAL INFRASTRUCTURE INTERDEPENDENCIES CONSIDERED FOR EBI ANALYSIS IN CURACAO

Impacts on other sectors (columns); Infrastructure inputs (rows)

Infrastructure inputs	Electricity	Transport	Water	Wastewater	Solid Waste
Electricity		Electricity input to transport assets (port and airport)	Electricity input to water supply (reverse osmosis)	Electricity input to wastewater treatment plants	Electricity input to waste facilities
Transport	Tourism growth increases demand for electricity		Tourism growth increases water usage	Tourism growth increases production of wastewater	Tourism growth increases production of waste
Water		Water input to transport assets (port and airport)		Water is transformed into wastewater	
Wastewater		Sewage removal requires road transport			Wastewater sludge disposed of in landfill
Solid Waste	Waste input to electricity generation	Municipal waste removal requires road transport			

Figure 20
CROSS-SECTORAL IMPACTS OF PORT AND AIRPORT CAPACITY EXPANSION, WASTE-TO-ENERGY, AND WATER DEMAND MANAGEMENT



9
IN FOCUS: FLOODING OF CURACAO'S TRANSPORTATION NETWORK

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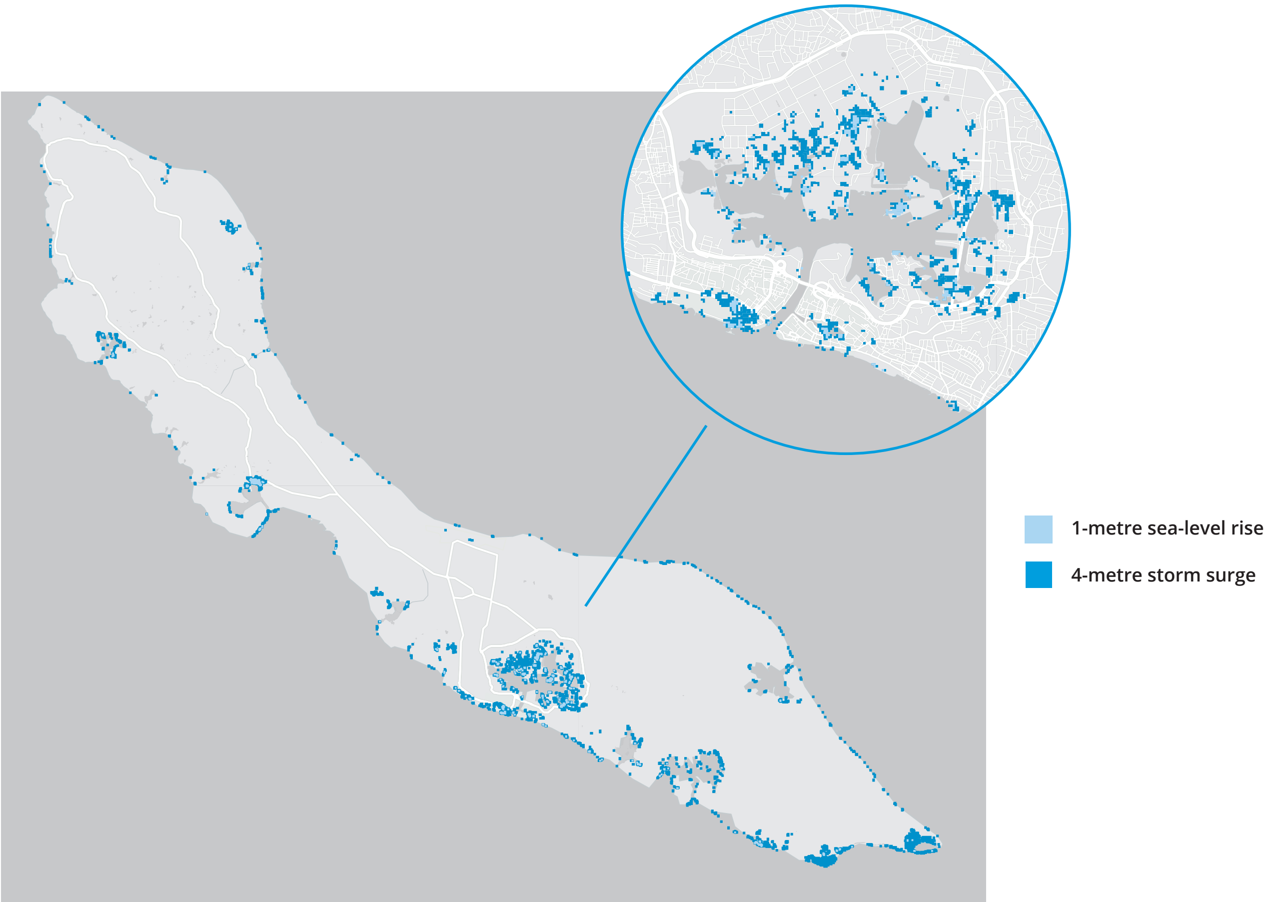
Sea-level rise due to climate change and storm surge pose serious threats to low-lying island nations such as Curacao and its systems of infrastructure

Critically, coastal and inland infrastructure assets are vulnerable to significant damage due to flooding, storm surges and erosion. The Government of Curacao has already implemented a number of initiatives to inform and reduce those risks, such as sea-level monitoring stations and a disaster risk management system. Nevertheless, the location and accuracy of flooding risks remains relatively poorly informed and is still to be systematically taken into account during planning and design of infrastructure.

The resilience of Curacao's road network can be assessed in the context of its vulnerability to flood hazards

Curacao's road network provides the backbone for its society – supporting social access and economic prosperity. Historic flooding on this network has caused large-scale disruptions that have impacted areas well beyond those directly inundated by flooding. Although flooding is a known issue, the limited availability of data and analysis has restricted evidence and insights. However, integrating available data for a set of hazard scenarios can illustrate key vulnerabilities linked to sea-level rise and/or storm surges of various magnitudes. The potential direct effects of a future 1-metre sea-level rise (forecasted for 2100) and a 4-metre storm surge event on the island are presented in **Figure 21** with a zoomed-in view of Willemstad.

Figure 21
AREAS VULNERABLE TO COASTAL FLOODING FROM 1-METRE AND 4-METRE STORM SURGES IN CURACAO AND WILLEMSTAD



Transportation and building information from Basiskaart

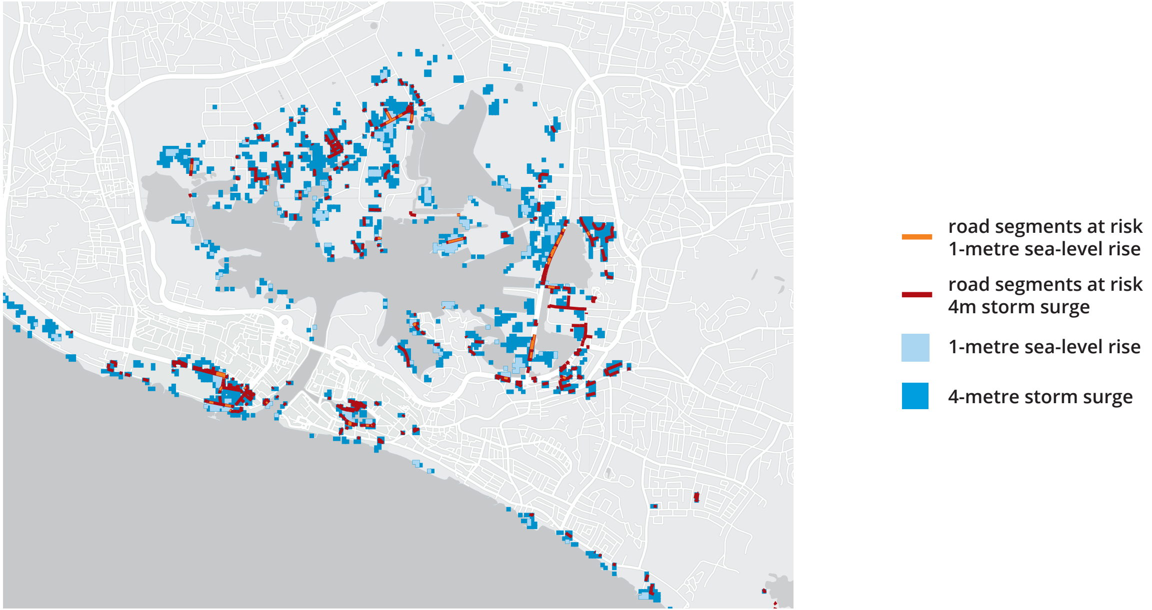
When overlaid with transport and social infrastructures (including healthcare, education, emergency services, tourism facilities, commercial facilities and government buildings) (**Figure 22**), this risk assessment provides a number of useful insights. In terms of total kilometres of the island's road network, the direct flood risk implications for Curacao are projected to be:

- 0.28% (4.2 km) of the road network and related assets (lighting, utilities, street furniture) at risk of flooding from a 1-metre sea-level rise
- 1.81% (27.4 km) of the road network and related assets (lighting, utilities, street furniture) at risk from a 4-metre storm surge event

In terms of social infrastructure, the direct flood risk implications are:

- 17 social infrastructure assets at direct risk of flooding from a 1-metre sea-level rise
  - Tourism facilities: 2 hotels, 5 restaurants, 3 commercial buildings
  - Additional facilities at indirect risk due to road flooding (through restricted access)
- 75 social infrastructure assets at direct risk of flooding from a 4-metre storm surge event
  - 14 hotels, 24 restaurants, 5 healthcare infrastructures, 8 banks, 1 educational (library), 16 commercial centres

Figure 22
ROAD SEGMENTS AT RISK OF FLOODING FROM 1-METRE AND 4-METRE STORM SURGES, WILLEMSTAD



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Coastal flooding also poses indirect risks. The flooding of important roads may deny access to social infrastructures such as schools or hospitals, even if these are not directly at risk. These indirect effects of coastal flooding are particularly important in areas of high economic activity or where large numbers of social assets are located. **Figures 23-25** highlight the priority areas of Punda, Pietermaai, Otrobanda, and Nieuwe Haven where flood risk poses a threat to nationally important assets and where investment in flood defences may provide the greatest benefits.

Figure 23
FLOOD RISK TO INFRASTRUCTURE ASSETS IN PUNDA AND PIETERMAAI

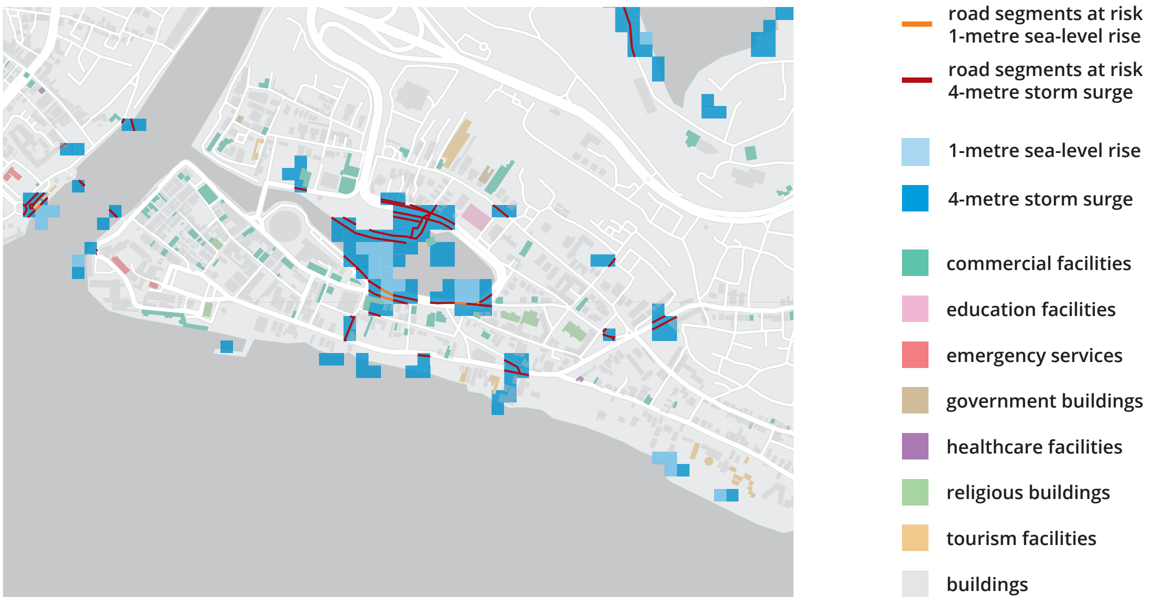

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Figure 24
FLOOD RISK TO INFRASTRUCTURE ASSETS IN OTROBANDA

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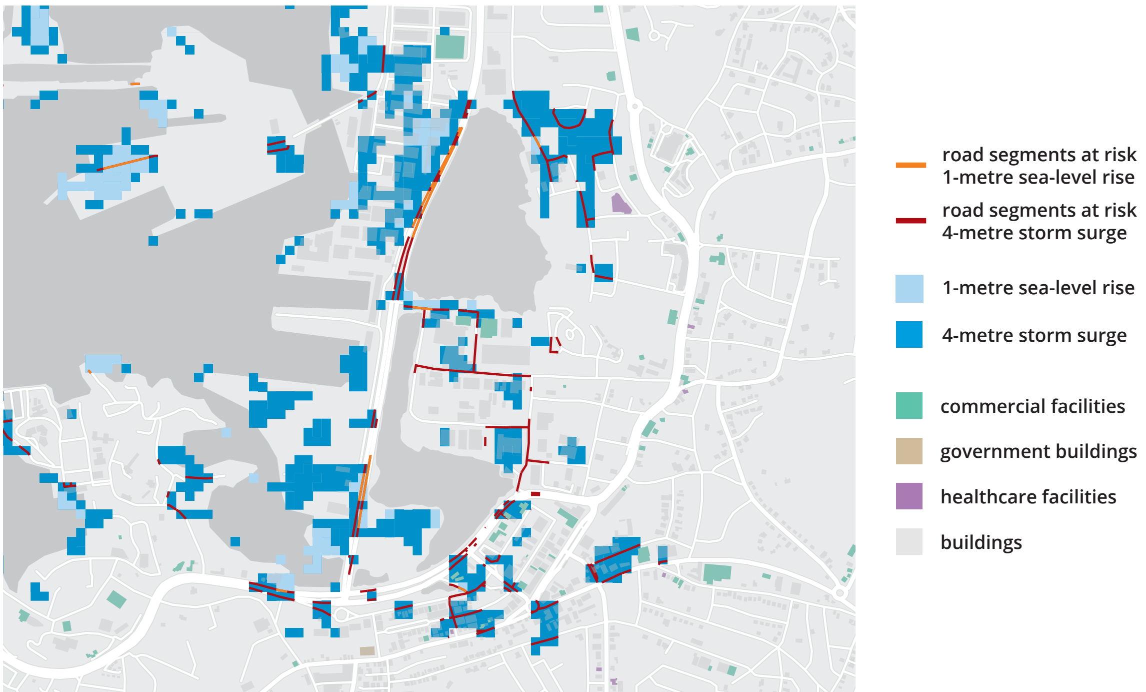
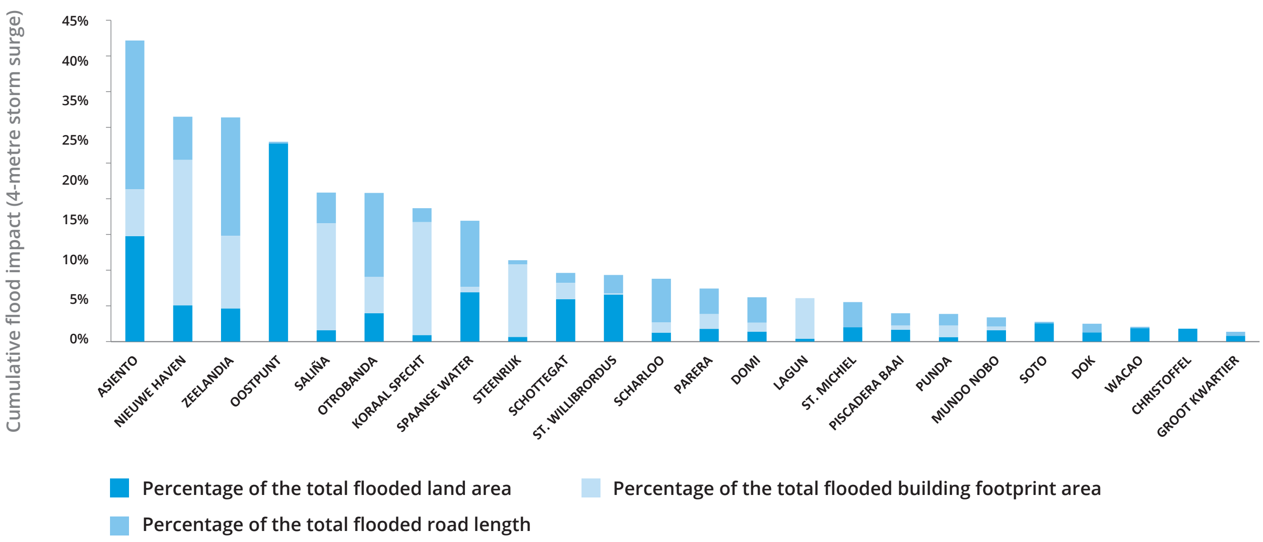
Figure 25
FLOOD RISK TO INFRASTRUCTURE ASSETS IN NIEUWE HAVEN



Transportation and building information from Basiskaart

Figure 26 illustrates the risk of a 4-metre inundation scenario in a selection of Curacao's geozones across three dimensions: 1) the percentage of the total flooded land area, 2) the percentage of the total flooded building footprint area (including residential and social assets), and 3) the percentage of the total flooded road length. Establishing a combined metric for these three dimensions (see the staged bars per geozone) gives an indication of which areas should be prioritized for risk reduction interventions. Asiento is the geozone with the highest cumulative flood impact across all dimensions and the highest percentage of flooded transportation assets. The total cumulative flood impact in Nieuwe Haven are smaller compared to Asiento. However, the percentage of the flooded building footprint area in Nieuwe Haven is highest across all geozones, a metric that provides insight into the number of people directly affected by a flood impact in the case of inaction. Oostpunt is the geozone with the 4th largest cumulative flood impact, though these flood impacts are exclusively on land areas. No building and few road segments are at risk. As such, an understanding of the type of flood risk in a geozone may also guide the investment of flood risk reduction mechanisms. If a large percentage of transportion assets is at risk in a specific geozone, investment in road drainage may be most appropriate. If only natural land is at risk, as is the case in Oostpunt, decision-makers may choose to designate these specific areas as flooding zones or invest in natural flood management solutions. Physical flood defences such as seawalls are recommended for areas of high economic importance, and with a large number of at-risk buildings. Consequently, depending on government priorities, geozone ranking of this type can form the basis for a prioritised approach to implementing interventions for flood risk reduction and resilience building.

Figure 26
PRIORITISATION OF RISK REDUCTION INTERVENTIONS



Each of the risk reduction solutions, summarized in **Figure 27**, involve different temporal and financial commitments for effective implementation. Large physical flood defence barriers, such as seawalls, can provide highly effective defences against coastal inundation, but can be capital intensive to design, build, and maintain. Seawalls are already present around coastal zones of Punda, while smaller permanent barriers have been built to provide storm surge protection to hotels and restaurants facing the sea in Pietermaai. In coastal areas of Curacao with lower population or building density, natural flood management solutions such as mangroves or wetland areas can provide effective barriers to flooding while prioritising environmental and ecosystem conservation. Such areas can be transformed into areas for tourism or recreation as is being planned with the Mangrove City Park in Otrobanda (Section 10). Temporary defences provide the quickest response to flooding, and can be deployed on short notice by emergency services in response to early warning systems. Many individual businesses already use temporary barriers in line with insurance company requirements to protect their assets from flood and water damage.

Figure 27
TYPES OF FLOOD DEFENCES THAT CAN BE IMPLEMENTED IN CURACAO

Physical flood defense infrastructure

- Large-scale, permanent structures such as sea walls provide strong defence against inundation but are implemented at a higher financial cost.

Environmental flood barriers

- Environmental barriers such as mangroves or wetland areas prioritize the natural environment and ecosystems, and can promote recreation activities and tourism growth.
- The construction of wetlands in low-density coastal zones can contribute natural flood defences to neighbouring areas.

Temporary flood protection

- Temporary flood defenses are flexible and can be moved on short notice to where there is an immediate threat of flooding. These can be used as part of a strategy incorporating early warning systems and emergency responses.

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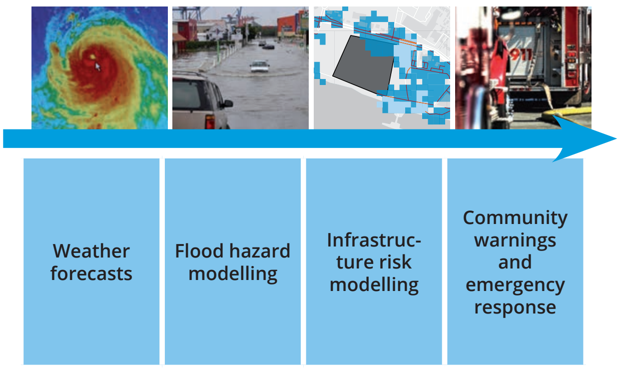
In line with the Sendai framework for disaster risk reduction, decision-makers can utilise real-time data to build resilience within Curacao's communities

Figure 28 shows how the integration of data on weather forecasts, the modelling of flood hazards and infrastructure vulnerability can be used to provide real-time information for flood risk management. Such a system could allow automated hazard warnings to be issued by the Meteorological Department to the Prime Minister's office, the Fire Department and authorities in vulnerable communities in order to coordinate a disaster risk response. An open access online flood warning system for residents and businesses would strengthen this response, along with the further development of temporary defences that can be deployed to critical infrastructure sites in the event of a major flood. These responses can be augmented by education and awareness campaigns (some of them already initiated by the Government of Curacao) to promote flood awareness at the household and community level.

Figure 28
PROMOTING RESILIENCE THROUGH REAL-TIME FLOOD RISK MANAGEMENT



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10
IN FOCUS: DEVELOPMENT PROJECTS IN CURACAO

Residential, commercial, or industrial development projects are made to foster economic and social development in Curacao. Regardless of whether they are public or private, they place a demand on infrastructure and the environment. The location of such developments can also be at risk, particularly with regard to flooding - as is the case for the transportation network. Notwithstanding the existence of holistic environmental impact assessment studies, infrastructure systems modelling can support part of the impact analysis of such projects, in the areas of long-term infrastructure capacity and hazard risk assessment.

The following development projects have been incorporated by the Ministry of Traffic, Transport and Urban Planning (VVRP) in the infrastructure planning model using geospatial data to assess flood risk under a variety of scenarios (**Figure 29**). The risks of flooding at these development project locations are shown in **Figures 30-33**. Where numbers of residents or users can be determined, forecast demands for infrastructure services created by the new development(s) are also integrated into the long-term model using per capita assumptions.

Figure 29
THE LOCATION OF SELECTED DEVELOPMENT PROJECTS IN CURACAO

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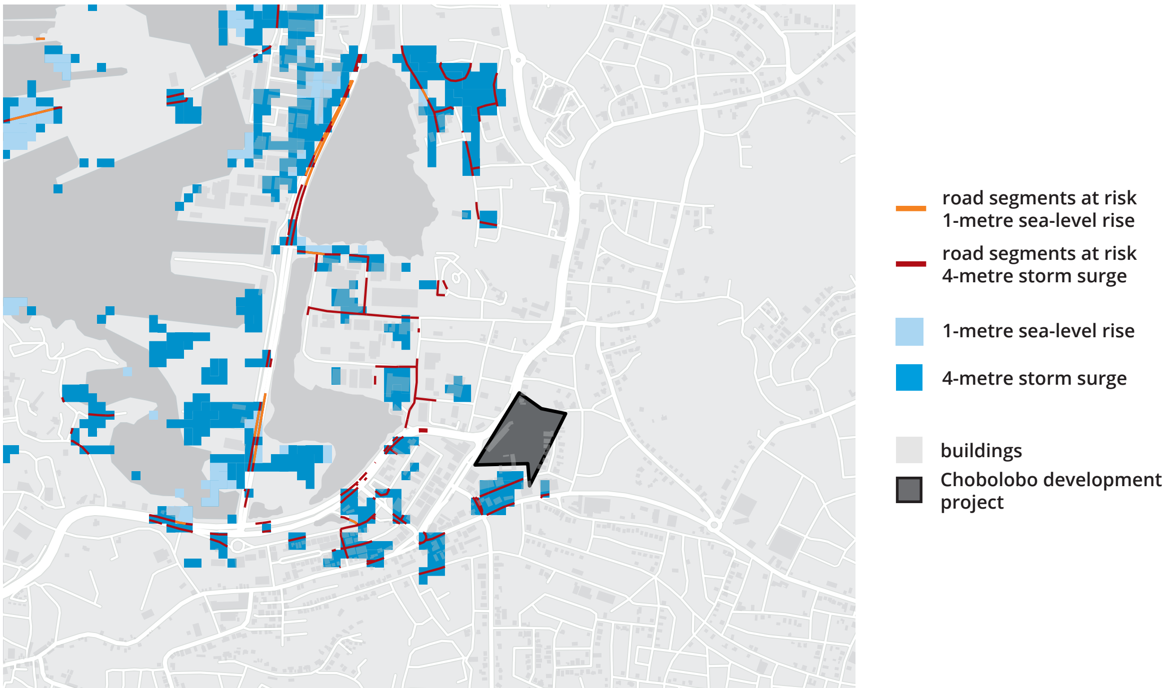
Name	**Chobolobo Plaza**
Date	2019 completion (phased construction)
Category	Retail/Commercial
Size	• 6,500 m² retail outlets • 2,733 m² restaurants • 7,800 m² commercial services
Project summary	Chobolobo Plaza will be a neighbourhood shopping centre, built in two phases, with partial demolition commencing in early 2018 in preparation for construction and an expected completion by mid-2019. The tenants will be fast food restaurants with drive-throughs and neighbourhood type stores.
Annual estimated infrastructure needs	• Energy: 5.6 Gigawatt hours (GWh)[23] (0.7% of Curacao's total energy demand) • Water: 67,886 cubic metres (m^3)/year[24] • Wastewater: 51,594 m^3/year • Substantial amounts of solid waste will be produced, including organic and food waste from restaurants • The development will require new road infrastructure and will increase traffic along major routes

Figure 30
FLOOD RISK TO CHOBOLOBO PLAZA



Transportation and building information from Basiskaart

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Name	**Boca Simon**
Date	Unknown
Category	Recreational
Size	1.84 hectare
Project summary	Boca Simon is a popular bay with an old fishing port and a *jeu de boules* pitch. Boca Simon falls into the Steenrijk zone including the neighbourhoods of Marie Pampoen and Kustbatterij and streets like Penstraat, Poeraristraat, Grebbelinieweg en Bramendiweg. The project aims to restore and revive the bay and create new facilities for recreation, such as a boardwalk.
Annual estimated infrastructure needs	There are few small buildings planned at the Boca Simon site. Therefore, infrastructure needs relate mostly to the expansion and maintenance of access roads, as well as ensuring adequate parking.

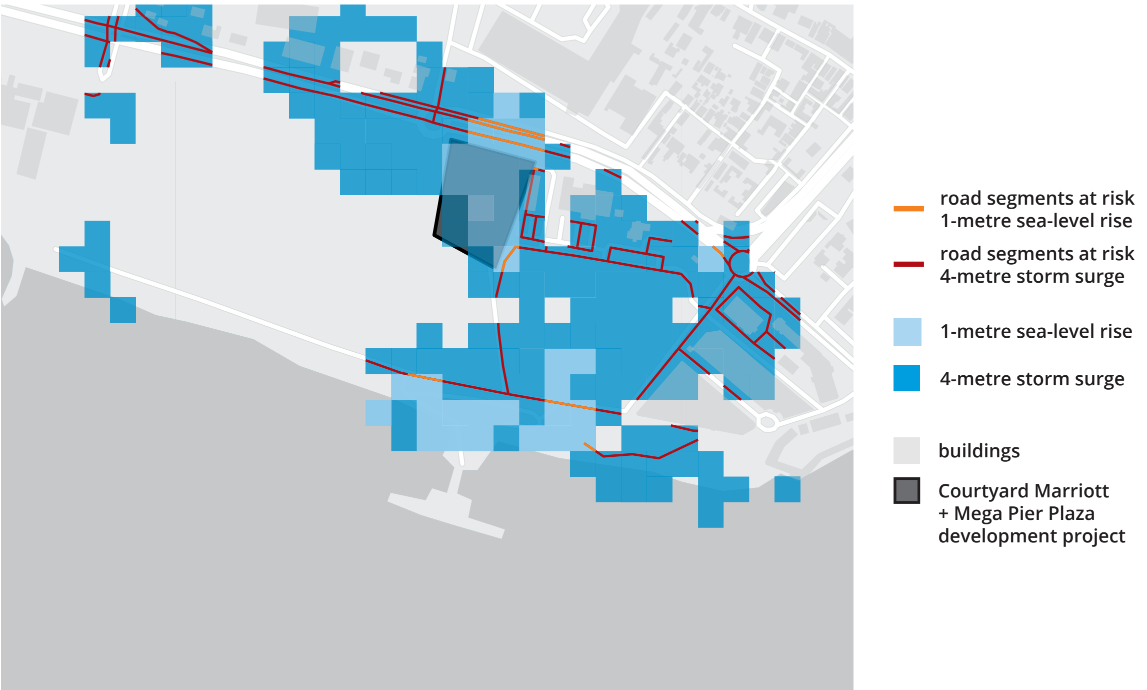
Figure 31
FLOOD RISK TO BOCA SIMON

Transportation and building information from Basiskaart

©CMC Real Estate

Name	**Courtyard Marriott + Mega Pier Plaza**
Date	2018-2020
Category	Tourism / Hotel development
Size	Hotel: 177 rooms/suites Plaza: 6 retail stores (23-70 square metres (m²)), 4 separate restaurant and cafe outlets, 1 sushi restaurant (37/60 m²), 1 sports bar and terrace (75 m²), 1 margarita bar, 2 branded restaurants (483 m²), 1 casino (600 m²), 1 radio station
Project summary	The Courtyard by Marriott brand hotel and Mega Pier Plaza is a planned development in the Rif area of Otrobanda. The property will be part of a mixed-use development that will include condominiums, retail space, an entertainment area, three restaurants and a casino. Once completed, the Courtyard by Marriott Curacao Hotel and Mega Pier Plaza will employ approximately 250 people directly and indirectly through its associated commercial activities.
Annual estimated infrastructure needs	• Energy: 3.7 GWh: 2.5 GWh (hotel) + 1.2 GWh (plaza)[23] • Water: 38,469 m³: 19,659 m³ (hotel) + 18,810 m³ (plaza)[24] • Wastewater: 69,116 m³: 53,453 m³ produced (hotel) + 15,663 m³ produced (plaza) • Solid waste: 1,571 tonnes produced (hotel only) • Transport: 184 parking spaces, accounting for one car for every two employees and every three hotel rooms

Figure 32
FLOOD RISK TO COURTYARD MARRIOTT + MEGA PIER PLAZA



Transportation and building information from Basiskaart

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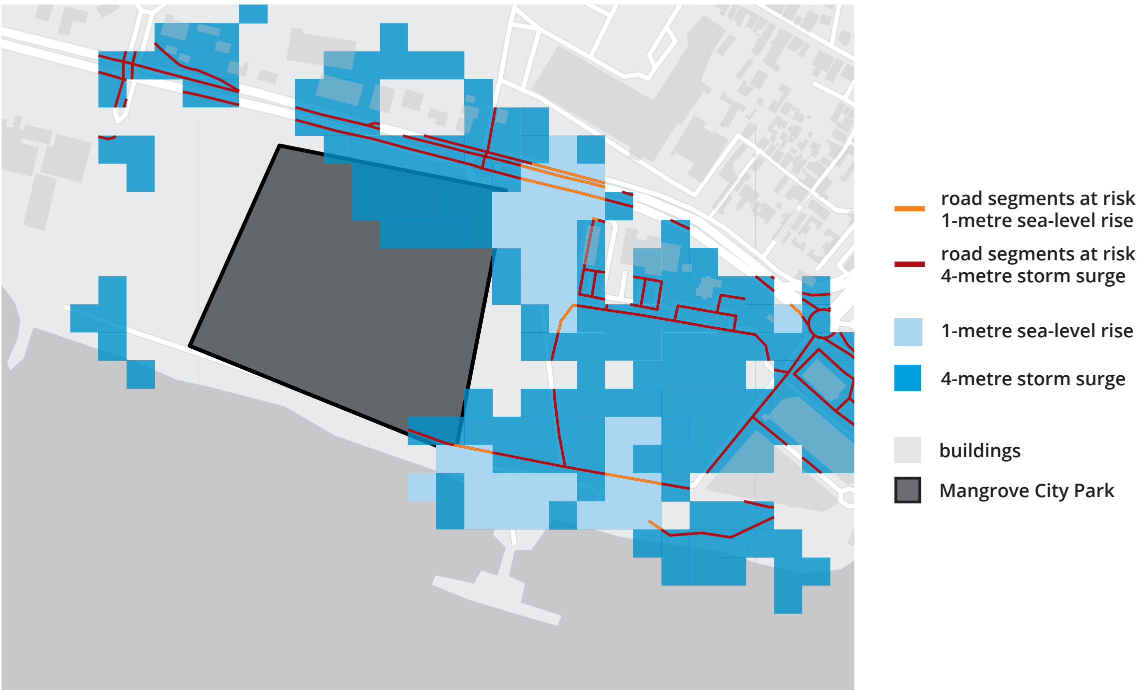
Name	**Mangrove City Park**
Date	Unknown
Category	City waterpark
Size	7.3 hectares

Project summary	The Mangrove City Park is a project focussed on preserving the mangrove in the Rif area, and will involve creation of clean mangrove city park for the enjoyment of nature. The project includes the construction of a boardwalk and watchtower.
Annual estimated infrastructure needs	The Mangrove City Park will require mostly transport-related infrastructure such as the provision and maintenance of access roads. Because of the nature of the project there are very limited needs across the other infrastructure sectors.

Figure 33
FLOOD RISK TO MANGROVE CITY PARK



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Name	**Wechi**
Date	Phased development over 10 years
Category	Housing/Residential
Size	2,500 houses, 2.6 / 2.7 persons per household.
Project summary	Wechi is a planned 134-hectare residential development accessible from the Weg naar Westpunt and consisting of a range of housing: student (5%), starter homes (22.5%), social housing (22.5%), and mid- to high-range houses (50%). The new district has three public areas: the area around the country house ('landhuis'), the green areas and the urban square. Approximately 80 hectares are net residential areas, with the rest required for roads, water drainage, green areas, facilities and a buffer zone along the road.
Annual estimated infrastructure needs	• Energy: 30 GWh (3.6% of Curacao's total electricity demand) • Water: 488,387 m^3 /year (3% of water demand) • Wastewater: 371,175 m^3/year produced (3% of wastewater treatment demand • Solid waste: 7,874 tonnes/year produced (3% of demand for solid waste management) • The development will require road infrastructure and will increase traffic along major routes, in particular the Weg naar Westpunt

11 FUTURE INFRASTRUCTURE PLANNING IN CURACAO

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The analysis presented within this report represents a snapshot of the application of the Evidence-Based Infrastructure approach and the National Infrastructure Systems Modelling for Curacao. Initiated in 2016 by the Ministry of Traffic, Transport and Urban Planning of Curacao, UNOPS, and the ITRC, and having involved a large number of stakeholders in the country, it is the first step towards building long-term, cross-sectoral knowledge and capacities for infrastructure planning and operation. The model also illustrates how exploiting interdependencies can reduce risks and promote savings that benefit multiple end users. Several examples, from the implementation of mutually beneficial demand reduction policies to the aversion of cascading failures, are highlighted for this purpose in the report.

Given the importance of taking a systems-of-systems approach, a number of cross-ministerial infrastructure planning bodies have been created in countries including the UK, Canada and New Zealand, and are being initiated in the Caribbean region, namely in Saint Lucia, under the Office of the Prime Minister. The formation of a similar body or of another form of cross sectoral cooperation in the Curacao context would allow the recommendations to be effectively implemented, followed and monitored – exploiting a multitude of opportunities for efficiencies, savings, planning, and improving the resilience of their infrastructure assets. Doing so would enable Curacao to maintain its position in the region as a pioneer of best practice infrastructure planning.

Accompanying this report is a national infrastructure database, including spatial data on infrastructure assets, hazards and risk area, **and an open-source analysis tool** to support long-term decisions using evidence collected in-country. **However, it represents only a preliminary picture of Curacao's infrastructure development, indicating that new data should be incorporated when available, or when new investments or policies are implemented by the government.** While these tools may primarily be used by government decision-makers, they can also improve the quality of infrastructure research undertaken at the University of Curacao, and inform the work of infrastructure analysts in the private sector. **The transfer of these tools to infrastructure stakeholders in Curacao will ensure that decision-makers in-country have greater access to infrastructure assessment capabilities while fostering ownership over the results and recommendations that emerge from its use.**

In the future, the modelling capability can be used to undertake a deeper dive into additional priority areas identified for further study. For example, transport and mobility problems prevalent in Curacao could be addressed using these tools in combination with information on travel behaviour, modes, and traffic congestion. Other areas such as watershed management on the whole island, supply or accessibility of health and education services, are also potential areas of use that could be further investigated.

These additional analysis will undoubtedly rely on the collection and provision of additional data, and on further multi-stakeholder cooperation, which should be supported as required.

APPENDIX A

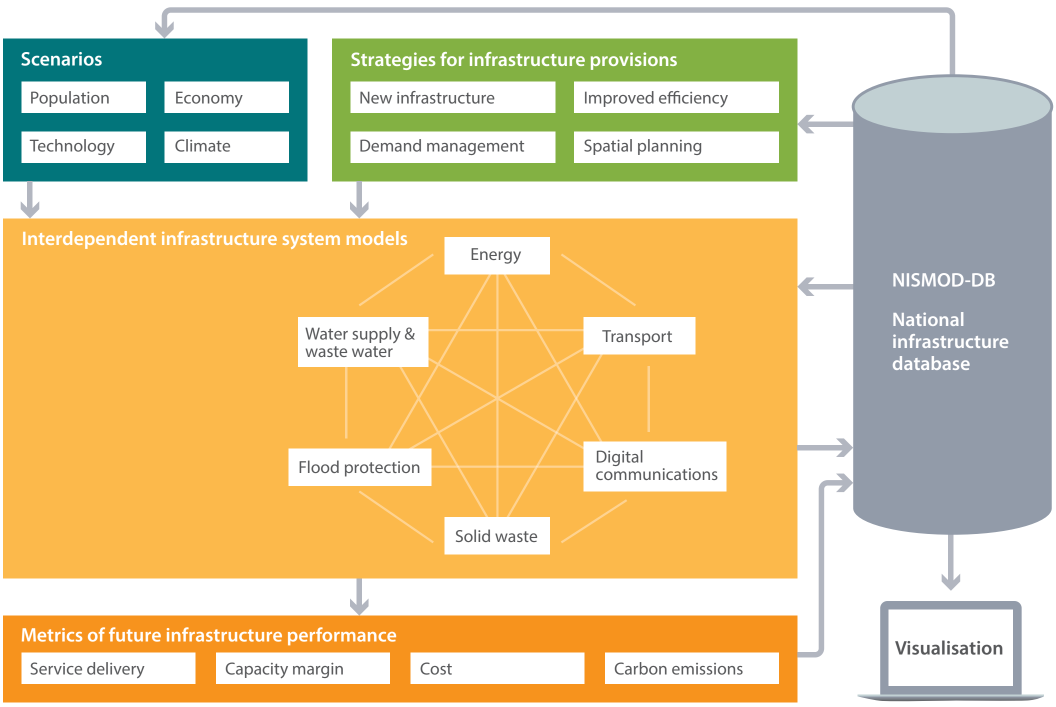
THE NATIONAL INFRASTRUCTURE SYSTEMS MODEL (NISMOD)

THE NATIONAL INFRASTRUCTURE SYSTEMS MODEL (NISMOD)

The recommendations in this report are based on analysis undertaken using the National Infrastructure Systems Model developed by the UK Infrastructure Transitions Research Consortium (ITRC). The ITRC is a collaboration of seven universities and over 50 partners from infrastructure policy and practice, and was launched in 2011 with the aim of developing and demonstrating a new generation of simulation models and methods to inform analysis, planning and design of national infrastructure systems. The consortium was backed by £4.7 million of funding from the UK Engineering and Physical Sciences Research Council (EPSRC) and was later awarded a further £5.3 million to continue the research programme through to 2020[25] . More information on the ITRC programme is available at https://www.itrc.org.uk/.

The NISMOD analysis framework contains a set of components outlined in **Figure A1**, including projections of future demand based on exogenous drivers (scenarios), a set of user-defined infrastructure interventions to meet this future demand (strategies), and performance metrics designed to assess the success of each strategy. The full set of data layers on infrastructure networks, demand, and performance is stored in a national infrastructure database, providing a scenario and output repository for the long-term planning and risk and vulnerability models. A visualisation function allows for the presentation of model outputs in the form of maps, time series and other graphics.

Figure A1
SCHEMATIC OVERVIEW OF THE COMPONENTS WITHIN THE NATIONAL INFRASTRUCTURE SYSTEMS MODEL (NISMOD)



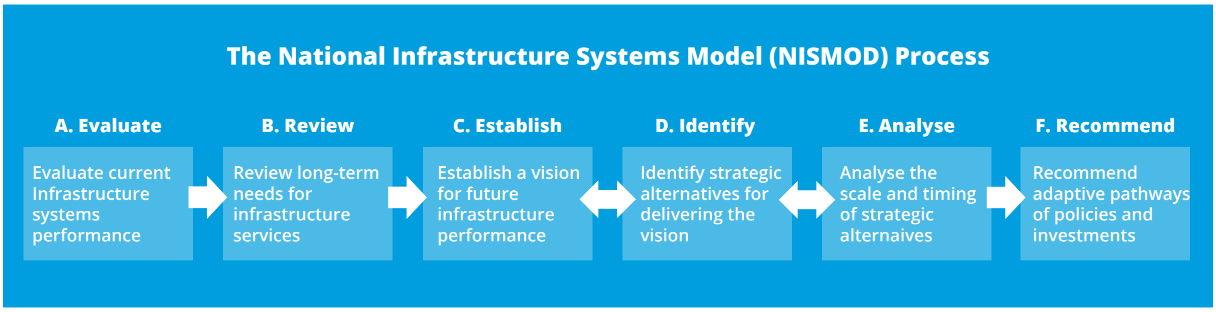
The future performance of the infrastructure systems are simulated using projections of demand for each sector. These modelled demand projections use scenarios to explore uncertainty in a range of possible futures, i.e. due to changes in: the global and national economy; population and demography at national and local scales; climate change; and technological development[25]. Where possible, the same scenarios are used to derive future needs across all sectors, ensuring consistency in assumptions. The uncertainty of these infrastructure needs, inherent in any projection of the future, is represented through different underlying demand driver forecasts i.e. low, moderate and high growth scenarios.

The model also encodes the ability of a decision-maker to respond to future needs through the provision of infrastructure strategies. At the most disaggregated level, strategies represent individual interventions that could be introduced by a decision-maker, where interventions include: the introduction of new or enhanced capacity, systems efficiency improvements or interventions that work to moderate demand. NISMOD has the ability to represent individual, or portfolios of interventions, that are aligned with strategy narratives here –described as the overarching narrative of a specific attitude to infrastructure development (across sectors) that then filters down into specific intervention choices (within sectors)[26].

The performance of strategies (in the context of a given scenario) is described using different performance metrics, which include: service delivery, risk reliability and resilience, capital and operating costs and carbon emissions. Such metrics have been chosen to align with the decision parameters of interest to infrastructure decision-makers within government and industry[27] and which are in line with performance metrics tracked for the purposes of measuring progress towards the United Nations Sustainable Development Goals (SDGs).

The application of NISMOD for the Curacao infrastructure assessment follows a set of steps, that applies this framework. These steps, shown in **Figure A2**, are known as the NISMOD process and have been designed to facilitate a systematic estimation of infrastructure needs and evaluate options for how those needs can be met. These steps are described more fully in the sections below.

Figure A2
OVERVIEW OF THE NATIONAL INFRASTRUCTURE SYSTEMS MODEL (NISMOD) PROCESS



STEP A. EVALUATE CURRENT INFRASTRUCTURE SYSTEMS PERFORMANCE

This step focuses on the assets currently in place, and the associated performance of the infrastructure systems. Relevant datasets were obtained from a range of Curacao's infrastructure stakeholders, including government and service providers, as well as open source datasets where available. This step also involves mapping of infrastructure asset locations.

STEP B. REVIEW LONG-TERM NEEDS FOR INFRASTRUCTURE SERVICES

Through stakeholder engagement, the main drivers of infrastructure demand for Curacao have been identified. These include: the residential population; future tourism numbers and climate change driven sea-level rise. Three future population growth scenarios have been developed, and are discussed more fully in Appendix B.1. This analysis reveals the broad range of uncertainty that should be considered in planning future infrastructure development on the island, and further evidence of this is shown in Appendices C1-4.

STEP C. ESTABLISH A VISION FOR FUTURE INFRASTRUCTURE PERFORMANCE

Through the evaluation of policy documents and targeted stakeholder interactions within country, with the explicit intention of tying national infrastructure goals to to Curacao's identified challenges, and in a broader sense, to the agenda of sustainable development as defined by the UN Sustainable Development Goals (SDGs), a vision for Curacao's future development has been identified. This vision has been encoded into a strategic approach for future infrastructure development. For the purposes of this assessment, two visions have been included which lie at opposite spectrums: an 'inaction' strategy (which assumes no further investments) and a strategy which uses demand management measures and additional capacity to achieve service delivery targets in all sectors. These strategies are used as examples in the analysis set out in Appendices C1-4.

STEP D. IDENTIFY STRATEGIC ALTERNATIVES FOR DELIVERING THE VISION

Further consultation and analysis was carried out to identify potential specific investment and policy options that are either confirmed, that are proposed in policy documents or that are potential measures which could be used in Curacao (as identified from other countries or regions). This set of potential interventions can be assigned to different strategies within the model, in alignment with the identified visions of development. The list of interventions identified during this process are set out in Appendix B.2.

STEP E. ANALYSE THE SCALE AND TIMING OF STRATEGIC ALTERNATIVES

Based on data inputs in Steps A-D, the model calculates a number of metrics on the performance of strategic infrastructure investments both sectorally and cross-sectorally. In particular, each strategy can be analysed by assessing its ability to meet future needs (for each of the given future scenarios of demand developed in Step B). Example results from these analysis are set out in the main document and in Appendices C1-4.

STEP F. RECOMMEND ADAPTIVE PATHWAYS OF POLICIES AND INVESTMENTS

Finally, the portfolios of investments and policies have been visualized and analysed as adaptable pathways, illustrating the sequencing of infrastructure interventions contained in a set of strategy portfolios. The results from these analysis are included in the main text of the report, aiming to provide guidance to decision-makers, increasing the robustness of choices about infrastructure given future uncertainties and to optimise performance both at a sector level and within the infrastructure system as a whole. Examples of these analysis are presented in the main document.

The analysis described in this report forms part of a broader infrastructure assessment for Curacao using NISMOD. The breadth specifically arising from the appraisal of a selection of different infrastructure strategies (investment and policy portfolios) that have been developed around specific strategy naratives. The results of this extended work will be further developed, with publication as an academic manuscript planned.

APPENDIX B

METHODOLOGY AND SUPPLEMENTARY FIGURES

METHODOLOGY AND SUPPLEMENTARY FIGURES

1. DRIVERS OF INFRASTRUCTURE DEMAND – POPULATION AND TOURISM

Demand for infrastructure in the long-term planning model is driven by residential population as well as the combined impact of stay-over tourists, and cruise ship tourists who do not stay on the island.

Figure B.1 illustrates the residential population forecast taken from the 'Curacao Population Projections 2015-2050'[1]. Of the proposed scenarios by the Central Bureau of Statistics, three were selected as the high ('high immigration'), moderate ('standard immigration') and low ('emigration wave') scenarios.

Alongside the residential population, tourists will continue to place demand on infrastructure and have historically demonstrated a disproportionately larger demand for infrastructure services compared to residents. The main tourism-related drivers that affect infrastructure are projected increases in 1) stay-over tourists and 2) cruise ship tourists (see below). The tourist numbers (total yearly tourists, tourists stay-over nights and cruise ship tourists) from the Curacao Tourism Board[2,3] were used as baseline data (2001-2016) for these tourist projections. Three scenarios have been developed for each category of tourist – high, moderate, and low – to encapsulate the range of tourism growth that could be seen on the island to the year 2050. The growth of tourists is assumed will be led by two major transport infrastructure constructions: the expansion of the airport terminal, affecting stay-over tourist numbers, and the construction of a new megapier, increasing cruise ship tourists.

In this example, the expansion of the airport terminal (to be finalised by the end of 2018) provides capacity for an additional 900,000 arrivals[4]. Each stay-over tourist is expected to stay for an average of 9 nights[2]. Currently, 28% of the the yearly airport throughput can be attributed to tourists. If these levels are maintained, this implies an extra 260,000 stay-over tourists following the expansion. Three scenarios have been constructed (see **Figure B.2**): a low infrastructure-led growth rate, which assumes that 50% of the total tourist capacity of the airport terminal is used by 2035; a moderate infrastructure-led growth rate, assuming that 75% of the total tourist capacity of the airport terminal is used by 2035; and a high infrastructure-led growth rate, assuming that the full capacity of the terminal for tourists is used by 2035. All three scenarios consists of a gradual increase of tourists to that capacity by 2035. After 2035, the growth rate is assumed to be 0%. For the peak calculations, the peak tourist month (December) has been utilised.

Regarding the construction of a second cruise terminal, the expected total capacity (including both cruise terminals) is expected to be 1 million cruise tourists per year[6]. Each cruise ship tourist is expected to stay for an average of 1 day. Three infrastructure-led cruise-ship scenarios have been developed (see **Figure B.3**): a low growth rate, assuming 50% of the total cruise ship capacity built in 2018 is utilised by 2035; a moderate growth rate, assuming that 70% of the capacity is utilised by 2035; and a high growth rate, assuming that the full capacity is utilised by 2035. For the peak calculations, the peak tourist month (December) has been utilised. For the calculations of tourists until 2018, the historic average growth rate of the past 5 years was applied for stay-over tourists (7%) and cruise ship tourists (14%).

The trend indicating a decrease in tourists staying in traditional hotels and an increase in tourists staying at privately owned apartments is considered to have a null effect on infrastructure, as the per-tourist energy/water consumption or waste/wastewater production is considered to not change as a result of this trend.

Figure B1
RESIDENTIAL POPULATION SCENARIOS, 2016-2050

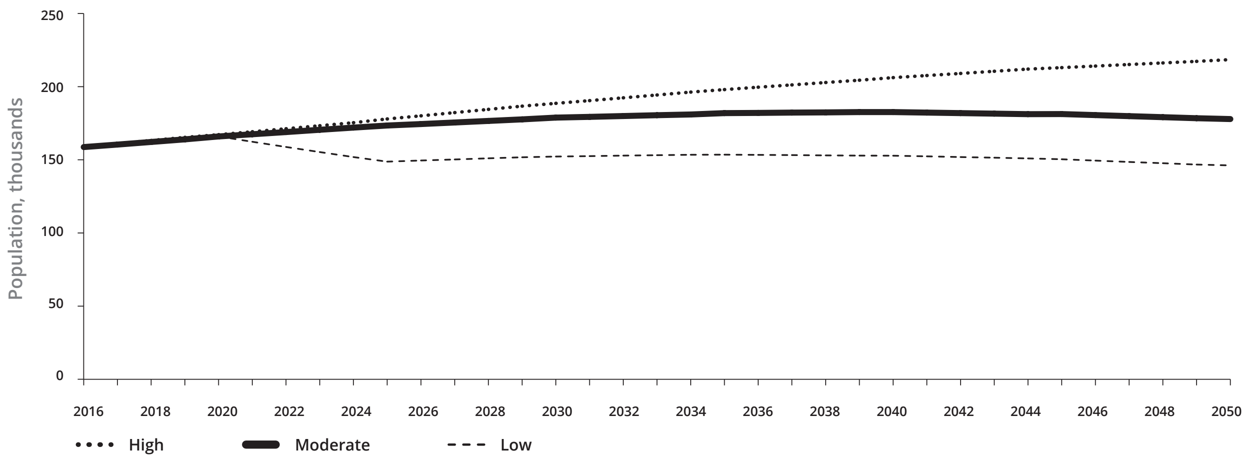


Figure B2
STAY-OVER TOURIST SCENARIOS, 2002-2050

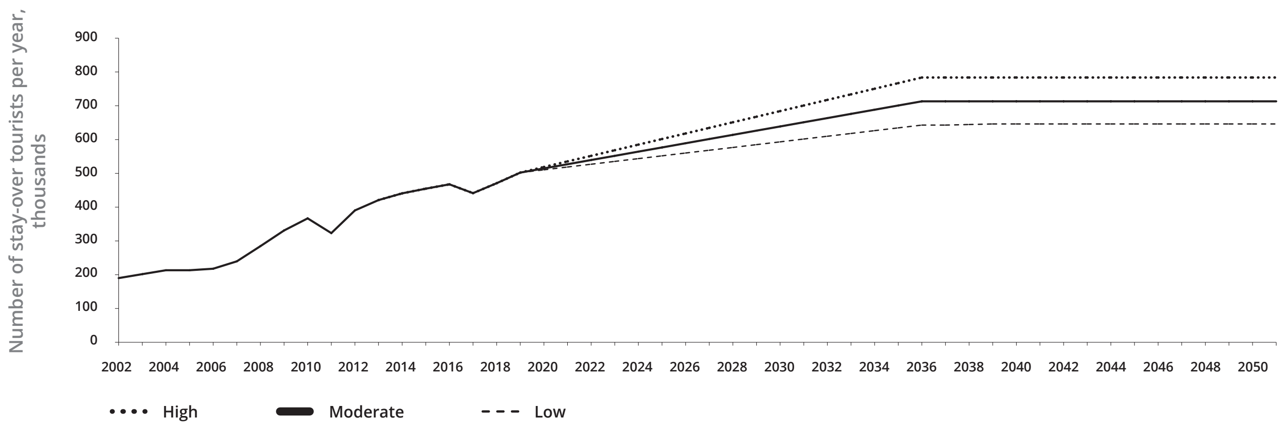
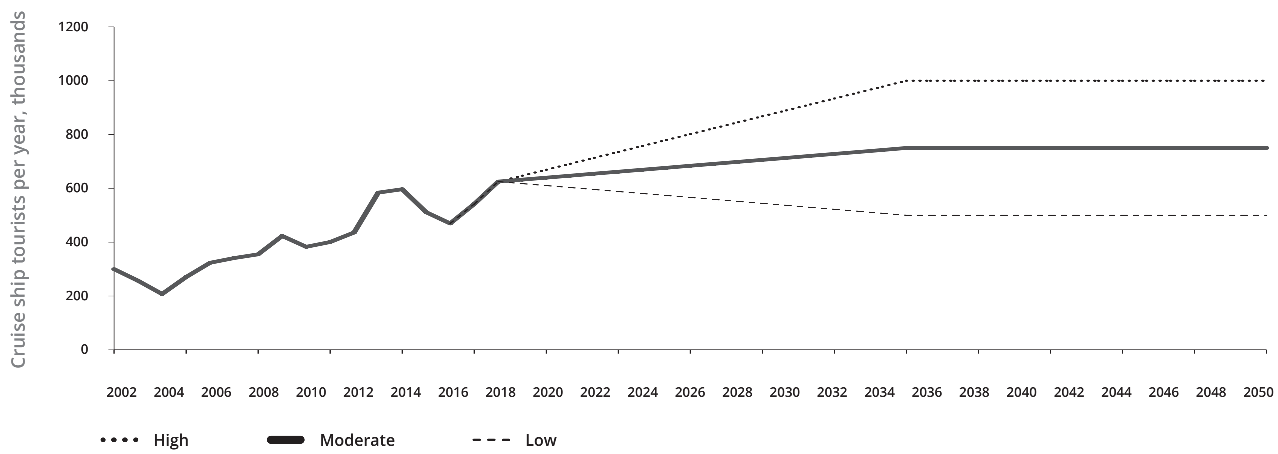


Figure B3
CRUISE SHIP TOURIST SCENARIOS, 2002-2050



2. DETAILED LIST OF CURRENT INFRASTRUCTURE AND PROPOSED INTERVENTIONS, BY SECTOR

B2.1 ENERGY

Expected	Supply (GWh)	Summary	Status	Description	Source
Current	476	Diesel	Operational	Current generation capabilities	11
Current	77	Gas	Operational	Current generation capabilities	11
Current	85	CUC	Operational	Current generation capabilities	11
Current	233	Wind	Operational	Current generation capabilities	11
Current	17	Solar	Operational	Current generation capabilities	11
			Additional capacity		
2018	190	Dual fuel diesel plant	Confirmed	Installation of a dual fuel diesel plant, operational at the end of 2018, is envisioned by Aqualectra (2018).	11, 28
2019	10	Seawater air conditioning (SWAC)	Confirmed	A pilot SWAC (Sea Water Air Conditioning) and or OWAC (Ocean Water Assisted Cooling) installation is proposed. OTEC could be combined with SWAC in the vicinity of large buildings with large cooling demands.	11, 28
2020	27	Solar micro-generation	Proposed	Installation of solar microgeneration to meet the National Energy Policy objective of achieving 55 MW of electricity production on Curacao by households and businesses by 2028. Such private and commercial investments in solar panel electricity production are encouraged through favourable fiscal conditions for solar generated electricity for households and commercial locations.	11, 28
2020	36	Wind generation	Confirmed	Development of another additional large-scale wind generation in the next 10 years.	11, 28
2021	80	Waste-to-energy plant	Confirmed	Installing a waste-to-energy plant (in line with waste intervention strategy) is part of the National Energy Policy. It aims to help resolve the (solid) waste problem by installing a 7–15 MW waste-to-energy facility by 2021.	11, 28
2022	10	SWAC full-scale	Proposed	A full SWAC installation, proposed by the National Energy Policy could replace water cooling via SWAC.	11, 28
2024	13	Solar micro-generation	Proposed	Installation of solar microgeneration to meet the National Energy Policy objective of achieving 55 MW of electricity production on Curacao by households and businesses by 2028. Such private and commercial investments in solar panel electricity production are encouraged through favourable fiscal conditions for solar generated electricity for households and commercial locations.	11, 28
2026	40	OTEC plant	Proposed	The development of an OTEC (Ocean Thermal Energy Conversion) plant was proposed in the National Energy Policy.	11, 28
2027	40	Solar micro-generation	Proposed	Installation of solar microgeneration to meet the National Energy Policy objective of achieving 55 MW of electricity production on Curacao by households and businesses by 2028. Such private and commercial investments in solar panel electricity production are encouraged through favourable fiscal conditions for solar generated electricity for households and commercial locations.	11, 28
			Reductions through demand management		
2020	-11	Technical grid improvements	Proposed	Intervention focuses on small, targeted annual technical improvements which increase efficiency and hence reduce demand.	11, 28
2020	-46	Reductions in peak demand for electricity in households (15%)	Proposed	Interventions focusing on a demand reduction, which is equivalent to a 15% reduction in peak consumption of domestic electricity through end-use energy efficiency buildings. Energy conservation may be achieved through more efficient design that would allow cool air and light to penetrate more easily.	11, 28

Expected	Supply (GWh)	Summary	Status	Description	Source
2020	-29	Reductions in peak demand for electricity in the service sector (10%)	Proposed	Implementation of peak demand reduction particularly in the service sector, which is equivalent to a 10% reduction in consumption of electricity (50% of total demand assumed for the residential, hotel, services, and industry) through air conditioning optimisation.	11, 28
2030	-177	Further household demand reduction (25%)	Proposed	Interventions focusing on ambitious demand reduction, which is equivalent to a 25% reduction in peak consumption of domestic electricity through end-use energy efficiency promotion, in lighting, cooling, water heating, appliances.	11, 28
2032	-40	Technical grid improvements	Proposed	Intervention focuses on highest possible targeted annual technical improvements which increase efficiency and hence reduce demand. This is achieved through reducing technical and administrative losses.	11, 28

B2.2 WATER

Expected	Capacity (m³/ year, thousands)	Summary	Status	Description	Source
Current	9,162	Desalination Fuik	Operational	Current generation	28
Current	9,169	Desalination Mundo Nobo (moving to Dokweg by 2021)	Relocating	The additional capacity from relocating the desalination plant from Mundo Nobo to Dokweg.	28
Current	30	Reuse plant	Operational	Current generation	28
			Reductions through demand management		
2018	-1,367	Water distribution network maintenance	Proposed	The replacement of 140 kilometres of water pipeline carried out by the Curacao Road Construction Company over the next three years is considered to have large social and environmental benefits. It is estimated that this leads to a 10% efficiency improvement.	28
2020	-219	Greywater reuse and rainwater harvesting in new builds	Proposed	An investment into regulating greywater reuse and rainwater harvesting into new buildings can meet 50% of residential water needs. Due to cost implications, this would be easier to implement (by the government) at the new build stage, rather than as a retrofitting activity. To estimate the number of people in new builds, the average number of residents is calculated for the moderate scenario to give the average number of additional residents per year (2016+2050)/35. In 2016, this is calculated as being 0.35% of the total residential population. To estimate the total impact on water demand, multiply 0.35% by 50% (the maximum impact of the strategy) and then by the percentage of water consumed by residents (84%, assuming 1 – 16% from the tourism split. Therefore, 0.035 × 0.5 × 84 = 1.5% of total water demand.	15
2022	-299	Water reuse toilet flushing in hotels	Proposed	Ensuring water reuse for toilet flushing in hotels can meet 13% of hotel water needs. On average between 2016 and 2050, 16% of total water demand is from tourists. Hence, 13% × 16% = 2% of total water needs can be reduced. It is assumed that it takes 4 years to pass this regulation and to assemble incentives for these practices, hence the installation year is 2022.	16
2023	-603	Water reuse for irrigation in hotels	Proposed	Enforcing water reuse for irrigation in hotels can reduce hotel water needs by 25%. On average between 2016 and 2050, 16% of total water demand is from tourists. Hence, 16% × 25% = 4% of total water needs can be reduced. It is assumed that it takes 5 years to pass this regulation and to assemble incentives for these practices, hence the installation year is 2023.	16

B2.3 SOLID WASTE

Expected	Capacity (tonnes/ year)	Summary	Status	Description	Source
Current	2,500,000	Landfill	Operational	Current treatment capacity	28
Current	100	Special waste incineration	Operational	Current treatment capacity	28
Current	25,000	Construction demolition waste	Operational	Current treatment capacity	28
Current	528	Greenforce	Operational	Current treatment capacity	28
Current	360	Greenforce	Operational	Current treatment capacity	28
Current	1,800	Recycle metals	Operational	Current treatment capacity	28
Current	2,400	Scrap recycling	Operational	Current treatment capacity	28
Current	720	Jamaiquino	Operational	Current treatment capacity	28
Current	240	Shred express	Operational	Current treatment capacity	28
Current	288	Illegal car battery collectors	Operational	Current treatment capacity	28
Current	960	Germans	Operational	Current treatment capacity	28
Current	720	Atco	Operational	Current treatment capacity	28
Current	900	Recycling station Van Rumpt	Operational	Current treatment capacity	28
Current	10,000	Illegal dumping	Operational	Current treatment capacity	28
Current	7,000	National repurposing	Operational	Current treatment capacity	28
Current	250	Curacao Clean Up	Operational	Current treatment capacity	28
		Additional capacity			
2018	10,000	Small-scale waste-to-energy construction (hazardous)	Confirmed	The building of small-scale waste to energy plant is considered an essential way for Curacao to process its hazardous waste.	28
2018	1,776	Expansion of Greenforce recycling	Proposed	The expansion of Greenforce recycling by 100% in 2018 as compared to 2017 is foreseen for the year 2018, and is a relatively inexpensive way to treat recyclables, while at the same time providing employment and increasing the island's self-sufficiency.	28
2018	480	New recycler (plastic)	Proposed	A new recycler coming to the island is envisaged by the recycling community, and is a relatively inexpensive way to treat recyclables, while at the same time providing employment and increasing the island's self-sufficiency.	28
2021	116,000	Construction of waste-to-energy plant	Confirmed	A waste to energy facility (type: grace furnace), as suggested in a recent feasibility report, is a large investment that has the potential to treat a large amount of waste.	19
2021	10,000	Treatment of previously untreated waste	Proposed	Treating the fraction of waste that is currently left untreated (e.g. through illegal dumping) is pivotal in order to ensure sustainable waste management. It is assumed that this fraction will be treated by the WtE facility implemented in 2021.	28
2022	10,000	Selikor recycling plant efficiency increase	Proposed	Increasing the effectiveness of the existing recycling plant at the Malpais site could highly increase the recycled waste, and is a relatively inexpensive way to treat recyclables, while at the same time it provides employment and increases the island's self-sufficiency.	28
2025	10,000	Anaerobic digester (organic)	Proposed	Building an anaerobic digester is a proven method to treat organic waste and produce decentralized renewable electricity, and it could be a potentially synergistic way of mixing solid biological waste with sewage sludge.	25

Expected	Capacity (tonnes/ year)	Summary	Status	Description	Source
2025	15,865	Recycling plant	Proposed	A small new recycling plant in 2025 is considered a relatively inexpensive manner of increasing supply.	28
2028	54,452	Recycling plant	Proposed	A larger recycling plant might be more costly initially, but prove highly beneficial in reducing emissions and meeting demand needs in the future.	19
2030	40,000	Expansion of recycling plant	Proposed	The expansion of existing recycling plants could be achieved through an environmental policy which reduces the harbour costs for recyclers, making it more cost-effective to recycle on the island.	28
		Reductions through demand management			
2025	-4,116	Waste reduction awareness campaign	Proposed	A waste prevention scenario is considered an easy, quick way to prevent the need for further waste treatment, save costs and adverse environmental impacts. This investment was taken from the high waste prevention scenario described in the waste to energy feasibility report by Boudewijn et al. (2011) who used a value of 1.6% of total waste arisings, representing 12.5% of the maximum potential (12.5%) for waste prevention observed in European studies.	19
2030	-4,116	Reuse awareness campaign	Proposed	A waste reuse scenario is an easy, quick way to reuse some materials. The value was taken from the low prevention scenario used in the reduction intervention above	19

B2.4 WASTEWATER

Expected	Capacity (m^3/ year)	Summary	Status	Description	Source
Current	639,480	Klein Kwartier	Operational	Current treatment capacity	28
Current	9,125	Abattoir	Operational	Current treatment capacity	28
Current	1,168,000	Klein Hofje	Operational	Current treatment capacity	28
Current	60,590	Tera Kora	Operational	Current treatment capacity	28
		Additional capacity			
2019	5,000	Klein Hofje renewal plan	Proposed	The implementation of the Klein Hofje renewal plan is considered essential to ensure wastewater treatment on Curacao. Public Works considers this optimization necessary (due to oversupply, outdated technology, failures of the technology, etc.).	21
2021	109,500	Capacity extension of existing plants (1)	Proposed	Capacity expansion of existing wastewater plants.	28
2022	730,000	Constructed wetlands	Proposed	The case for constructed wetlands represents a high level of environmental awareness, that is highly likely to pay off in regard to employment and further environmental benefits (e.g. increased air pollution, wastewater treatment; visitor attraction).	28
2025	730,000	Constructed wetlands expansion	Proposed	Expansion of the above project.	28

Expected	Capacity (m^3/year)	Summary	Status	Description	Source
2025	2,000,000	New wastewater treatment plant A (serving the east)	Potential	A medium size new wastewater plant, of similar size as the largest currently existing wastewater plant (Klein Hofje) and implemented in 2025 would reflect environmental ambition towards meeting the wastewater treatment needs.	28
2030	1,000,000	Capacity extension of existing plants (2)	Potential	Consecutive investments in wastewater treatment facilities or expansion of existing facilities at 5-year intervals allow for the feasible development of wastewater treatment capacity.	28
2035	1,500,000	Capacity expansion of treatment plant A	Potential	See above	28
2040	2,000,000	New wastewater treatment plant B	Potential	See above	28
2045	1,750,000	Capacity expansion of treatment plant B	Potential	See above	28
			Reductions through demand management		
2020	-219,115	Greywater reuse and rainwater harvesting in new builds	Proposed	Enforcing greywater reuse and rainwater harvesting from the water intervention above will reduce needs for wastewater treatment by the same percentage as the water reductions specified above.	15
2022	-298,511	Water reuse toilet flushing in hotels	Proposed	Ensuring water reuse for toilet flushing in hotels from the water intervention above will reduce needs for wastewater treatment by the same percentage as the water reductions specified above.	16
2023	-603,442	Water reuse for irrigation in hotels	Proposed	Enforcing water reuse for irrigation in hotels from the water intervention above will reduce needs for wastewater treatment by the same percentage as the water reductions specified above.	16

APPENDIX C

SECTORAL CAPACITY MARGINS IN LOW, MODERATE, AND HIGH SCENARIOS

SECTORAL CAPACITY MARGINS IN LOW, MODERATE, AND HIGH SCENARIOS

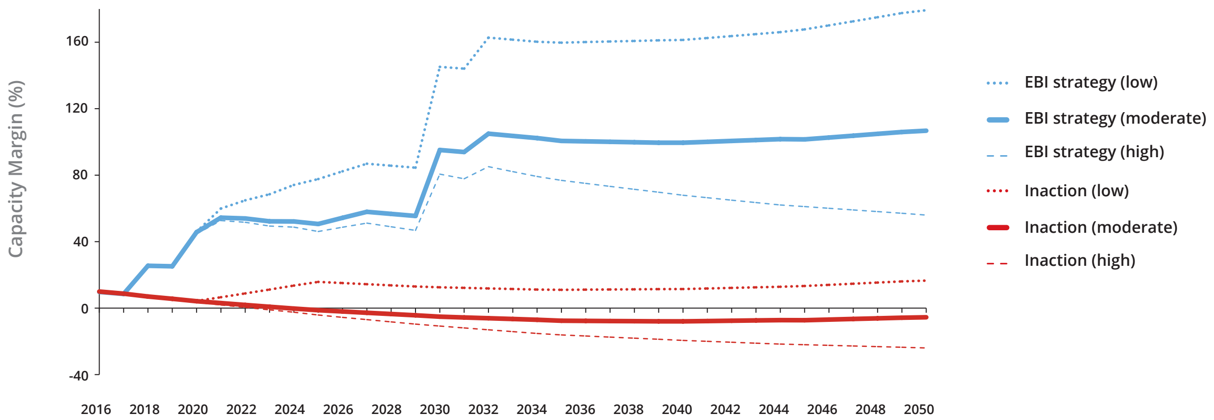
The charts throughout the main text only refer to the moderate growth scenario. The following charts are included to enable comparisons between the different growth scenarios for each of the sectoral results with regard to capacity margins, with both inaction and EBI strategies.

C.1 ELECTRICITY

Figure C.1 shows the capacity margin for the electricity sector, expressed as a percentage of total annual demand. The red line illustrates the case of inaction, and the blue line shows the performance of the infrastructure-led strategy defined in this model (« EBI strategy »).

The capacity calculations have been calculated using the following formula:
Capacity Margin (%) = Capacity Margin (GWh) / Annual Demand (GWh) * 100

Figure C1
ELECTRICITY CAPACITY MARGIN, LOW, MODERATE AND HIGH SCENARIOS, 2016-2050

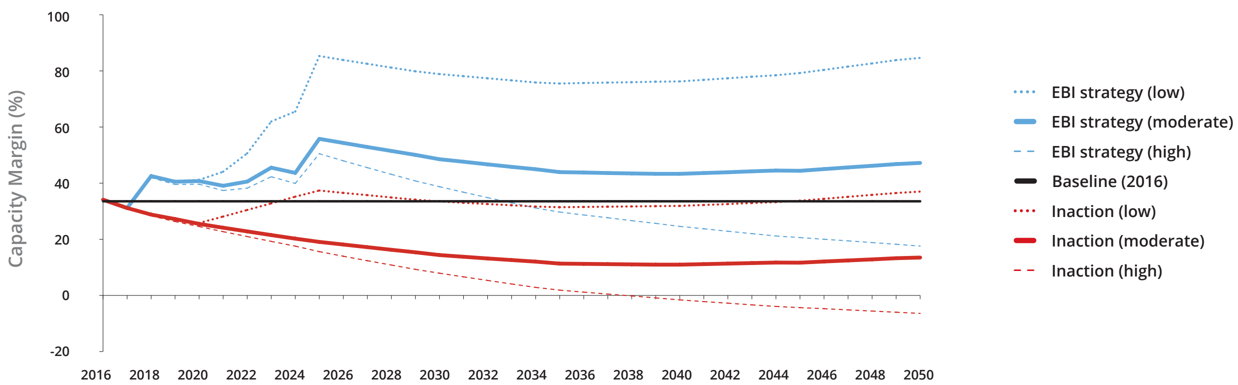


C.2 WATER

Figure C.2 shows the capacity margin for the water sector, expressed as a percentage of annual demand. The black line denotes a target of maintaining a 30-40% capacity margin.

The capacity calculations have been calculated using the following formula:
Capacity Margin (%) = Capacity Margin / Total demand * 100 (m^3/year)

Figure C2
WATER CAPACITY MARGIN, LOW, MODERATE AND HIGH SCENARIOS, 2016-2050

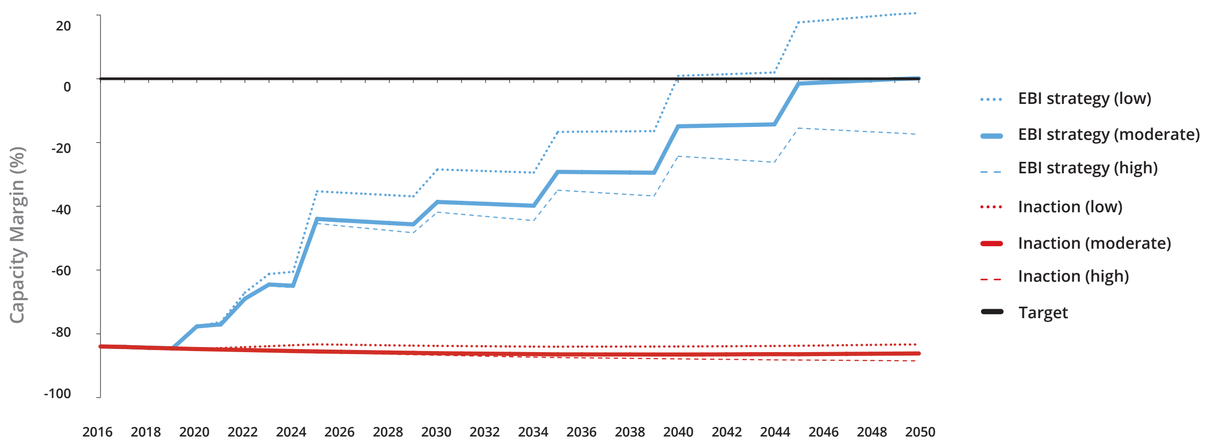


C.3 WASTEWATER

Figure C.3 shows the capacity margin for the wastewater sector, expressed as a percentage of annual demand. The black line denotes the international target of treating all wastewater.

The capacity calculations have been calculated using the following formula:
Capacity Margin (%) = Capacity Margin / Total demand * 100 (m^3/year)

Figure C3
WASTEWATER CAPACITY MARGIN, LOW, MODERATE AND HIGH SCENARIOS, 2016-2050

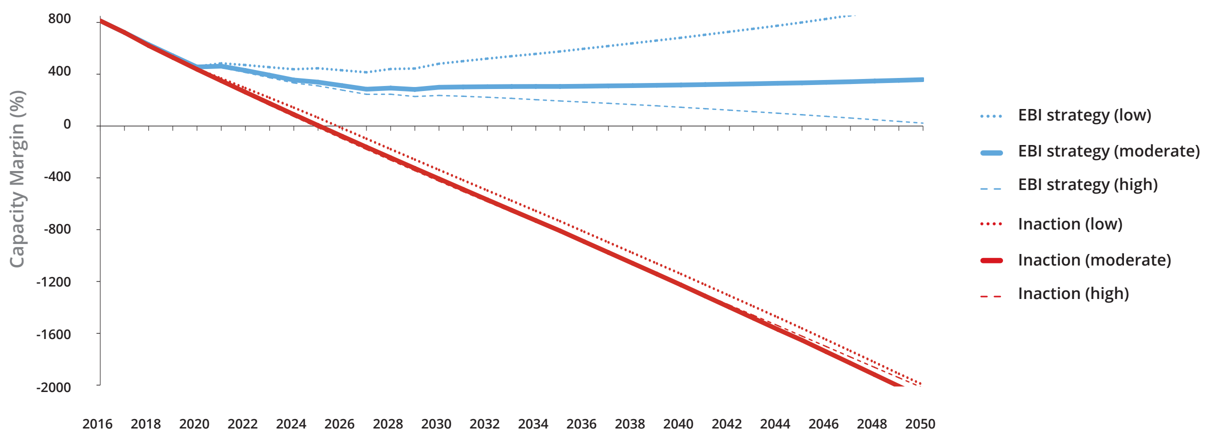


C.4 WASTE

Figure C.4 shows the shows the capacity margin for the waste sector, expressed as a percentage of annual demand. The black line denotes the international target of treating all waste. The red line decreases steeply, as the landfill capacity for solid waste is decreasing.

The capacity calculations have been calculated using the following formula:
Capacity Margin (%) = Capacity Margin / Total demand * 100 (tonnes / year)

Figure C4
WASTE CAPACITY MARGIN, LOW, MODERATE AND HIGH SCENARIOS, 2016-2050



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