



Participatory planning of the future of waste management in small island developing states to deliver on the Sustainable Development Goals

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ABSTRACT

Waste management is particularly challenging for Small Island Developing States (SIDS) due to their high per-capita infrastructure costs, remoteness, narrow resource bases and high dependence on tourism. The lack of integrated planning frameworks considering these SIDS-characteristics has stalled progress on sustainable waste management. To address this challenge, this paper proposes an integrated methodology for long-term waste management planning to deliver on the United Nations' Sustainable Development Goals (SDGs) in SIDS. This explicitly combines multi-level participatory SDG visioning and back-casting with waste infrastructure modelling. This methodological development is piloted using a national-scale demonstration on Curacao. Three island-specific waste management portfolios (*Inaction*, *Circular Economy*, *Technology-led*), developed through stakeholder back-casting, are modelled for SDG delivery using a national accounting model under different socio-economic futures. The results highlight the importance of waste prevention and material re-use strategies within islands that engage local populations. Evidence-based identification and evaluation of waste management strategies, grounded in participatory processes, can itself contribute to SDG delivery.

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1. Introduction

Strategic planning of waste management for sustainable development is a grand challenge, particularly for Small Island Developing States (SIDS). To date, waste infrastructure development in many SIDS has failed to yield sustainable development outcomes (Agamuthu and Herat, 2014; Dornan, 2014). This can be attributed to a number of reasons. Firstly, the fragmented approach to planning used in the past lacks stakeholder target setting and visioning for sustainable outcomes, thereby disconnecting infrastructure development from its management and users (Harris et al., 2017). National decision-makers often focus on short-term visions, political agendas and immediate financial elements (Hornsby et al., 2017). Potential long-term impacts on

environmental, social and financial sustainability outcomes are generally of secondary concern. Secondly, the challenge of strategic planning in SIDS is exacerbated by the absence of appropriate data collection and management systems (Simpson, 2012). Lastly, SIDS face unique characteristics which are often disregarded in the process of planning the future of waste management. The small size, high tourist environmental impact, and dis-economies of scale leading to high per-capita costs for infrastructure can, if not considered, create lock-ins that reinforce unsustainable practices for decades to come (Eckelman et al., 2014; Briguglio, 1995; UNEP, 2008).

These SIDS challenges are evident across numerous infrastructure sectors, but are particularly prominent in the solid waste sector (UNEP, 2015; Mohee et al., 2015). To date, limited waste disposal space, under-developed infrastructure, lack of regulations and poor enforcement, barriers to moving waste from one country to another, and limited recycling opportunities due to economies of scale have stalled progress on sustainable waste management in most SIDS (UNEP, 2015; Deschenes and Chertow, 2004; Zsigraiová et al., 2009). In addition to increasing waste generation attributed to population growth, SIDS also need to deal with the large

Abbreviations: AD, Anaerobic Digester; KPI, Key Performance Indicator; MT, Million Tonnes; NGO, Non-Governmental Organisation; RDM, Robust Decision Making; SDG, Sustainable Development Goals; SIDS, Small Island Developing States; WtE, Waste-to-Energy.

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quantities of imported material and packaging and the excess amount of waste produced by tourists, including stay-over and cruise-ship generated wastes (Willmott and Graci, 2012). However, the specific development challenges of SIDS have rarely been considered in national, strategic and long-term planning of waste.

Yet, these specific challenges of SIDS provide an opportunity to use waste management planning to leap-frog directly to programmes that meet the United Nations Sustainable Development Goals (SDGs) and related targets (UN, 2015). SIDS' small size facilitates national cooperation, stakeholder inclusion and adoption of local strategies for improved environmental and human outcomes. To materialise on this opportunity requires an evidence-based planning methodology that enables decision-makers in SIDS to evaluate waste management investments that systemically impact on SDGs, while considering SIDS-specific characteristics.

Within the waste infrastructure sector, academic and practical progress has been made with respect to future waste management planning (Marshall and Farahbakhsh, 2013; Van Ewijk and Stegemann, 2016; Ghisellini et al., 2016) and sustainable development (Morrissey and Browne, 2004; Seadon, 2010). However, most conventional approaches to investment evaluation fail to consider infrastructure at a national scale and are not suited to consider future uncertainties or the complex relations between social, technical, economic and environmental dimensions of sustainability (Truffer et al., 2010; Malekpour et al., 2015; Lienert et al., 2013). Rational models that prescribe an evaluation of alternative solutions (Alexander, 1984) are based on predicted futures (Walker et al., 2013) and typically restrict infrastructure planning to efficiency considerations (Leach et al., 2015). Lack of information and tools as well as the dynamic socio-technical environments led some researchers to suggest narrowing down on complexities (Enserink et al., 2013; Mulvihill and Kramkowski, 2010). Planning for sustainable development outcomes however requires innovative solutions (Voss et al., 2009), exploration and learning throughout the planning process (Mulvihill and Kramkowski, 2010; Steurer and Martinuzzi, 2005; Walker et al., 2013).

To address these challenges, research has recently been developed for both strategic national infrastructure modelling to evaluate infrastructure investments under uncertainty (Hall et al., 2016; Ives et al., 2017) and for participatory strategic foresight for sustainability planning (Tuominen et al., 2014; Robinson, 1990). However, despite the positive impact of stakeholder participatory visioning on infrastructure modelling and decision-making for sustainability outcomes (Opdyke and Javernick-Will, 2014), few studies have attempted to integrate these different approaches. This can be attributed to the disciplinary separation from which these approaches originate and the difficulty in bringing together the numerous actors and perspectives relevant to decision-making at a national scale. Moreover, the tools required to deliver evidence on how national infrastructure options perform on relevant SDG targets remain poorly developed and under-exploited.

The aim of this paper is to develop and apply SIDS-specific methodology that integrates participatory SDG visioning with national modelling in order to assist SIDS decision-makers in evaluating investment trade-offs for delivery on SDG targets. The methodology is tested in the SIDS Curacao for the waste sector. Despite the waste focus however, the methods presented are sufficiently generic and flexible to be adapted to other infrastructure sectors.

The rest of the paper is organised as follows: Section 2 outlines the conceptual underpinnings of the approach, following an introduction to the different steps of the proposed methodology in section 3. Section 4 presents the materials, data, and methods used. Section 5 discusses the results of the application of the proposed methodology to Curacao. Section 6 elaborates the theoretical and

managerial contributions and the limitations of the approach and section 7 provides concluding remarks.

2. Sustainability planning approaches

The methodology presented here is developed generically, as to apply to any infrastructure sector, and is informed by a holistic, integrated approach. Drawing mainly on the decision-analysis and sustainability planning literature, this approach acknowledges that the design of sustainable, robust and implementable solutions is a "wicked problem" (Rittel and Webber, 1973), as it involves a complex system with incomplete, contradictory, and changing requirements that are difficult to monitor and evaluate. Thus, sustainability transition planning requires an understanding of technical, social, economic and environmental issues as well as compromises between solutions and actors (Moallemi and Malekpour, 2018). Scholars have argued for the need to move away from traditional prediction or linear optimisation approaches towards scenario planning and decision-making under uncertainty (Hallegatte, 2009; Lempert et al., 2009). This involves understanding, testing and evaluating possible investment strategies for their robustness to a range of different possible futures. While such decision-making under uncertainty methods are prominent in the water sector (Groves and Lempert, 2007; Kalra et al., 2015) and for flood risk management (Lempert et al., 2013; Groves et al., 2014), their application to other sectors, including the waste sector, presents a novel avenue.

The literature on methodologies and applications associated with such scenario planning involves different focuses, mainly driven by the aim of the analysis and the academic disciplines in which methods for achieving this aim have evolved. For the purpose of this paper, it is useful to differentiate between: a) the *application* of scenario planning with the aim to evaluate investments that contribute to SDGs despite uncertain futures and b) the *generation* of future scenarios, where the process of scenario generation itself aims to contribute to attaining desirable, sustainable futures (Vergragt and Quist, 2011; Hoejer et al., 2011). The former is driven mainly by the discipline of engineering, using quantitative scenario modelling approaches to explore what *could* happen. The latter originates from the social sciences and focuses on what *should* happen (Robinson, 1990; Hirschorn, 1980).

2.1. Quantitative approaches

Quantitative methods for long-term planning, such as exploratory modelling, enable modellers to systematically investigate impacts of different uncertainties (Lempert et al., 2003; Walker et al., 2013; Bankes, 1993; de Haan et al., 2016). Combined with Robust Decision Making (RDM) (Lempert et al., 2003), such methods can aid policy-makers in determining infrastructure options whose performance is relatively robust to key socio-economic uncertainties (e.g. Hall et al. (2016); Otto et al. (2016)), thereby encouraging them to act despite uncertainty (Maier et al., 2016). Given the success of these methods in providing evidence for infrastructure investment decisions in a number of developed countries, Bhawe et al. (2016) highlight the potential of RDM approaches for wider application in developing country contexts, as applied for example in Ives et al. (2019).

Nevertheless, two key challenges remain with regards to the application of such quantitative methods to long-term planning for SIDS. Firstly, quantitative scenario modelling can only be as good as the inputted data. Inevitably, such data is uncertain, restricted by commercial or governmental sensitivities, or patchy. This is the case in SIDS, where a lack of appropriate data collection and management systems has hampered progress towards sustainable

development (Simpson, 2012). Secondly, while such quantitative scenario modelling approaches deal with the uncertainty of the future, they do not capture the contextual complexities of sustainability transitions (Moallemi and Malekpour, 2018). Qualitative, participatory approaches have the potential to address both these challenges.

2.2. Qualitative, participatory approaches

Within the social sciences, there has been a growing effort in utilising qualitative scenario planning for long-term decision-making (Loorbach, 2007). This type of applied research explicitly involves stakeholders with the aim of assisting in data collection, scenario generation (Spaeth and Scolobig, 2017; Walker et al., 2010; Hermans et al., 2017; Khanlou and Peter, 2005) and discussions about how change can be directed (Peterson et al., 2003). It has thus been considered more likely to yield coordinated actions from a range of actors (Robinson et al., 2011), thereby co-producing knowledge (Gidley et al., 2009; Chaudhury et al., 2013; Johnson et al., 2012). Back-casting is the most common method in participatory scenario planning, which uses normative views to envision desirable futures (Vergragt and Quist, 2011; Dreborg, 1996). Eames and Egmore (2011) recommended back-casting as a sustainability foresight tool for its emphasis on considering long-term desirable futures in an exploratory manner, rendering the tool applicable to the SDG focus of this paper.

Despite this progress, many participatory methods face significant limitation with respect to stakeholder selection, participation rate, time and resource constraints (Cairns et al., 2013; Ballard, 2005). The SIDS context allows overcoming these constraints, as the small environment enables an engagement with a large majority of national infrastructure decision-makers as well as stakeholders from different backgrounds (Stortone and De Cindio, 2015).

3. An integrated methodology: waste planning for SDG attainment

The proposed methodology involves four steps (I–IV) which form a closed loop: (I) Understand current system: that consists of identifying and mapping the current system. (II) Identify future needs: scenarios, policy strategies and SDG targets. (III) Simulate and evaluate: this includes modelling the proposed policy packages on the desired SDG indicators under future scenarios as well as the evaluation of trade-offs. (IV) Recommendations: transparently presenting potential policies and recommendations for delivering on SDG targets, while reflecting on the process. Each of these steps makes use of best-practice methods and methodologies within the field and is carried out through reflexive stakeholder engagement processes, which form the central foundation of the methodology as visualised in Fig. 1. The interdisciplinary effort in developing this technique contributes to the robustness of the suggested methodology.

The participatory approaches applied in this framework involve those stakeholders that are able to influence, or are affected by, the planning outcome (Malekpour et al., 2017). Depending on the context, stakeholders may be easily identifiable when responsibilities are clearly defined or may need to be discovered using systematic methods such as semi-structured interviews, snow-balling and workshops (Reed et al., 2009). The following paragraphs summarise the steps of the proposed methodology.

3.1. Step (I) current system

This stage involves data collection to map both the physical system characteristics and stakeholders underpinning the waste

infrastructure sector. Multi-level stakeholder mapping, as proposed by Sova et al. (2015), allows identification of influential stakeholders which are interviewed in order to collect data and to help understand the sustainability performance of the current waste system.

3.2. Step (II) future needs

While mapping the system is a helpful starting point, it needs to be complemented with an analytic modelling framework to enable strategic decision-making. The modelling framework used here builds upon the long-term national infrastructure system modelling expertise in Otto et al. (2016), Hall et al. (2016), and Thacker et al. (2017), who use the following three properties: (i) scenarios, which are considered exogenous and utilised to deal with uncertainty, (ii) strategies, which are endogenous and can represent visions of the future with fixed investment plans, and (iii) Key Performance Indicators (KPIs), which are used to evaluate strategies. The choice of these generic properties allows transferability of the methodology beyond the waste sector.

In translating qualitative scenarios into quantitative ones, accurate data for each of the three properties (scenarios, strategies, KPIs) is collected by drawing upon expert interviews, stakeholder engagement and national databases. Key data may be missing and resultant gaps must then be filled from other sources, possibly from regional datasets or with the use of expert judgements, both of which require various assumptions. Hence, this step includes encoding the confidence of each dataset and transparently documenting data gaps to allow for iterative updating once better data becomes available. This process can also assist in highlighting key uncertainties arising from the modelling and in identifying further data needs.

3.2.1. Scenario development

Key drivers of long-term infrastructure needs in SIDS must be understood to inform scenarios. Stakeholders identify drivers with the highest uncertainty and of highest importance, following the methodology by Jaeger et al. (2007). Typically, critical uncertainties considered in a long-term infrastructure assessment include demographic changes, economic growth changes and fuel price changes (Otto et al., 2016; Hall et al., 2016; Ives et al., 2017). Quantitative changes in these trends are to be identified using national demographic, economic and tourism information and complemented with expert judgements from stakeholders.

3.2.2. Strategy development

This step is undertaken in parallel with scenario development. Influential actors are interviewed with the aim of determining an aspirational sustainable development vision until 2050 in the waste sector. Normative back-casting helps design strategies needed to achieve the vision. According to the typology of policy tools from Rodić and Wilson (2017), interviewees are tasked to consider feasible investments using five categories (legal, economic, land-use, infrastructure, information) as well as two different intervention points (demand reduction and capacity interventions). Unlike in most participatory foresight studies, consensus is not the main objective of this step. Instead, the aim of the process is to group the different investments under contrasting visions for sustainable infrastructure. This allows diversifying the portfolio of strategies for achieving the vision, so that the analysis does not represent the perspective of any individual stakeholder, but rather examines a combination of different stakeholder views from multiple backgrounds who are able to feasibly put these strategies into practice (Varho and Tapio, 2005, 2013; Tapio, 2003). This method also aligns with the methodology used in Otto et al. (2016) for infrastructure

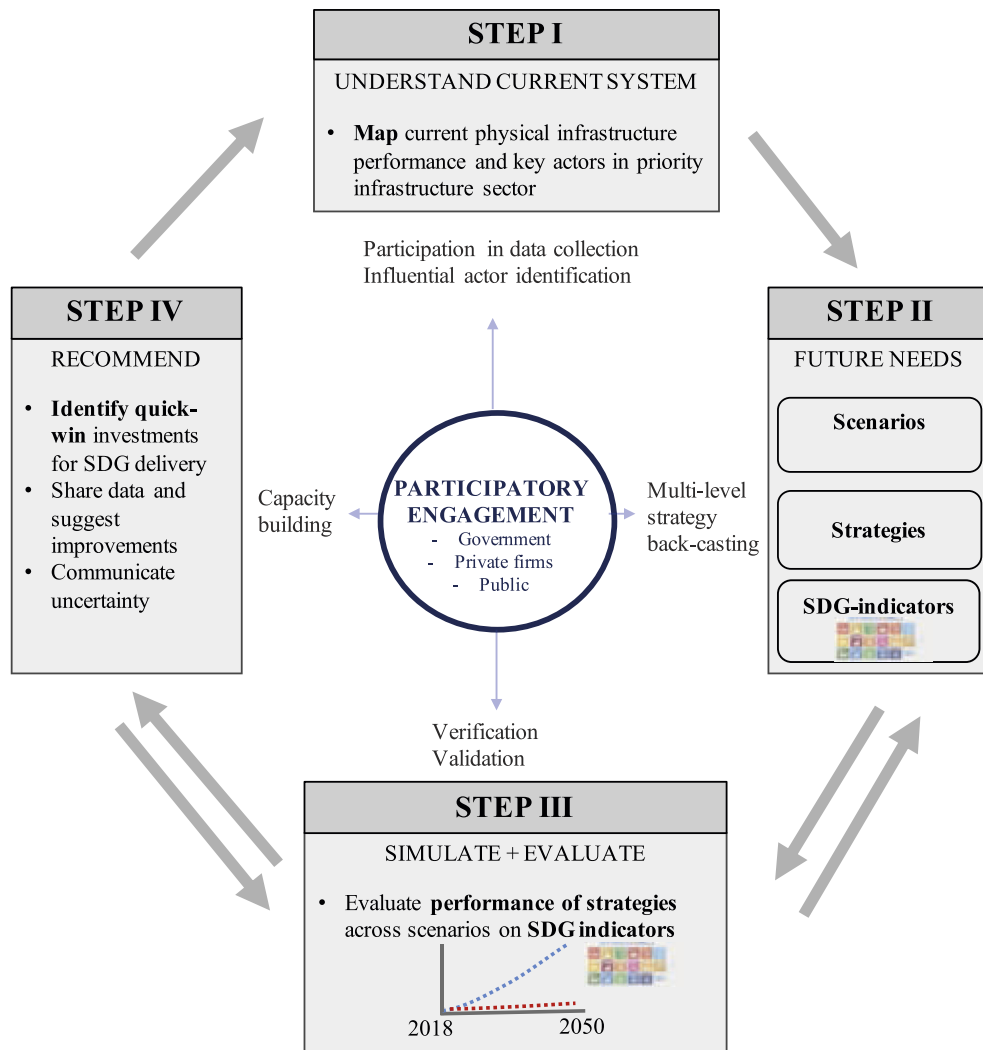


Fig. 1. Proposed infrastructure planning methodology for SDG attainment.

performance assessments, which focuses on providing different strategies to explore the implications of realistic alternative investment options rather than producing an optimal strategy. For computational feasibility, it is desirable to limit the number of possible visions to two contrasting ones. Investments opposed to by all stakeholders are taken off the list.

3.2.3. SDG-driven performance indicators

In light of the desire to develop a methodology that can be applied to other infrastructure sectors, the following three generic KPIs have been identified in the literature to represent infrastructure performance (Otto et al., 2016): service provision, carbon and cost. These broadly represent three sustainability pillars that can be linked to the SDGs: social, environmental, and economic. Within the SIDS sustainable development context, national employment is further considered a relevant performance indicator for national infrastructure planning by regional stakeholders. A systematic review of SDG goals, targets and indicators resulted in allocation of SDG indicators as KPIs. These are complemented with waste-specific SDG indicators, consistent with the focus of this paper (see Table 1). As such, the KPIs referred to in this paper include four SDG indicator dimensions, which are judged against a cost

indicator. Further SDG criteria may be added to this list based on context-relevant factors.

3.3. Step (III) simulate and evaluate

The penultimate stage of the framework involves quantitative modelling of stakeholder back-casted *strategies* on the selected SDG *indicators* under different socio-economic *scenarios*. Thereby, data should be iteratively verified and validated with in-country stakeholders. The modelling inherent in this step follows the methods on long-term infrastructure planning documented in detail by Hall et al. (2016), which can be applied to the waste sector.

In line with good practice in decision-making under uncertainty, the modelling tool, hereafter referred to as strategic planning tool, is constructed in a simple manner to support decisions rather than provide exact solutions (Morgan et al., 1990).

3.4. Step (IV) recommendations

This step involves recommending those strategies which are robust to a number of plausible futures and that deliver on SDG targets and indicators. It also includes deliberation with

Table 1
SDG targets and indicators applicable to the waste sector in SIDS. Wording for SDG targets and indicators was shortened.

Sustain-ability pillar	Minimum indicator for infrastructure assessment	SDG targets applicable to national planning in the waste sector in SIDS	SDG indicator applicable to national planning in the waste sector in SIDS	SDG indicator used
Environ-mental	Carbon	9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable. 12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse.	9.4.1 CO ₂ emission per unit of value added 12.5.1 National recycling rate, tons of material recycled	CO ₂ e/tonne waste National recycling rate
Social	Service provision National employment	12.4 By 2020, achieve the environm-entally sound management of [] wastes. 9.3 Increase the access of small-scale industrial and other enterprises, in particular in developing countries.	12.4.2 Treatment of waste, generation of hazardous waste 9.3.1 Proportion of small-scale industries in total industry value added	Waste treated Nationals employed
Financial		9.a Facilitate sustainable and resilient infrastructure development in develop-ing countries to [] SIDS.	9.a.1 Total official international support to infrastructure	

stakeholders to refine the system design by reflecting upon the system boundaries, scenarios, strategies and KPIs so that additional indicators can be considered, and/or further scenarios and strategies designed in the next round of analysis. Sharing and improving this data in iterative loops together with stakeholders from different backgrounds will be essential because sustainable infrastructure systems require multi-level research collaboration and information sharing, not just within government, but also with research centres, organisations and the local population. This may also help to remove some of the institutional and mental barriers to effective implementation and to encourage behavioural change. Most importantly, the results of this study should become accessible to start-ups, consumers, funding bodies and investors, offering novel opportunities for new sustainable businesses to be involved. Encouraging an appropriate investment climate is an instrumental part for the success of the latter.

4. Materials and methods

The proposed methodology is demonstrated for the SIDS Curacao, a 444 km² island 60 km northeast of Venezuela, with approximately 150,000 inhabitants and more than 750,000 yearly tourists, including both stay-over and cruise ship tourists (Ministry of Health Environment and Nature, 2014). The analysis focuses on Curacao's waste sector, which has been identified an urgent priority in the countrys National Development Plan and the National Report of Curacao (Ministry of Health Environment and Nature, 2014; TAC, 2013).

In applying the proposed methodology on Curacao, information on the island's current waste infrastructure and management was assimilated. Only waste disposed of on Curacao was considered. This includes Municipal Solid Waste (MSW), commercial waste, stay-over tourist-generated waste, and cruise ship tourist-generated waste discarded on the island. The timescale for this analysis is from the reference case 2018 until 2050, so as to evaluate the SDG indicators and capture the long lead- and life-times of infrastructure assets (Ives et al., 2017).

Data on the current waste system, collected from CBS (2017) and Boudewijn et al. (2011), was complemented with data collected through interviews in 2017/18. Data confidence was transparently encoded into the strategic planning tool. Following steps I and II of the proposed methodology, interviews were used to contextualise the waste sector, fill data gaps, and identify and develop context-specific scenarios and strategies for future waste provision. In doing so, a list of Curacaos waste stakeholders was collated according to the classification of key waste stakeholders by UNEP (2015). Of these, 20 participating stakeholders were selected with the help of a matrix where each participant was characterised according to

their background organisation (public administration, politics, business, research, non-governmental organisation, community member) and their level and field of education. This allowed capturing a wide range of views by taking more problem interpretations as well as solutions into consideration. Semi-structured interviews were conducted with participants full consent. Care was taken to create an environment where respondents feel comfortable in sharing their perspectives, following best practice in action research (Sova et al., 2015).

Parameters for the proposed strategies were obtained using expert elicitation. This included capacity, national employment, cost and CO₂ emissions data. CO₂ emissions factors were characterised based on Global Warming Potential (GWP100) (IPCC, 2014; Turner et al., 2015). Cost and CO₂ emissions parameters were based on national and regional datasets, as shown in Table 2. The emissions savings from carbon sequestration in landfills or soils were excluded (Christensen et al., 2009). Only direct emissions were considered, because the economy as a whole was not modelled.

In the calculation of future waste scenarios, the average Caribbean waste generation rate of 1.1kg/capita/day - taken from the World Bank (2012) dataset - was applied for residential waste generation and the upper bound rate of 14kg/capita/day in this dataset was applied to stay-over and cruise ship tourists. The remaining waste fraction on Curacao not met by this proportion was utilised to estimate a per-capita commercial waste generation rate, confirmed by in-country stakeholders and the local waste company. Table 3 provides an overview of the data for computing the future waste scenarios.

4.1. Data analysis

In modelling the performance of waste strategies, a strategic planning tool, in the form of a national accounting model, was built. Proposed treatment strategies were characterised by waste stream. Future waste generation was allocated to the available waste treatment path, favouring non-landfill-based allocation first. Throughout the modelling, a number of assumptions were made: Only differences between strategies and the baseline (inaction) strategy were modelled for CO₂-emissions and costs. Construction of the technologies begins with a lead-in time and starts to operate at its maximum capacity upon commissioning. Waste generation per-capita is constant through time. For WtE and AD, the upper-end values from (Pfaff-Simoneit, 2013) were applied in light of the small-scale installation in SIDS. A constant annual cost for transferring waste is assumed when the landfill reaches full capacity. Only waste generated by cruise ship-tourists on the day of the cruise ship visit was included.

Table 2
Annual operating carbon and cost data for computing Curacao's future waste management strategies.

Parameter (Unit)	Cost (USD/tonne waste)	Reference	Carbon (tonne CO ₂ e/tonne waste)	Reference
Landfill Curacao	65–101	CBS (2017)	0.388	CBS (2017)
Landfill mainland (shipped)	65–101	CBS (2017)	0.580–1.500	IPCC (2014)
Windrow composting	25–40	Pfaff-Simoneit (2013)	0.019–0.350	(IPCC, 2014))
Recycling - PET	08–12	Greenforce (2017)	0.155	Turner et al. (2016)
Recycling - mixed paper	08–12	Greenforce (2017)	0.559	Turner et al. (2016)
Recycling - glass	08–12	Greenforce (2017)	0.395	Turner et al. (2016)
Reuse				
Prevention				
Incineration	28–140	Bogner et al. (2007)	0.8	
Anaerobic digestion	65–80	Pfaff-Simoneit (2013)	0–0.170	IPCC (2014)
Waste-to-Energy - Grate furnace	30	Boudewijn et al. (2011)	0.3	Christensen (2015)
Material recovery facility	45–60	Pfaff-Simoneit (2013)		

Table 3
Data for computing Curacao's future waste scenarios.

Parameters	Value	Unit	Source
Total residential population (2016)	158,698	population	CBS (2017)
Tourist stay-over nights (2016)	3,605,350	stay-over tourists/year	Curacao Tourism Board (2016)
Cruise tourists (2016)	469,498	cruise tourist/year	Curacao Ports Authority (2017)
Total waste (2016)	257,244	tonnes/year	Boudewijn et al. (2011)
Per capita municipal waste arising	0.402	tonnes/year	World Bank (2012)
Per stay-over tourist waste arising	0.014	tonnes/day	World Bank (2012)
Per cruise-ship tourist waste arising	0.014	tonnes/day	World Bank (2012)

5. Results: application of the methodology

5.1. Step (I) current system

Curacao's Ministry of Health, Environment and Nature, the responsible body for waste management and related policies, was considered a key influential actor by all stakeholders. The Ministry noted the importance of waste management measures such as prevention, awareness and recycling. While a number of such initiatives already exist, the extent to which waste minimisation strategies are being employed effectively is limited to date. Fig. 2 shows the key stages, influential actors and quantitative waste flow data of Curacao's current waste management system. The main waste management company, Selikor, collects domestic waste, cleans up a portion of unmanaged waste sites and manages the only 45-ha sanitary landfill site as well as a Waste Drop-Off Centre. The most influential local recyclers include Greenforce, the Caribbean recycling company, Antillean Scrap Co. and the Caribbean Recycling Company. Special wastes (narcotics, confidential documents and chemical wastes) are treated by the Curacao Incinerator Company, which is 70% owned by Selikor. This implies the importance of Selikor as a national actor in the waste management system. The remaining waste fraction is incinerated, landfilled or remains unmanaged. These three treatment options are considered least desirable by Curacao's waste stakeholders.

Curacao's current waste sector was classified as unsustainable by the majority of stakeholders. Despite the seemingly large fraction of 38% recycling and re-use, approximately 1 in 4 recyclers on the island are operating illegally or use environmentally-harming practices, such as allowing battery discharge to leach into soils. While a small-scale waste drop-off centre for separating wastes exists at the Malpais landfill site, it is currently used sparingly. A notable sustainability 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 of toxic waste substances, which results in significant risks to terrestrial and marine environments.

5.2. Step (II) future needs

Population, tourism and economic growth were identified as the main drivers of future waste generation on Curacao. Accordingly, varying population and tourism growth-related waste factors, which reflect various economic growth potentials for Curacao, were used to construct low-, moderate- and high-waste growth that capture future uncertainty (see Fig. 3).

Application of participatory back-casting resulted in the identification of two contrasting sustainable waste visions (i.e. strategies) with associated investments (see Table 4). One group of influential actors highlighted that the only sustainable measures for future waste management include ambitious policies promoting circular economy and demand-side actions such as prevention and awareness. Interventions suggested by this group of stakeholders were collated in the *Circular Economy* strategy (W1). This includes the Ministry of Health, Environment and Nature, which state their 3-fold aim as being: 1) low emissions, 2) low landfilling, and 3) low overall waste generation. The other group of influential actors took a more pragmatic stance, questioning the feasibility of demand-side measures in the Curacao context. They considered sustainable waste management as achieving waste management service provision through recycling and energy-generating technologies that quickly reduce Curacao's dependence on its landfill. These investments were collated in the *Technology-led* strategy (W2), which were backed mainly by the waste company. Rather than representing mutual exclusion, the name of each strategy represents the broad focus of that strategy. Notably, both strategies involve hazardous waste management and recycling as important aspects for sustainable waste management. However, measures of how the upscaling of recycling can be achieved differed between the two

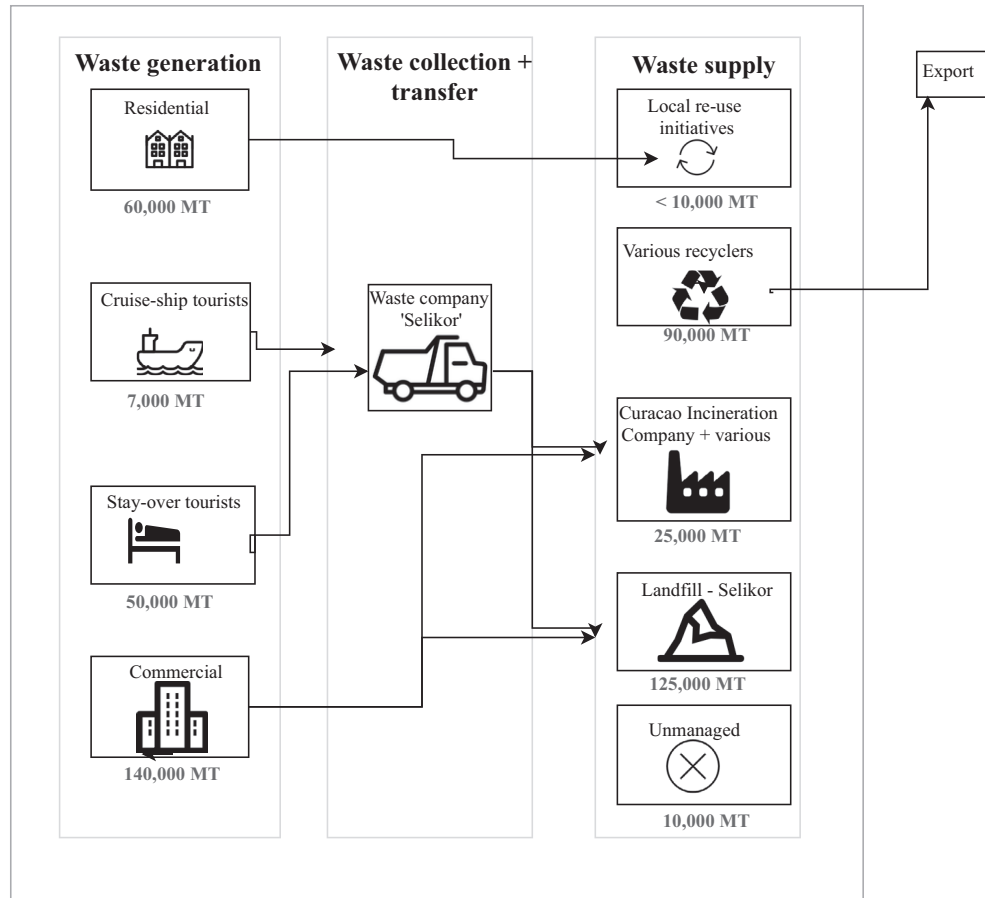


Fig. 2. Curacao's current waste system. MT refers to million tonnes.

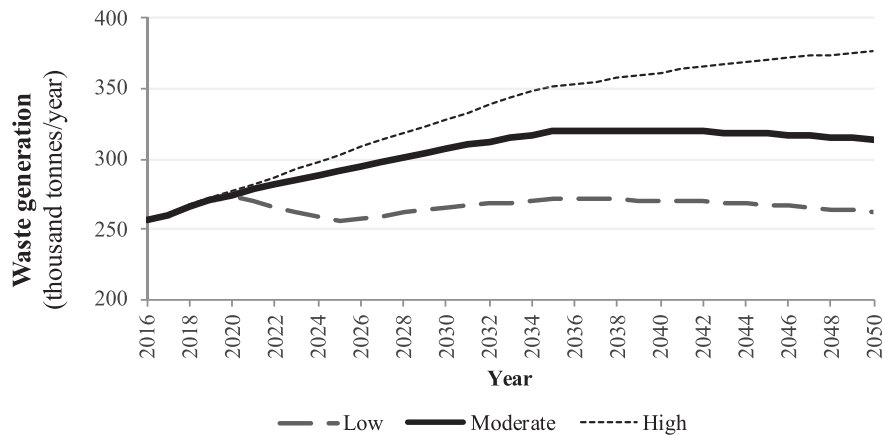


Fig. 3. Curacao's future waste scenarios until 2050. Calculations were based on waste generation factors for SIDS (Mohee et al., 2015; World Bank, 2012), residential growth scenarios developed by ter Bals (2014), and tourism growth scenarios.

strategies. These two strategies (W1 and W2) are assessed against a baseline *Inaction* strategy (W0).

5.3. Step (III) strategy evaluation

Results are presented for the moderate-growth scenario unless otherwise stated. Simulation of the strategies on identified KPIs finds that unless waste management interventions are pursued (the *Inaction* strategy), landfill capacity runs out in 2026 under all

future scenarios (see Fig. 4a).

This landfill depletion results in less than 50% of waste treated in 2030 (see Fig. 4b). Conversely, both the *Circular Economy* and *Technology-led* strategy meet their vision of treating 100% of waste generated in 2030. While the *Circular Economy* strategy achieves this with 64% of total waste either reduced, re-used or recycled, the *Technology-led* strategy does so by treating 50% of waste using energy-producing technology (see Fig. 4b).

Table 4
Overview of the three waste management strategies (*Inaction*, *Circular Economy* and *Technology-led*), related policy instruments and investments (either demand change or infrastructure technology) for Curacao resulting from the back-casting process.

Strategy name	Policy instruments	Demand change	Infrastructure technology
W0 <i>Inaction</i>		Demand growth (unmanaged)	
This strategy assumes no further investment in waste management beyond the 2016 base year, which results in landfill depletion by 2026. Waste management service provision will deteriorate with increasing socio-economic growth and the landfill fills up. No maintenance occurs and assets are not replaced.			
W1 <i>Circular Economy</i>	Reduction harbour tax Law + enforcement on untreated waste Loan recycling + subsidy land - (paper) Promotion home composting Subsidy land Subsidy for household chickens Import ban non-biodegradable for municipal solid waste Subsidy re-use centre Subsidy re-use centre Regional law Ban plastic bottles non-recyclables Subsidy for use building materials	Prevention foil + foam waste Waste reduction due to awareness citizen initiative Re-use centre for large items home furniture Re-use centre commercial for textiles and other Limit cruise ship waste Reduction of certain plastic bottle use Glass collection for re-use industry	2018: Incinerator (hazardous) 2018: Expansion recycling 2020: New recycler (plastic) 2021: Enforcement + collection + recycling of untreated waste 2021: Recycling stations (paper) 2025: Home composting 2030: Expansion recycling 2040: Home composting
W2 <i>Technology-led</i>	Law + enforcement on untreated waste EU funding		2018: Incinerator (hazardous) 2018: Expansion recycling 2021: Waste-to-energy facility 2021: Enforcement + collection + recycling of untreated waste 2022: Selikor recycling plant efficiency increase 2025: Anaerobic digester 2030: Deposit scheme recycling and infrastructure glass 2030: Deposit scheme recycling and infrastructure PET
Waste prevention, re-use and recycling potentials identified by stakeholders are met by strong waste reduction incentives and policy instruments to encourage recycling of economically-viable recycling streams. A focus is placed on increasing the efficiency of existing recycling initiatives, thereby reducing the need for new infrastructure.			
Investment into building new recycling infrastructure, alongside investments in a Waste-to-Energy (WtE) and Anaerobic Digestion (AD) plant suitable for SIDS. Materials left over from recycling are used for fuels in WtE, and the remainder is landfilled.			

5.3.1. SDG performance in 2030

With regard to SDG delivery, the *Circular Economy* and *Technology-led* strategies contribute to all assessed SDG indicators in 2030 (see Fig. 5).

As previously noted, both strategies fully deliver on SDG indicator 12.4.2 "Treatment of waste". The *Circular Economy* strategy outperforms the other two strategies with regard to the target 12.5.1 "National recycling rate, tons of material recycled". It recycles 56% of total waste arisings compared to 29% and 36% in the *Inaction* and *Technology-led* strategies, respectively. Moreover, both strategies result in an average of 35% fewer CO₂ emissions when compared to *Inaction*. Those investments within the *Circular Economy* strategy that do not involve export of recyclables, such as waste reduction or re-use of glass and plastic, score particularly high on the SDG indicator 9.4.1 "CO₂ emission per unit of value added". Further considering the saved emissions due to the avoidance of material production increases this score. Additionally, the *Circular Economy* allows an important part of the monetary flows involved to remain within the island in the form of wages for local workers and revenues for local operators, with up to 35% more local employment compared to the *Technology-led* strategy. This can deliver on SDG indicator 9.3.1. "Proportion of small-scale industries in total industry value added". The SDG performance of the different strategies can be judged against the associated costs. By 2030, the *Circular Economy* strategy is found to be the least costly under all future growth rates (see Fig. 5).

5.3.2. SDG performance under uncertain futures

The relative performance of the waste management strategies on the KPIs differs increasingly over time across the different future waste growth scenarios (see Fig. 6).

Until 2050, the *Technology-led* is the only strategy which averts landfill depletion and ensures 100% waste service provision in the moderate-growth scenario (see Fig. 6a), mainly due to the installation of a WtE plant in 2021, which has the potential to treat up to 44% of waste generated (moderate-growth). This delivers on SDG target 12.4. "Sound management of all wastes". In the low-growth scenario however, the WtE plant would need to be operated under capacity, as suggested by the blue low growth dashed line above 100% of waste treated, which may have economic implications. In comparison to the *Technology-led* strategy, the *Circular Economy* strategy treats less than 80% in the moderate-growth scenario, depleting landfill capacity.

The *Circular Economy* strategy outperforms the other strategies with respect to the number of nationals employed (see Fig. 6b) and the national recycling rate (see Fig. 6c) under all future scenarios.

With regard to cumulative CO₂-emissions, the *Circular Economy* strategy was found to outperform the other two strategies only in the low-growth scenario (see Fig. 7d).

The largest contribution per tonne to the low CO₂ impacts was from the import ban, the waste prevention awareness campaign and the glass re-purposing initiatives. However, the *Circular Economy* strategy results in depletion of the landfill in the moderate-

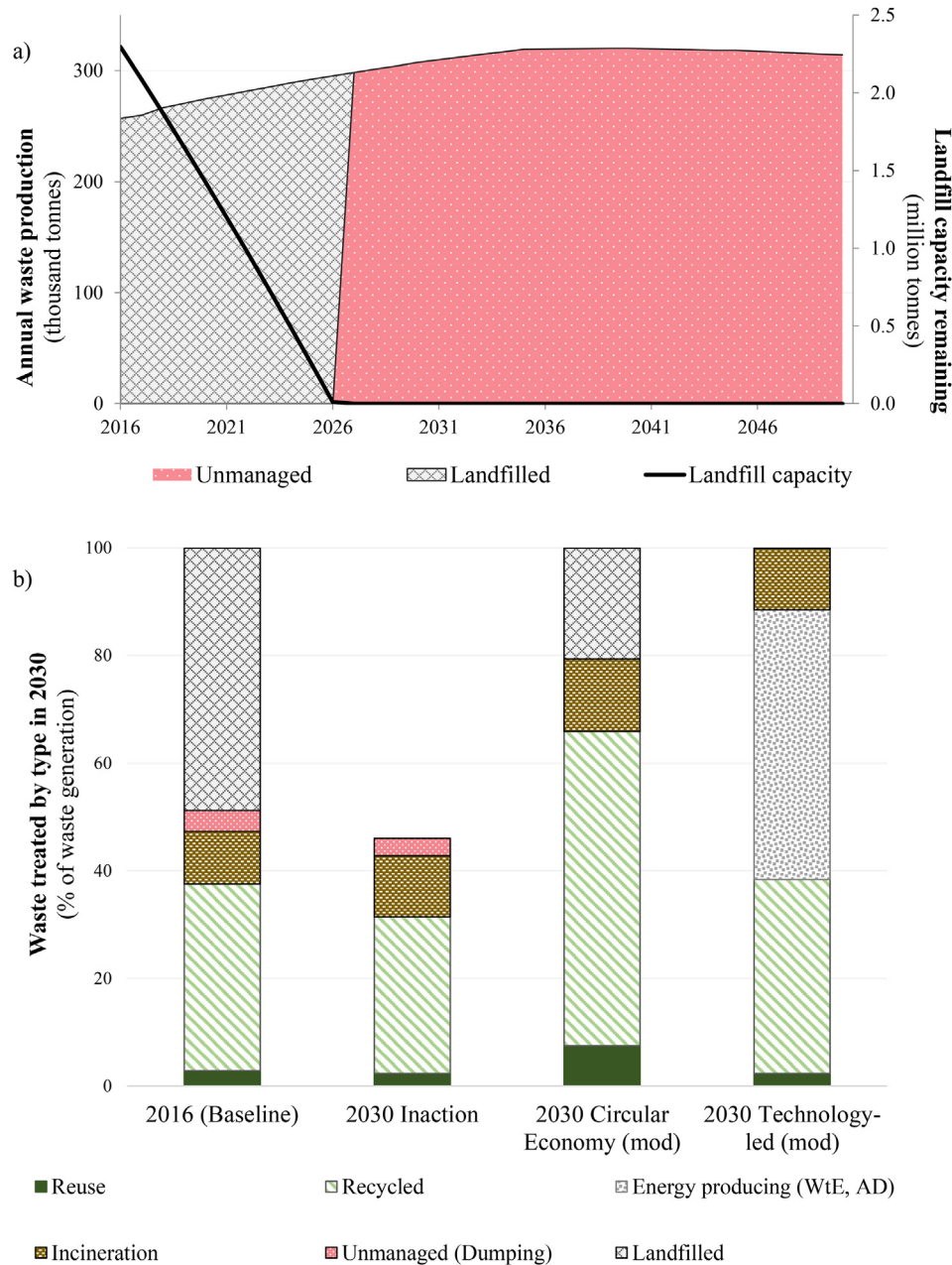


Fig. 4. Waste treatment in the waste sector, by strategy, where a) shows the decreasing landfill capacity in the *Inaction* strategy and b) illustrates the waste treatment composition of the different strategies in 2030.

and high-growth scenario, as its investments alone are not sufficient to treat the increasing waste fraction. This explains the relatively larger emissions in the moderate- and high-growth scenario compared to the *Technology-led* which does not lead to landfill depletion.

The most inexpensive options are found in the *Circular Economy* strategy and include waste demand management through import bans or waste prevention campaigns (see Fig. 7e).

The increased cost of this *Circular Economy* strategy in the high-growth scenario can be attributed to the increased export of excess waste which cannot be fully treated by this strategy. Nevertheless, compared to *Inaction*, both waste treatment strategies are significantly less expensive, as significantly less excess waste is sent to other countries for landfill.

Consequently, results from the quantitative analysis find that in

a future Curacao characterised by relatively little growth in waste generation, *Circular Economy* investments outperform all other strategies on the identified KPIs. Under a future high waste generation however, the *Technology-led* strategy appears more favourable with regard to waste treatment, reaching a shortfall in treatment capacity at a later date, around 2043 as compared to 2032 in the *Circular Economy* strategy. When this capacity is overstretched, costs and carbon associated with exporting the remaining waste fraction are in the same order of magnitude as in the *Inaction* case.

5.4. Step (IV) recommendations

The evaluation presented in Step III reveals that the *Inaction* case not only performs worse compared to the two other waste

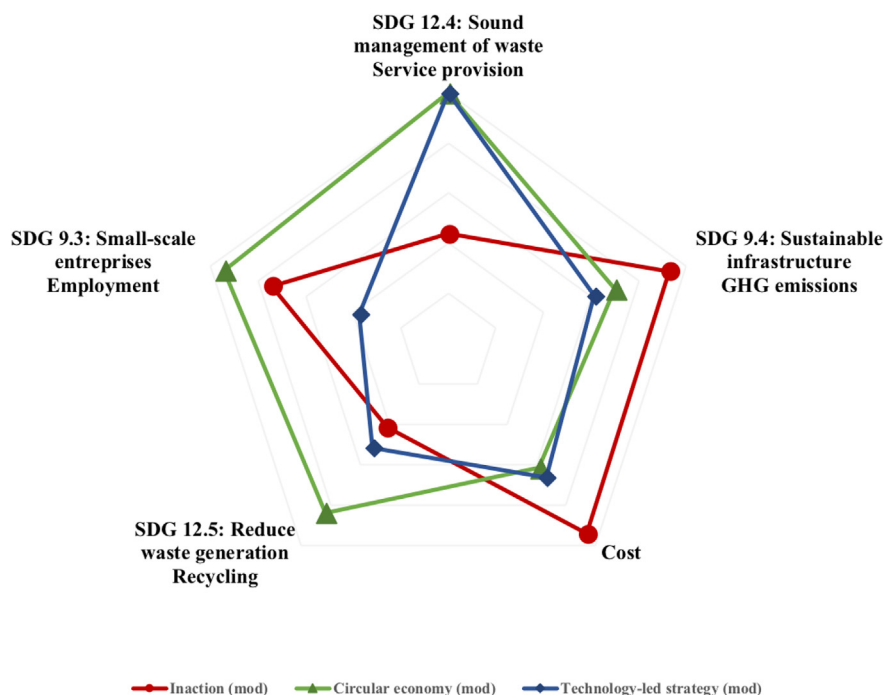


Fig. 5. Relative performance of waste management strategies (*Inaction*, *Circular Economy*, *Technology-led*) on the SDG and cost performance indicators in 2030 for the moderate-growth scenario. The scale is based on maximum values across strategies to allow for comparison.

treatment strategies, it locks Curacao into a future with higher costs and carbon emissions through the need for export of the untreated waste fraction, thus potentially stalling progress on achieving SDG targets. Adoption of the *Circular Economy* strategy has the highest potential to contribute to SDGs, especially in the near future and under a low-waste growth scenario. It outperforms the other strategies given the little infrastructure requirements, thus saving costs and carbon while contributing to local job creation and reducing waste treatment needs. Within the *Circular Economy* strategy, a number of specific investments were identified which score highly on all SDG indicators and include least regret. This includes the waste reduction campaigns and the reduction of the harbour tax for recyclers, a main barrier to the expansion of recycling capacity, and a financial incentive such as a per-unit rebate for sorted recyclables to ensure more effective use of existing recycling infrastructure. According to stakeholders, households with a yearly waste generation amount under the free allowance for landfill have little motivation to sort recyclables. A financial incentive to encourage such behaviour has proven highly effective in the past and was considered a quick win by a number of in-country stakeholders for increasing Curacao's recycling potential.

The sustainability benefits from the *Circular Economy* strategy must be evaluated against those of the *Technology-led* strategy. The latter treats the largest percentage of waste into the future, but is less flexible to different future growth scenarios given the high per-unit operating costs. Moreover, its high costs, the technical expertise and maintenance requirements reduce its potential contribution to national employment. As such, it may be advisable to defer a decision on WtE into the future when there is more available information on future waste generation. Data uncertainties should be addressed and a hybrid mix of strategies could be further tested in an iterative loop of the methodology, a suggestion made in the presentation of initial results. This could be led by the most influential waste management stakeholders on Curacao, including the Ministry of Health, Environment and Nature, the waste management company Selikor, local recyclers as well as local

environmental NGOs who proposed the sustainable waste management investments through sustainability back-casting.

Curacao stakeholders that attended a capacity-building workshop for the use of the strategic planning tool stressed the importance of collaboration and additional data collection and sharing amongst infrastructure operators, policy advisers, professors and students from the local university. This can assist in the exploration of the consequences of investments before actions are taken.

6. Discussion

In the past, actors in SIDS would need considerable time, effort and skilled personnel to perform waste management planning, which resulted in unsustainable practices without consideration of local needs or proposals (Harris et al., 2017). The methodology and tools developed here provide an engaged approach that helps model the performance of stakeholder back-casting strategies on SDG indicators while accounting for key uncertainties. This combination of local stakeholder engagement methods with top-down modelling assessments addresses the SIDS-specific need identified by Kelman and West (2009) for holistic approaches and integrating local knowledge (UNEP, 2014). This approach can increase the confidence of decision-makers that infrastructure capacity can efficiently match demand into the future, while simultaneously avoiding risks of potentially costly lock-ins that stall progress on sustainable development. Potential users of this methodology, such as infrastructure commissions, government organisations and industry bodies, can weigh up the performance of these strategies before making their decisions, thereby depoliticising investments. As discussed by Moallemi and Malekpour (2018), stakeholders participation in all stages of planning enables an understanding that models do not necessarily provide solutions, but rather support the decision-making process.

The application of such a participatory approach in this study highlights that the process of multi-level participatory strategy development itself can help increase trust in modelling, identify

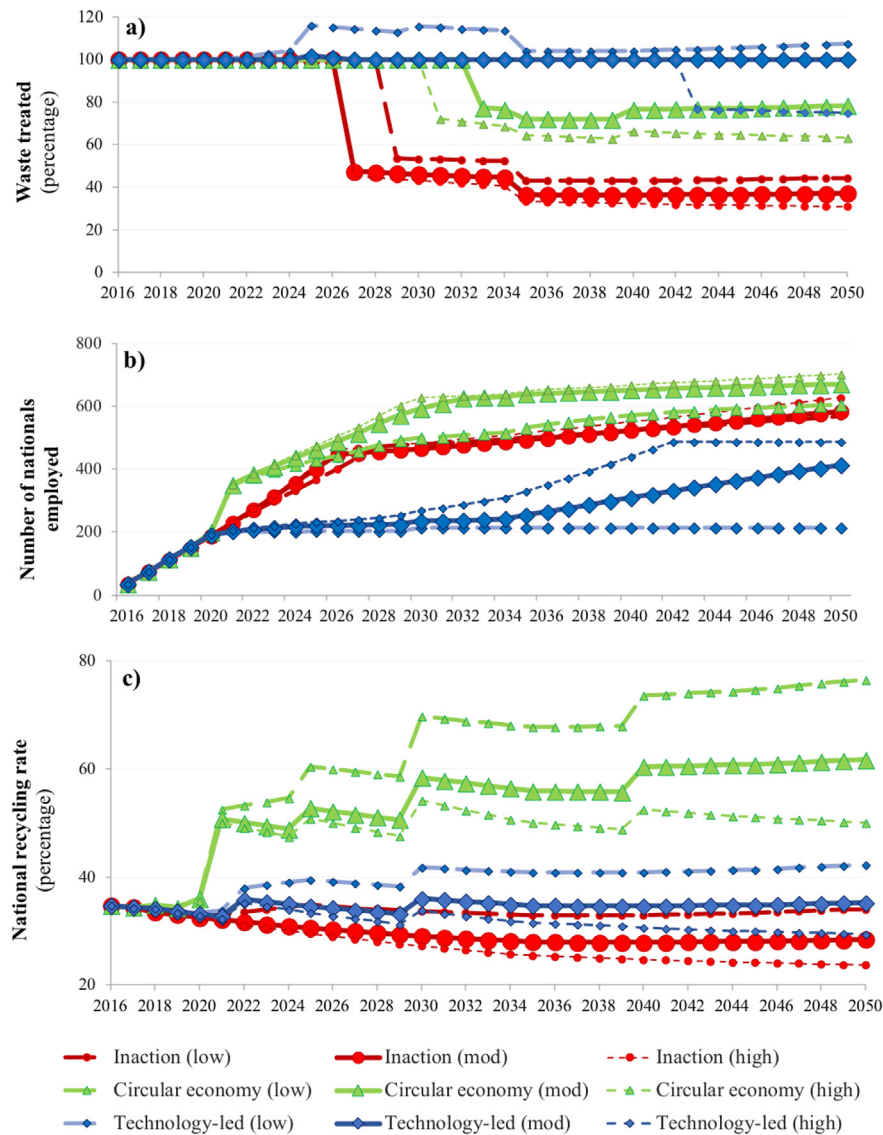


Fig. 6. Performance of the three waste treatment strategies from 2016 until 2050 on SDG performance indicators: a) service provision (waste treated), b) local employment, c) national recycling rate.

current sustainability issues and allow compliance with legislative settings and ensure the social acceptance of investments. Nevertheless, in a developing country context where capacity of all stakeholders is generally low, scenario planning should be seen as only the first stage of a long-term capacity-building process (Chaudhury et al., 2013). Iterative processes are necessary to maintain, and to reflect on and refine, potential strategies.

Application of the integrated planning methodology to Curacao's solid waste sector addresses two specific SIDS needs (Diaz, 2017), namely: 1) involving professionals from different disciplines not only engineering in the management of solid wastes with the aim of assigning tasks to specific individuals for sustainable development outcomes, and 2) integrating local expertise throughout the process of national decision-making as opposed to the application of policies and regulations used in industrialised countries. Finally, the process and clear labelling of confidence in the data collected throughout the application of the methodology and its associated strategic planning tool responds to the well-documented need for transparency in decision-making (Forsyth,

2011) and a clear treatment of uncertainty, rather than presenting absolute results (Stirling, 2010).

6.1. Contextual implications

While for most of the results presented there are still great uncertainties and gaps regarding potential for waste treatment, investment costs, CO₂-emissions and employment, the application of the proposed methodology to Curacao nevertheless provides evidence as to which of the stakeholder-proposed waste management investments perform satisfactorily across SDG indicators under uncertain futures. The implementation of waste reduction and re-use initiatives could be a least-regret option for Curacao, following the terminology of Hallegatte (2009). The immediate implementation of such initiatives can delay landfill depletion and buy Curacao time until more accurate information becomes available, thereby reducing uncertainty. Implementation of such initiatives could be supported by policies relating to: education and awareness of waste reduction; legal frameworks which ban non-

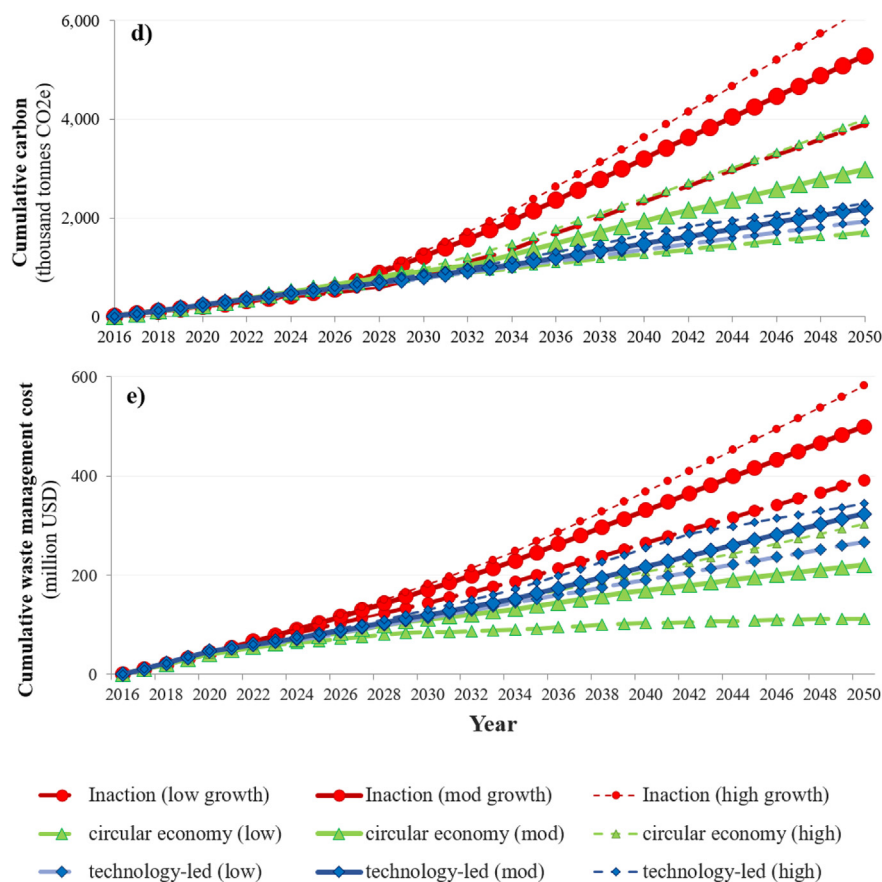


Fig. 7. Continuation of Fig. 6, showing the performance of the three waste treatment strategies from 2016 until 2050 on SDG and cost performance indicators: d) cumulative cost, e) cumulative carbon.

recyclables; subsidies to encourage industries which re-use glass, plastic or other material for building purposes; or a harbour tax reduction to increase the financial viability of recycling. The high recycling costs, especially those associated with export of recyclables for further treatment, suggest the need for inter-island recycling cooperation. Moreover, the notable absence of waste prevention, reduction and re-purposing investments in a sustainable waste management vision by half of the engaged stakeholders on Curacao reveals the importance of overcoming commonly-discussed behavioural (Barr et al., 2001), cultural (Squires, 2006), and institutional (Thaman et al., 2003; Dever and Every, 2002) issues related to such initiatives. It further reinforces Mohee et al. (2015)'s conclusion that environmental awareness campaigns at educational and community level are required to contribute to efficient waste management in SIDS.

Technology investments are shown in this study to be most sustainable for Curacao under a high-waste scenario, for example in the case that additional cruise ship waste is to be handled on Curacao. When more information is available that suggest future high levels of waste, a WtE and AD technologies are recommended. These should be designed to treat the non-recyclable waste fraction, thereby not reducing the potential to deliver on SDG target 12.5.1 "National recycling rate". Implementation of such technologies however requires overcoming commonly discussed cost and economies-of-scale barriers (Yadav et al., 2017). International funding for such technologies, through for example a waste levy on cruise ships, may provide one way of addressing this barrier. In light of the accumulation of unsustainable practices by the tourism industry on SIDS (Gössling et al., 2015), such funding may be

considered a form of Corporate Social Responsibility (CSR). Furthermore, such funding could deliver on SDG target 9.a "Facilitate sustainable infrastructure development in SIDS". However, addressing policy and contextual issues with respect to such levies requires further finessing as well as global cooperation. This is also the case for other policy recommendations which target specifically tourism-generated waste, such as hotel-funded re-use techniques or small-scale ADs for closed-loop organic waste management by the tourism sector. Inter-island coordination on such initiatives is fundamental to their success. Whatever the funding, community monitoring processes are recommended to ensure no adverse social justice failures associated with the implementation of waste management initiatives, such as the location of a potential WtE plant.

6.2. Waste management implications

The finding that investing in education, prevention and re-use initiatives is far less expensive, nearly carbon-free, and more effective at treating waste than spending money on building technology treatment capacity is consistent with other literature from developed countries (Hall et al., 2017). Adoption of such initiatives can be achieved through education and awareness campaigns in schools and companies as well as subsidies for material re-use centres. The result that landfill is one of the most expensive waste management options for the SIDS Curacao contradicts previous island waste modelling results, which assumed continuous landfill use into the future (Renou et al., 2008). Even though Chen et al. (2005) conclude that landfilling in small islands may be

the most expensive waste management option, the authors disregard alternative considerations such as waste prevention, reduction or re-use. In fact, the global waste management literature to date has not stressed the low lock-in potential and robustness associated with waste-reduction and re-use initiatives under scenarios of uncertain future waste generation. These factors are related to the ability of these initiatives to reduce landfill dependence, a particular concern for space-limited SIDS (UNEP, 2015; Dever and Every, 2002).

Results of the methodology demonstration on Curacao further confirm previous literature findings that recycling still loses much of its material value (Van Ewijk and Stegemann, 2016), despite the direct contribution to SDG indicator 12.5.1 "National recycling rate". Less cited in the literature to date is the importance of proper enforcement and control of recycling initiatives in SIDS to ensure their sustainability.

6.3. Theoretical implications

With respect to theoretical implications, the evaluation of different waste management options embedded in the proposed methodology implies that the existing waste-related SDG indicators are not sufficient or well aligned with their respective SDG targets. In particular they do not capture absolute waste reduction nor guarantee best environmental performance. This is attributed to two key findings. Firstly, results showed how waste prevention initiatives reduce the total amount of recyclable waste. Focusing only on recycling rate indicators, as proposed by the current SDG indicators, can undermine waste prevention initiatives which are more sustainable. Secondly, the Curacao case illustrated the environmentally harmful consequences of unregulated recycling initiatives. This suggests that the current SDG indicators are insufficient to meet their respective SDG targets. Rather than relying on such a relative performance criterion (recycling rate), as is the case in many developed countries, it may be desirable to focus on absolute target setting and de-materialisation indicators, such as those proposed by UNEP (2015). The recommendation by Van Ewijk and Stegemann (2016) on a clear differentiation between open-loop and closed-loop recycling can contribute to long-term sustainability, especially in the island context. The methodological development of SDG indicators in the future should also consider such differentiation.

6.4. Further research

The use of a strategic waste planning tool in this methodology allowed testing multiple scenarios and evaluating the potential of different strategies to deliver on SDG indicators at a national scale. More-detailed and ambitious research is now required to improve the accuracy of the results though: 1) filling data gaps, 2) updating and improving existing data, and 3) complementing the analysis with more detailed modelling and capacity studies. Firstly, to estimate more representative values, up-to-date infrastructure inventory, cost and CO₂-emission data, as well as more representative waste generation coefficients for the tourism sector would be necessary. Regional effort is required to collect such data for research purposes. Secondly, existing datasets should be updated and improved. The focus should lie on the collection of data with least confidence and the most impact on the model. This includes life-cycle CO₂ emission data for prevention and re-use initiatives. Research is required to overcome data collection barriers related to prevention and re-use, as summarised by Zorpas and Lasaridi (2013). Sensitivity analyses should be used to test the uncertainty associated with the data used, the subjective modelling choices, and the methodological assumptions. Thirdly, future work is

needed to apply Life-Cycle assessments and feasibility studies around investment options considered feasible by stakeholders.

The analysis is to be further extended to sample the future scenario space more extensively and to test a larger set of possible strategies, which can be updated or further developed by in-country stakeholders. Research could also be undertaken to explore methodologies for visualisation of spatial-temporal results as well as testing for coordination, management and legitimacy capacity of the various local organisations that might be involved in the implementation of the recommended initiatives. This could be combined with further strategic foresight workshops for SDG achievement in other infrastructure sectors, following the work of Wilkinson and Eidinow (2008). Research has already demonstrated the benefits of applying long-term infrastructure planning across sectors (Adshead et al., 2018). Future work may also test the methodology on other SIDS and more globally. In fact, Thacker et al. (2018) find that 72% of the SDG targets can be influenced by infrastructure, including from the solid waste, energy, transportation, water and digital communications sectors. This highlights the potential to not only extend the methodology in this paper to other sectors, but to also systematically assess impacts across a broader range of SDG targets, as demonstrated by Adshead et al. (2019).

7. Conclusion

Strategic sustainability planning for the future of waste is challenging due to the fragmented nature of infrastructure operation and management as well as the uncertainty and difficulty of understanding future sustainability consequences of today's investments. This paper puts forward an integrated waste management planning methodology to address this gap. This combines the complementary methods of participatory back-casting and robust national infrastructure assessments in order to test the performance of stakeholder-developed strategies on SDG targets under uncertain futures in the contained system environment of SIDS. Thereby, the proposed methodology allows overcoming weaknesses of the sole application of technocratic infrastructure modelling, which typically does not consider context-specific solutions (Dornan, 2014; Voss et al., 2007) as well as the absence of objective evidence-based evaluations in purely qualitative back-casting studies. Rather than recommending exact solutions, the proposed methodology enables decision-makers to evaluate the consequences of actions before committing to them, thereby depoliticising investment spending. Taking such a long-term approach can also help ensure that waste investments are adaptive and robust to some of the main future uncertainties SIDS face into the coming decades. The aim hereby is to enable SIDS strategists to learn from waste infrastructure decisions that have locked many developed countries to high emissions and unsustainable practices, and instead unlock sustainable development outcomes.

Application of the planning methodology to Curacao highlights: a) how sustainable waste management strategies can be co-created with a range of national stakeholders, and b) how different future waste management strategies compare based on SDG indicators under uncertain futures. Results show that the *Circular Economy* strategy outperformed all other strategies with regard to delivery on SDG indicators in the low future waste growth scenario by 2030. The *Technology-led* strategy however was the only strategy able to meet waste management needs under a high-growth future scenario.

For Curacao, this implies the need for adopting low-regret and adaptive waste management options first until more information on future needs is available. Investment in low-regret circular economy initiatives now can reduce the potential for locked-in

future emissions and economic dependency from large-scale technologies. Involving the local population through back-casting enabled an identification of potential change makers to implement prevention and re-use initiatives. Coordination of inter-island recycling hubs, funded by the tourism industry, could help address barriers to scaling recycling efforts whilst delivering on SDGs. Results further suggest the feasibility of implementing laws which restrict certain tourism-generated waste streams which cannot be dealt with locally. These laws need regional and global cooperation so that tourism is not adversely affected.

Sustainability transitions towards circular economy mechanisms thus require regional and global support, both politically and financially, in order to achieve their full sustainable development potential. At the same time, the analysis highlights the need to address deficiencies in using the current list of waste-related SDG indicators to evaluate the sustainability of waste management programmes, specifically in their inability to reward absolute waste prevention and to encourage sustainable recycling.

Despite the potential usefulness of the proposed planning methodology, moving forward towards sustainable waste management requires not only technological advances and decision-support tools, but also iterative, effective and integral stakeholder engagement, cultural and behavioural acceptance, experimentation and innovation spaces that involve local communities. Thereby, it is imperative to encourage local, national, regional and international cooperation, data collection and sharing of best practices. Combining technological best practices with coordinated efforts from local populations can provide a substantive step towards achieving sustainable development in SIDS, and eventually, globally.

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