Infrastructure Strategies for Achieving the Global Development Agendas in Small Islands

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Abstract Small island developing states face particular challenges to ensure their infrastructure promotes social, economic, and environmental well-being. Closing the achievement gap for the Sustainable Development Goals (SDGs) involves prioritization and coordination across multiple sectors. With an application to the country of Saint Lucia, this paper develops a stakeholder-driven analysis framework integrating four interdependent infrastructure sectors (electricity, water, wastewater, and solid waste). Drawing on extensive consultation with decision-makers in-country—134 stakeholders from 18 government ministries, agencies, academia, or the private sector—the analysis identifies specific interventions that could be implemented over the next decades to meet future needs for sustainable infrastructure services. These interventions are congruent with the government's development plans. Long-term, cross-sectoral portfolios of investments and policies ("strategies") are developed which demonstrably reach the targets of the SDGs and Saint Lucia's emissions reduction commitments under the Paris Agreement. The sequencing of these investments or policies is designed to optimize their efficiency and impact over time, identifying "quick wins" while ensuring that there is sufficient action to provide services in the long-term sustainably. A comparison of costs associated with each strategy suggests that accounting for interdependencies and taking a long-term perspective can save costs over the life of infrastructure investments. This process of infrastructure assessment is applicable beyond the small island context, allowing practitioners a means to undertake systematic assessment of a country's future infrastructure needs and to develop appropriate solutions aligned with its national objectives and international commitments.

Plain Language Summary Infrastructure is crucially important to achieving many development outcomes, including social (e.g., poverty, health, and education), economic, and environmental targets. Providing infrastructure services such as energy, water, and waste management has often been undertaken without accounting for the linkages between these sectors. Given that demand for these services is projected to grow around the world, this article recognizes that meeting countries' future needs in the most efficient and cost-effective way will require infrastructure to be planned as a system. Here, we design a consistent method for doing so and demonstrate how the unique challenges of a country can be assessed and incorporated into the infrastructure planning process. Importantly, this process ensures that countries are able to align their planning as closely as possible with major international agreements such as the Sustainable Development Goals and the Paris Agreement on Climate Change.

1. Introduction

Infrastructure systems, including energy, transport, telecommunications, water, and waste management, provide essential services for the well-being of people, the economy, and the planet. Infrastructure is widely regarded as being necessary for economic development (Aschauer, 1993; Straub, 2008; Sutherland et al., 2009) but also impacts on other important aspects of society including human development, social inclusion, and environmental sustainability (OECD, 2017). As a result, infrastructure will play a central role in nations' ability to meet the sustainability targets they aspire to (A. J. Bhattacharya et al., 2016; Thacker et al., 2018). In order to do so, decision-makers at all levels require improved methods and frameworks within which to assess the suitability of their current infrastructure systems, plan for future needs, and implement investment and policy actions that enhance the sustainability of the national infrastructure system within the technical, financial, and political confines of their national contexts.
This study proposes such an assessment framework and applies it in a small island context. Small islands face a unique set of infrastructure challenges due to their size, remoteness, and vulnerability to environmental threats (Adeoti et al., 2020). Moreover, many of these countries are reliant on tourism and must design their infrastructure systems to serve a large number of visitors in addition to their resident populations (Vitová et al., 2019). An approach to infrastructure modeling that accounts for these specific challenges to improve future performance of the national infrastructure system is therefore required. In this assessment, infrastructure performance is guided by the global development commitments defined in the 2030 Agenda for Sustainable Development, adopted by the United Nations (2015), and the climate commitments negotiated under the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) (2015).

The 17 Sustainable Development Goals (SDGs) represent the objectives at the heart of the 2030 Agenda, which are now widely used as a means of shaping sustainability initiatives in government or the private sector (OECD, 2017; Prakash et al., 2017; UNDP, 2016). Of the 169 targets contained within the UN SDGs, 72% can be directly or indirectly influenced by actions targeting one or more infrastructure sectors (Thacker et al., 2019). The SDGs are now increasingly addressed within objectives for infrastructure development; however, so far this has been limited to a focus on individual sectors, projects, or types of infrastructure. While systems approaches are widely called for and there have been successful cross-sectoral approaches, notably integrating energy and water (Fader et al., 2018; Yillia, 2016) and water and waste (Dilekli & Cazcarro, 2019; Hülsmann & Ardakanian, 2018), methods for infrastructure planning that spans multiple interdependent infrastructure sectors are still in their infancy (Adseh et al., 2019).

The Paris Agreement committed signatory nations to work to keep the global temperature rise within this century to below 2°C above preindustrial levels and to pursue efforts to limit it further to 1.5°C (UNFCCC, 2015). The agreement requires each Party to define their individual commitments in terms of emission reductions, or Nationally Determined Contributions (NDCs), in addition to strengthening their abilities to deal with climate change impacts through adaptation measures. Naturally, infrastructure decisions are central to meeting these reductions, particularly those around clean energy transitions (Cui et al., 2019; Iyer et al., 2017), transport (International Transport Forum, 2018), and waste management (Powell et al., 2018), and complement actions in other sectors such as forestry, agriculture, and industry. Decisions made within the policymaking domain of climate mitigation can have implications, both positive and negative, for achieving various SDG targets (Fuso Nerini et al., 2019). While each country party to the agreement has communicated its individual mitigation commitments, often with clear reference to related and prioritized SDG targets, the structure of these varies widely in terms of content, form, scope, and coverage (Roelfsema et al., 2020; Taibi & Konrad, 2018).

Recent calls to more closely align the infrastructure agenda with the SDGs and the Paris Agreement recognize that major investment gaps will need to be filled in the coming decades (Bhattacharya et al., 2019). This creates an opportunity for new methodologies to allocate investment where potential impacts are greatest, shaping better infrastructure investments and policies in key sectors (Rozenberg & Fay, 2019). Scenario and integrated assessment modeling have been developed to determine the broader social, economic, and governance transformations required to ensure successful achievement of the SDGs. These methods have provided a means by which to assess potential future social, economic, and environmental states of the world as a result of human and natural influences (Moss et al., 2010) and to explore the long-term consequences of anthropogenic climate change and available response options (Kriegler et al., 2010). These are integral to informing appropriate actions across infrastructure sectors in order to achieve climate targets and broader development goals (van Vuuren et al., 2015) and have been used as a basis for assessing selected policy actions (van Vuuren et al., 2011).

The use of narratives describing alternate socioeconomic scenarios (Riahi et al., 2017) has provided useful tools for policymakers seeking to leverage infrastructure decisions to meet climate and development targets (Böhmelt, 2017). It has also been used to identify transformational challenges required to achieve sustainable development within planetary boundaries (TWI2050, 2018), broadening the scope of potential solutions in order to model policy pathways maximizing SDG target achievement (Moyer & Bohl, 2019) and to set out an agenda for their design, implementation, and monitoring (Sachs et al., 2019).

While providing tools for exploring possible futures and appraising selected policy interventions, constructing place-specific solutions to meet goals at a national level continues to be a challenge. It is nonetheless
clear from these previous studies that achieving global goals is likely to require multiple interventions that are sequenced through time. We thus consider hard and soft interventions in infrastructure systems (i.e., investments in gray and green infrastructure, but also policy interventions such as regulation and pricing), recognizing that combinations of several such interventions are usually required in order to achieve sustainability goals. Together, these form “strategies” or adaptable sequences of interventions which navigate the infrastructure systems toward achieving goals for service provision.

In the development context, cross-sectoral infrastructure investment portfolios have been used to compare approaches to meeting projected infrastructure needs across a range of futures (Ives et al., 2019), though were not linked to a holistic national plan, such as one aligned with the SDGs. On the other hand, cross-sectoral infrastructure planning has loosely linked in national development targets without attempting a methodological approach to strategy development (Adshead et al., 2018). This paper builds on these previous studies to systematically develop infrastructure investment and policy portfolios aligned with the objectives and targets of both global development agendas, applying the approach to the small island country of Saint Lucia. This approach considers four infrastructure sectors—electricity, water supply, wastewater, and solid waste—chosen due to the interdependent nature of their functions and the ability to model the four sectors together in terms of supply and demand at a national level.

1.1. Saint Lucia’s Infrastructure Challenges

Infrastructure forms the backbone of Saint Lucia’s society, delivering services that provide the daily needs of its citizens while supporting a tourism-based economy that brings hundreds of thousands of visitors to the island each year. However, Saint Lucia is, or will soon be, vastly undersupplied with the infrastructure it needs in the four key sectors addressed in this study. As shown in Figure 1, electricity is the only one of these infrastructure services which currently meets the population’s needs, though the capacity margin will be eroded in future unless generation capacity is increased, demand is reduced, or efficiencies are integrated into the network. Water supply, wastewater treatment, and solid waste—chosen due to the interdependent nature of their functions and the ability to model the four sectors together in terms of supply and demand at a national level.

Figure 1. Current and projected infrastructure capacity in relation to needs to 2030 across four key sectors in Saint Lucia.

Saint Lucia relies on diesel-based generation for its electricity supply, which supplies 99% of the island’s electricity needs (LUCELEC, 2018). While supply levels are currently adequate, this implies the need for fuel imports, which have a cost to the government of around 10% of GDP annually and affect consumers through high residential electricity tariffs (Centre for Process Innovation [CPI], 2017). In the water supply sector, Saint Lucia faces large water security challenges in the dry season due to reduced river flows, low volumes of storage, and
high demand from tourists, meaning that only around 40% of peak demand may be met during these periods (Saint Lucia Water and Sewerage Company, personal communication, 2019). Siltation of the island’s main dam has led to a reduction in reservoir and storage capacity, reducing supply to treatment plants. Nonrevenue water losses are a major concern of the island’s water utility: approximately 30% of total water supply is lost through physical leaks in the transmission system and a further 26% from theft or metering inaccuracies (Government of Saint Lucia [GoSL] 2018b). Only around 2% of wastewater is treated through secondary processes, with existing treatment infrastructure operating vastly under capacity (Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives Saint Lucia, 2017). Untreated wastewater is associated with public health risks, including high levels of bacteria and the transmission of water-borne diseases. Untreated wastewater discharges threaten the safety of public and tourist beaches, as well as terrestrial and marine ecosystems that draw tourists to the island. As a small island, Saint Lucia’s landfill capacity for solid waste is limited, with one dumpsite closed at the end of 2019 and the remaining site projected to reach the end of its lifespan by 2023 (Saint Lucia Solid Waste Management Authority [SLUSWMA], personal communication, 2019). This creates the risk of increases in dumping and informal waste incineration or the need to export waste abroad at high cost. The increasing frequency and magnitude of climate hazards poses a threat to all infrastructure on the island, requiring that solutions be designed with resilience aspects in mind (Government of Saint Lucia [GoSL], 2018b). Given the interconnectedness of the infrastructure system, this implies considering the impacts of system failure across each of these sectors, as well as the housing, economic, and social facilities they serve.

The next section outlines the steps in the process of infrastructure assessment in Saint Lucia, describing the formulation of infrastructure strategies and justifying the assumptions used in the study. Comparative strategy results are shown at the level of individual infrastructure sectors. The cross-sectoral performance implications of each of these strategies are discussed with regard to the SDGs and greenhouse gas emissions. The results lead us to discussion of broader themes and transferable lessons for the future of national infrastructure planning in the context of sustainable development.

2. Methods

In order to conduct this study, a national infrastructure assessment process was developed, consisting of a series of analysis steps outlined in Figure 2. This process reconfigures prior methods designed to support sustainable infrastructure delivery through a structured assessment approach that introduced key steps...
such as projecting future needs, setting performance targets, and identifying implementation options for infrastructure (Thacker et al., 2017). The participatory nature of this approach is well suited to infrastructure planning in small island contexts (Fuldauer et al., 2019), which, due to their small sizes, avoid constraints of stakeholder selection and participation faced in larger countries (Cairns et al., 2013). As a result, a large proportion of Saint Lucia’s key infrastructure stakeholders and experts could be consulted: data and feedback were obtained from 134 individual across 18 entities, including government ministries, departments, agencies, utilities, local consultancies, academia, and the private sector and used to populate the assessment framework.

This process is structured as follows. First, a series of infrastructure-relevant targets aligned with Saint Lucia’s global development commitments or other international benchmarks are developed. Second, the current performance of the infrastructure system in relation to these targets is established. Third, the key factors driving the need for future infrastructure are considered and quantified. Fourth, the full range of confirmed, proposed, or potential investments or policies within each assessed sector is compiled from policy documents, data sets, and in-country consultation with the national government. These four steps feed into the fifth: the generation of a set of distinctive strategies composed of sets of investments and policies. These portfolios are designed to identify the type, size, and timing of various infrastructure interventions that can be implemented to meet the targets established in the first step, including the inaction route, which sets no performance targets.

2.1. Select Key Targets in Order to Align Infrastructure Planning With the SDGs, the Paris Agreement, and National Policy Priorities

Infrastructure performance targets used in this assessment were arrived at after a collaborative process of engagement with decision-makers in the Government of Saint Lucia, which also served to highlight development challenges facing the country. Key indicators and targets (contained in supplementary data) were identified through (1) consultation with government entities to identify desired outcomes and feasible quantified achievement levels across strategic policy areas; (2) consultation of key national policy and strategy documents, such as the Third National Communication on Climate Change and the National Policy on Wastewater Management; (3) targets set according to quantifiable international commitments, specifically the SDGs and Saint Lucia’s NDCs under the Paris Agreement; (4) the extension of these targets to maintain ambitious development objectives post-2030; and (5) targets based on international best practice, such as outcomes achieved in the United States or the European Union.

2.2. Evaluate Current Performance of the Infrastructure System

Current infrastructure performance refers here to the ability of the infrastructure system to deliver on the targets outlined in the previous section—specifically, infrastructure-linked SDG and mitigation targets related to security of supply (e.g., capacity margins), environmental sustainability (e.g., recycling rates), and emission reductions. In order to assess this, data on the type and capacity of infrastructure in each of the four sectors addressed—electricity, water supply, wastewater, and solid waste—were collected and verified. The demand breakdown by end user (e.g., domestic, industry, or tourism) and the current supply portfolio (e.g., diesel, wind, desalination, or recycling) was disaggregated for each sector, accounting for the interdependent function of certain types of infrastructure across sectors. Using this information, performance values for the targets in Section 2.1 could be ascertained. Current gaps in infrastructure provision or performance were identified.

2.3. Assess the Key Factors That Will Drive the Need for New Infrastructure Investments and Policies

Future needs for infrastructure are driven by several factors, including changing demography. Demand driver scenarios in Saint Lucia were formed of two components: residential population growth and tourism growth, which are combined to estimate peak number of infrastructure users on the island for any given day. Economic development in the tourism sector is similarly a driver of infrastructure needs. Other drivers, such as climate change, are recognized as being nonstationary exogenous drivers which may affect the future supply of or demand for infrastructure, for example, by reducing water availability.
UN DESA (2019) provides population projections underpinned by various assumptions around future fertility, mortality, and migration. Under the medium variant, Saint Lucia is expected to maintain its population at a similar level by 2050, while the Caribbean region as a whole is projected to grow by a rate of 8.8%. Under alternative variants, changes in Saint Lucia’s population range between 9% decline and 15% growth by 2050.

Tourists have historically demonstrated a disproportionately larger demand for infrastructure services compared to residents, requiring greater amounts of energy and water per capita for luxury and leisure activities, and generating more waste per person than the average resident (Zorpas et al., 2014). Tourists can be divided into two types: stay-over tourists, who arrive by air for an average of 9 days (Saint Lucia Air and Sea Ports Authority (SLASPA), personal communication, 2019), and cruise ship tourists, who spend less than a day on the island, generally at beaches, restaurants, and tourist-oriented zones. Since cruises provide electricity, water, and waste disposal services for their guests, these types of tourists generally rely less on services provided on-island. However, the influx of cruise ships at certain times of the day and year put high stress on the island. A significant number of stay-over visitors also arrive by boat or yacht at the island’s marinas, staying on average 2.4 days (SLASPA, personal communication, 2019).

Tourism growth will be driven in large part by major transport hub projects that will increase visitor numbers to the island: the planned expansion of Hewanorra International Airport and the recent agreement to construct and operate a new cruise port in Vieux-Fort. The current two-phase expansion of the airport will provide for up to 750,000 additional annual arrivals, more than tripling its current capacity (Airports Worldwide, 2010). For the cruise terminal, three growth scenarios have been constructed based on SLASPA projections for increased passenger throughput (SLASPA, personal communication, 2019). However, the cruise ship trend is highly variable and there is a need to continually update these projections to provide an accurate assessment of the port’s impact on Saint Lucia’s future tourism numbers.

To represent the most likely scenario for future needs, results are calculated using a “moderate” scenario for combined population and tourist growth derived from the medium variants in both the population and tourism projections. Per capita assumptions around infrastructure use are derived from government-published statistics outlining the demand breakdown by sector—for example, electricity and water consumption (Central Bureau of Statistics, 2018), and solid waste generated (SLUSWMA, personal communication, 2019). Stay-over and cruise ship tourist demand is derived from annual demand under the categories “hotels,” or “boats,” respectively, incorporating the average number of days each type of tourist spends on the island (SLASPA, personal communication, 2019). A portion of commercial demand is also attributed to the tourist sector.

2.4. Compile Strategic Options to Outline the Range of Potential Interventions That Can Be Undertaken in the Country

A strategic infrastructure plan is composed of a sequence of investments and policies. As a first step, this study uses stakeholder input to catalog the broad range of possible interventions that might be implemented as part of Saint Lucia’s future infrastructure delivery in the addressed sectors. This step additionally classifies future interventions according to their likelihood of implementation: confirmed, proposed, or potential. Through consultation with decision-makers in government ministries and agencies, a list of projects or policies that have received confirmed funding by the government or other donors, or are currently in the implementation stage, is assembled. Next, a wide search of national policy documents identifies solutions considered feasible by experts and proposed in planning documents or studies. This list is broadened by considering past studies from the wider Caribbean region, which allows the details of certain interventions to take shape. Finally, some interventions are classed as potential means of reaching ambitious long-term targets. These aspirational solutions tend to provide needed capacity not otherwise accounted for in existing studies and are implemented in the analysis if other solutions are still inadequate.

There is already a wealth of infrastructure studies and appraisals for Saint Lucia undertaken by its various government ministries and agencies, as well as by external consultants and organizations, detailing potential development and policy options for the energy (CPI, 2017; Department of Sustainable Development, 2019; Government of Saint Lucia [GoSL], 2017; Inter-American Development Bank, 2015; Torbert et al., 2016), water supply (GoSL, 2018a, 2018b; Santander, 2006; Stantec, 2015), wastewater (GEF-IWCAM, 2011; Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives Saint Lucia, 2017;
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Montoute & Cashman, 2015), and solid waste (CPI, 2017; Tsai, 2013) sectors. Additionally, studies applied elsewhere in the region provide insight around the feasibility of a variety of infrastructure solutions in the Caribbean context (Amadio, 2014; GIZ, 2015; Inter-American Development Bank [IDB], 2018; Llanes & Kalogirou, 2019; Phillips & Thorne, 2013; UNEP/CAR-RCU, 2009; UNEP-CEP, 2010). Together with the sector-specific analyses, these form a valuable resource of potential options for the country’s future, which inform the integrated national infrastructure planning approach developed here.

2.5. Generation of Infrastructures Strategies Composed of Selected and Sequenced Cross-Sectoral Infrastructure Interventions

In prior studies, infrastructure strategies are developed and tested using simulation models to assess various combinations of interventions in relation to their performance across indicators (Hickford et al., 2014). These strategies have generally been organized by broader categories of infrastructure system transformation: behavioral change, system efficiencies, capacity investment, etc. (Otto et al., 2016). While addressing the direction of infrastructure policy across the system as a whole, they are useful in defining national policy alternatives in each sector (Hall et al., 2016). This assessment adopts a strategy generation method based on similar principles, but one organized around global development outcomes. By establishing quantified target objectives at the outset of the process, it provides a means by which to define an optimal implementation of investments and policies to achieve the given set of targets.

Strategy portfolio specification is run for each sector utilizing the set of predefined interventions outlined in Section 2.4. For each strategy, the selection of interventions is optimized to achieve its performance targets by specified dates. Where an investment or policy straddles sectors, such as effluent reuse or water use efficiencies, the same magnitude of the chosen intervention is applied to each relevant sector.

The first case, “Inaction” implies that no further projects are implemented, while demand for infrastructure continues to increase according to per capita growth assumptions. As such, this case is not strictly a strategy but serves as a counterfactual to assess the extent of infrastructure performance decline linked to the selected demand growth scenario.

The “Business-as-usual” (BAU) strategy incorporates short-term projects confirmed by the Government of Saint Lucia. Future projects or interventions are implemented only to maintain current infrastructure performance, and no ambitious efforts are undertaken to improve it.

The “National sustainability strategy” is constructed to achieve specific user-defined targets for infrastructure performance aligned with specific SDG targets. The strategy also constrains maximum emissions levels in the electricity and waste sectors according to Saint Lucia’s NDCs under the Paris Agreement. This strategy is thus aligned with all infrastructure-related targets for the analyzed sectors set within both global agendas.

3. Results

The next sections summarize the components of an interdependent infrastructure analysis incorporating four of Saint Lucia’s key sectors under a moderate demand projection. These results bring together infrastructure demand projections and supply options over time to address the country’s pressing development challenges based on principles common to the global agendas. Sustainability targets derived from the SDGs and the Paris Agreement underpin and inform the sequencing of these interventions across sectors. While an extensive list of options has been inputted into the model, similar intervention types are grouped here for simplification. Following the individual sector results, the cross-sectoral implications of the strategies are compared in relation to the global agendas, demonstrating the alignment of each strategy with key SDG and Paris targets.

3.1. Electricity

Saint Lucia’s diesel capacity is sufficient to meet demand into the future, but increasing energy demand will narrow this margin. As its population grows and it scales up its tourist capacity, its demand may increase by up to 30% by 2050 (Figure 3(a)). At the moment, there is just one solar installation, providing for 1% of total electricity demand.
Favorable conditions for solar, wind, and geothermal energy on the island make these the prime supply-side components of a national sustainability strategy aiming to achieve the government's 2030 renewable generation target of 35% and subsequent scale-up to 50%. Saint Lucia has begun to tap this potential through solar and wind installations confirmed by 2022 (Figure 3(b)), which will increase its renewables share to 14% while maintaining strong reserve margins. However, additional solar generation in the short term is considered feasible before large investment in battery storage and upgrades are required (Torbert et al., 2016). An expansion of distributed solar generation is actively under assessment (Department of Sustainable Development, 2019). While contributions to national supply would be small, the resilience of the sector would stand to increase as other critical facilities such as schools, health centers, desalination plants, and water treatment facilities achieve self-sufficiency from the national grid. Saint Lucia's geothermal resources provide another untapped renewable energy source identified as a key component of the govern-

**Figure 3.** (a) Current electricity performance and future needs driven by moderate demand projections. (b) Implementation and sequencing of a National Sustainability Strategy incorporating feasible investments and policies to meet relevant SDG and mitigation targets. Supply interventions converted to estimated GWh using appropriate load factors for each technology. SDG, Sustainable Development Goal.
ment’s renewable energy strategy. Due to technical constraints on exploiting this resource economically, the majority of its projected capacity may not come online until after 2030 but can play a major role in achieving enhanced sustainability in the sector over the long term.

Demand reductions and system efficiencies in the electricity network are considered relatively low-cost interventions that could be feasibly implemented by 2030 to reduce national energy demand by over 5%, including through LED street lighting, lighting and cooling efficiencies in new buildings, and a focus on energy use reductions in the tourism sector (GoSL, 2017; Torbert et al., 2016). Due to their relative ease of implementation, these interventions provide “quick wins” for policymakers.

3.2. Water Supply

Water shortages in Saint Lucia are particularly acute during the dry season (Figure 4(a)) when river flows can decrease by up to 50% (Santander, 2006). These often coincide with high-demand periods, such as the high season for tourists (December–February). To account for the additional strain on water resources

Figure 4. (a) Current water supply performance and future needs driven by moderate demand projections. (b) Implementation and sequencing of a National Sustainability Strategy incorporating feasible investments and policies to meet relevant SDG and mitigation targets. SDG, Sustainable Development Goal.
posed during these periods, and the higher daily margin required to ensure reliable supply, this analysis applies a peaking factor used in previous studies (e.g., Verma et al., 2015) to the average daily water use in order to estimate maximum demand. These needs are projected to increase with additional tourist numbers. Meanwhile, the resilience of the water sector faces chronic and increasing pressures from (a) drier dry seasons linked to decreasing precipitation and (b) a greater frequency of extreme weather events that reduce water storage capacity due to sediment run-off and embankment collapses (GoSL, 2018a).

Given the geographical disparities between water availability on the island, achieving a resilient water sector will require distributed interventions beyond dependence on the island’s main treatment plant. Eliminating the gap between reliable water supply and peak demand is directly linked to the achievement of several water-related SDG targets—notably 6.1, 6.2, 6.4, and 6.6—in addition to its potential to influence those related to agriculture, health, and economic outcomes. Figure 4(b) shows a feasible pathway to a secure year-round water supply, combining a range of confirmed and potential future solutions including additional water storage (dam capacity and storage tanks), desalination plants, and demand and loss reductions. The decentralized nature of these interventions, several of which have been confirmed by the government, allow for the targeting of communities where water shortages are most acute.

Crucially, more than 50% of water supply is lost in the transmission system as nonrevenue water, roughly half through leakage. Large-scale loss reductions have precedent in similar contexts (IDB, 2018) and can incorporate steps such as establishing metering zones for better monitoring of flows and pressure, establishing a comprehensive asset management strategy, and undertaking pipe replacement to increase transmission efficiency up to 80%–90%. With concurrent development of wastewater infrastructure, the potential to reuse effluent for irrigation or other uses provides additional water supply capacity in the longer term.

### 3.3. Wastewater

Only 2% of wastewater in Saint Lucia is currently treated. The majority is collected in septic tanks and/or discharged into the environment. The island’s one operational wastewater treatment plant is utilized far below design capacity due to undersized sewer pipes unsuited to carrying larger volumes to the plant (Figure 5(a)). This status quo approach to wastewater treatment threatens the viability of Saint Lucia’s main tourist attractions, namely pristine beaches and natural ecosystems, with associated health and economic consequences.

To improve the efficacy of Saint Lucia’s wastewater treatment system, a number of centralized and community-based treatment options are considered in a sustainability strategy, starting with measures to efficiently utilize the existing plant which can increase the treatment rate by over 5 times (Figure 5(b)). Halving the share of untreated wastewater by 2030 is a central performance target aligned with the SDGs which can set the stage for further improvements post-2030.

In smaller communities, decentralized treatment solutions may be more cost effective. Wetlands are particularly appropriate for rural communities due to their simple design, operation, and maintenance and have already demonstrated improved and coordinated water resources management in the national context (GEF-IWCAM, 2011). Furthermore, the strategy benefits substantially from synergies with the water supply sector, targeted interventions in hotels, new homes, and industrial facilities, can provide relatively low-cost solutions that will reduce wastewater generation across the island.

### 3.4. Solid Waste

Solid waste management in Saint Lucia faces a looming capacity shortage as both landfills are due to close by 2023, when solutions must be in place to manage nearly 100 thousand tonnes of waste annually. Common to small islands, space is extremely limited, and the government has committed to phase out new landfill requirements. There are no recycling facilities, waste transfer stations, or compost facilities on the island. Informal recycling operations, which collect recyclable materials for export, are increasingly squeezed as international markets such as China and India restrict their imports.

With unmoderated waste generation projected to increase by 12% to 2050 (Figure 6(a)), a strategic plan to develop and implement solutions must be prioritized to reduce the risk of illegal dumping and informal
waste incineration. In addition to mobile incinerators which are being introduced to treat waste diverted from one of the island’s dumpsites, harnessing waste through incentives in the recycling and compost industries can achieve ambitious targets in line with international best practice (Figure 6(b)). The diversion of waste from landfill can similarly help the country reduce methane emissions in line with its commitments under the Paris Agreement. Distributing waste management to smaller-scale facilities across the island will add redundancy, increasing the resilience of the system to climate hazards, which currently relies on functional road networks to collect and transport all waste to one centralized landfill site.

Nearly 50% of Saint Lucia’s solid waste is organic (Tsai, 2013), presenting an opportunity to divert compostable material from landfill for use in the agriculture sector. Although initiatives for backyard composting exist—such as in schools or hotels—they do not provide a significant contribution to the management of waste at a national scale. A recently opened facility in the neighboring island of Saint Vincent suggests that large-scale commercial composting could play a part in Saint Lucia’s national waste management strategy.
Another large component of the waste stream can be addressed with a renewed focus on recycling initiatives, with regional cooperation agreements providing a means to undertake Caribbean recycling initiatives in an economically viable way. A new recycling plant in neighboring Martinique, currently operating under capacity, could serve as a destination for Saint Lucia’s plastic, which comprises 22% of its waste. Paper (10%) and glass (7%) are other major waste components that could feasibly be separated from the landfill waste stream.

To summarize the results, Figure 7 shows the composition of each strategy in 2030 for each of the four sectors, corresponding with the end date of the SDG agenda.

### 3.5. Cross-Sectoral Implications for the SDGs

While these results demonstrate strategic pathways to align supply-side options with future demand for infrastructure, this study also sheds light on each strategy’s cross-sectoral performance in relation to global development outcomes. Previous work by Adshead et al. (2019) developed a means to illustrate the links...
between infrastructure implementation and specific development outcomes using a set of performance indicators defined in the national context. Applying this framework to Saint Lucia, we get a clearer sense of how different strategies may or may not lead to the achievement of key targets of the SDGs.

Using a subset of 18 SDG targets across six goals, Figure 8 shows how development outcomes most directly linked to electricity, water, wastewater, and solid waste infrastructure in Saint Lucia may fare under each strategy. Given a current estimated achievement level of 36% across these targets, based on measured indicators assigned to each target, a course of inaction sees this drop to 24% by 2030 as future demand growth outpaces current capacity. A BAU approach makes slight gains in the short term due to the implementation of a handful of confirmed projects, but these improvements are halted and begin to marginally decline thereafter due to growing demands. In contrast, an infrastructure strategy based on sustainability objectives demonstrates a path to full achievement of these targets by 2030.
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Sector-specific impacts unique to Saint Lucia’s development challenges can be identified in these results. Sustainable Development targets that prioritize a secure energy supply (e.g., 7.1, 7.3, and 11.1) fare relatively well in all strategies, due to Saint Lucia’s implementation of strong reserve margins for diesel generation, which are entrenched in its Electricity Supply Act (Government of Saint Lucia, 1994). Targets centered on environmentally sustainable energy and waste solutions (e.g., 7.2, 9.4, 12.5, and 14.5) fare poorly and decline over time without strong interventions. The impact of sudden events such as the depletion of landfill capacity has immediate and visible effects across numerous targets. In order to ensure that progress toward SDG achievement is sustained into the future, planned infrastructure interventions must also incorporate resilience to the threat of climate impacts and other external shocks.

3.6. Cross-Sectoral Implications for the Paris Agreement

Given that its contribution to global emissions is low, Saint Lucia—along with other small island countries—has generally prioritized adaptation measures to protect its people and infrastructure from the regular threat of climate change-related hazards, and to build resilience to their impacts. This adaptation focus forms a major component of its commitments under the Paris Agreement. Nevertheless, the country is also committed to reducing its greenhouse gas emissions to levels that will restrict global temperature increase to 1.5°C above preindustrial levels and has used its NDCs as an opportunity to promote synergies between its climate commitments and other development priorities. Atypically for small island countries, Saint Lucia’s mitigation NDCs extend beyond its energy sector plans to highlight sectoral strategies for a range of sectors, including transport, fisheries, waste, land use, environmental management, and coastal zone management (Atteridge et al., 2020).

To derive the results of the cross-sector infrastructure analysis outlined in the previous sections, the model introduced the government’s mitigation targets as stated in the NDCs to help define the conditions for strategic investments and policies, which were assigned per-unit emissions values based on the type of fuel or technology used. Based on BAU emissions projections from 2010, these mitigation targets assume a 16% reduction in emissions by 2025 and a 23% reduction by 2030 (Government of Saint Lucia, 2015a). In the electricity sector, energy efficiency interventions proposed in the NDCs, such as buildings and appliances, were integrated into the strategy selection. While waste proposals were not quantified in the NDCs, overall reductions were achieved in this sector through a shift away from landfill toward lower emitting waste solutions. Although a high-emitting sector, transport interventions could not be integrated in the model; its emissions contributions are nevertheless shown here for comparison.

Figure 9 shows the baseline emissions, in tonnes of CO₂ equivalent, associated with Saint Lucia’s main emitting sectors at the last reporting period in 2010 (Government of Saint Lucia, 2015b). Over the next decade, meeting a rising demand for infrastructure services through a BAU portfolio of diesel and landfill capacity, in addition to continued fossil fuel use in the transport sector, will result in a failure to meet its mitigation commitments. A national sustainability strategy can bring emissions in these two sectors to target levels, largely by shifting the country to a renewables-based energy portfolio, as well as by removing large quantities of methane-producing waste from landfill sites, to be treated instead through recycling and compost initiatives. In order to achieve its full greenhouse gas reduction commitments under the Paris Agreement, further emission reductions in the transport sector, as well as industry and agriculture, are required.
Earth’s Future

4. Discussion

4.1. What Have We Learned From Applying an Integrated Planning Approach to a Small Island?

The methodological approach developed here provides a systematic process for infrastructure decision-makers, through stakeholder-driven participatory modeling, to formalize pathways to meeting global development targets. As suggested previously, the small island context of Saint Lucia provides an illuminating study in which to apply this approach given the ability to access a wide and comprehensive range of the island’s infrastructure decision-makers, planners, and practitioners.

Importantly, this study has demonstrated the benefits of infrastructure planning across sectors, suggesting that societal benefits can be amplified—and delivered more cost effectively—when the infrastructure system is addressed in a holistic way. Often, silo-based planning of individual sectors fails to capture these benefits and may lead to sector-specific plans with conflicting outcomes or objectives. Infrastructure practitioners may envision monetary benefits associated with a particular project. In the case of a small island, where tourist revenue is the island’s economic lifeline, plans for a new port, expanded airport, or resort development are often sought after for their expected income and employment benefits. But, with residential needs already vastly undersupplied by water, waste, and other infrastructure, how can these major new facilities be supported?

In Saint Lucia, the government’s own projections indicate 101 and 57% increases in annual stay-over and cruise tourist arrivals, respectively, linked to planned expansions of its air and cruise transport hubs by 2050. This assessment has incorporated these projections to quantify the expected additional pressures on the island’s existing infrastructure across other sectors. At the same time, on the solutions side, interdependent measures can address multiple sectors at once. Cumulative water efficiency measures integrated in a sustainable infrastructure strategy were shown to reduce wastewater generation by 12%. With the development of wastewater treatment technology, treated effluent may contribute an additional 8% of water supply for...
uses such as irrigation. While not currently under consideration, waste-to-energy and anaerobic digestion technologies may provide solutions that address challenges unique to Saint Lucia and other small islands, such as limited space for landfill and high amounts of organic waste. In Saint Lucia, proposals have shown that these could treat the majority of the island’s nonorganic and nonrecyclable waste and would introduce energy self-sufficiency by generating electricity for the grid. If not feasible on the island, these technologies may also form part of a regional infrastructure strategy, whereby another island relies on waste inputs from its neighbors in order to maintain its investment operating at capacity.

Addressing interdependence has relevance both for meeting infrastructure demand in the long term and for increasing system resilience. Given its interconnectedness, the risks of service disruption posed by specific climate and weather hazards to Saint Lucia’s infrastructure sectors can have much broader impacts across the island’s social assets such as hospitals, schools, and government buildings.

Cost savings associated with cross-sectoral solutions can make them attractive to policymakers. National infrastructure systems designed in line with Saint Lucia’s global commitments may require short-term investment in modern, high-tech facilities and networks—but long-term savings make these strategies most cost effective. Incorporating demand-side and efficiency-side measures in all sectors will bring total infrastructure requirements down—as well as the costs required to supply them. Similarly, investing in more sustainable technologies and solutions will cost governments less in the long term as demand is more efficiently met and operating expenses decrease. Using per-unit generation costs for relevant technologies derived from national accounts and international energy statistics (LUCELEC, 2018; NEA/IEA/OECD, 2015), the total cumulative costs associated with the portfolios of investments and policies used in this analysis are shown for the country’s electricity sector (Figure 10). Continuing along the current path to meet increased demand requires less short-term investment in capital expenditure but results in increased costs over time. Interdependent infrastructure sector modeling can identify strategies that lower operating costs in future years, leading to reduced financial commitments for national governments. Further, shifting away from a reliance on diesel-based energy generation will increase the country’s energy independence by decreasing its vulnerability to fluctuations in international fuel prices. While data were insufficient to estimate costs across other sectors, these patterns of reduced costs are expected to apply in a similar manner.

Figure 10. Long-term costs associated with inaction, business-as-usual, and a national sustainability strategy for Saint Lucia’s electricity sector.

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4.2. Dynamic and Adaptive Infrastructure Planning Has Transferable Principles That Can Be Applied to a Wide Range of Countries of Differing Sizes, Contexts, and Stages of Development

Finance and governance of infrastructure are major pieces of the development puzzle, and the adoption of robust and rigorous assessment methodologies allows decision-makers to make investments with a greater potential for impact. The development of tools and methods that decrease uncertainty, and thus mitigate risks, around sustainable infrastructure project delivery is key to attracting international investment necessary to fund ambitious infrastructure plans. A well justified infrastructure strategy helps to build confidence that investments will be used and will yield returns while being consistent with environmental, social, and governance commitments. Furthermore, infrastructure strategies directly linked to the likely achievement of specific global development targets, such as those included in the SDGs and the Paris Agreement, can provide justification for these large-scale financial commitments. Beyond what has been presented here, there is much scope to pursue scenario assessment of future changes in various aspects of the enabling environment in relation to infrastructure project implementation (Thekdi & Lambert, 2014).

In order to avoid inappropriate infrastructure strategy selection—specifically, those that may face implementation barriers related to the enabling environment—this analysis has relied on stakeholders’ opinions as to the potential success of investments and policies, and the timeframe for their implementation. For simplicity, the analysis has filtered out projects presently considered unfeasible in Saint Lucia, such as waste-to-energy. However, given the pace of technology change and shifting political winds, incorporating them alongside relevant risk indicators could provide a more thorough and adaptive assessment. These should necessarily account for future political, financial, regulatory, and other barriers that may affect the projects’ future implementation and may act as constraints or optimization criteria in the modeling exercise.

A strong enabling environment is required to facilitate sustainable and resilient development across the infrastructure lifecycle. In Saint Lucia, the National Integrated Planning and Program (NIPP) unit, embedded within the Department of Finance, is tasked with a major responsibility to drive forward this integrated approach to policymaking, coordinating aspects of regulation, finance, project delivery, operations and maintenance, and human capacity. Following a model that has been increasingly employed in other countries (National Infrastructure Commission, 2018; PICC, 2012; Treasury, 2019), the unit provides a means to move away from a siloed approach to infrastructure. This governance model can ensure that national priorities and targets are established and pursued collectively with the input of all relevant stakeholders in the Government of Saint Lucia, research institutions, and the private sector and regularly informed by the latest available data. Results from this assessment suggest that this will provide Saint Lucia with an infrastructure planning approach that will be cheaper, more efficient, and more closely aligned with national goals and international commitments in the long run. Providing decision-makers with evidence-based tools required to undertake strategic infrastructure assessment will better equip the government to make effective investments and policies in the future.

5. Conclusion

This paper has developed and demonstrated the application of a systematic national infrastructure assessment to a small island context, consisting of a stakeholder-driven analysis framework that aligns national infrastructure planning with the SDGs and the Paris Agreement. It provides the elements required to effectively assess current and future infrastructure performance, propose a range of strategic options, group these options into policy and investment portfolios, and compare their performance on development outcomes and emissions targets. The results demonstrate that Saint Lucia faces an ambitious, yet feasible, path to reaching relevant 2030 targets and addressing key development challenges through strategic interventions in the electricity, water, wastewater, and solid waste sectors.

The application of this methodology to Saint Lucia was limited in certain ways. First, island-wide data on the transport sector were insufficient to model current performance of the road network and to assess future transport options in relation to relevant SDGs and NDCs. As a result, the implications for emission reductions in the sector, which will be crucial to meeting the country’s NDCs, have been largely omitted from this analysis. A second limitation regards the costs associated with each strategy developed for this analysis, which have been shown only for the electricity sector, due to a lack of costed estimates for other infrastructure types in Saint Lucia.
In Saint Lucia, this study marks only the first step of a journey toward sustainable and resilient infrastructure planning. An iterative assessment process incorporating the methods demonstrated here may provide alternative results defined by the government’s shifting priorities, feasibility of investment and policy implementation, and demand driver uncertainties at a given point in time. These principles can be used to inform more robust, coordinated planning and policy solutions, bringing together knowledge and insight from national and local government, the private sector, research and nongovernmental organizations together in a central decision-making framework. Geospatial hazard and adaptation analysis can complement long-term infrastructure planning by assessing the long-term and short-term threats to infrastructure assets posed by climate change and extreme weather events.

The challenges facing small islands in the coming decades are stark: demographic uncertainties, increased intensity of climate change, and the urgent need to ensure reliable, clean, and affordable infrastructure services for residents and visitors. With infrastructure so crucial to Saint Lucia’s development, the consequences of inaction or a business-as-usual approach to infrastructure planning will limit the island’s social and economic potential. This study demonstrates how a combination of infrastructure systems analysis and decision analysis, informed by quantified performance metrics, and help to create an actionable infrastructure strategy that maps out a pathway toward a more sustainable future for the island.

Data Availability Statement

The data and targets used for the generation of results graphs are available at the following link https://www.dropbox.com/s/3nxd7f4589jb9vu/Supplementary%20data.xlsx?dl=0 and are cited in the references.
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