Section 1: Overview

Extreme vulnerability to external fuel price shocks and the desire to play their part in mitigating the impacts of climate change have prompted Small Island Developing States (SIDS) to diversify fuel resources and attract new investments in electricity infrastructure as they prioritize energy efficiency and security. Long-term investment planning tools are essential for informing these decisions. However, it is common practice in SIDS to focus only on generation expansion planning (GEP), neglecting (or only subsequently accounting for) investments in transmission infrastructure. Furthermore, there is sparse empirical literature on energy policy that explicitly accounts for the unique economic (e.g. high debt and limited fiscal space) and geographic (e.g. small size, diseconomies of scale and isolated electricity generation) features of SIDS. This is often due to difficulties in obtaining data and the fact that long-term investment planning tools are often proprietary. In this paper, we contribute to the scarce literature on energy planning and policy relevant to the SIDS context by empirically evaluating optimal investment decisions for the electricity sector. We use Jamaica – the largest English-speaking Island in the Caribbean – as a case study over a planning horizon up to 2040. We also provide a flexible, freely accessible tool for conducting bottom-up investment planning and energy policy analysis that can be used to corroborate or evaluate plans generated by proprietary models. Finally, we provide a practical demonstration of minimum cross entropy (MCE) as a second-best approach for addressing data gap issues common to SIDS and other developing countries. Ultimately, we provide a platform that encourages empirical energy-related research in developing countries, expanding the extant literature.

GEP-only models may fail to account for loop flow, a phenomenon intrinsic to electrical networks that cause electricity to flow along parallel lines instead of desired, pre-determined contract paths. While research suggests that loop flow can misalign private and social costs and potentially misallocate resources, the impact of loop flow also increases with the size and complexity of the network (Chao and Peck, 1996). So is a SIDS like Jamaica too small and is’ network topology insufficiently complex to make loop flow an insignificant economic consideration, or does loop flow have an important impact on decision making? This is the first question this study answers.

The second question we address concerns modelling approaches used for generation and transmission expansion planning (GTEP). Unlike GEP, GTEP co-optimizes both generation and transmission investments. However, SIDS typically optimize these two investment decisions sequentially. That is, generation investments are first optimized, and once decisions are made to build new power plants, transmission line investments are optimized to accommodate the added generation capacity. This, however, can potentially lead to cost overruns due to the substitutability of local generation and remote generation facilitated by transmission lines. Recent advancements have allowed for simultaneous optimization of generation and transmission investments, but research primarily focuses on larger more developed countries that lack the distinguishing economic and geographic features of SIDS. In light of this, we pose the second question: How do the two modelling approaches affect system cost and investment decisions?

As expected, the common practice of sequentially optimizing investment decisions increases costs while failing to account for loop flow under-estimates costs. However, these errors are marginal for the Jamaican case, ranging between US $9.2 million and US $3.33 million, which are each less than 1% of total cost over the planning horizon. In terms of capacity decisions, model specification marginally affects the timing of investments. Under the sequential planning framework however, a small hydro-power plant is unnecessarily built, justifying the use of simultaneous co-optimization as the most efficient approach. Most importantly, despite a vision of increasing investments in renewable energy (RE) technologies, without policy interventions, Jamaica will likely miss its renewable energy target of 30% by 2030. Our model is therefore a useful tool in power systems planning as well as in ex ante evaluation of renewable energy policies.
Section 2: Methodology and Data
We utilize a dynamic optimization framework based on the Direct Current Optimal Power Flow (DCOPF) model described in Krishnan et al. (2016) and modified in accordance with the Long-term Investment Planning model designed by Purdue University’s State Utility Forecast group (SUFG), developed for selected contiguous African countries. Our objective is to minimize the net present value of investment and operational costs of the Jamaican power sector up to 2040, subject to operating parameters of the network, technical features of generation and transmission infrastructure and variable renewable energy (VRE) technologies, as well as expected electricity demand from a social planner’s perspective. We model generation capacity and transmission line investment decisions as binary variables to better reflect the real-world problem. We solve the planning problem as a Mixed Integer Linear Program (MILP) in the General Algebraic Modelling System (GAMS), using IBM/Cplex solver. We specifically optimize investment decisions with and without constraints representing Kirchhoff’s voltage laws (KVL) to determine the impact of loop flow on investment decisions.

The Office of Utilities Regulation (OUR), Petroleum Corporation of Jamaica (PCJ), the Meteorological Office of Jamaica and the US Energy Information Administration (EIA) provide the relevant data. Input data includes supply-side information (such as technical features of existing and candidate generating units and transmission lines), demand-side data (such as historical and forecasted demand) and price data associated with investment and operating costs. To overcome some gaps in data with respect to electricity demand, we utilize MCE (Golan, Judge, and Miller, 1996; Kullback, 1959; Shore and Johnson, 1980) to spatially distribute hourly demand for Jamaica based on historical hourly demand data and annual demand forecast per customer class. While this is a second-best approach, given the scarcity of empirical work relevant to the SIDS context, this study makes a practical demonstration of how data gaps can be addressed in empirical studies without making additional assumptions beyond what is already known about the variable of interest.

Section 3: Results and Insights
We find that sequentially optimizing generation and transmission investment decisions, as has been the historical practice in Jamaica, increases costs when compared to the simultaneous planning method by US $9.2 million. Failing to account for loop flow under-estimates costs by US $3.33 million. However, each of these represent less than 1% of total cost over the time horizon. This is likely due to the small size and near-radial topology of the Jamaican electricity network. This result also suggests that sequential investment planning, though sub-optimal, may not have significantly distorted Jamaica’s previous investment plans. However, relative to the simultaneous model, the sequential model results in the unnecessary construction of a small hydro-power plant. This is because, during the first stage of the sequence when generation capacity decisions are made, transmission investments, which may facilitate remote generation by existing units, are not considered until the second stage – after the generation capacity decisions have already been made. Consequently, sequentially planning for generation and transmission infrastructure increases costs by US $9.2 million (roughly JD $1.182 billion). This justifies the modest additional computational requirements of simultaneous co-optimization.

Using the simultaneous model as the most efficient framework, our results indicate that Jamaica needs to invest in 979.3 MW of additional capacity by 2040. This includes 745 MW of natural gas, 150 MW of wind capacity, 47.3 MW of hydro capacity and 37 MW of solar capacity. Note that this 37 MW solar power plant is exogenously imposed on the model since plans are already afoot to construct this power plant in 2019. Otherwise, no solar plants would be built due to the variability of sunlight and low availability factors. This implies that wind and hydro technologies are the best RE options for Jamaica. Utility-scale solar power would likely have to be supported by storage technologies and an incentive policy.

Section 4: Conclusions
In this paper, we contribute to the scarce literature on energy-related matters relevant to Small Island Developing States by empirically evaluating optimal investment decisions for the electricity sector in Jamaica up to 2040. We find that simultaneously co-optimizing generation and transmission investment decisions is less costly than the traditional sequential approach and is worth the modest additional computational requirements of simultaneous co-optimization. Though imperfect, our use of MCE is a practical demonstration of how this method may be utilized in an environment with sparse data, minimizing the disincentive for researchers to do research on small islands or developing countries with limited data infrastructure. Finally, we observe implications for Jamaica’s ambition to increase the use of renewable resources such that they account for 30% of the country’s generation portfolio by 2030. Assuming a business-as-usual scenario, this target is too costly; a cost-minimizing planner makes investments resulting in a maximum of 17% RE generation long after the target year. External government intervention may therefore be required to achieve this objective.