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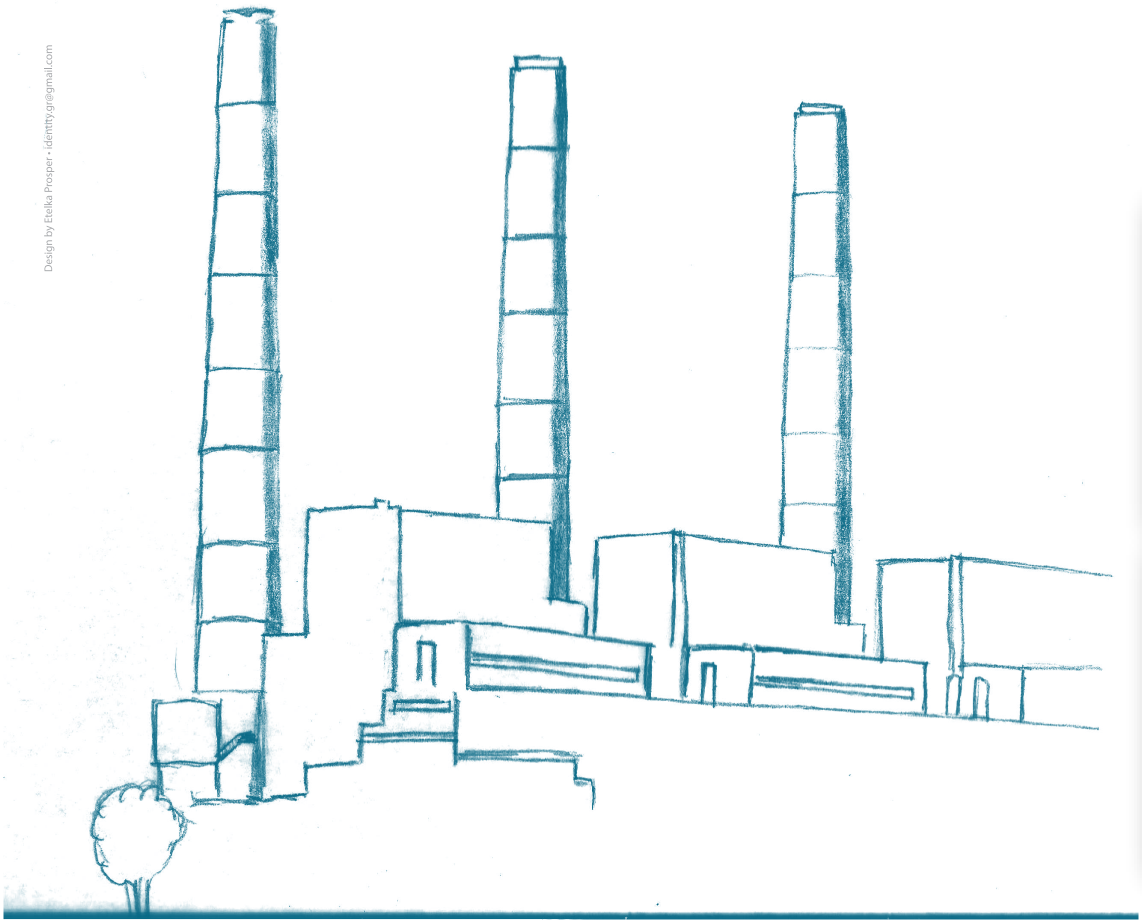
Benefit-Cost Analysis

Comparing Grid-Scale Thermal Energy Generation Technologies in Haiti



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Haïti Priorise
Un plan de développement alternatif

Comparing Grid-Scale Thermal Energy Generation Technologies in Haiti

Haïti Priorise

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Canada

Academic Abstract

In this paper, we attempt to quantify the costs and benefits of installing new electricity generation capacity in Haiti using coal, natural gas, and oil burning thermal generators with differing levels of efficiency. We consider costs and benefits in comparison to a counterfactual scenario wherein electricity is purchased from diesel burning independent power producers (IPPs) at the current Power Purchase Agreement (PPA) price. The benefits of installing thermal generation capacity come therefore in the form of cost savings to Haiti's energy utility, as well as, in some cases, reduced carbon dioxide emissions for the world. Costs are presented as the average yearly capital, operating, and maintenance costs associated with the installation and operation of one megawatt (MW) of generation capacity at grid scale, as well as increased carbon dioxide emissions in some cases. We consider the sensitivity of the benefit-cost ratio (BCR) estimates to changes in the discount rate, the cost of fuel and the capacity factor for each technology. We consider different scenarios for fuel use, each of which allows for changes in the costs of inputs, heat rate, and carbon emissions, due to uncertainty about the future of the natural gas market in the Caribbean.

Abbreviations in this Report

ACC – Advanced Combined Cycle

ACT – Advanced Combustion Turbine

BCR – Benefit-Cost Ratio

CCC – Conventional Combined Cycle

CCT – Conventional Combustion Turbine

CO2 – Carbon Dioxide

EDH – Electricité d'Haïti

GDP – Gross Domestic Product

GOH – Government of Haiti

INGO – International Non-Governmental Organization

IPP – Independent Power Producer

IRENA – International Renewable Energy Agency

kWh – Kilowatt Hour

LNG – Liquid Natural Gas

MDB – Multilateral Development Bank

MW – Megawatt

MWh – Megawatt Hour

NG – Natural Gas

O&M – Operating and Maintenance

PPA – Power Purchase Agreement

USD – United States Dollar

Policy Abstract

Overview and Context

Haiti is the poorest country in the Americas, and one of the poorest in the world, with a GDP per capita of only 818.3 USD in 2015 (World Bank, 2017). Among the many issues that coincide with such poverty is a severely underdeveloped and under maintained electricity system. The per capita consumption of electricity in Haiti is significantly lower than other Caribbean countries, and is only two percent of the neighboring Dominican Republic (World Bank, 2015, p.5). Only 35% of Haitians have access to electricity through electrical grids. In rural areas that figure is 11% (World Bank, 2015). The Haitians who do have access to electricity face frequent blackouts and may only be able to access power during certain hours of the day.

Haiti's economic woes are intertwined with issues in the energy sector. While a weak national economy influences the poor state of the energy sector, the lack of available electricity can similarly hamper economic development, creating a "catch 22" situation that may require outside intervention to remedy. The lack of reliable electricity supply is cited by business owners as the most binding constraint to private sector development (World Bank, 2015, p.5). There is little doubt that improving the electricity market is a key step for Haiti towards an improved economy and improved welfare for citizens.

In this paper, we consider the possible benefits and costs that could be associated with increasing Haiti's generation capacity using either coal, conventional combustion turbine, advanced combustion turbine, conventional combined cycle and advanced combined cycle thermal generators. There are numerous issues with Haiti's power grid, including its lack of connectedness, and high levels of commercial and technical losses, due in part to aging and damaged infrastructure. For these reasons, we choose to consider the marginal costs and benefits of adding an additional MW of capacity for each technology.

Implementation Considerations

The primary costs of adding thermal generation capacity to the grid are (i) the costs of capital, and (ii) the operating and maintenance (O&M) costs, which for thermal generators is mainly the cost of fuel. It is important to consider the potential sources of fuel available to Haiti, and the potential factors that could affect their prices moving forwards. Natural gas is still not easily accessible in Haiti, but it is possible that in the future infrastructure could be built to expand such a market. For now, liquid fuels are the primary fuel source for electricity generation in Haiti.

Installing additional thermal generation capacity could generate more benefits than costs, depending on the assumptions integrated into our model. Although the ability of Electricité d'Haïti (EDH) to invest in long term generation capacity is questionable due to their financially unsustainable practices, our analysis shows that thermal energy projects can, in some contexts, generate positive net economic benefits.

The success of our proposed interventions would be measured through the costs they save EDH and the carbon dioxide emissions that are reduced compared to plausible alternative forms of electricity generation. There should be no need to come up with complicated indicators to monitor the success of our intervention besides the average yearly cost of the project and the amount of electricity dispatched into the grid. The success of the project will be apparent from the decreased cost of electricity per kWh compared to PPA prices.

These interventions could be implemented by EDH, or by IPPs. However, EDH's finances are in quite poor shape, which constrains their ability to finance good projects. Haiti's public investment management is also run inefficiently, so we may need to look to actors outside the country to help with financing (World Bank, 2015, p.2). Electricity projects could present potential opportunities to partner with multilateral development banks (MDBs), development agencies, philanthropists or other INGOs.

The technologies we consider have a predicted lifespan of approximately 25 years according to estimates from EIA (2017, p.4). Thus, costs and benefits of the project are subject to some level of uncertainty. Two of the key parameters that anchor our analysis are the current costs of thermal technologies (both their capital costs and their operating and maintenance costs), as well as the current PPA prices. Both are subject to change in the lifespan of any installed generation capacity. Oil volatility will impact the PPA price of electricity as well as the operating costs associated with our interventions. Our results correlated with the amount of energy actually dispatched into the grid. Due to the different sources of uncertainty, we conduct analysis to see how the benefits and costs calculated with our model are influenced by changes in inputs.

Grid-scale thermal generation technologies can produce inexpensive electricity, but are also responsible for the emission of carbon dioxide (CO_2), a greenhouse gas that contributes to global climate change. While there are social costs associated with CO_2 emission, these costs should be weighed against the benefits of generation. Obviously, one of the benefits could be cheaper electricity, in which case we can imagine some kind of trade-off between environmental concerns and cheap energy. However, it is also possible that the addition of grid scale thermal energy generation will actually lead a net decrease in CO_2 emissions, when compared to the technologies that would be used to produce electricity in its absence. The emissions from diesel burning IPPs is probably somewhere in between our cleanest thermal technology (ACC) and our dirtiest (Coal).

There are some unavoidable risks associated with expanding generation capacity, such as the risk of natural disasters that could damage installed capital, risks associated with fuel price volatility, or risks associated with an unstable political system. If EDH maintains the current level of technical and commercial losses, the financial feasibility of the interventions also could be called into question. Investing in thermal electricity generation capacity is financially risky however, it may be less risky than alternatives like solar or wind because a large percentage of the cost is not sunk. In a country as unstable as Haiti, generation technologies with lower capital costs may be attractive to investors.

Rationale for Intervention

There are two main benefits that could emerge from investing in thermal energy generation. The first is cost savings. These cost savings could help make EDH more financially sustainable or lead to improved electricity supply for consumers. The other benefit of generating electricity using grid scale thermal is that in some cases, there is a net reduction in carbon dioxide emissions when compared to plausible alternatives. IPPs currently produce power by burning diesel or other fossil fuels, the combustion of which will produce carbon dioxide (CO_2), a harmful greenhouse gas that contributes to global climate change. While thermal generation will also produce CO_2, the amount emitted can be much less than would have alternatively been produced, due to higher levels of efficiency. Thus, by generating electricity using our proposed technologies, power producers could, in some cases, supply electricity which is cheaper and cleaner than is currently being purchased from IPPs.

The primary beneficiary of our proposed interventions are the consumers and producers of power in the PPA market, as a result of a shift in the supply curve. The rest of the world could also benefit because of carbon emissions that are reduced as a result of using more efficient generation methods than current IPPs.

We do not consider the possible changes in consumer surplus that could indirectly result from improved electricity supply, but rather value the newly available electricity at the market price charged by IPPs. This presumes that PPA markets are not constrained, which may not be the case. However, this ensures that our estimates are conservative and defensible. We also do not consider the benefits of economic growth, a process that will likely require electricity expansion of Haiti's electricity systems. While electricity is an undeniable prerequisite for economic growth, we are hesitant to attribute discrete benefits to marginal expansions of generation capacity. Growth is also a challenge to incorporate into our model without double counting, since in many ways, economic growth results from improved access to electricity, the value of which we already include in our analysis.

In table 1 we provide summary of the costs and benefits of the four technologies under our baseline assumptions. The range of possible costs and benefits incurred as a result of each intervention in different scenarios is broad, and we discourage readers from taking these values out of context. The baseline scenario that gives rise to the estimates in table 1 assumes that the non-coal generators will use heavy fuel oil (HFO) due to a limited natural gas supply in Haiti. The cost of inputs, heat rates and carbon emissions all reflect these assumptions.

Table 1 – Summary of the Costs and Benefits of the Proposed Interventions (2017 USD)

Technology	Benefit (USD)	Cost (USD)	BCR	Quality of Evidence
Coal	1,265,119.20	644,534.06	1.96	Medium
CCT	1,265,119.20	780,099.46	1.62	Medium
ACT	1,265,119.20	684,409.89	1.85	Medium
CCC	1,268,747.210	530,161.01	2.39	Medium
ACC	1,271,010.898	500,136.25	2.54	Medium

Notes: All figures assume a 5% discount rate and assume the use of HFO or Coal.

1. Intro

In this paper, we estimate the costs and benefits of adding a marginal amount of grid-scale thermal electricity generation to Haiti's electricity infrastructure.

This paper is written as part of the Haïti Priorise project, an initiative which aims "to identify, analyze and prioritize interventions that will deliver greater benefit per dollar spent, helping move Haiti towards a more prosperous long term future" (CCC, 2017). Haïti Priorise should, in theory, allow a range of potential interventions to be compared based on their Cost-Benefit ratios (BCRs). By ranking the interventions based on their BCRs, Haïti Priorise can provide some guidance with respect to where parties willing to finance Haitian development could most efficiently allocate their money.

The authors have worked on four papers within this project, which share the same assumptions, and level of analysis. We encourage readers to refer to all of these papers when considering investment options in the Haitian electricity market. These papers address the following subjects:

1. Comparing Grid-Scale Renewable Energy Generation Technologies in Haiti
2. Comparing Grid-Scale Thermal Energy Generation Technologies in Haiti
3. The Potential Providing Electricity using Isolated Grids in Haiti
4. The Potential of Reforming Haiti's Electricity Institutions

2. Context

The Poorest Country in the Western Hemisphere

Haiti is one of the poorest countries in the world and has shown little improvement in the past decades. GDP growth in Haiti averaged 1.2% annually from 1971 to 2013, compared to the Latin America and Caribbean (LAC) average during this period of 3.5% (World Bank, 2015, p.4). When we account for population growth, the story is even worse. Haiti's GDP per capita decreased by an average of 0.7% per year between 1971 and 2013, (World Bank, 2015, p. 4). While much of the developing world has seen rapid growth in the years since World War II, Haiti has clearly been left behind. According to the World Bank (2015, p.1), 59 % of Haitians are considered "poor", meaning they live on less than 2 dollars a day (2005 USD, PPP). 24 % are considered "extremely poor" meaning they live on less than 1.25 dollars a day (2005 USD PPP).

Natural Disasters

Part of the reason Haiti has struggled so much economically in the recent past can be attributed to a high number of natural disasters. Haiti experienced 137 natural disasters between 1971 and 2014. As a result, Haiti lost an estimated 180% of its GDP, and saw more than 2% of its current population lose their lives (World Bank, 2015, p.22). Relative to its neighbors, Haiti seems to have been both more exposed and more vulnerable to natural disasters. Between 1971 and 2014, Haiti had more than twice as many floods and thrice as many draughts as their neighbor the Dominican Republic (World Bank, 2015, p.22).

The worst of Haiti's disasters have occurred in the past decade. In 2008, tropical storms and hurricanes caused an estimated loss of 15% of GDP as well as many deaths (World Bank, 2015, p.21). This, however, pales in comparison to the damage caused by the 2010 earthquake. It is estimated that the January 12, 2010 earthquake killed more than 200,000 people and destroyed the equivalent of 120% of Haiti's annual GDP (World Bank, 2015, p.15). This unprecedented natural disaster put further strain on a country whose economy was struggling to grow. The earthquake destroyed roads, schools, hospitals, transmission lines, and much more of the infrastructure essential for Haiti's economy.

Electricity in Haiti

Haiti's economic condition both influences, and is influenced by, its failing electricity market. Only 35 % of Haitians have access to electricity through grids. In rural areas that figure is 11 % (World Bank, 2015). Per capita consumption of electricity in Haiti is significantly lower than other Caribbean countries, and is only two percent of the neighboring Dominican Republic (World Bank, 2015, p.5).

The inability to access electricity has serious implications for all Haitians, but is especially harmful for commercial and industrial enterprises. The lack of reliable electricity supply is cited by business owners as the most binding constraint to private sector development (World Bank, 2015, p.5). Businesses in Haiti also face some of the highest costs for electricity in the region, making it hard for them to operate competitively. Households also suffer from lack of available power, and are forced to adopt coping strategies such as using small diesel generators to power household appliances, or burning kerosene oil for light. Those Haitians that do have access to electricity through grids face shortages, and it is estimated that those with connections only have electricity for 5-9 hours a day (Worldwatch Institute, 2014, p.26).

Haiti's electricity sector is also a serious financial burden on Haiti's economy. EDH requires a transfer that averages $ 200 Million USD each year to cover operating costs. This is equal to 10% of the national budget or 2% of GDP (World Bank, 2015, p.68). EDH's significant financial losses are partly due to high levels of commercial and technical losses in the electrical grid which prevent EDH from collecting revenue. If EDH could reduce technical losses sufficiently and improve the collection of payments for electricity that is consumed, it is reasonably certain that they could operate in a more financially sustainable way. Reforming EDH could make all other interventions on both the supply and demand side of Haiti's electricity market more feasible.

The Potential of Thermal Generation

One option for improving Haiti's electricity supply is the installation of additional thermal generation capacity. Thermal energy is generated when combustible fuels are burned. This energy can then be converted to mechanical energy, which can then be used to produce electricity. This method of generating electricity can be simple and cost effective (depending on the local availability of fuel), but can also contribute substantially to pollution and greenhouse gas emissions. The costs of emissions should be considered, but should be weighed against the potential for cheap energy which is a crucial prerequisite for Haiti's economic development. The costs of carbon emissions should be compared to the benefits of electricity produced when judging any combustion technology

The types of fuels used in thermal generators include coal, natural gas, and a number of different types of oil, such as gasoline, diesel, or heavy fuel oils (HFOs). In a country like Haiti, access to some fuels, like natural gas may be limited, or very costly. For Haiti to import large amounts of natural gas would require substantial investment in a specialized terminal for which the upfront investment costs would be substantial. While there has been some development on this front, such as the Maurice Bonnefil LNG Regasification Terminal project in Port Au Prince, which will have 15,000 cubic meters of storage capacity, significant investment would be needed to secure a large-scale supply chain for natural gas outside of Port Au Prince. However, investment may be viable. A report from IDB (2014) suggested that a market could be established in the Caribbean and affordable natural gas could be distributed at a net economic benefit. We consider such a scenario as an addition to our model, but consider a baseline scenario where natural gas is not available and generators substitute HFO in the place of natural gas.

It should be stated in no uncertain terms that “fixing” Haiti’s energy problems will be incredibly challenging and that just because an intervention has high potential net-benefits does not mean that those benefits can be actualized without other considerations. This paper addresses the possible benefits of introducing additional thermal energy sources to Haiti’s electricity generation capacity which we find to be considerable. However, we believe any interventions that adds generation capacity to Haiti’s electricity market would ideally be preceded by institutional reforms. High technical and commercial losses greatly reduce the impact of new generation, and an inefficient pricing system put in place by EDH that distorts market factors means that businesses and consumers may not be able to access the benefits of improved power supply. We have analyzed the possible effects of reforms to Haiti’s electricity system in another paper for Haïti Priorise, and we encourage anyone interested in improving Haiti’s electricity market to consider our recommendations made in that paper.

3. Theory

The Benefits of Improving Electricity Supply in Haiti

In our analysis, we assume that EDH, Haiti’s electrical utility (or some other actor that serves the same function) will generate electricity for the grid by burning fuel like coal, natural gas, or oil. While basic microeconomics tells us a shift in the supply curve would theoretically lead to a change in the price paid by consumers, such theory is typically only relevant for competitive markets in equilibrium. Haiti’s prices for electricity are set nationally, and have not changed since 2009. Thus, we choose to omit the implications for consumers of a change in the cost of supplying power and focus instead on the reduction in the cost paid by the power producer.

In our model, we assume the cost of producing power in the counterfactual scenario would be equal to the average price currently paid to IPP's through PPAs. Thus, the benefit of the newly generated electricity is equal to the value that EDH pays for it in the closest thing we have to a market. It is worth noting that market distortions could make such a price a non-equilibrium representation of value. However, using PPA prices should give us a conservative estimate of benefits. This is something we believe is important for an exercise such as Haïti Priorise.

Capacity Factor and Dispatchability

One concept central to our understanding of the benefits generated by thermal generation is the concept of the capacity factor. The capacity factor is a measure of how much electricity is generated by an energy source versus it's potential generation. Thermal electricity generation technologies should be able to generate a relatively constant output of power, with the exception of some downtime for maintenance.

In the case of renewables sources of generation such as wind and solar, the intermittency of supply results in cases where the technology is generating but the energy cannot be dispatched into the system. This is often due to the system's limitations in absorbing supply stress or lack of demand at that point in time. The thermal sources discussed here are slightly different. Small thermal systems such as CTs and diesel generators come with great flexibility, they can be turned on and off as needed by the system. The larger systems with a steam cycle, such as CC and coal, must run most of the time as they have lengthy and expensive cool down and heat up periods. In both of these situations, the supply is not intermittent. Technologies such as coal are often positioned to serve the baseload: the volume of electricity that is demanded at all times. Therefore, dispatchability tests are not conducted for these technologies, instead the sensitivity of results are only tested against capacity factor, which is a planning question rather than a source of risk.

The capacity factor enters our model as simple multiplier to each technology that converts the total amount of electricity that a 1 MW generator could produce in a year, if operated without a stop (8760 MWhs), to the expected generation planned in the electricity system. Our capacity factor estimates come from EIA (2017) and represent American averages. However, we elevate the capacity factor for some technologies that are typically used to satisfy only peak loads in America (non-combined cycle combustion turbines), it is common to see the use of technologies such as gas turbine or even diesel to satisfy baseload in relatively smaller grids.

It is possible that the capacity factor could be even higher than is listed in our model. In our model, we consider the marginal benefits of an additional MW of capacity. Because Haiti has such a high level of excess demand, it seems unlikely that excess supply would be an issue at the margin. Even considering these arguments, the model we have built includes different scenarios for capacity factor, and can tell us how the costs and benefits change in response to higher or lower capacity factors.

4. Calculation of Costs and Benefits

Benefits, Costs, and Stakeholders

The following sections will explain how we estimated the costs and benefits of adding different thermal energy technologies. However, before we explain our calculations of costs and benefits, it is worth explaining the stakeholders we have included in our model.

The first of two major stakeholders we consider in our model is called the "Partnership". The Partnership is the group of actors responsible for the financing, implementation and management of the intervention. It could be limited to just EDH, or some other power producer acting independently, or could include a donor, philanthropist, MDB, etc. We consider this stakeholder as the primary beneficiary of improved electricity supply, and the primary payer of costs associated with generation. The Partnership is assumed to accumulate benefits and costs for Haiti, but we can also imagine a case where foreign donors transfer costs from Haitian actors to actors from elsewhere.

The other stakeholder we consider is denoted as "All Countries". This stakeholder is comprised of other people on earth who benefit from a reduction in CO_2 emissions. While this includes Haitians, the percentage of the global population comprised of Haitians is relatively low, and so we find it more informative to separate these benefits from those we apply to Haiti.

Table 2 – Benefits, Costs and Stakeholders

	Stakeholders			
	Globe			
	Haiti		All Countries	Total
	Partnership	Total		
Benefits				
Value of electricity dispatched	X	X		X
Reduced carbon emissions			X	X
Costs				
Capital expenditure	X	X		X
Operating costs	X	X		X
Increased carbon emissions			X	X

In Table 2 we show the stakeholders in our model, and the costs and benefits that we attribute to them. Notice that the Partnership assumes the costs and benefits of power generation, but the benefits (or costs) of reduced (increased) CO_2 emissions are attributed to All Countries.

Our model calculates the costs and benefits that accrue to both the Partnership as well as to the global community that benefits from a net reduction in carbon emissions. This model is setup to reflect the economic value from the perspective of Haiti as a country and then whole world. If the net benefits for Haiti are positive, that means that it is possible to find a financing mechanism to implement and operate the intervention in a financially sustainable way. However, recommending and comparing alternative financing mechanisms are beyond the scopes of this paper. To conduct such analysis, it is important to include the transfer among different partners. These transfers could include the subsidies paid on fuel, PPA price paid to IPPs, price charged to consumers, and the interest rate paid to financiers among others.

Costs

In our model, we consider two major sources of costs: the annualized cost of capital and the annual cost of operations and maintenance.

The annualized cost of capital is calculated by taking the average installation cost per MW of capacity for a given generation technology, and spreading the costs over the lifespan of the asset. We include the costs of financing the project to get equal annual costs. The annualized costs of capital for the four interventions is shown in Table 3. Capital costs are taken from EIA (2017). Since costs are based on American data, some uncertainty is present as to the relevance to Haiti. It is worth noting that the financing rate of interest is the same as the discount rate in these calculations, since the main aim of Haïti Priorise is to determine economic costs and benefits. When looking at financing the project, it is likely that the interest rate will be different, depending on the actors involved.

Table 3 – Capital Costs of Grid Scale Thermal (2017 USD)

			Annualized Cost (2017 USD)		
Technology	Cost per MW (2017 USD)	Lifespan (Years)	@ 3%	@ 5%	@ 12%
Coal	$ 3,246,000	25	$ 186,410	$ 230,311	$ 413,864
CCT	$ 973,000	25	$ 55,877	$ 69,036	$ 124,057
ACT	$ 676,000	25	$ 38,821	$ 47,963	$ 86,189
CCC	$ 917,000	25	$ 52,661	$ 65,063	$ 116,917
ACC	$ 1,023,000	25	$ 58,748	$ 72,584	$ 130,432

Source: US EIA (2017)

The cost of operations and maintenance is the costs associated with ensuring that installed generation capacity can continue to operate over its lifespan. It includes labor costs, repair costs, and the costs of replacing parts. In the case of the thermal technologies we discuss, it would also include the costs of fuel. Our model considers the fixed O&M costs (the costs that are incurred even if no power is generated), as well as the variable O&M costs (the costs associated with each additional MWh generated). We multiply the fixed O&M costs by the total capacity (which in this case is standardized to 1 MW) and we multiply the variable O&M costs by the amount of electricity generated in a year. These calculations are shown for all four technologies in

Table 4.

We consider three scenarios for prices in our analysis. The first uses the EIA (2017a) estimates for variable O&M costs, which are relevant to the United States. These estimates assume the non-coal generators will burn natural gas. Haiti however will not have the same access to fuels or natural gas as the united states. Scenario two considers the same types of fuels used, but takes estimates of natural gas prices in Haiti from IDB (2014) which considers large scale investment in LNG facilities around the Caribbean. Coal prices in Scenario 2 are taken from the EIA (2017b), and then doubled to account for shipping coal to Haiti. Doubling the price of coal is equivalent to a freight rate of slightly less than one cent per ton mile, assuming coal is shipped from the United States. The base scenario used for the majority of our analysis assumes the same costs for coal in Haiti, but assumes that Haitians will burn HFOs instead of natural gas in the non-coal generators. Prices for HFOs come from EIA (2017b) and reflect lower heat rates found in EIA (2017a).

Table 4 – Operating and Maintanance (O&M) Costs of Grid-Scale Thermal

		Variable O&M per MWh (2017 USD)			
Technology	Fixed O&M/MW (2017 USD)	Scenario 1 (US NG/Coal)	Scenario 2 (Haiti NG/Coal)	Base Scenario (Haiti HFO/Coal)	Total O&M per Year for Scenario 3 (2017 USD)
Coal	$ 37,800.00	$ 4.47	$ 49.39	$ 49.39	$ 414,222.38
CCT	$ 7,340.00	$ 15.45	$ 130.37	$ 91.26	$ 702,857.64
ACT	$ 7,040.00	$ 10.37	$ 117.16	$ 82.01	$ 632,049.83
CCC	$ 13,170.00	$ 3.60	$ 84.71	$ 59.30	$ 465,097.60
ACC	$ 15,370.00	$ 3.27	$ 77.26	$ 54.08	$ 427,551.89

Source: US EIA (2017a), US EIA (2017b)

Benefits

Value of electricity delivered to consumers

The first benefit we attribute to our intervention is the value of the electricity being generated to the partnership. We value this benefit using the average price of the electricity had it been purchased through a PPA, which in August 2016 was 0.166 USD/kWh according to Thys (2017). The calculation for the benefits of electricity is simply the total electricity generated by installed capacity for a given technology multiplied by the PPA price. We use a capacity factors of 87%, which is found in the US EIA (2017) paper as an estimate for baseload generation. US data suggested that combustion turbines (CCT and ACT) typically had a lower capacity factor, since they were typically only used to satisfy peak demand. However, when considering marginal additions to Haiti's energy mix, it seems likely that any new generation would generate optimal benefits through as much use as possible and thus resemble base generation. Systems that use technologies such as CT to only serve the peak often rely on nuclear, hydro, and coal for baseload, which hardly the case for Haiti. We will however examine the impacts of changes in these assumptions in our sensitivity analysis. The benefits of electricity generated are shown in

Table 5.

Table 5 – Benefits of Electricity Generated by Grid-Scale Thermal

Technology	Capacity Factor	Expected Electricity produced per MW of capacity (MWh/Year)	Annual Value of Generation (2017 USD)
Coal	87%	7,621.20	$ 1,295,604.00
CCT	87%	7,621.20	$ 1,295,604.00
ACT	87%	7,621.20	$ 1,295,604.00
CCC	87%	7,621.20	$ 1,295,604.00
ACC	87%	7,621.20	$ 1,295,604.00

Sources: US EIA (2017a), Thys (2017)

The second (potential) benefit is the reduced carbon emissions. We calculate this benefit using estimates of the per kWh CO_2 emissions of diesel generators, which we assume in some cases would be replaced with more efficiently generated electricity in our interventions. By multiplying the yearly emissions abated by the social cost of carbon, we obtain the annual impact of our intervention on the environment. The values for the social costs of carbon at different discount rates are taken from Tol (2011), the same estimates used by all members of the Haïti Priorise project to ensure comparability.

The annual values of CO_2 abated are shown in

Table 6. We estimated these by taking the carbon content of fuels from US EIA (2016). These values are calculated using the baseline scenario that assumes the use of HFOs.

Table 6 – Costs and Benefits of Changing Carbon Emissions as a Results of Grid-Scale Thermal (2017 USD)

		Annual Value of Carbon Dioxide Change from Counterfactual		
Technology	Expected Tonnes of CO_2 per MWh Generated	@ 3% (22.9 USD/Tonne)	@ 5% (5.18 USD/Tonne)	@ 12% (0 USD/Tonne)
Coal	0.839	$ (16,606.76)	$ (3,756.46)	$ 0
CCT	0.952	$ (36,273.42)	$ (8,205.08)	$ 0
ACT	0.855	$ (19,434.96)	$ (4,396.20)	$ 0
CCC	0.652	$ 16,038.89	$ 3,628.01	$ 0
ACC	0.595	$ 26,046.31	$ 5,891.70	$ 0

Sources: Tol (2011); US EIA (2016)

Net Benefits, Cost Benefit Ratios and Sensitivity Analysis

The goal of Haïti Priorise is to rank interventions according to their benefit-cost ratios. The benefit-cost ratio takes all the economic benefits of the intervention and divides them by the costs. This should, in theory give us a general sense of how much benefit is being generated for every dollar of cost. For example, a benefit cost-ratio of one would mean that for each dollar of cost, a dollar of benefits is generated. Benefit-cost ratios greater than one mean that an intervention generates more benefits than costs. Benefits cost ratios below one imply the opposite.

If all the interventions were analyzed correctly, and if all the interventions were feasible at an appropriate scale, a resource constrained donor who valued all stakeholders equally would (theoretically) maximize the impact of their money by funding interventions with the highest benefit-cost ratios. However, in practice, not all the interventions will have been analyzed the same way, and not all of the interventions will be feasible at different scales. It is also important to remember that the way that costs and benefits are distributed to stakeholders is a concern for most people, so a general benefit-cost ratio may not be good enough way of prioritizing interventions. Especially in the case of energy projects, costs and benefits will be highly contextual, and there are many limitations to simply looking at an average BCR. We have attempted to estimate benefits conservatively so as to not oversell any potentially bad interventions. Our estimates of the Economic benefit-cost ratios of each intervention, using 3 different discount rates are listed in Table 7. These estimates use baseline assumptions of pricing fuel in the US market and use of HFO for all technologies except for coal.

Table 7- Economic Benefit-Cost Ratio for Summary for Baseline Assumptions (Global Point of View)

Technology	BCR @ 3%	BCR @ 5%	BCR @ 12%
Coal	2.05	1.95	1.53
CCT	1.59	1.62	1.53
ACT	1.83	1.85	1.76
CCC	2.47	2.39	2.17
ACC	2.66	2.54	2.27

The economic benefit-cost ratios include the costs and benefits applied to all stakeholders, including both the partnership in Haiti, and the beneficiaries around the world who benefit from reduced CO_2 emissions. We display the same estimates, but this time from the point of view of just the Partnership/Haiti in Table 8.

Table 8 –Benefit-Cost Ratios Summary for Baseline Assumptions (Haiti Point of View)

Technology	BCR @ 3%	BCR @ 5%	BCR @ 12%
Coal	2.11	1.96	1.53
CCT	1.67	1.64	1.53
ACT	1.89	1.86	1.76
CCC	2.44	2.39	2.17
ACC	2.60	2.53	2.27

The benefit-cost ratios displayed in Table 7 and Table 8 suggest that thermal generation technologies can be a good investment for both Haiti and the world. Coal appears to generate the good benefit to cost ratio for lower discount factors, but the BCR drops significantly as the discount factor increases, likely due to coal's high fixed capital cost. At all the discounting factors used in this model, advanced combined cycle seems to be a better investment than coal, due to a higher proportion of costs being related to operations and maintenance rather than capital expenditure. The combined cycle generators perform better in our analysis than the conventional combustion turbines, but this in part due to the fact that all technologies are assumed to be serving base load, although this could change as we change assumptions about capacity factor.

These results are based on assumptions about the capacity factor of thermal generation technologies, the costs of installed capacity and discount rates. All of these can be incredibly context specific and thus we should consider the implications of possible changes in the value of inputs to the model.

First, let us consider the impact of capacity factors on our results. In our baseline assumptions, generators were producing electricity for the grid 87 % of the time. However, we can imagine scenarios where supply of electricity in a grid exceeds demand, or where inefficiencies attributable to aging infrastructure make it impossible to dispatch certain volumes of electricity into the grid. If intermittent renewables capacity is installed sufficiently, and if they are given dispatch priority, it could hamper the ability of gird scale thermal plants to dispatch all the electricity they could have potentially generated. In Table 9 we show estimates that we obtain from our model for different levels of generation, assuming a 5% discount rate and assuming the baseline scenario where HFO is burned instead of natural gas.

Table 9 – Sensitivity of Economic Benefit-Cost Ratio to Capacity Factor (5% Discount Rate)

	Capacity Factor			
Technology	21.75%	43.5%	65.25%	87%
Coal	0.87	1.38	1.72	1.95
CCT	1.25	1.48	1.57	1.62
ACT	1.49	1.71	1.80	1.85
CCC	1.66	2.09	2.28	2.39
ACC	1.66	2.16	2.40	2.54

Note: All figures assume a 5% discount rate

The results in Table 9 show how a lower capacity factor make the benefit cost ratios of technologies with lower capital costs look more attractive, even if lower efficiency levels make their operating costs higher. Notice that when capacity factor drop to half of our base assumption, coal becomes the least attractive option. Especially in a place that is as vulnerable to natural disasters and political turmoil as Haiti, it may actually be plausible to imagine a power plant generating a fraction of its potential output over the course of its life. If a hurricane or earthquake were to damage a generation facility before the end of its expected lifespan, we might expect the average electricity dispatched to be well under its potential output in a more ideal scenario.

Let us also consider the implications of a higher PPA price, something that could happen in the case of an oil shock or due to higher perceived financial risk on the part of IPPs. Such an increase would increase the relative value of electricity generated by alternative sources. In Table 10 we display how the economic BCR would change to reflect different electricity prices, using a 5% discount rate.

Table 10 – Sensitivity of Economic BCR to the Value of Electricity Dispatched (5% Discount Rate)

	Value of Electricity (2017 USD/kWh)			
Technology	$0.150	$0.166	$0.180	$0.200
Coal	1.76	1.95	2.12	2.35
CCT	1.47	1.62	1.76	1.95
ACT	1.67	1.85	2.00	2.23
CCC	2.16	2.39	2.59	2.88
ACC	2.30	2.54	2.75	3.06

Note: All estimates assume a 5% discount rate

Table 10 shows how the value of thermal generation increases with the price of electricity sold in the market. Haiti currently benefits from preferential oil prices from Venezuela through the Petrocaribe program, but a dip in world oil prices could put pressure on Venezuela's ability to subsidize oil exports. If Haiti is confronted with a large spike in their observed price of oil, natural gas or coal could look relatively more attractive. In some senses, using HFOs as fuel in generators increases Haiti's vulnerability to fluctuations in world oil prices, whereas coal or natural gas usage would hedge against this. It is important to mention that the ranking of the technologies does not change as a result of fluctuations in current PPA prices as they all produce the same output.

Other Scenarios for Fuel Usage

We are also interested in the benefits and costs associated with the usage of different fuels. Haiti is an island country that would need to import natural gas via either an underwater pipeline or in boats from other countries. They might also choose to substitute petroleum based fuels such as HFOs instead, although these fuels do not allow generators to operate as efficiently. In Table 11 we consider three scenarios. The first assumes that natural gas and coal can be purchased at American prices and thus use the average variable O&M costs from EIA (2017) for all technologies. Scenario two assumes the use of natural gas and coal as well, but assumes that prices in Haiti would vary significantly. The price of natural gas is taken from IDB (2014) estimations of import prices in Haiti, which include the average costs of large scale investment in infrastructure to import natural gas. Coal prices come from March 2017 average coal export prices data found on the EIA website. The third scenario has been used thus far as our baseline, and assumes that the non-coal burning generators will use HFO as their fuel source. We assume that HFO prices will be roughly the same as world averages obtained from the EIA, and that coal prices are the same as in scenario 2. In the third scenario, we also change the heat rate and the carbon emissions to reflect the usage of HFOs instead of natural gas.

Table 11 – Benefit-Cost Ratios for Three Fuel Use Scenarios (World Point of View)

Technology	Scenario 1: US Domestic Coal and NG Prices	Scenario 2: Haiti Import Coal and NG Prices	Scenario 3: Haiti Import Coal and HFO Prices (Baseline)
Coal	4.14	1.95	1.95
CCT	6.55	1.19	1.62
ACT	9.51	1.34	1.85
CCC	12.11	1.77	2.39
ACC	11.35	1.89	2.54

Note: All estimates assume a 5% discount rate

First let us consider scenario 1 as a reference point. If it were possible to access natural gas and coal at the average United States prices, natural gas burning generators are incredibly cost effective ways of generating electricity. Coal looks relatively bad, compared to even the least efficient generator. However, this scenario is not likely to be relevant to Haiti at any point in the near future. Scenario two considers the same fuels but using prices that more closely resemble their estimated prices if Haiti were to invest in infrastructure for importing liquid natural gas, as calculated in the IDB (2014) paper. In this scenario, coal generation looks significantly more attractive, due to much lower fuel costs than natural gas burning generators. Scenario three which uses HFO prices makes non-coal technologies look better than in scenario two, but not better than coal. Since scenario two and three seem relevant to Haiti, it can be inferred that Coal might me the most feasible way of producing cheap thermal electricity.

5. Conclusion

In general, our estimates seem to imply that thermal electricity generation will produce benefits that exceed costs, under a number of different assumptions. Coal is characterized by high capital costs, and relatively low operating costs, meaning that it achieves optimal benefits when it is used as much as possible (ie. the capacity factor is high) and when discount rates are low. Natural gas or liquid fuel burning generators are characterized by relatively low capital costs, but higher operating costs associated with fuel meaning they can be better than coal in scenarios where generators are not run around the clock (ie. low capacity factors) or when the costs of investment (discount rates) are higher. Lower efficiency generators (CCT or ACT) might be more appropriate investments in the future when peak and base loads become more differentiated. However, for now all electricity produced will likely be considered baseload, and therefore we would prioritize investment in the most efficient technologies. Energy projects are complex, and the costs and benefits can vary substantially in different contexts. When considering investment in any expansion of generation capacity, site specific feasibility studies that are significantly more rigorous than our report will be essential.

Our main takeaways for policymakers:

1. Thermal energy technologies could potentially help generate cheaper electricity than is currently being purchased from IPPs.

2. Based on the assumptions in our model, coal generation appears to be less cost effective than burning liquid fuels like HFOs.
3. While combined cycle generators have a higher capital cost than other non-coal generation technologies, they are also the most cost effective. While this could change once base demand is satisfied and peak demand becomes a more pressing concern, we see investment in combined cycle generators as a logical first step towards improving Haiti's electricity generation capacity.

Table 12 – Summary of Grid Scale Renewables with Base Assumptions (2017 USD)

Technology	Discount Rate	Benefits (USD/MW)	Costs (USD/MW)	Benefit-Cost Ratio (Global)	Quality of Evidence
Coal	3%	$ 1,265,119.20	$ 617,240.02	2.05	Medium
	5%	$ 1,265,119.20	$ 648,290.52	1.91	
	12%	$ 1,265,119.20	$ 828,087.28	1.53	
CCT	3%	$ 1,265,119.20	$ 795,008.38	1.59	Medium
	5%	$ 1,265,119.20	$ 780,099.46	1.62	
	12%	$ 1,265,119.20	$ 826,915.11	1.53	
ACT	3%	$ 1,265,119.20	$ 690,306.03	1.83	Medium
	5%	$ 1,265,119.20	$ 684,409.89	1.85	
	12%	$ 1,265,119.20	$ 718,239.81	1.76	
CCC	3%	$ 1,281,158.09	$ 517,758.96	2.47	Medium
	5%	$ 1,268,747.21	$ 530,161.01	2.39	
	12%	$ 1,265,119.20	$ 582,015.07	2.17	
ACC	3%	$ 1,291,165.51	$ 486,300.60	2.66	Medium
	5%	$ 1,271,010.90	$ 500,136.25	2.54	
	12%	$ 1,265,119.20	$ 557,984.36	2.27	

6. References

Aguirre, J., 2014. Impact of Rural Electrification on Education: A Case Study from Peru. Research Center, Universidad del Pacifico (Peru) and Department of Economics 1–18.

Allien, N., 2016. Interview with EDH.

Anonymous, 2017. IPP PPA Prices per kWh.

Anonymous, 2016. Interview with a Doctor.

Bloomberg New Energy Finance, World Energy Council, 2013. World Energy Perspective: Cost of Energy Technologies.

Blum, N., Wakeling, R., Schmidt, T., 2013. Rural electrification through village grids - Assessing the cost competitiveness of isolated renewable energy technologies in Indonesia.

Brown, N.L., 1978. Solar Energy for Village Development.

Chen, S.X., Gooi, H.B., Wang, M., 2012. Sizing of energy storage for microgrids. IEEE Transactions on Smart Grid 3, 142–151.

Costa, P.M., Matos, M.A., 2006. Economic analysis of microgrids including reliability aspects, in: Probabilistic Methods Applied to Power Systems, 2006. PMAPS 2006. International Conference on. IEEE, pp. 1–8.

Di Bella, C.G., Norton, L.D., Ntamatungiro, J., Ogawa, S., Samake, I., Santoro, M., 2015. Energy Subsidies in Latin America and the Caribbean: Stocktaking and Policy Challenges.

Earth Spark International, 2016. Les Anglais Micro-Grid Factsheet.

EarthSpark International, 2015. Scaling Sustainable Energy for All: EarthSpark International and the Case for Micro-Grid Infrastructure.

Energy and Security Group, 2016. Haitian Solar Powered Microgrid Potential: Town Ranking Report.

EPRI, 2003. Costs of Utility Distributed Generators, 1-10 MW: Twenty-Four Case Studies.

ESMAP, 2002. Rural Electrification and Development in the Philippines: Measuring the Social and Economic Benefits.

Foroudastan, S.D., Dees, O., 2006. Solar Power and Sustainability in Developing Countries.

Golumbeau, R., Barnes, D., 2013. Connection Charges and Electricity Access in Sub-Saharan Africa.

Government of Haiti, Department of Public Works, Transportation and Communication, 2015. SREP Investment Plan for Haiti.

Greacen, C., Engel, R., Quetchenbach, T., 2013. A Guidebook on Grid Interconnection and Islanded Operation of Mini-Grid Power Systems Up to 200 kW.

Hutton, G., Rehfuess, E., others, 2006. Guidelines for conducting cost-benefit analysis of household energy and health interventions, in: Guidelines for Conducting Cost-Benefit Analysis of Household Energy and Health Interventions. OMS.

Inter-American Development Bank, 2014. Natural Gas in the Caribbean: Feasibility Studies (Final Report I and II).

IRENA, 2016a. The Power to Change: Solar and Wind Cost Reduction Potential to 2025.

IRENA, 2016b. Solar PV in Africa: Costs and Markets.

IRENA, 2015a. Renewable Power Generation Costs in 2014.

IRENA, 2015b. Renewable Energy in Hybrid Mini-Grids and Isolated Grids: Economic Benefits and Business Cases.

IRENA, 2015c. Battery Storage for Renewables: Market Status and Technology Outlook.

IRENA, 2012a. Renewable Energy Technologies Cost Analysis Series: Hydro.

IRENA, 2012b. Renewable Energy Technologies Cost Analysis Series: Solar Photovoltaics.

IRENA, IEA-ETSAP, 2013. CSP Technology Brief.

Ishigaki, Y., Kimura, Y., Matsusue, I., 2014. Optimal Energy Management System for Isolated Micro Grids.

Kashi, B., 2015. Risk management and the stated investment costs by independent power producers. Energy Economics 49, 660–668.

Kurtz, J., Saur, G., Ainscough, C., 2014. Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison.

Larocque, A., 2014. Comprehensive Planning for Electric Power Supply in Haiti – Regulatory, Institutional & Tariff Report.

Larocque, A., Nadeau, D., Landry, M., 2014. Comprehensive Planning for Electric Power Supply in Haiti - Expansion of the Supply for Electricity Generation.

Lenin Balza, Christiaan Gischler, Nils Janson, Sebastian Miller, Potential for Energy Storage in Combination with Renewable Energy in Latin America and the Caribbean.

Lucky, M., Auth, K., Ochs, A., Fu-Berteaux, X., Weber, M., Konold, M., Lu, J., 2014. Haiti Sustainable Energy Roadmap.

Machala, M., 2011. Kerosene Lamps vs. Solar Lanterns. Stanford University.

McMannus, R., 2015. Interview with Rachel McMannus.

Mills, E., 2003. Technical and Economic Performance Analysis of Kerosene Lamps and Alternative Approaches to Illumination in Developing Countries.

Nicolas Allien, 2017. 100 kW diesel Quote.

NREL, 2014. Distributed Solar PV for Electricity System Resiliency.

Paul L. Joskow, 2011. Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies.

Pauschert, D., 2009. Study of Equipment Prices in the Power Sector.

Perkins Engines Company Limited, 2012. 400 Series 404D-22G ElectropaK.

Perkins Engines Company Limited, 2007. Perkins 1104D-E44TAG ElectropaK.

Rangarajan, K., Guggenberger, J., 2011. Cost Analysis of Renewable Energy-Based Microgrids for Rural Energy Management, in: IIE Annual Conference. Proceedings. Institute of Industrial Engineers-Publisher, p. 1.

Rao, N.D., Agarwal, A., Wood, D., 2016. Impacts of Small Scale Electricity Systems: A Study of Rural Communities in India and Nepal.

Singh, R.J., Barton-Dock, M., 2015. Haiti: Towards a New Narrative (Systematic Country Diagnostic.

Smith, K.R., Rogers, J., Cowlin, S.C., 2005. Household fuels and ill-health in developing countries: what improvements can be brought by LP gas? World LP Gas Association Paris, France.

Squires, T., 2015. The Impact of Access to Electricity on Education: Evidence from Honduras.

Staton, D.M., Harding, M.H., 1998. Health and Environmental Effects of Cooking Stove Use in Developing Countries.

The World Bank, 2017. Haiti Overview [WWW Document]. URL http://www.worldbank.org/en/country/haiti/overview (accessed 3.13.17).

The World Factbook — Central Intelligence Agency [WWW Document], 2017 URL https://www.cia.gov/library/publications/the-world-factbook/rankorder/2004rank.html (accessed 3.15.17).

Thys, P.K., 2017. Interview with Pierre Kénol Thys, IDB Energy Specialist.

Tol, R.S.J., 2011. The Social Cost of Carbon.

UNdata Country Profile Haiti [WWW Document], 2017. URL http://data.un.org/CountryProfile.aspx?crName=haiti (accessed 3.13.17).

U.S. Energy Information Administration (US EIA), 2017a. Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2017.

United States Energy Information Administration (US EIA), 2017b. Short-Term Energy Outlook Data Browser - March 2017.

United States Energy Information Administration (US EIA), 2016. Carbon Dioxide Emissions Coefficients.

Verner, D., Egset, W., 2007. Social Resilience and State Fragility in Haiti. World Bank Publications.

Wärtsilä, Marine Solutions, 2016. Wärtsilä 46F Product Guide.

Wilson, M., Jones, J.B., Audinet, P., 2010. Benefits of Electrification.

World Bank, 2017. Data on Statistical Capacity: SCI Dashboard [WWW Document]. URL http://datatopics.worldbank.org/statisticalcapacity/SCIdashboard.aspx (accessed 3.13.17).

World Bank, 2008. The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits. The World Bank.

Zhang, J., Smith, K.R., 2007. Household air pollution from coal and biomass fuels in China: measurements, health impacts, and interventions. Environmental Health Perspectives 848–855.

Haiti faces some of the most acute social and economic development challenges in the world. Despite an influx of aid in the aftermath of the 2010 earthquake, growth and progress continue to be minimal, at best. With so many actors and the wide breadth of challenges from food security and clean water access to health, education, environmental degradation, and infrastructure, what should the top priorities be for policy makers, international donors, NGOs and businesses? With limited resources and time, it is crucial that focus is informed by what will do the most good for each gourde spent. The Haïti Priorise project will work with stakeholders across the country to find, analyze, rank and disseminate the best solutions for the country. We engage Haitans from all parts of society, through readers of newspapers, along with NGOs, decision makers, sector experts and businesses to propose the best solutions. We have commissioned some of the best economists from Haiti and the world to calculate the social, environmental and economic costs and benefits of these proposals. This research will help set priorities for the country through a nationwide conversation about what the smart - and not-so-smart - solutions are for Haiti's future.

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