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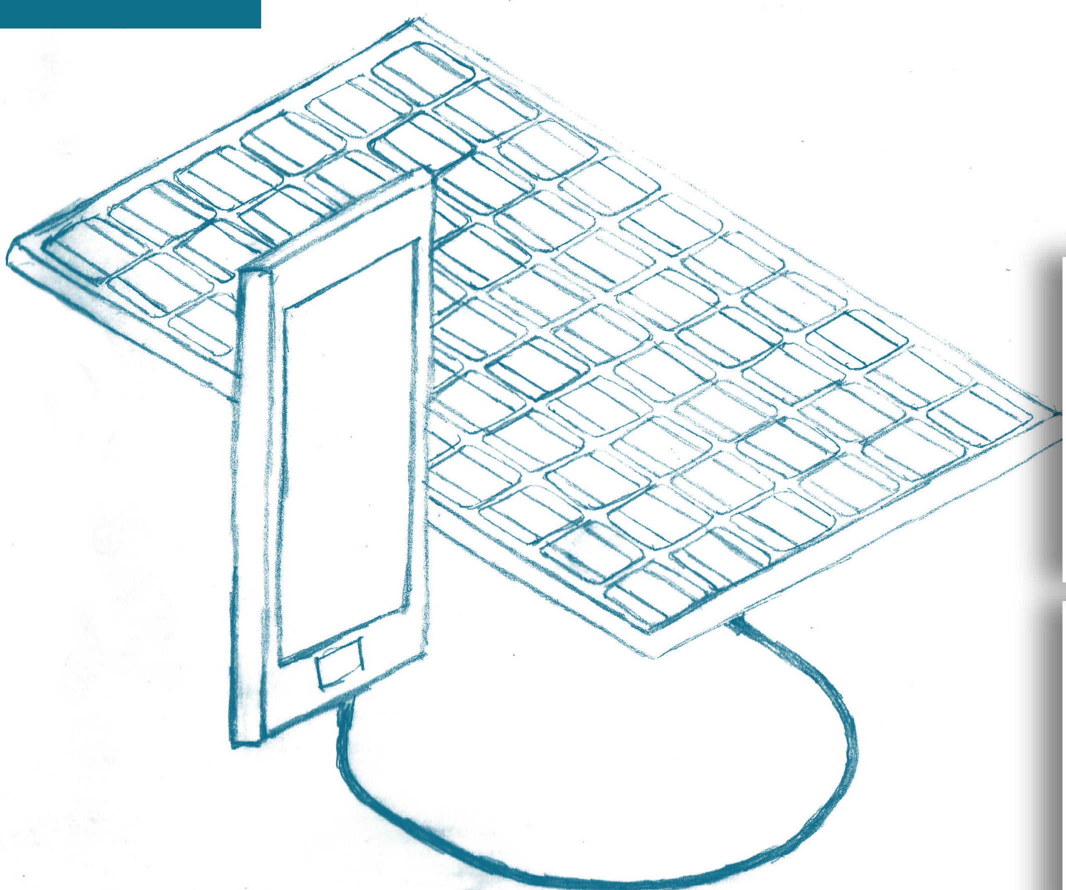
Benefit-Cost Analysis

Providing Electricity using Isolated Grids in Haiti



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Haïti Priorise
Un plan de développement alternatif

Providing Electricity using Isolated Grids in Haiti

Haïti Priorise

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Abbreviations in this Report

BCR – Benefit Cost Ratio

CCC – Copenhagen Consensus Centre

CO_2 – 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

MDB – Multinational Development Bank

MW – Megawatt

MWh – Megawatt Hour

O&M – Operating and Maintenance

PPA – Power Purchase Agreement

Solar PV – Solar Photovoltaic (solar panels)

Academic Abstract

In this paper, we estimate the costs and benefits of installing new isolated electricity grids in Haiti, with four possible choices of generation technologies. We estimate costs and benefits in comparison to a counterfactual scenario in which we assume that consumers will cope with the lack of an electrical grid by burning kerosene oil for light, and use small generators and storage equipment to generate electricity in order to power appliances. We consider different combinations of technologies that could be used to generate or store electricity, including diesel generators, solar panels, batteries and small scale hydro. The benefits of building isolated grids in our model is cost savings to consumers, as well as reduced carbon dioxide emissions for the world. Costs estimated include the average annualized capital, operating, and maintenance costs associated with generation and distribution equipment, 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, and the dispatchability of electricity generated. Our estimates suggest that the isolated grids could be a more cost effective way of supplying Haitians in remote areas with electricity than existing coping methods. We also briefly consider the costs of transmitting electricity generated in larger grids to isolated grids in our Appendix.

It is important to highlight that this study is mainly a pre-feasibility analysis and its results must be treated as such. Secondary sources of data used here are crude and to make decisions about projects one needs to collect primary data on most of the assumptions, particularly about the current coping mechanisms.

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 would be associated with supplying electricity to people in Haiti who live in remote areas that are not connected to the country's main electricity grids. We consider grids that use combinations of solar panels (Solar PV), batteries, diesel generators and small scale hydro to generate and store electricity. We also consider the implications of two different sizes of grids to get a sense of how such projects scale up.

Implementation Considerations

The primary costs of building isolated grids and using them to supply Haitians with electricity are (i) the costs of capital, and (ii) the operating and maintenance (O&M) costs.

Installing isolated grids in remote parts of Haiti 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 new projects is challenged due to their financially unsustainable practices, our analysis shows that isolated grids can, in some contexts, generate positive net economic benefits.

The success of our proposed interventions would be measured through the costs they save consumers, the revenue they generate for implementers, and the carbon dioxide emissions that are reduced compared to plausible alternative forms of electricity generation.

Isolated grids could be installed 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 interested parties 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.

An isolated grid, like the ones we consider in our model, could last for at least 20 years, or longer. Thus, the costs and benefits of a project are subject to some level of uncertainty especially into the future. Two of the key parameters that anchor our analysis are the current costs of generation and storage technologies (both their capital costs and their operating and maintenance costs), as well as the current costs for those who use strategies to cope without access to electricity. Both are subject to change in the lifespan of any project. We provide estimates of costs and benefits that are based on general assumptions. In the real world, these assumptions will vary for different potential sites. We conduct sensitivity analysis to see how outputs such as the benefit-cost ratio could react to changes in the inputs.

Some of the generation configurations we consider include diesel generators, the use of which will lead to 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 electricity generation. We might imagine some kind of trade-off between environmental concerns and cheap energy. However, it is likely that installing isolated grids and new energy generation capacity will actually lead a net decrease in CO_2 emissions, when compared to ways consumers would cope with a lack of grid access. Consumers without electricity will likely burn kerosene to produce light, and may use small diesel generators to power appliances like TVs or refrigerators.

There are some unavoidable risks associated with installing isolated grids in a country like Haiti, such as the risk of natural disasters that could damage installed capital, or risks associated with an unstable political system. If EDH or other actors were to invest heavily in the national electricity grid, the relative benefits of isolated grids could be called into question. Investing in the electricity sector in Haiti is undoubtedly financially risky, but the electricity needs of Haitians are great enough that the economic benefits could be high enough to justify such risks.

Rationale for Intervention

There are two main benefits that could emerge from investing in isolated grids in Haiti. The first is cost savings that result from consumers substituting electricity for more expensive power sources like diesel generators or kerosene fuel. These cost savings should benefit both consumers as well as electricity producers, depending how the price is set. The other benefit of generating electricity using the technologies we propose is that in some cases, there is a net reduction in carbon dioxide emissions when compared to current coping strategies. Haitians in isolated regions could cope with a lack of electricity access by burning diesel or kerosene, both of which will produce carbon dioxide (CO_2), a harmful greenhouse gas that contributes to global climate change. While some electricity generation configurations that we consider for use in isolated grids use diesel generators, the amount of carbon dioxide emitted can be much less than would have alternatively been produced, due to improved levels of efficiency as the size of generator increases. We also consider solar and hydro generation, both of which do not emit CO_2 as they generate electricity. Thus, by generating electricity using our proposed technologies, net CO_2 emissions relative to power consumption should decrease.

In our estimations, we do not consider consumer surplus that would result from an increase in quantity consumed. Rather, we value the newly available electricity equivalently to the coping costs associated with power before the intervention, due to insufficient data about the demand function of Haitians in isolated villages. This is a considerable omission, and it means our estimations of benefits may be significantly less than actual benefits that would be generated by such a project. However, we prefer to estimate benefits in this way because we would rather end up with estimates that are conservative, as opposed to overly optimistic. To this end, we also choose not to include the possible benefits of economic growth, a process that will likely require expansion of Haiti's electricity systems. While electricity is an undeniable prerequisite for economic growth, we are hesitant to attribute discrete benefits to marginal improvements of Haiti's electricity infrastructure. Growth is also a challenge to incorporate into our models 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 a summary of the costs and benefits of installing isolated grids that use four technologies for electricity generations, under the baseline assumptions of our model. The range of possible costs and benefits incurred as a result of increasing access to electricity is broad, and we discourage readers from taking these values out of context.

Table 1 – Summary of the Costs and Benefits Associated with Isolated Grids with Different Technologies

Generation Technology	Benefit (2017 HTG)	Cost (2017 HTG)	BCR	Quality of Evidence
Diesel Generators Only	66,262,585.23	47,237,177.44	1.40	Medium
Diesel and Solar Panels	66,273,853.59	60,716,743.66	1.09	Medium
Diesel, Solar Panels and Batteries	66,548,199.74	56,462,794.58	1.18	Medium
Small Hydro	66,700,614.27	47,196,486.16	1.41	Medium

Notes: All figures assume a 5% discount rate and a Social Cost of Carbon Dioxide of 353.97 HTG/Tonne.

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1. Intro

In this paper, we estimate the costs and benefits of installing isolated electrical grids in remote parts of Haiti.

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 similar assumptions, all consider ways of improving Haiti by improving electricity markets. 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. Using Isolated Grids to Distribute Electricity 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 is 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 some 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 that affect both the supply and demand side of Haiti's electricity market more feasible.

Using Isolated Grids to Distribute Electricity

In order to increase Haitian's access to electricity, policy makers have a few options. One option is to improve the existing transmission and distribution infrastructure in order to extend existing grids to Haitians living in remote areas. This requires investment in transmission lines, which can be quite costly, especially in a remote area that is a sufficiently far from an existing grid. Extending existing grids also means consumption is added to existing markets where existing supply is already typically insufficient to meet existing demand.

It therefore seems plausible that in some cases, installing new grids that have their own distribution and generation could be preferable to expanding existing grids. The downside of isolated grids is that, in most cases, electricity will typically be generated at a much smaller scale and may be less cost efficient than grid scale generation methods. We consider technologies that can be used at small scale, like solar panels and batteries, diesel generators, and pico-hydro generation. While the price of electricity generated may be higher for these technologies, the value of supplying electricity to unelectrified areas can also be quite high. This high value, combined with the lack of transmission costs can make isolated grids an economically viable way of distributing electricity to residents of remote areas.

It should be stated in no uncertain terms that "fixing" Haiti's energy problems will be incredibly challenging and that just because an intervention like isolated grids may have high potential net-benefits does not mean that those benefits can be actualized without other considerations. This paper addresses the possible benefits of installing isolated grids in Haiti to improve access to electricity. However, we believe any interventions that involve improving Haiti's electricity infrastructure 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 Access to Electricity for Consumers in Haiti

Isolated grids can be used to expand access to electricity to remote communities. In our model, we assume that consumers do not have the ability to purchase electricity before the installation of a grid. However, we assume their demand for energy is partially satisfied by coping strategies, such as burning kerosene for light or using small diesel generators to generate electricity on site for some richer consumers. For this reason, we consider the effect of providing electricity a shift to the supply curve, as opposed to serving a totally new market. Consumers will consume electricity from new grids instead of energy from kerosene or diesel generators.

In our analysis, we assume that an entirely new grid will be installed. While there are a number of places in Haiti that have some existing infrastructure (see Earth Spark (2016)), calculating the cost of a completely new grid for our primary analysis should prevent us from under estimating costs. We will see how changes in the cost of capital would affect our results in the sensitivity analysis later in this document.

Issues Estimating Consumer Surplus with Limited Data

Our analysis is based, in part, on data we were able to obtain for two Haitian grids. The first of these grids is the Les Anglais micro grid, which serves approximately 450 consumers. The second is the significantly larger Les Cayes grid, which serves approximately 45,000 costumers. The Les Anglais grid was a pilot project implemented by Earth Spark, a non-profit interested in setting up microgrids in Haiti. The Les Cayes grid is one the larger main grids in Haiti managed by EDH. The data we used listed the yearly consumption for consumers of different classes. In an ideal world, we would estimate demand functions for different possible grid sizes grid and use these functions to estimate how consumer surplus increases as supply changes. However, since we only have data for the quantity consumed in the two grids in a state where electricity is already available, estimation of consumer demand functions a challenge. We therefore calculate the consumer surplus as the quantity consumed multiplied the change in price that results from our intervention (the difference between the coping costs and the average cost of electricity generated). This is equivalent to assuming that the price elasticity of demand is equal to zero. While this seems unrealistic, conversations with those involved in micro grid instillation have indicated that changes in consumption behavior are typically overestimated and thus the price elasticity of demand may actually be fairly low. We acknowledge the issues with this estimation methodology, and we encourage others to collect more data on electricity demand before making any investment in infrastructure.

Estimating the Coping Costs of Lighting

In order to estimate the consumer surplus increase for customers with new access to electricity, we need to understand the ways they coped without electricity before, and the costs of such strategy. We believe that Haitians without access to electricity will typically burn kerosene in lamps to generate light. Burning kerosene in lamps costs money, and also does not generate as much light as an electric lightbulb. Thus, to compare the consumer spending on light before and after access to electricity is improved will not capture the improvement in the quality of light. To account for this, we manipulate the costs of kerosene light to make sure that the energy costs are in lumen equivalent terms, which is to say that the price of lighting before and after the intervention reflect the same amount of light, as measured in lumens. This is the method of estimating coping costs used in World Bank (2008).

In our model, we used a price of kerosene of 200 gourdes per gallon, based on discussions with staff from Earth Spark (2016). This translated to just slightly over five gourdes per kWh of energy. We then looked at the average lumen efficiency (the amount of energy it takes to generate a lumen) of kerosene lamps and electric lightbulbs based on data in Wilson et al. (2010). From these calculations, we can estimate what the cost of a kWh worth of light from a lightbulb would be, if it were produced using kerosene. We use this estimate as the cost of electricity for consumers who would only use electricity for lighting after electrification. We end up therefore with a very high estimate of the coping cost of energy for those consumers that only use electricity for lighting. We recommend that in cases where an actual grid was to be installed, significantly more primary data should be collected to get a more complete picture of consumer demand for electricity.

Estimating the Coping Costs of Generating Electricity

Some consumers will use electricity for more than just lighting. Some will run appliances like televisions or refrigerators. Businesses will need electricity to run machinery. We considered the coping costs of running small diesel generators to produce this electricity. We estimated the cost of running such generators by combining annualized capital costs, and fuel costs. We then divided these costs into the expected generation per year to get a per kWh coping cost of not having electricity access for wealthier households and small businesses. We assumed that for these consumers, kerosene would not be used for lighting, especially given its high relative price. This may not be accurate in all cases, underscoring the need for more serious data collection.

Capacity Factor and Dispatchability

Two concepts central to energy economics is dispatchability and the capacity factor. The capacity factor is a measure of how much electricity is generated by an energy source versus it's potential generation. Technologies like solar panels and hydro will have variable electrical output, depending on the weather and the flow of the river. Dispatchability, on the other hand, describes the proportion of electricity generated that can be actually dispatched into a grid and consumed. Dispatchability is an important concept, especially when considering intermittent renewables like solar. Just because a string of solar panels is generating 30 kWhs of electricity does not mean that a full 30 kWh out will be consumed. Demand will fluctuate throughout the day, reflecting shifts from working hours to leisure hours to sleeping hours. Supply and demand will not always be in sync when using intermittent renewables. Thus, the dispatchability will reflect the specific nature of the grid where new capacity is installed.

The capacity factor and dispatchability enter our model as simple multipliers to each technology that converts the total amount of electricity that a 1 MW generator would produce in a year under ideal conditions (8760 MWhs) to the expected dispatched electricity. We assume a dispatchability of 100% for generation using solely diesel, a dispatchability of 75% for a grid that uses solar panels and a diesel generator, a dispatchability of 90% for a grid that uses solar, diesel and batteries, and a dispatchability of 75% when using small hydro.

It is possible that the capacity factors or dispatchability could be significantly different than those used in our model. 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 or dispatchability. When installing actual projects, data will need to be collected to get more accurate predictions of these factors.

Multiple Grid Sizes and Consumer Classes

In our analysis, we considered four classes of consumers. These were small households who only used light, larger households and small businesses who used appliances, larger businesses who used electricity for machinery, and government buildings like hospitals. We divided consumers into these classes so as to incorporate different cooping costs for different types of consumers and different overall levels of consumption. We assumed that the small households would cope by burning kerosene for light, and that the other consumer classes would cope by using small diesel generators. While not all consumers would have employed these coping methods, such estimates give us an approximation of the potential cost savings available to consumers who are granted access to electricity through grids.

We also considered different sizes of grids. The first is a small grid modelled after the village of Les Anglais, which has 100kW of electricity generation capacity. This grid is weighted more towards light only households and has few businesses. The larger grid we consider is based on the Les Cayes grid, which is one of Haiti's main (non-isolated) grids and has a generation capacity of 11,600 kW. This grid has significantly more consumers in the larger household and business category.

The customers in each class are shown in XXXX

Customer Class	% of Connections in Small Grid	% of Connections in Large Grid
Share of Consumer 1 (Small Household – Just Light)	67%	13.9%
Share of Consumer 2 (Large Household & Small business)	32%	84.6%
Share of Consumer 3 (Large Business)	1%	0.5%
Share of Consumer 4 (Public Establishments)	0%	0.9%

4. Calculation of Costs and Benefits

Benefits, Costs, and Stakeholders

The following sections will explain how we estimated the costs and benefits of installing isolated grids of different sizes and that employ different technologies for electricity generation. However, before we explain our calculations of costs and benefits, it is worth explaining the stakeholders we have included in our model.

The first 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 solely EDH, or some other power producer acting independently, or could be a team including a donor, philanthropist, MDB, etc. This stakeholder is the primary payer of costs associated with generation, and receives the revenue from customers who pay for electricity.

We also consider the consumers who access the grid as a key stakeholder in our model. The consumers benefit from a lower price of as they move from coping strategies to actually purchasing electricity. Consumers pay a cost for electricity, but this is mainly a transfer to the Partnership.

The final 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, ad 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	Customers	Total		
Benefits					
Reduced Cost of Electricity for Consumers		X	X		X
Reduced Carbon Emissions				X	X
Revenue from Sale of Electricity	X		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 power generation, but also gains the benefit of revenue. Reduced (or 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. We can separate the costs and benefits by stakeholder or add them together. While the main goal of the project is to calculate the overall economic (or “social”) benefit of the intervention, it is helpful to be able to extract the costs and benefits that are assumed by the agent that would presumably implement the intervention (Partnership) in order to see if the project could be financially (and not just economically) viable.

Costs

In our model, we consider sources of costs in two major categories: the annualized cost of capital (both of distribution and generation) and the annual cost of operations and maintenance. The first category includes the costs of installing generators and setting up the grid infrastructure. We obtained costs for the generation technologies from a few different sources, listed in Table 3. Our research seemed to indicate that for solar panels, batteries, and diesel generators, there was very little economies of scale. Hydro has very significant economies of scale, and this will make it a very attractive option for larger grids with the appropriate water resource.

The annualized cost of capital is calculated by taking the average installation cost per kW of capacity (or kWh in the case of batteries) 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. We also include the costs of installing each generation system, renting land and training staff. Since costs are based on international data, some uncertainty is present as to the relevance of these estimated prices 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.

We include in our estimates, the cost of connecting each consumer to the grid. This cost is 36,219 gourdes per kW (based on estimates found in Golumbeau and Barnes (2013) as well as conversations with members of Earth Spark and USAID), which we will annualize over the period of the project and include in our total costs.

Table 3 –Installed Capital Costs of Grid Generation Technologies (2017 HTG)

Technology	Small Scale Capital Cost per kW/kWh	Larger Scale Capital Cost per kW/kWh	Lifespan (Years)
Solar Panels	30,772.73	30,305.00	10
Diesel Generator	148,917.73	150,347.00	20
Battery	115,150.73	113,878.00	12.5
Hydroelectric Dam	337,675.00	202,604.00	25

Sources: IRENA. (2015a), IRENA. (2012), EPRI (2003)

The cost of operations and maintenance (O&M) 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 diesel generators, it would also include the costs of fuel. We were able to find some estimates of costs broken down into fixed and variable components, but in some cases estimates of O&M were one or the other. We multiply the fixed O&M costs by the total capacity, and we multiply the variable O&M costs by the amount of electricity generated in a year. These values are shown for all four technology mixes in Table 4.

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

Technologies	Fixed O&M per kW (2017 HTG)	Variable O&M per kWh (2017 HTG)
Diesel Generator	5,627.72	0.67
Diesel and Solar	5,627.72	0.4
Diesel, Solar and Batteries	7,320.22	0.25
Small Hydro	3,039.10	0

Source: EPRI (2003), IRENA (2012), IRENA (2015)

Benefits

Value of Electricity Delivered to Consumers

The first benefit we attribute to our intervention is the cost savings that accrue to consumers as they switch to consuming electricity instead of employing coping methods like kerosene lighting. We value this benefit by taking the difference between our estimates of what consumers were paying to cope with a lack of electricity before the installation of isolated grids, and the per kWh cost of electricity after the grids were installed. We will examine the impacts of changes in these assumptions in our sensitivity analysis. The benefits of electricity generated are shown in Table 5. In our analysis, we assumed that consumption would be the same in all scenarios, but that the total generation would increase as dispatchability dropped. Thus, the value of electricity consumed is the same in all scenarios, but the amount generated is not. We assume that 98 MWh of electricity will be consumed each year, and that there is a 16% technical loss rate in the grid.

Table 5 – Benefits of Electricity Dispatched in Isolated Grids

Technology Combination	Dispatchability Factor X Capacity Factor	Expected Quantity of Electricity Generated per Period (MWh)	Value of Electricity over 20 Years, Discounted @ 5% (HTG)
Just Diesel	100 %	117	65,700,000
Diesel and Solar	75 %	130	65,700,000
Diesel, Solar and Batteries	90 %	156	65,700,000
Hydro	100 %	130	65,700,000

The second benefit is the reduced carbon emissions. We calculate this benefit using estimates of the per kWh CO_2 emissions of burning kerosene and using diesel generators, as well as the per kWh carbon emissions of generation in each scenario. By multiplying the difference by the social cost of carbon, we obtain the 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 values of CO_2 released by each combination of generation technologies are shown in

Table 6.

Table 6 – Costs of Emitting CO_2 when Generating Electricity for Isolated Grids

		Value of reduction in Carbon Dioxide Emissions (2017 HTG)		
Generation Scenario	Expected Emissions of CO_2 Avoided (Tonnes/kWh Consumed)	@ 3% (22.9 USD/Tonne)	@ 5% (5.18 USD/Tonne)	@ 12% (0 USD/Tonne)
Diesel Only	0.0098	3,059,775.58	575,667.53	0
Diesel and Solar	0.0096	3,119,668.95	586,935.89	0
Diesel, Solar and Battery	0.00034	4,577,867.66	861,282.04	0
Hydro	0	5,387,978.05	1,013,696.56	0

Sources: Tol (2011); US EIA (2017)

Note that the amount of CO_2 emitted with the Solar diesel combo seems to be almost the same as the amount of carbon released with just diesel generation. This is in part because we assume a higher dispatchability for electricity generated by a diesel generator on its own higher that the system that burns diesel and uses solar panels.

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. Our estimates of the economic Benefit-Cost Ratios (BCRs) of each intervention, using 3 different discounting rates, and using the small grid assumptions, are listed in Table 7, and for the large grid are listed in Table 8.

Table 7- Economic Benefit-Cost Ratio Summary for Small Grid (100kW)

Technology Mix	BCR @ 3%	BCR @ 5%	BCR @ 12%
Diesel Only	1.55	1.40	1.07
Diesel and Solar	1.24	1.09	0.78
Diesel, Solar and Battery	1.41	1.18	0.76
Hydro	1.83	1.41	0.78

Table 8- Economic Benefit-Cost Ratio Summary for Larger Grid Grid (11,600kW)

Technology Mix	BCR @ 3%	BCR @ 5%	BCR @ 12%
Diesel Only	3.76	3.58	3.00
Diesel and Solar	4.59	3.32	2.36
Diesel, Solar and Battery	4.13	2.94	2.02
Hydro	12.17	7.65	3.95

The economic benefit-cost ratios include the costs and benefits applied to all stakeholders, including the Partnership, consumers, and the beneficiaries around the world who benefit from reduced CO_2 emissions.

The benefit-cost ratios displayed in Table 7 and Table 8 suggest that grid technologies could be a net positive investment for both Haiti and the world. It appears that larger grids in general yield significantly higher net benefits. It also appears that hydro can scale significantly, but also drops off more sharply with respect to the discount rate.

It is important to remember that these results are based on assumptions about the dispatchability of renewables, 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 and dispatchability on our results. In our baseline assumptions, we assumed dispatchability levels between 75 and 100 percent for all technologies. 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 diesel to dispatch all the electric. In Table 9 we show estimates that we obtain for each set of technologies, but for different levels of dispatchability, assuming a 5% discount rate.

Table 9 – Sensitivity of Economic Benefit-Cost Ratio to Dispatchability (Small Grid @ 5% Discount Rate)

	Dispatchability			
Technology	25%	50%	75%	100%
Diesel Only	0.47	0.85	1.15	1.40
Diesel and Solar	0.54	0.87	1.09	1.25
Diesel, Solar and Battery	0.77	1.01	1.13	1.20
Hydro	1.41	1.41	1.41	1.41

Note: All figures assume a 5% discount rate

The results in Table 9 show how a lower dispatchability can reduce the BCR below 1. Especially in a place that is as vulnerable to natural disasters and political turmoil as Haiti, it may actually be plausible to imagine a grid 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 case of a cost overrun. While results thus far have been calculated assuming a small grid with 100kW of generation capacity, we might be interested in how these technologies scale up. In Table 10 we list the BCRs for the four technologies under different scenarios for cost overrun.

Table 10- Economic Benefit-Cost Ratio for with Different Capital Cost Overruns (Small Grid@ 5% Discount Rate)

Technology Mix	5% Cost Overrun	10% Cost Overrun	25% Cost Overrun
Diesel Only	1.38	1.35	1.29
Diesel and Solar	1.06	1.04	0.97
Diesel, Solar and Battery	1.13	1.09	0.98
Hydro	1.35	1.30	1.15

Note: All figures assume a 5% discount rate

Notice that the cost benefit ratio for the hydro drop faster than for the other technologies, since hydro has so much upfront capital cost. Notice as well that cost overrun can be the difference between the project generating net benefits and net costs.

Conclusion

In general, our estimates seem to imply that Isolated Grids could produce benefits that exceed their costs, but these results are sensitive to the assumptions incorporated into our model. Of the possible technologies, we consider, small scale hydro, or diesel generation seem to offer good benefits relative to costs. Solar currently seems expensive, although this could change in time. Our sensitivity analysis indicated that the results were highly correlated with dispatchability, and that cost effectiveness increased with scale, especially for hydro.

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.

We conclude with some general recommendations for those parties interested in investing in isolated grids in Haiti:

1. The benefits of installing hydro can be high, especially in larger grids, and if capital can be financed cheaply. Even at small scale with a very high upfront capital cost, hydro could be a feasible option. This will not, however, be an option for all areas due to limited water resources.

2. Solar Panels and Batteries may not be the most effective technologies for supplying electricity to a grid at this time. Diesel generators, despite their carbon dioxide emissions may be a more cost effective way of generating electricity. This is subject to change as solar technology develops or as fuel prices increase. Higher social costs of carbon could also change this.
3. Fixed costs for connecting a customer to a grid can potentially be quite high. In order to maximize cost effectiveness, grids would ideally be installed, ceteris paribus, in areas where consumption would be the highest per consumer.

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Appendix A: Extending our Model to Understand the Benefits of Extending Existing Grids

Preface

As we were writing our papers on grid scale generation and isolated grids, CCC expressed some interest in a potential extension to our project to consider combining grid scale generation with transmission to isolated grids. While we did not have a lot of time to complete an additional research project in the same level of depth as our other 4 papers, we also realized such as an extension could be done without too much extra work with a few simplifying assumptions. We present these results to stimulate further thought and to see if there is any potential for such projects, but urge readers to consider the many flaws with such a simplistic analysis. Any actual project would need significantly more detailed analysis and better data.

The Cost of Electricity Generation

In our Grid scale generation models, we looked at the cost of producing electricity at for 9 technologies (Solar PV, CSP, Wind, Hydro, Conventional Combustion, Advanced Combustion, Advanced Combined Cycle, Conventional Combined Cycle and Coal). From these models, we estimated the per kWh cost of dispatched electricity under different assumptions.

The Cost of Transmission

Through conversations with EDH, we were able to obtain rough estimates of the cost of transmission lines per kilometer. These costs differ depending on the voltage level. For example, the cost of a 23-kV wire is $70,000/km and for a 12.47 kV wire is $50,000/km. We can therefore roughly estimate the costs of transmitting electricity to small isolated by multiplying the distance a transmission line needs to span by the costs of the wire per km. We need to know, therefore, how far we need to extend transmission lines in in order to connect an isolated grid. We were able to get a map roughly detailing Haiti's existing energy infrastructure which we have included here as Figure 1. From this map, it appears that most parts of the country are not too far from a large thermal or hydro electric generator. It looks like most villages that we would want to connect lie within 20-30km of existing generation or transmission. If we were to link multiple grids using grid scale transmission, the average distance needed per grid may be even lower, perhaps around 10km. The capital costs can be annualized and spread out over the life span of the asset.

Figure 1 –Haiti's Electricity Grid

Réseau métropolitain de Port-au-Prince : 12 communes Port-au-Prince, Carrefour, Delmas, Tabarre, Cité soleil, Pétion ville, Kenscoff, Gressier, léogane, Croix-des-bouquets, Thomazeau, et Ganthier
Réseau interconnecté du nord 23 KV : Grande rivière du nord, Bahon, Cap-haitien, Quatier morin, Milot, Acul du nord, Plaine du nord, Limbé et Port margot
Réseau interconnecté du Nord- Est, 23 KV : 7 Communes For liberté, Ouanaminthe, Ferrier, Terrier Rouge, Trou du nord, Caracole, Sainte Suzanne et Limonade
Réseau interconnecté de l'Artibonite, 23 KV : Artibonite, Gros mornes, Ennery, Gonaïves, Marchand, Esther, Desdunes, Grande saline et petite rivière de l'Artibonite Bas Artibonite, Saint marc, Verrettes, Liançourt, Montrouis et Desarmes
Réseau interconnecté des Cayes 12.47 KV : Les Cayes, Cavaillon, Saint Louis du Sud, Torbeck Arniquet et chantal 23KV Camp- Perin, Maniche, Carrefour valiere, Port-salut, et Saint Jean du Sud
Réseau interconnecté de Petit Goave 23 KV : Fauché, Aquin, Grand Goave, Miragoane Paillant, Saint Michel du Sud, et Fonds des Nègres (Dans les nippes), vieux Bourgs d'Aquin et Aquin
Réseau interconnecté de Jacmel, 23 KV : Jacmel, Cayes-Jacmel, Marigot et Pérédo

Benefits of Transmission

The main reason why we would want to connect transmission lines to small isolated grids is to give Haitians living in such areas access to cheap electricity produced from our grid scale technologies.

We already considered the benefits of electricity consumption for Haitians in an isolated grid earlier in this paper, finding the difference between coping costs (the costs of using kerosene or small generators to produce electricity) and the cost of electricity produced using other technologies, and multiplying this value by their level of consumption observed in electrified isolated grids. We were able to obtain some consumption data through contacts at the Les Anglais microgrid and EDH. While this calculation overlooks the possible changes, we would normally observe in consumer behavior as a result of a price change, discussions with stakeholders involved in isolated grid projects suggested that changes in consumer behavior as a result of electrification were often over estimated and may not be substantial. Faced by limitations in terms of available data on the demand function of Haitian consumers in isolated grids, we saw this method of estimation as a flawed but not totally unreasonable way of moving forward.

We reuse the isolated grids model, but change the costs of supplying electricity to reflect grid scale generation and add in the costs of transmission lines. We will also change the inputs for carbon emissions to reflect the emissions of grid scale technologies. The costs and benefits of the isolated grid are therefore the same broadly speaking, but the way we calculate the CAPEX and carbon emissions will reflect the different values associated with grid scale generation and transmission.

The Inputs

I have chosen to include the costs of grid scale generation for 3 technologies in this extension rather than all 9 in order to keep tables and calculations manageable for a variety of assumptions. I have opted to include Wind Turbines, as well as Conventional Combined Cycle and Conventional Combustion. I chose Wind because it was the only renewable source not already covered in the isolated grids model and because it was one of the stronger options when considering grid scale renewables. I chose the conventional thermal because it is one of the simplest types of thermal plant making it more feasible for Haiti, and I chose conventional combined cycle because it had the lowest levelized cost of energy out of all of the grid scale technologies.

The estimated price per kWh of dispatched electricity obtained for these three technologies from models 1 and 2 are shown in Table 11, using 3%, 5% and 12% as the discount rate.

Table 11

	Average Cost of Dispatchable Electricity (2015 USD/kWh)		
Technology	3% Discount Rate	5% Discount Rate	12% Discount Rate
Wind Turbines	$0.1048	$0.1182	$0.1741
Conventional Combustion	$0.0237	$0.0254	$0.0326
Conventional Combined Cycle	$0.0122	$0.0138	$0.0206

The price of electricity charged to the consumer also needs to include the cost of transmission lines. To get this value, I assume an average isolated grid will require 10 km of 12.47kv transmission lines which has an associated capital cost of 500,000 USD. This will enter our model in the same way as the other capital costs, first being annualized and then evenly distributed to the cost of each kWh consumed. We will also do this for distribution costs.

Results

The benefit-cost ratios associated with each technology and for different discounting rates are listed in Table 12.

Table 12 – Benefit Cost Ratios of Grid Scale Transmissions to Isolated Grids

	Benefit-Cost Ratio (Economic)		
Technology	3% Discount Rate	5% Discount Rate	12% Discount Rate
Wind Turbines	1.92	1.52	0.88
Conventional Combustion	2.47	1.97	1.11
Conventional Combined Cycle	2.59	2.05	1.14

Based on the figures presented in Table 12, it appears that the transmission of cheap electricity to small villages could yield a net economic benefit. Fixed costs are very high as a percentage of the cost per kwh and the costs of electricity generated are very low, meaning that if consumption levels increase, or if the size of grids increase, the benefit-cost ratio of transmitting electricity should be even higher. However, as the distance of transmission increases, transmission could also become unviable.

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.

Haïti Priorise

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