**Bahman Kashi**
Founder - Economist; Adjunct Lecturer
Limestone Analytics: Queen's University

**Jay Mackinnon**
Economist
Limestone Analytics

**Juan Belt**
Senior Economist
Limestone Analytics

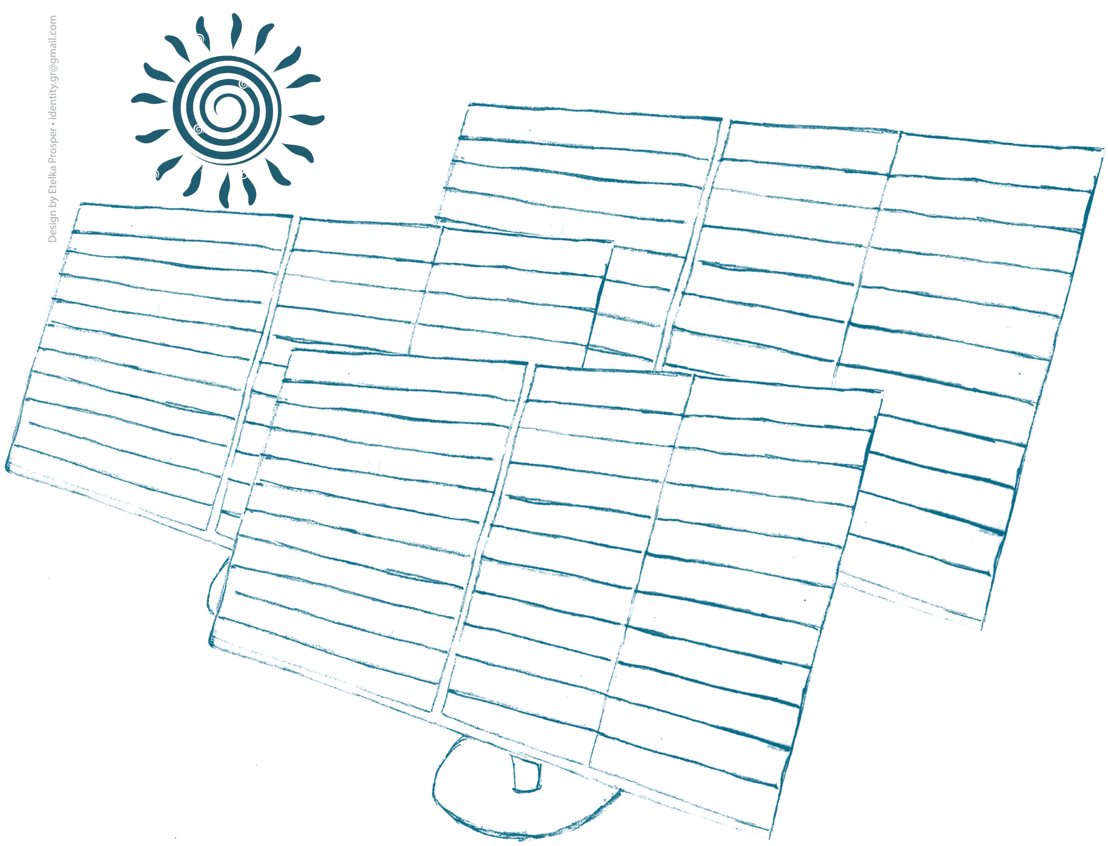
**Nicolas Allien**
Renewable Energy and Energy Efficiency Consultant
Ministry of Public Work, Transportation and Communication

**Bénaël Jean-Louis**
Studies and research supervisor
Marketing directionnel, Société Générale Haïtienne de Banque, S.A. (SOGEBANK)

**Benefit-Cost Analysis**

# Comparing Grid-Scale Renewable Energy Generation Technologies in Haiti





COPENHAGEN CONSENSUS CENTER

Haïti Priorise
Un plan de **développement** alternatif

# Comparing Grid-Scale Renewable Energy Generation Technologies in Haiti

## Haïti Priorise

Bahman Kashi
*Founder - Economist; Adjunct Lecturer*
*Limestone Analytics: Queen's University*

Jay Mackinnon
*Economist*
*Limestone Analytics*

Juan Belt
*Senior Economist*
*Limestone Analytics*

Nicolas Allien
*Renewable Energy and Energy Efficiency Consultant*
*Ministry of Public Work, Transportation and Communication*

Working paper as of April 19, 2017.

info@copenhagenconsensus.com
www.copenhagenconsensus.com

This work has been produced as a part of the Haiti Priorise project.

This project is undertaken with the financial support of the Government of Canada. The opinions and interpretations in this publication are those of the author and do not necessarily reflect those of the Government of Canada.

Canada

## Academic Abstract

In this paper, we attempt to quantify the costs and benefits of installing new electricity generation capacity in Haiti in the form of solar photovoltaics (PV), concentrated solar power (CSP), hydroelectric and wind turbines. 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 renewable generation capacity come therefore in the form of cost savings to Haiti's energy utility, as well as in the form of reduced carbon dioxide emissions for the world. Costs are presented as the average yearly capital, operating, and maintenance costs associated with the instillation of one megawatt (MW) of generation capacity at grid scale. We consider the sensitivity of the benefit-cost ratio (BCR) estimates to changes in the discount rate, the cost of fuel and the dispatchability of electricity generated.

# Abbreviations in this Report

$CO_2$ – Carbon Dioxide

CSP – Concentrated solar power

EDH – Electricité d'Haïti

GDP – Gross Domestic Product

GOH – Government of Haiti

INGO – International Non-governmental organizations

IPP – Independent Power Producer

IRENA – International Renewable Energy Agency

kWh – Kilowatt Hour

LAC – Latin America and the Caribbean

MDB – Multinational Development Bank

MW – Megawatt

MWh – Megawatt Hour

O&M – Operating and Maintenance

PPA – Power Purchase Agreement

Solar PV – Solar photovoltaic (solar panels)

USD – United States Dollar (currency unit)

USD PPP – United States Dollars, under the assumption of Purchasing Power Parity

# 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 concentrated solar power (CSP), solar photovoltaic systems (Solar PV), hydroelectric or wind turbines. 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. While we do not prescribe exact locations where the technologies should be used, existing studies like Worldwatch (2014) have considered where a limited amount of hydro could be built, and show the high potential for both wind and solar power in many parts of Haiti.

## Implementation Considerations

The primary costs of adding generation capacity to the grid are (i) the costs of capital, and (ii) the operating and maintenance (O&M) costs. Capital costs for renewable sources of electricity have dropped sharply in recent years and some renewable electricity generation technologies are now competitive with conventional technologies.

The interventions we propose could save more costs than they generate, 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 renewable 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 they help reduce. 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 all have a predicted lifespan of approximately 25 years (IRENA, 2015a, p.24). 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 renewable technologies, and the current PPA prices. Both are subject to change over time. The price of renewables is subject to a downward trend with time. Oil volatility can impact the PPA price on an ongoing basis. Our results are also strongly correlated with the dispatchability in a given grid.

Due to the different sources of uncertainty, we conduct analysis to see how the benefits and costs obtained with our model are influenced by changes in inputs.

Renewables are being used in many parts of the world as a way of producing energy that is in most cases clean, and in some cases, inexpensive. While Haiti has not been able to embrace the full potential of renewables yet, Haiti is a suitable place for such projects, at least from a geographic perspective. Haiti has been identified as an ideal site for both wind and solar generation (Worldwatch, 2014; Government of Haiti 2015). The main concerns that would keep such projects from being implemented would stem from questions regarding stakeholder's ability to finance and maintain infrastructure once it is constructed. We strongly advise that any interventions that target Haiti's electricity supply or demand are accompanied by institutional reforms, to unleash the maximum benefits per dollar spent in the power sector.

There are some unavoidable risks associated with expanding generation capacity, such as the risk of natural disasters that could damage installed capital, 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 could also be called into question. However, Haiti needs electricity and even if the energy is not paid for, it is still generating economic benefits. Investing in renewable electricity generation capacity is financially risky, which is a constraint on the feasibility of any proposed project. The social, financial and economic factors must be attended to closely when considering investing in renewable generation capacity.

## Rationale for Intervention

There are two main benefits that would emerge from investing in renewable energy generation. The first is cost savings. These cost saving could help make EDH more financially sustainable. The other benefit of generating electricity using renewables is the reduction in carbon dioxide emissions. IPPs, now, produce power by burning diesel or other fossil fuels, the combustion of which will produce carbon dioxide, a harmful greenhouse gas that contributes to global climate change. Thus, by generating electricity using renewables, power producers can supply electricity which is cleaner than currently available options.

The primary beneficiaries of our proposed interventions are the consumers and suppliers of power in the PPA market, as a result of a shift in the supply curve. The rest of the world also benefits because of carbon emissions that are prevented from new generation using renewable energy sources instead of fossil fuels.

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 a summary of the costs and benefits of the four technologies under our baseline assumptions. However, the range of possible costs and benefits we could apply to each intervention in worst and best case scenarios is broad, and we discourage readers from taking these values out of context.

Table 1 – Summary of the Proposed Interventions

| Technology | Annualized Benefit (2015 USD) | Annualized Cost (2015 USD) | BCR | Quality of Evidence |
|---|---|---|---|---|
| Wind | 267,824.84 | 186,372.23 | 1.44 | Medium |
| Solar PV | 163,670.74 | 160,423.95 | 1.02 | Medium |
| Concentrated Solar Power | 223,187.37 | 471,670.14 | 0.47 | Medium |
| Hydro | 386,858.11 | 254,666.88 | 1.52 | Medium |

Notes: All figures assume a 5% discount rate and are for 1 MW of installed capacity

1. INTRO ....................................................................................................1
2. CONTEXT ....................................................................................................1
The Poorest Country in the Western Hemisphere .................................................. 1
*Natural Disasters* .................................................................................... *2*
*Haiti's Assets* .................................................................................... *2*
Electricity in Haiti .................................................................................... 3
The Importance of Renewable Solutions .................................................................. 3
The New Economics of Renewable Energy .................................................................. 4
3. THEORY ....................................................................................................6
Understanding the Benefits of Improving Electricity Supply in Haiti ............................. 6
Capacity Factor and Dispatchability ........................................................................ 7
4. CALCULATION OF COSTS AND BENEFITS ....................................................................8
Benefits, Costs, and Stakeholders ........................................................................... 8
Costs .................................................................................................... 9
Benefits .................................................................................................... 11
*Value of electricity delivered to consumers* ........................................................... *11*
Net Benefits, Cost Benefit Ratios and Sensitivity Analysis ........................................... 13
5. CONCLUSION ....................................................................................................17
6. REFERENCES ....................................................................................................20

# 1. Intro

In this paper, we estimate the costs and benefits of adding a marginal amount of grid-scale renewable 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 spend 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.

## Haiti's Assets

Haiti possesses some key resources that could be a reason for optimism. Haiti has a young workforce that could help drive economic growth under the right conditions. Haiti is also close to major markets in North America and Central America, and has signed beneficial trade agreements with both the United States and Canada that could create a market for exports if Haiti were positioned to take advantage of such a thing.

Perhaps more relevant to this paper is Haiti's significant potential to harness the power of renewable energy. Haiti is extremely well suited to both wind and solar generation, and has a limited but significant capacity for hydroelectricity as well. If Haiti can exploit such natural resources, it would be able to produce clean energy cheaply enough to even make more developed nation envious.

## 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.

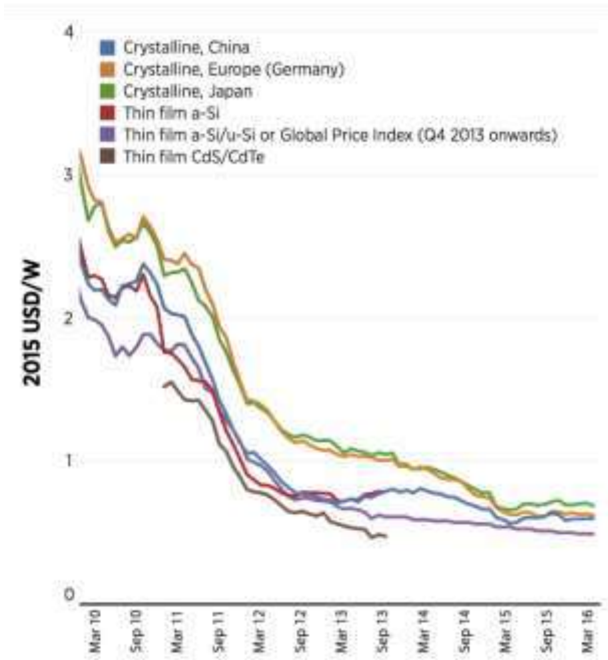
## The Importance of Renewable Solutions

Climate Change is one of the most pressing concerns facing humans today. Carbon dioxide and other greenhouse gasses released by humans are leading to increasing average air temperatures, acidification of the oceans, and increasingly disruptive weather patterns (Obama, 2017). It is important that when addressing ways of supplying Haiti's electricity demands, we consider the environmental implications of possible interventions. While Haiti is not currently a large contributor to global emissions due to its underdeveloped economy, Haiti's vulnerability to extreme climate conditions means that it has a lot of "skin in the game" when it comes to fighting global climate change. Haiti's relatively underdeveloped electricity grid means that it can incorporate clean renewables into its energy supply in a big way.

## The New Economics of Renewable Energy

Most of Haiti's electricity (85 %) is generated by burning fossil fuels such as diesel. This is both economically inefficient, and contributes to climate change. Haiti's reliance on fossil fuel also makes them vulnerable to shocks in the global price of oil.

Figure 1 – Solar PV Prices 2010-2016 (Reprinted from IRENA 2016b, p.35)




Luckily, the prices of alternative energy sources are decreasing. The global price of solar panels has decreased exponentially, and in the past few years have become more competitive with more conventional sources of energy. In Figure 1 – Solar PV Prices (Reprinted from IRENA 2016b, p.35) the average price of Solar PV sold in Europe is listed for five and a half years. The price per watt has dropped sharply over this period. Haiti is exceptionally well suited to solar generation with global horizontal irradiance (GHI) of 5-7 kWh/$M^2$, a value more than twice that of Germany, a country heavily invested in solar (Worldwatch Institute, 2014, p.50).

Wind Turbines are also becoming cheaper. In 2015, the international renewable energy agency (IRENA) estimated that onshore windmills could produce electricity for as cheaply as 0.05 USD per kWh under ideal circumstances. Haiti sees variance in the amount of wind available in different areas. However, high wind speeds close to population centers make wind an attractive option for Haiti.

Hydro also holds great potential, and is widely used around the world to produce cheap electricity. Haiti already has at least 60 MW of installed capacity, running at various levels of efficiency, but studies reflect that there is potential for at least 100 MW of additional grid scale hydropower capacity (Worldwatch, 2014, p.63) and even more if we consider smaller scale generation. While this will not be enough to satisfy the predicted growth in Haiti's energy demand, it could be part of a low-cost mix of generation technologies.

Renewable energy sources look even more cost effective if we consider the costs of carbon emissions that they forgo. If consumers were forced to pay for the expected damage caused by releasing carbon dioxide into the atmosphere, the cost of renewable energy would look even less expensive.

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 benefits does not mean that those benefits can be actualized without other considerations. This paper addresses the possible benefits of introducing renewable energy sources to Haiti's electricity generation capacity. However, we believe any interventions that adds generation to Haiti's electricity market should be accompanied 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

## Understanding 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 using renewable energy sources. We capture the value of new generation through cost savings for EDH. These savings can improve financial stability for EDH, and/or be passed on to consumers in the form of reduced prices or improved reliability.

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 primarily relevant for competitive markets in equilibrium. Haiti's prices for electricity are set nationally, and have not changed since 2009. Thus, we are reluctant to make assumptions about 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. This makes our estimates of benefits conservative.

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 benefits of the newly generated power are 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 renewables 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. The renewables we are looking at are not able to generate a constant output of power, due to fluctuations in the wind, sunshine and flow of water. Thus, just because a MW of capacity is installed does not mean that a MWh of generation is possible every hour.

Given the intermittent nature of sunshine, wind, and water flow, even when power is generated by these sources there may not exist demand for its consumption. Furthermore, renewable technologies may produce more power than the grid can accommodate. Haiti's transmission and distribution capacity is in a poor shape, and their ability to accommodate fluctuation in supply is not guaranteed. This referred to by the dispatchable share of generation in our model.

The capacity factor enters our model as a simple multiplier to each technology that converts the total amount of electricity that a 1 MW generator would produce in a year (8760 MWhs) under ideal conditions to the actual generated electricity. Our capacity factor estimates come from IRENA (2015) and represent global averages.

It is possible that Haiti's underserviced electricity grid might be unable to handle all the electricity produced by some of the technologies when they are operating at peak capacity, such as solar during the brightest parts of the day. It is also possible that for the dispatch-able share to be reduced due to misalignment of consumer demand with intermittent renewable output. However, this is not a major issue for our model because we consider the marginal benefits of an additional MW of capacity, and because Haiti has such a high level of excess demand that 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 dispatchability, and can tell us how the costs and benefits change in response to higher or lower dispatchability factors.

# 4. Calculation of Costs and Benefits

## Benefits, Costs, and Stakeholders

The following sections will explain how we estimated the costs and benefits of different renewable energy sources. 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 every person on earth who benefits from a reduction in $CO_2$. While this includes Haitians, the percentage of the global population comprised of Haitians is relatively low, 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 |

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 of reduced $CO_2$ emissions are attributed to All Countries.

## 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 are shown in Table 3. 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 the financial viability of the project, it is possible to input a separate interest rate should we be so interested.

Table 3 – Capital Costs of Grid Scale Renewables (2015 USD)

| | | | Annualized Cost (USD) | | |
|---|---|---|---|---|---|
| Technology | Cost per MW (USD) | Lifespan (Years) | @ 3% | @ 5% | @ 12% |
| Wind | $1,560,000 | 25 | $89,587.48 | $110,685.83 | $198,899.95 |
| Solar PV | $1,810,000 | 25 | $103,944.45 | $128,423.95 | $230,774.95 |
| CSP | $5,550,000 | 25 | $318,724.68 | $393,786.14 | $707,624.83 |
| Hydro | $2,800,000 | 25 | $160,798.04 | $198,666.88 | $356,999.92 |

Source: IRENA (2015a)

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. 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. Note that we are not able to decompose fixed and variable costs in all cases. However, where only one is included, it should be sufficient for our estimations.

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

| Technology | Fixed O&M per MW (2015 USD) | Variable O&M per MWh (2015 USD) | Total O&M per Year (2015 USD) |
|---|---|---|---|
| Wind | | $24 | 75,686.40 |
| Solar PV | $32,000 | | 32,000.00 |
| CSP | $70,000 | $3 | 77,884.00 |
| Hydro | $56,000 | | 56,000.00 |

Source: IRENA (2015a)

## 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 0.17 USD/kWh according to Thys (2017). The calculation is simply the total dispatchable electricity generated by installed capacity for a given technology multiplied by the PPA price. We assume a baseline dispatchability of 50% for each technology, and use capacity factors from the IRENA (2015a) paper. We will 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 Renewables

| Technology | Dispatchability Factor X Capacity Factor | Expected Electricity Dispatched per MW (MWh/Year) | Annual Value of Generation (2015 USD) |
|---|---|---|---|
| Wind | 18% | 1,576.80 | $ 261,748.80 |
| Solar PV | 11% | 963.60 | $ 159,957.60 |
| CSP | 15% | 1,314.00 | $ 218,124.00 |
| Hydro | 26% | 2,277.60 | $ 378,081.60 |

Sources: Thys (2017); IRENA (2015a)

The second benefit is the benefit of reduced carbon emissions. We calculate this benefit using estimates of the per kWh $CO_2$ emissions of diesel generators, which we assume would be replaced with clean energy in our interventions. By multiplying the yearly emissions abated by the social cost of carbon, we can see the annual impact of our intervention on the environment. The values for the social costs of carbon as 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.

Table 6 – Benefits of Reducing Carbon Emissions

| | | Annual Value of Carbon Dioxide Reduction | | |
|---|---|---|---|---|
| Technology | Expected Electricity Dispatched per MW (Average MWh) | @ 3% (22.9 USD/Tonne) | @ 5% (5.18 USD/Tonne) | @ 12% (0 USD/Tonne) |
| Wind | 1,576.80 | $26,861.28 | $6,076.04 | $0 |
| Solar PV | 963.60 | $16,415.22 | $3,713.14 | $0 |
| CSP | 1,314.00 | $22,384.40 | $5,063.37 | $0 |
| Hydro | 2,277.60 | $38,799.62 | $8,776.51 | $0 |

Sources: Tol (2011); IRENA (2015a)

## 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 possible 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 a good enough way of prioritizing interventions. We have attempted to estimate benefits conservatively so that if our interventions are implemented, the results are at least as good as we have implied. Our estimates of the economic benefit-cost ratios of each intervention, using 3 different discounting rates are listed in Table 7.

Table 7- Economic Benefit-Cost Ratio for Summary for Baseline Assumptions (World's Perspective)

| Technology | BCR @ 3% | BCR @ 5% | BCR @ 12% |
|---|---|---|---|
| Wind | 1.75 | 1.44 | 0.95 |
| Solar PV | 1.30 | 1.02 | 0.61 |
| CSP | 0.61 | 0.47 | 0.28 |
| Hydro | 1.92 | 1.52 | 0.92 |

The economic benefit-cost ratios from the world's perspective include the costs and benefits applied to all stakeholders, including the benefits from reduced $CO_2$ emissions. We display the BCR from Haiti's perspective in Table 8.

Table 8 – Economic Benefit-Cost Ratios Summary for Baseline Assumptions (Haiti's Perspective)

| Technology | BCR @ 3% | BCR @ 5% | BCR @ 12% |
|---|---|---|---|
| Wind | 1.58 | 1.40 | 0.95 |
| Solar PV | 1.18 | 1.00 | 0.61 |
| CSP | 0.55 | 0.46 | 0.28 |
| Hydro | 1.74 | 1.48 | 0.92 |

The benefit-cost ratios displayed in Table 7 and Table 8 present a complicated set of results to decipher. It seems clear that CSP is a comparatively bad investment, but for other technologies the results are slightly more ambiguous. Wind, Solar PV and Hydro all have BCRs above one when discounted at lower rates, but below one when discounted at 12%. This suggests that renewable energy sources could in theory be used to produce cheaper electricity than diesel burning IPPs if we assume a low discount rate, but this result is based on enough sensitive assumptions that we would not want to assert that renewables offer great potential for Haiti without a long list of qualifications.

It is important to remember that these results are based on assumptions about the dispatchability of renewables, the discount rate, the costs of installed capacity and discount rates. All of these can be incredibly context specific and thus we should consider the implications of changes in their values.

First, let us consider the impact of capacity factors and dispatchability on our results. Our baseline assumptions allow for 50% of the potentially generated electricity to be dispatched into the grid. This is based on the outdated electrical infrastructure in Haiti, lack of institutional support for renewables as well as the need to update modernize the EDH dispatch center. However, it is conceivable that in a scenario where significant investments are made into the electrical grids, intermittent renewables like wind or solar could have different dispatchability. In Table 9 we show our estimates that we obtain from our model for different levels of dispatchability, assuming a 5% discount rate.

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

| | Dispatchability | | | |
|---|---|---|---|---|
| Technology | 25% | 50% | 75% | 100% |
| Wind | 0.72 | 1.44 | 2.16 | 2.87 |
| Solar PV | 0.51 | 1.02 | 1.53 | 2.04 |
| CSP | 0.24 | 0.47 | 0.71 | 0.95 |
| Hydro | 0.76 | 1.52 | 2.28 | 3.04 |

Note: All figures assume a 5% discount rate and are for 1 MW of installed capacity

The results in Table 9 show how a higher dispatchability make the benefits of grid-scale renewables significantly higher. Assuming a grid was properly equipped to be able to transmit and distribute the amount of energy generated by the proposed renewables, and assuming that enough excess demand exists to consume all the electricity generated, we could imagine higher levels of dispatchability. However, the more intermittent renewables we include in any grid's generation mix, the more we will have to consider the possibility of excess supply, and the accompanying drop in dispatchability. It is possible that dispatchability could also be improved through energy storage option (like batteries or pumped hydro), however such considerations exceed the limited scope of our analysis.

Let us also consider the implications of a higher PPA price, something that could happen in the case of an oil shock. The price of electricity sold by diesel burning IPPs should increase to reflect the change in this input. 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 (USD/kWh) | | | |
|---|---|---|---|---|
| Technology | $0.150 | $0.166 | $0.180 | $0.200 |
| Wind | 1.30 | 1.44 | 1.56 | 1.72 |
| Solar PV | 0.92 | 1.02 | 1.10 | 1.22 |
| CSP | 0.43 | 0.47 | 0.51 | 0.57 |
| Hydro | 1.38 | 1.52 | 1.64 | 1.82 |

Note: All figures assume a 5% discount rate and are for 1 MW of installed capacity

Table 10 shows how the value of renewable generation increases with the price of electricity sold in the market. While it is obvious that the value of electricity generation capacity is linked with the value of electricity, it is interesting to consider how investment in renewables could be used as a way to hedge against oil volatility. 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, renewables would begin to look more attractive.

## 5. Conclusion

In general, our estimates seem to imply that some sources of renewable sources of electricity generation have benefits that could exceed costs. This is partially due to extremely high PPA prices, making many technologies compare favorably. Concentrated solar seems to be unviable at this time, primarily due to high costs of capital, but this could change in the future. Hydro fairs best when discounted at a lower rate and when a high cost of carbon is incorporated into the model, but it is important to remember that there are a limited number of sites where hydro can be installed, meaning Haitians will need to use other technologies to satisfy their projected electricity demand. Solar PV and wind turbines both look like they could be used as part of Haiti's electricity grid, especially in contexts where dispatchability is not a constraining factor, but if they become widely used, their intermittent nature might become an issue. While there are ways of accommodating non-dispatchable sources of electricity, many of these solutions are expensive, and it might be more reasonable to balance renewable sources of generation with efficient thermal. For more information on the potential of grid scale thermal, we recommend readers consider reading our Haïti Priorise paper on this subject. In general, the authors would stress that the benefits and costs of electricity generation are context specific, and that site-specific feasibility studies would be used to identify where projects could be used effectively. However, it seems that in some cases, as Haiti's electricity market expands, there may be potential for grid scale renewables to find a place in a new national generation mix. Some general takeaways for anyone interested in investing in renewable energy generation in Haiti are:

1. Concentrated solar seems to be economically infeasible at this time, due to high capital costs.
2. Hydropower already is, and can continue to be, an economically efficient way of generating electricity

3. Wind has a great deal of potential, and should be considered as a potential source of investment.
4. Based on our assumption, grid-scale Solar PV offers some potential economic benefits, but these are minor compared to wind and hydro. We would recommend prioritizing these other two technologies before solar when considering investments in grid scale generation.
5. The costs and benefits of electricity generation are sensitive to dispatchability, discounting factors and the price of electricity sold in relevant markets. The estimates in this paper are based on aggregations and assumptions. Site specific feasibility studies will be necessary before any investment.

Table 11 – Summary of Grid Scale Renewables at Base Assumptions

| Technology | Discount Rate | Benefits (USD/MW) | Costs (USD/MW) | Economic Benefit-Cost Ratio | Quality of Evidence |
|---|---|---|---|---|---|
| Wind | 3% | $288,610.08 | $165,273.88 | 1.75 | Medium |
| | 5% | $267,824.84 | $186,372.23 | 1.44 | |
| | 12% | $261,748.80 | $274,586.35 | 0.95 | |
| Solar PV | 3% | $176,372.82 | $135,944.45 | 1.30 | Medium |
| | 5% | $163,670.74 | $160,423.95 | 1.02 | |
| | 12% | $159,957.60 | $262,774.95 | 0.61 | |
| CSP | 3% | $240,508.40 | $396,608.68 | 0.61 | Medium |
| | 5% | $223,187.37 | $471,670.14 | 0.47 | |
| | 12% | $218,124.00 | $785,508.83 | 0.28 | |
| Hydro | 3% | $416,881.22 | $216,798.04 | 1.92 | Medium |
| | 5% | $386,858.11 | $254,666.88 | 1.52 | |
| | 12% | $378,081.60 | $412,999.92 | 0.92 | |

## 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.

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.

Hotel in Port au Prince, 2016. Interview with an Anonymous hotel.

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.

Inland Revenue, 2016. General depreciation rates.

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.

Obama, Barack. 2017. "The Irreversible Momentum of Clean Energy." *Science* 355 (6321): 126–29. doi:10.1126/science.aam6284.

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, 2016. Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016.

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.

Haïti Priorise

Un plan de **développement** alternatif

**For more information visit www.HaitiPriorise.com**

## COPENHAGEN CONSENSUS CENTER

Copenhagen Consensus Center is a think tank that investigates and publishes the best policies and investment opportunities based on social good (measured in dollars, but also incorporating e.g. welfare, health and environmental protection) for every dollar spent. The Copenhagen Consensus was conceived to address a fundamental, but overlooked topic in international development: In a world with limited budgets and attention spans, we need to find effective ways to do the most good for the most people. The Copenhagen Consensus works with 300+ of the world's top economists including 7 Nobel Laureates to prioritize solutions to the world's biggest problems, on the basis of data and cost-benefit analysis.