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Benefit-Cost Analysis

Costs and Benefits of Agroforestry in Haiti:

Value Chain that Includes Environment and Health

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Haïti Priorise
Un plan de développement alternatif

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Academic Abstract

Between 70% and 95% of the energy used for cooking in Haiti is from solid fuel (wood and charcoal), which is very detrimental to the country's forest. This paper suggests tackling the deforestation issue both upstream and downstream. It identifies three interventions that can work in synergy to boost afforestation and contribute to strengthen the agroforestry value chain in Haïti: optimal agro-silviculture; carbon pricing infrastructure and biogas scale up for cooking. These interventions are evaluated from a private and social perspective using the cost-benefit analysis (CBA) approach. A broad range of services is included for each intervention, namely: timber, agro-crops, environmental, nutrition and health benefits for the first one; timber and environmental benefits for the second one; and natural gas, slurry, environmental and health benefits for the third one. Carbon sequestration is the common environmental benefit to all of these three interventions. No previous CBA study has considered such an integrated and quantitative approach for the agroforestry value chain in Haïti before. The cost and benefit data used in this analysis come from a large variety of sources, including existing literature, field observation and personal communication with local experts or agents. Using the medium discount rate of 5% and the medium scenario of 3x GDP per capita for the Value of a Disability-Adjusted Life Year (DALY), the BCRs are 2.99 and 2.18 for the optimal agro-silviculture and biogas scale up interventions respectively. Still, *daily cost for households using natural gas is estimated to be 38% and 21% less expensive than that for charcoal and propane respectively.* The carbon pricing infrastructure has a BCR of 1.29 at the medium discount rate. Sensitivity analysis is provided for the discount rate of 3% and 12%, the DALY value of 1x and 8x GDP per capita, exclusion of social benefits and the price of natural gas.

Policy Abstract

Overview and Context

Solid fuel (wood and charcoal) accounts for 70% to 95% of the energy used for cooking in Haiti. Given that systematic program to efficiently use this energy source is limited, this situation is very detrimental for the country's forest. The deforestation problem has been traditionally approached by resorting to repressive measures. The use of hard power does not always give the expected results, specifically in the case of wicked problem. It is appropriate to also consider soft power, as conveyed in the new modes of governance.

In this context, the current paper suggests tackling the deforestation issue both upstream and downstream. It identifies three interventions that can boost afforestation and contribute to strengthen the agroforestry value chain in Haïti: optimal agro-silviculture, carbon pricing infrastructure, and biogas scale up for cooking. Agro-silviculture is a land use administration system in which trees are grown around or among crops or pastureland. This intervention will cover about 257.000 smallholder farmers on 252.000 has, representing an additional 9.2% of forest coverage, excluding savanna and rocky bare lands. Moringa is the chosen species that will be managed for its different high-value products, including nutrition, health and environmental benefits. For the second intervention, infrastructure (in the form of certified documentation, processes and regulations) is needed in order to connect the new afforestation area to the international carbon market. Any species suitable for marginalised land may be chosen by the 256.000 smallholder farmers on 251.000 has of savanna and rocky bare lands targeted. Finally, the third intervention (biogas) refers to a mixture of different gases (mostly methane) produced by the breakdown of organic matter in the absence of oxygen. Once the biogas is purified, it is referred as natural gas. This intervention intends to cover about 397.000 households representing 16% of total households and cooking energy need. An estimated 350 million of cubic meter of natural gas will be produced. Since biogas is a substitute for charcoal, tapping the potential of this local source of energy will end up putting a downward pressure on deforestation. It is an indirect support to promote afforestation in Haiti. It should be noted that the first and second interventions are to be implemented in rural areas and thus, represent the upstream ones. As for the third intervention, industrial level biogas in urban areas are considered in this study; hence it represents the downstream one.

Implementation Considerations

Costs for the agro-silviculture intervention are essentially private and include labour (clearing, ploughing, planting, weeding, harvesting) and other costs (land, seedlings, fencing, transportation). Total costs amount to 32.58 million HTG (129,185 HTG per ha) for the first year and 23.94 million HTG (94,945 HTG per ha) in the subsequent years. With recent scientific research that aims to demonstrate the many nutritional and health benefits of moringa, this culture has seen a renewed interest in Haiti since 2013. The fact that the plant is resistant creates the risk of neglecting the technical itinerary. Promotion and training are important to make the farmers aware of issues during the development and harvesting of the plant. For example, leaves and pods are sometimes harvested by using a long pole or climbing the tree; which is not very convenient and risks to cause the flowers to fall and the branches to break. Moreover, intermediate agents need to be trained in the transformation, packaging and labelling of the products targeted for the international market in order to ensure a standard approach to marketing. The *Ministère de l'Agriculture, des Ressources Naturelles et du Développement Rural* (MARNDR) can have overall responsibility for this intervention, in partnership with other ministries (such as MSPP - *Ministère de la santé publique et de la population),* the private sector (such as *Rezo Moringa Doliv Ayiti*) and international agencies.

For the second intervention, infrastructure costs to market the carbon and produce behavioral changes in farmers include costs with the Verified Carbon Standard (VCS) Program (registration fee, carbon units issuance levy, methodology approval process administration fee, expert application fee, verification annual fee) and costs with a contractor (methodology development fee and complete program documentation, verification fee). These social costs amount to 1.55 billion HTG in the first year and 1.04 billion in subsequent years. They are in addition to the traditional afforestation costs which amount to 27.34 billion (109,023 HTG/ha) in the first year, but only 482.28 million (1,923 HTG/ha) in the following years. As such, the social costs represent about 5% of the total costs in the first year, but 68% of the total costs in the subsequent years. Such intervention has not been done before in Haiti. The Ministry of Environment, in collaboration with MARNDR would be responsible for the implementation. At 453 HTG/t. CO_2 eq, carbon price on the international market is currently low. There is a risk that this price increases in the future, which can put a stress on government finances, but can be offset by a proportional increase in carbon tax.

As for the biogas intervention, it has been estimated that 100 plants are required, with a total bio-digester volume of 467 million m^3. The total investment costs in year one is substantial (81.35 billion HTG).[1] Costs sum up to 6.46 billion HTG in the following years. While these costs are mostly private, given the many social and economic benefits of this intervention, a public-private partnership can be considered. Moreover, good governance is required to attract private investments. Even though pilot biogas projects have been implemented at the community level in Haiti, no such project or program has been implemented at the industrial level. The private sector, in partnership with *Direction Nationale de l'Eau Potable et de l'Assainissement* (DINEPA – the organism responsible for drinking and waste water), MARNDR, *Ministère de l'Énergie et des Mines*, other ministries, and international donors are possible implementers for this intervention. Promotion and training are needed to address cultural, technical and other possible constraints.

Rationale for the Interventions

Benefits for the agro-silviculture intervention include direct income from the sale of leaves, seeds and timber from moringa, as well as from the sale of peanuts. Part of these products is also used for consumption by the family of the smallholder farmer. Consumption of these high nutrient products contributes to decrease malnutrition, a significant risk factor for infant and child mortality rate. The agro-forestry system is also valued as a carbon sink (CO_2 reduction), for its biodiversity and its regulating services (water flow, erosion prevention, disturbance moderation, waste treatment, pollination) generating a wide range of indirect environmental benefits. It should be noted that this intervention also generates recreational services that are not quantified in the indirect benefits. Consequently, the BCR of 2.99 under the medium

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[1] The costs to build these plants are estimated at 78.74 billion HTG, or an average of 61.537 HTG/m^3 of bio-digester (78,740/(467/365)).

scenario (discount rate of 5% and DALY valued at 3x GDP per capita) for this intervention could be slightly underestimated.

As for the carbon pricing intervention, it includes all the benefits of the first one, except for nutrition and health. It generates a BCR of 1.29 under the medium scenario. For the biogas intervention, the main benefit comes from the sale of natural gas. Other direct income comes from the sale of organic fertilizer. Economic benefits for households include energy, time and money saved from using a more efficient fuel and cook stove. For example, *daily cost for households using natural gas is estimated to be 38% and 21% less expensive than that for charcoal and propane respectively*. Indirect values include: health benefits (reduced Household Air Pollution due to cleaner cook stoves), environmental benefits (reduction in the use of charcoal by up to 380,000 tons). This intervention generates a BCR of 2.18 under the medium scenario. The benefits are shared with the biogas promoters, the households using biogas and the whole society in terms of better health and reduced greenhouse gas emission. Other external effects exist, but were not included in the analysis, for example: higher employment prospect, improved trade balance, better sanitation. A summary table of the BCR follows for each intervention during the 20 year-period.

Cost Benefit Table

Summary Table of the BCR (Costs and Benefits in billion gourdes, 5% discount rate)

Interventions	Benefit	Cost	BCR	Quality of Evidence
Optimal agro-silviculture	963.12	321.93	2.99	Medium
Carbon pricing Infrastructure	51.47	39.96	1.29	Limited
Biogas scale up	290.20	132.97	2.18	Medium

Source: Author's calculations

Notes:

1. For the agro-silviculture intervention, social costs and benefits (carbon, biodiversity, regulation and health) are included. DALY is valued at 3x GDP per capita.
2. For the carbon pricing intervention, social costs and benefits (carbon, biodiversity, regulation) are included, but not health benefits.
3. For the biogas scale up intervention, social costs and benefits (carbon and health) are included. DALY is valued at 3x GDP per capita.

Sensitivity analysis is done for each intervention. On the particular case of the biogas scale up, if health and environmental benefits are not included, the BCR from a private perspective still remains high (1.86) under the same set of medium scenario parameters. Given the high investment cost for the biogas plants, it is suggested to use a staggered approach and a public/private partnership for the implementation of these plants.

1. Introduction and Context

The world leaders at the United Nations (UN) Summit on Sustainable Development agreed on the action plan in September 2015 *Transforming our world: the 2030 Agenda for Sustainable Development* (UN, 2015). This plan stresses the need for bold and transformative steps to move the world onto a sustainable and resilient path. It features 17 Sustainable Development Goals (SDGs) and emphasizes their integrated nature; which demonstrates the scale and ambition of the plan. Two of these 17 SDGs (SDGs 2 and 15) are particularly relevant for agro-forestry. Specifically SDG 2.4 states: ''By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.'' As for SDG 15, it stipulates: ''Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.''

Notwithstanding, between 70% and 95% of the energy used for cooking in Haiti is from solid fuel (wood and charcoal), according to the UNEP (2011) annual review and Haiti *Enquête Mortalité, Morbidité et Utilisation des Services* (EMMUS) by Cayemittes *et al.* (2013) respectively. Given that there has been no systematic program to efficiently use this energy source and renew it, this situation is very detrimental for the country's forest. Today, the original forest area is only 3.5%, according to FAO (2015a), though other sources put it as high as 30% (Churches *et al*., 2014). Efforts of the Haitian government, through the Ministry of Environment, demonstrate its willingness to tackle the problem of deforestation by addressing the production of charcoal and predators of the environment. The problem has been traditionally approached by resorting to repressive measures. Obviously, given the current situation, the use of hard power did not give the expected results. It is appropriate to also consider soft power, as conveyed in the new modes of governance (WHO, 2011).

This soft power approach is all the more important that we are facing a *wicked* problem. Indeed, the causes of deforestation in Haiti are complex. Tenure insecurity is one that is particularly studied. The farmers have no incentive to engage in sustainable farming practices, given that they face uncertainty in the medium and long term due to the system of indirect tenure (*de-mwatyé*), They are more concerned with short-term needs like providing food and clothes to their families. Consequently, they practice a mining agriculture (Hilaire, 1995). They diversify their sources of income (livestock, charcoal production, labor supply to other farmers, etc.) to fight poverty and inequality. They prioritize non-forestry, even on high slope surfaces; which allows them to have more frequent income but to the detriment of the soil stability.

In this context, the current paper suggests tackling the deforestation issue both upstream and downstream. It identifies three interventions that can boost afforestation and contribute to strengthen the agroforestry value chain in Haïti: optimal agro-silviculture; carbon pricing infrastructure and biogas scale up for cooking. Agro-silviculture is a land use administration system in which trees are grown around or among crops or pastureland. It can be managed to be linked to different markets for high-value products, including non-traditional market such as carbon. The selected species for the first intervention is benzoil or *benzoliv* in creole (*Moringa olifeira*). This tree largely takes care of itself and thus is ideal for the Haitian farmers. It is a high-growth species and is known to be edible (the leaves and pods), on top of having environmental and health benefits. The agricultural crop considered is groundnuts, also called peanuts (*pistash* in creole). It is a source of food and income in the Haitian rural sections. By choosing moringa as the preferred forest species, two crucial issues in Haiti are addressed: food security and poverty. Although one crop is featured in this intervention, rotation is recommended in order to improve soil fertility. Possible other agricultural crops include: sorghum, corn, beans, sugar cane, coffee and vetiver. For the second intervention, infrastructure (in the form of certified documentation, processes and regulations) is needed in order to connect the new afforestation area to the international carbon market. Any species suitable for marginalised land may be chosen by the farmers. Finally, the third intervention (biogas) refers to a mixture of different gases (about 55 to 65% methane, CH_4) produced by the breakdown of organic matter in the absence of oxygen. Once the biogas is purified, it is referred as natural gas or LNG (Liquified Natural Gas) with 95% of methane. Since biogas is a substitute for charcoal, tapping the potential of this local source of energy will end up putting a downward pressure on deforestation. It is an indirect support to promote afforestation in Haiti. It should be noted that the first and second interventions are to be implemented in rural areas and thus, represent the upstream one. As for the third intervention, industrial level biogas in urban areas are considered in this study; hence it represents the downstream one.

While studies have previously addressed deforestation in Haiti with some CBA dimension (USAID, 1990; SFA, 2015; MARNDR-BRH, 2016), to our knowledge, none has considered such an integrated approach for Haiti before. Moreover, the cost benefit analysis (CBA) presented for each intervention takes into account a broad range of services. Thus, the forest is managed not only for its timber, but also for services such as nutrition and health, carbon sink, biodiversity, regulation. Likewise, the CBA for biogas accounts not only for the production of biogas itself, but also the slurry, the environmental, health and social benefits. Such comprehensive CBA studies on any of these three related interventions have not been done for Haiti before. Consequently, this paper represents a substantial contribution to the literature.

The rest of the paper is outlined as follows. After conducting a literature review in the next section, we present the data sources and methodology in the third section. The key estimates of the BCA for each of the three interventions are provided and discussed in section 4. The paper ends with a conclusion in section 5.

2. Literature Review

2.1. At the international level

Among the many different forest species, it is interesting to note the interest for Moringa in international development organizations, particularly those linked to the United Nations system (FAO, UNICEF, WFP).[1] FAO mentions Moringa as an asset to combat desertification, protect crops in arid zones and contribute to improved food security in rural and peri-urban households

[1] FAO: Food and Agriculture Organization; UNICEF: United Nations Children's Fund (formerly UN International Children's Emergency Fund); WFP: World Food Program.

(increased availability of high nutritional value over long periods throughout the year, improved income through the sale of production and also the establishment of small processing units of the plant's products). Today, these agencies see Moringa as a way to fight malnutrition around the world, particularly in Africa, Asia and to a lesser extent in America (FAO, 2016; WFC, 2015).[2]

It is important to emphasize the establishment of financial mechanisms for the development of the sector by international financial groups such as the Moringa Fund. According to the MARNDR-BRH (2016) document prepared by Agroconsult Haiti SA, this investment fund has a final investment objective of 100 million Euros (€). The investment zone targeted by this fund is Latin America and Africa (Southern Sahara). The Fund invests from € 4 to 10 million per year in cost-effective, large-scale agroforestry projects with high environmental and social impacts. It should be noted that in 2014, the African Development Bank (ADB) invested € 10 million in the Moringa Fund.

The second intervention has also some prominence at the international level. According to World Bank (2014), about 40 national and over 20 sub-national jurisdictions (including the US and China: the world's two largest emitters) have put a price on carbon. ''Together these carbon pricing instruments cover almost 6 Gt CO2 e or about 12% of the annual global GHG emissions.'' Leaders presently unite, via the Carbon Pricing Leadership Coalition (CPLC, 2015), in calling for a price on carbon. Convened by World Bank Group President and the International Monetary Fund's Managing Director, this Carbon Pricing Panel includes prominent members and is joined in this effort by the OECD Secretary General.

Meanwhile, structures are in place to link foresters around the world to the international carbon market. For example, the Verified Carbon Standard (VCS) program develops and manages standards and frameworks to vet environmental and sustainable development efforts, build their capacity and connect them to funding. By ensuring robust, practical and transparent standards, VCS can reliably quantify benefits and drive investment in responsible, high-performing projects

[2] The World Forestry Congress (WFC) is a key event for the international forestry community. It is organised jointly by the FAO and the host country, and convenes every six years.

and programs (VCS, 2016). Consulting firms, such as Winrock International[3] are being created to help farmers in this process.

In spite of this effort, market price of carbon on the international market is on a declining trends to the point that it is currently below the social price of carbon at reasonable discount rate. In fact, the current price at the European Climate Exchange (ECX) is at €4.30 (or about $US 4.60) per ton of CO_2 equivalent, from a peak of €9.43 (or about $US 11.90) in 2012. It should be noted that, at the discount rate of 3% and 5%, social cost of carbon is $US 22.9/t CO_2 and $US 5.18 respectively (Tor, 2011).

Finally, with installed global production capacity of more than 800 billion cubic feet per year – representing nearly 14.5 GW of renewable generation capacity, biogas is gaining a lot of traction at the international level (Pike Research, 2012).[4] The fast-growing market reached $17.3 billion in global revenue in 2011. Still, biogas remains a relatively minor player within bioenergy in the world. Regionally in 2012, there were an estimated 576 landfills across the United States which captured biogas from decomposing municipal solid waste. Meanwhile, more than 7,000 on-farm anaerobic digesters (AD) facilities across Germany produced an estimated 2,291 megawatts (MW) of power from manure waste and crop residues. At least 11 billion cubic feet per year of renewable natural gas (RNG) production capacity was expected by the end of 2012. Even though biogas production is the highest in Europe, it is also relatively substantial in North America and Asia Pacific (see figure 1).

[3] https://www.winrock.org/about/

[4] 1 m^3 (@ 101.325 kPaa and 15° C) = 35.3147 cubic feet (cf) natural gas (@ 14.73 psia and 60° F).

Figure 1: Biogas production (ktoey-1) at 2012 and trend to 2022 in different regions of the world5

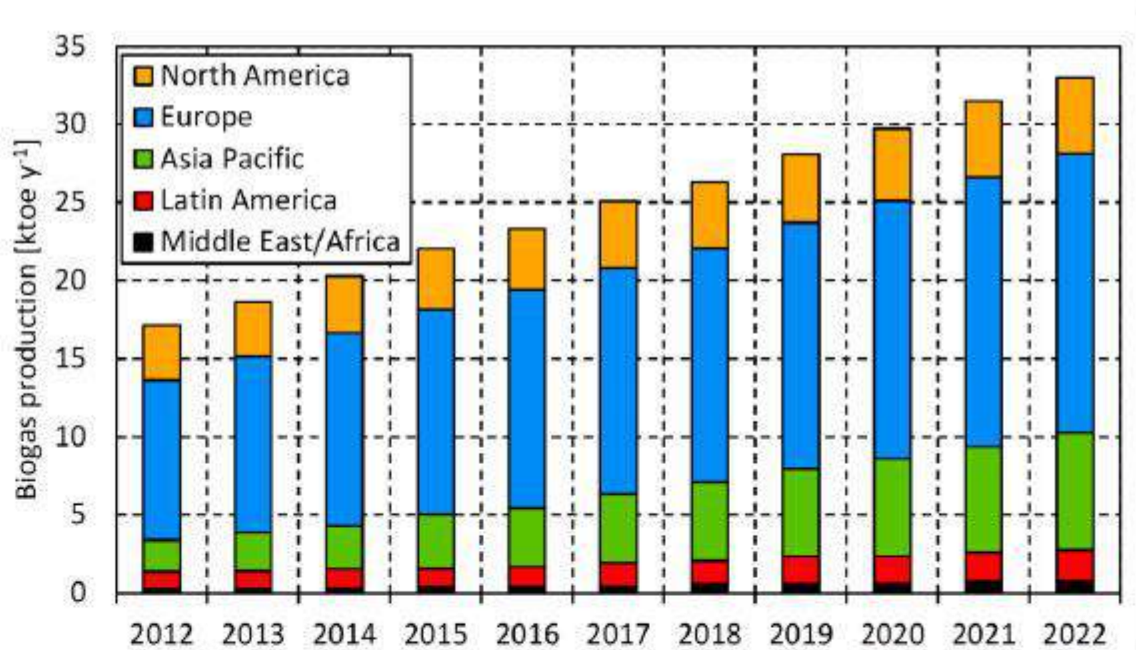
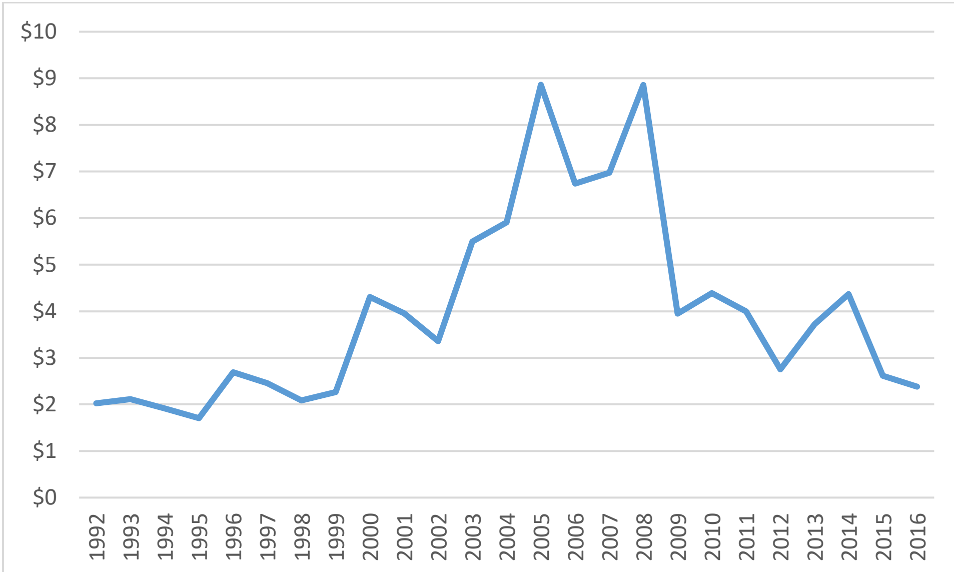


Figure 1. Biogas production at 2012 and trend to 2022 in different areas of the world (Pike Research, 2012).

While opportunities abound, low natural gas prices are expected to impede market growth. The following figure describes the trend from 1992 to 2016.

ktoey^{-1} = kiloton of oil equivalent per year.

Figure 2. Trends in natural gas prices, US$/MBTU, 1992 to 2016[6]



Source: Index Mundi: http://www.indexmundi.com/commodities/

From a high of 8.9 $/MBTU in 2005 and 2008, it is at a low of 2.4 $/MBTU currently. This corresponds to a high of 0.314 $/m^3 and a low of 0.085 $/m^3. To put this into perspective, propane price is correlated to natural gas price, with the same declining recent trend (from a high of about 1.50 $/gallon in 2008 and 2011 to a low of 0.47 $/gallon currently).

2.2. At the national level

Moringa has been known in Haiti for more than a century, but has been largely overlook. Since the 1980s, the area of Limonade / Quartier Morin, in the North department, has the highest concentration of this tree, which is well integrated with cropping and livestock systems in this area. During the 1990s, institutions such as the Pan-American Development Fund (PADF), Mouvement Paysan Papaye (MPP) and other actors encouraged the production of Moringa in several areas of the country (MARNDR-BRH, 2016). It is only in 2013 that the Moringa culture has seen a renewed interest throughout the country with the promotion campaign launched in the context of the National Program for the cultivation and use of Moringa oleifera with the support of the *Commission Nationale de Lutte contre la Faim et la Malnutrition* (COLFAM - National Commission for the Fight against Hunger and Malnutrition) in coordination with MARNDR,

[6] MBTU = Million of British Thermal Unit.

Ministère de la santé publique et de la population (MSPP-Haitian Ministry of Health) and *Ministère de l'Environnement* (MDE). Today, the tree is found at different categories of presence in all the departments of the country (MARNDR-BRH, 2016; Table 13 and Figure 1). Besides, the *Ministère de l'Éducation Nationale et de la Formation Professionnelle* (MENFP), in partnership with UNICEF, WFP and many other organisations, has recently integrated moringa powder in its school cafeteria program (MENFP, 2016).

As for the biogas intervention, there has been some recent biogas projects in Haiti. They are implemented either by some Intergovernmental Organisations (IGO), International Non-Governmental Organizations (INGOs), the Haitian government or a combination of these entities. Among others, we can mention: A pilot project entitled "Community Biogas and Upgraded Public Latrines", started in 2008; a multi-party cooperation pilot project — *Université Quisqueya* (Haiti), *Institut National des Sciences Appliquées* (INSA) in Lyon (France), *Société de Rhum Barbancourt* (Haiti) and others, started in December 2009; the Development Innovation Ventures (DIV) initiative; the two biogas production units built by Viva Rio (a Brazilian NGO) for *Kay Nou* community, a camp for the 2010 earthquake victims; the DINEPA (2010) biogas strategy benefiting from the support of a Biogas Technical Working Group with members from prominent organizations such as USAID (United States Agency for International Development), UNEP (United Nations Environment Program), UNICEF (United Nations Children's Fund), UNOPS (United Nations Office for Project Services) and Viva Rio; the facility set up in Cité Soleil by the Brazilian battalion of the UN to convert human waste to biogas. It should be noted that all of these interventions have either a pilot or project status; none has been designed as (or converted to) a program. More details on these above-mentioned projects can be found in Ariste (2015).

To the best of our knowledge, the carbon pricing infrastructure has no prominence in Haiti yet. However, the Haitian government has submitted its new climate action plan to the UN Framework Convention on Climate Change (UNFCCC). In this Intended Nationally Determined Contribution (INDC), the country is considering access to carbon markets to finance part of the conditional measures of its contribution (MDE, 2015). Other objectives in this INDC related to our interventions include: 1) reduce the country GHG emission between 5% and 31% compared to the reference scenario by 2030; 2) seed 137,500 hectares (ha) of forest by 2030 by privileging local species (including 100,000 ha conditionally between 2020 and 2030) and 3) reduce solid fuel consumption by 32% by 2030.

3. Data Sources and Method

The costs and benefits used in this analysis come from a large variety of sources, depending of the interventions. Accordingly, they will be presented separately for each intervention. It should be noted that all costs and benefits are discounted using a 3%, 5% and 12% rate; the 5% rate being the medium scenario. All values in US$ were converted to Haitian gourde (HTG) using the exchange rate of 1 US$ = 63.38 HTG (average buy and sell price, BRH, July 2015).[7]

3.1 Optimal agro-silviculture intervention

In order to come up with an estimate of the incremental costs for this intervention, we took into account two categories of costs: labour (clearing, ploughing, planting, weeding, harvesting) and other costs (land, seedlings, fencing, transportation, promotion and training). Because the tree component is the focus of this intervention which happens mostly on non-irrigated lands, some inputs used to increase crop yield, such as improved seed and fertilizers, were not considered. Field data collected by one of the CCC local agent and author's personal contact as well as the MARNDR-BRH (2016) document were used to estimate these costs. Where necessary, adjustments were made using CCC-provided assumptions or author's collected data. Costs are provided on one ha basis to reflect the fact that Haitian farms are parcelled out and to make the measures more meaningful.[8] They are estimated at 129,185 HTG/ha during the first year and 94,945 on the following years. Costs are also provided for the whole intervention to reflect the policy maker perspective; they are estimated at $32.58 billion for the first year and 23.94 for the following years. A breakdown is provided in Table 1.

[7] BRH: Banque de la République d'Haiti. http://www.brh.net/taux_de_change.html

[8] The land measure used in Haiti is *carreau (carr.)*. 1 *carreau* ≈ 1.3 ha. The annual land rental cost varies from 7.500 gourdes/carr in irrigated zone to 3.500 gourdes in wetland areas. It is less in the mountain areas, about 2.500 gourdes. The cost varies from one region to another depending on the degree of isolation.

Table 1: Breakdown of incremental annual costs for the optimal agro-silviculture intervention

Type of cost	Cost in Year 1 (HTG/ha)	Cost in following years (HTG/ha)	Total cost in year 1 (millions HTG)	Total cost in following years (millions HTG)
Land rental additional cost	1,923	1923	484.93	484.93
Promotion & training	300	60	75.65	15.13
Labour				
Clearing, ploughing	10,000	5,000	2521.74	1260.87
Seedlings -moringa	24,000	0	6052.18	0
Seedlings -Groundnuts	6,000	6,000	1513.04	1513.04
Planting moringa	5,000	0	1260.87	0
Planting groundnuts	2,500	2,500	630.44	630.44
Weeding (3x/year)	33,600	33,600	8473.05	8473.07
Harvesting moringa	24,000	24,000	6052.18	6052.18
Harvesting groundnuts	8,000	8,000	2017.39	2017.39
Transportation moringa leaves	4,800	4,800	1210.44	1210.44
Transportation moringa pods	7,200	7,200	1815.65	1815.65
Transportation groundnuts	1,862	1,862	469.55	469.55
Total	**129,185**	**94,945**	**32,577.10**	**23,942.66**

Source: Author's compilation and MARNDR-BRH (2016)

It should be noted that the intervention covers about 257.000 smallholder farmers on 252.174 has, representing an additional 9.2% of forest coverage. It excludes savanna and rocky bare lands. The program lifespan is 20 years.

For the incremental direct benefits, the same sources were used: field data collected by one of the CCC local agent and author's personal contact as well as existing literature (USAID, 1990; CNSA, 2012; FAO, 2015b; MARNDR-BRH, 2016). Direct benefits include: income from the sale of moringa leaves, seeds and timber, as well as peanuts. It is assumed moringa leaves are harvested four times a year for an average yield of 0.75 kg per tree each time (MARNDR-BRH, 2016). With a density of 400 trees per ha, this gives 1200 kg of leaves per year (see Table 2). As for the seeds, they are harvested three times a year for an average yield of 1.5 kg per tree each time; which gives 1,800 kg of seeds per ha. Groundnuts yield in Haiti is estimated at 950 kg/ha (CNSA, 2012; FAO, 2015b). The price of 1 kg of unshelled groundnut is 129 HTG.[9] Timber is sold as posts after 20 years. Price per tree/post (850 HTG) is net of harvesting cost and is considered

[9] Based on the price of 1 marmite (2.45 kg) of shelled peanuts for 450 HTG and the ratio shelled: unshelled for peanuts of 0.70.

a conservative estimate. With a density of 400 trees/ha, this gives an undiscounted total of 340,000 HTG or 211,820 after a 5% discount rate is applied (10,593 HTG/ha/year).

This intervention also includes incremental indirect benefits: environmental (carbon sink, biodiversity and regulation) and health. As shown in Ariste and Lasserre (2001), taking into account the capacity of a forest stand to capture carbon dioxide increases the market value of the stand and forest activity becomes socially more profitable (positive externality). There are methods to estimate this indirect benefit and internalize the farmer production function.

The carbon locked in a forest can be evaluated by the following equation:

Carbon value = $Price\ for\ 1\ ton\ of\ CO_2$ *emission**$Qtity\ of\ CO_2\ stored$ *per ha* *(1)*

Price of one tonne of CO_2 emission varies very considerably worldwide (EESI, 2012). The European Climate Exchange (ECX) lists the price of one metric ton of CO_2 equivalent on the international market. As shown in the section on international context, the market price is currently below the social cost of carbon. For our estimates, using the exchange rate of US$ 1 = 63.38 HTG, we retain the social costs found in Tol (2011): 1.451; 328 and 0 HTG/t. CO_2 e. for discount rates of 3%, 5% and 12% respectively. This implicitly assume the international social price of carbon is applicable to Haiti.

The second element of the equation is the quantity $of\ CO_2\ stored$ by one ha of forest. Depending on, amongst others, age, climate zone, type of forest and soil, one ha of trees captures 1 to 10 tons of CO_2 per year. As an indication, trees in Europe capture on average 200 tons of CO_2 per ha over a period of 40 years; or an average 5 t/year (SICIREC, 2009). Besides the CO_2 trees capture, they have a positive influence on the carbon capture of the entire biosphere (including shrubs, other plants and soil) in the surrounding area, both under and above ground. Thus, the accumulated carbon capture of one ha of forest can range from 300 tons (7.5 t/year) in Europe to over 600 tons (15 t/year) in the tropics, where forest growth is faster (SICIREC, 2009). Besides, CCX (2009) estimates that an oak-pine forest in the South-Central US captures about 2.3 t/acre/year or 5.7 t/ha/year (1 ha = 2.471 acres); which is roughly consistent to SICIREC estimates for trees in Europe. In Haiti, given the tropical climate and the effect of the entire biosphere, we conservatively assume one ha of natural forest can capture 9 tons of CO_2 per year.

Still from a societal point of view, forest offers a diverse set of habitats for plants, animals and micro-organisms. Consequently forest holds the majority of the world's terrestrial species and should also be valued for its biodiversity. Few studies or entities address this point.[10] Tao et al (2012) estimated that respondents would pay for the forest restoration and protection about 238 yuan per mu yearly (about 558 $US per ha per year)[11] in China while this value is about 9 $US in Tanzania (Schaafsma et al, 2014). These values represent about 8.2% and 1.3% of these countries' GDP respectively. It has been assumed that willingness to pay for biodiversity in Haiti is 4.7% of the country's GDP (average of the values in China and Tanzania); which translates to 1,711 HTG/ha. In developing countries, Markandya et al (2008) found that the majority of values for non-timber forest products (NTFP) are less than $100/ha/year, many less than $10/ha/year in terms of flow of values. These figures were obtained from an analysis of 40 studies. It should be noted that the Ecosystem Service Valuation Database (ESVD) permits to draw values from a more comprehensive, updated source and based on country income level as well as specific ecosystem services (Van der Ploeg and de Groot, 2010).[12] Still, in this study, we also account for the income level and type of ecosystem services.

The third environmental benefit included in this analysis is regulating services (water flow, erosion prevention, disturbance moderation, waste treatment, pollination, soil fertility maintenance). Flood is a serious recurring problem in Haiti mostly because of anthropogenic circumstances: deforestation, soil erosion and poor draining system. After such floods, the outcome is usually heavy in terms of number of victims.[13] Thus, forest regulating services are very important for Haiti and should be accounted for. De Groot et al (2012) from The Economics

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[10] Among the few of them, The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on recognizing, demonstrating and capturing the value of nature.

[11] Using the conversion parameters: 1 ha = 15 mu and $US 1 = 6.4 yuan.

[12] http://es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/ . Consultation of this database does not generate substantially higher cases when filtered by income level of country and type of ecosystem services.

[13] More than 30 floods causing deaths, missing people and property damages have been reported since the 1960s (Haiti Reference, 2016). For example, the floods that hit the regions of Fond-Verrettes, the South-East and the South in May 2004 were responsible for 1,232 deaths; 1,443 disappeared and 31,130 people losing their property. The weather disturbance of November 1st 2014 in the north and west of the country caused nine deaths in addition to the hundreds of flooded houses, numerous plantations destroyed and a large number of cattle taken away.

of Ecosystems and Biodiversity (TEEB) review different studies about forest evaluation. They mentioned that the value of regulating water flow per ha was $2 in Australia (Curtis, 2004) and $682 in Malaysia (Kumari, 1996) in 2007 International $. These values represent less than one percentage point of Australian GDP, but up to 7.9% of Malaysian GDP. The value of regulating water flow in Haiti was estimated as the average of these GDP percentages (4% of Haitian GDP or 1,430 HTG/ha in 2016).

Regarding the health benefits, they can be evaluated by the equation summarized as:

*Health Benefit = DALYS avoided * value of DALY * discount factor* *(2)*

Where: *DALY* is the Disability-Adjusted Life Year, an indicator that takes simultaneously into account morbidity and mortality; value of DALY = 1x, 3x or 8x GDP per capita.

For each intervention with health benefits, we first estimate the DALYs avoided using the Global Burden of Disease. Then, we identify the years in which those DALYs are avoided, we discount the DALYs avoided and multiply them by the value of one DALY in the year when the life is saved.[14]

In the case of the first intervention, moringa has the potentiality to decrease maternal and child malnutrition, a risk factor responsible for 59.8% of diarrhea, which accounts for 2.9% of total DALYs in Haiti (GBD, 2015). According to *Enquête Mortalité, Morbidité etUtilisation des Services* (EMMUS-V, 2012; Demographic and Health Survey by Cayemittes et al, 2013), there were 88 deaths per 1000 live births before age 5 in Haiti.[15] We then estimate the number of deaths among infants and children before age 5 (23,360).[16] We assume consumption of moringa leaves and pods can deliver 30% of the 14% reduction in under-5 mortality rate delivered by the Generasi intervention in Indonesia (Mahmood et al, 2010; Lubina et al, 2015). This gives a

[14] A discount factor is applied to the DALY avoided because it is a stream of benefits that happen into the future. Discounting it in equation (2) brings it to an annualized equivalent. Then, using the NPV formula does the appropriate discounting of that annualized value. Thus, health benefits are discounted twice, which is not the case for immediate benefits.

[15] Which is a high infant and child mortality rate compared to the Latin America and Carribean rate of 24 and 18 deaths per 1000 in 2010 and 2015 respectively (UN IGME, 2015).

[16] Using the crude birth rate of 25.8 per 1,000 found for Haiti in 2012 in the World Bank Database, we have (0.0258*10,288,828*0.088). Note that the 2015 under-5 death estimate from UN IGME is 18,000 for Haiti; 90% uncertainty level: 14,000 and 23,000.

reduction of 4.2% due to moringa, which we apply to the number of under-5 deaths per ha (0.093). This gives us the reduction in the number of under-5 deaths per ha (0.004). The DALYs for an under-5 life saved is 64.9 (Haiti life table from CCC). We then discount this number and multiply it by the reduction in the number of under-5 deaths per ha to get the DALYs per life saved per ha (at a 5% discount rate for example, 0.0745). These DALYs are finally converted to a dollar value based on 1 DALY = 3x GDP per capita. Sensitivity analysis is provided, with 1 DALY = 1x GDP per capita and 8x GDP per capita.

Chronic malnutrition may also causes stunting, which is relatively prevalent in Haiti - 22% among children under 5 (USAID, 2014). Even though stunting usually does not pose an immediate threat to life, studies found that it reduced wage income later in life. From a survey of eight low and middle income countries, Horton and Steckel (2013) found that achieved adult height was associated with wages, the median increase being 4.5%. Moreover, the same source expects a stunting intervention package to be effective at 20%.[17] In spite of the fact that growing moringa is not an intervention aimed at reducing stunting, leaves and pods of this plant have substantial nutritional values (USDA, 2016; Waterman, n.a) and can be an important source of many essential nutrients in Haiti. However, the leaves may also contain high levels of anti-nutrients, which can reduce the absorption of minerals and protein (Teixeira et al, 2014). Also, reviews suggest the evidence for agriculture interventions on nutrition is weak (Girard et al, 2012; Webb and Kennedy, 2014; Oley et al, 2015). Still, this should not be equated with evidence of no impact (Webb et Kennedy, 2014). Having said that, we assume that moringa consumption can deliver only 15% of the 20% of the effectiveness of a stunting intervention. This results in moringa being effective at only 3% in reducing stunting. Table 2 presents the estimates of all private and social benefits included. Annual benefits sum up to 294,233 HTG/ha or 74.2 billion HTG for the whole intervention.

[17] The other 80% reduction requires changes to the underlying determinants of nutrition, such as increased agricultural production, increased empowerment of women, investments in sanitation, etc.

Table 2: Breakdown of incremental annual benefits for the optimal agro-silviculture intervention

Type of benefits	Price per unit (HTG)	Number of units	Benefits (HTG/ha)	Total Benefits (million HTG)
Private				
Sale of moringa leaves	10	1,200 kg/ha	12,000	3,026.1
Sale of moringa pods	75	1,800 kg/ha	135,000	34,043.5
Sale of groundnuts, unshelled	128.84	950 kg/ha	122,393	30,864.3
Sale of timber, after 20 yr, 5% d.r.[a]	850	400 posts	10,593	2,671.2
Incr. wage due to reduced stunting, 5% d.r.	1.52	1 ha	1.52	0.4
Social				
Carbon, 3% d.r.	1451.30	9 t CO_2/ha	13,062	3,293.9
Carbon, 5% d.r.	*328.30*	*9* t CO_2/ha	*2,955*	*745.2*
Carbon, 12% d.r.	0	9 t CO_2/ha	0	0
Biodiversity	1,711	1 ha	1,711	431.5
Regulation	4,355	1 ha	4,355	1,098.3
Health, 3x GDP pc, 3% d.r.	109,407	0.1107 DALY	12,111	3,054.1
Health, 3x GDP pc, 5% d.r.	*109,407*	*0.0745* DALY	*8,151*	2,055.5
Health, 3x GDP pc, 12% d.r.	109,407	0.0324 DALY	3,545	894.0
Total private			**279,987**	**70,605.5**
Total social, 3x GDP pc, 5% d.r.			**17,172**	**4,330.4**
Grand Total, 3x GDP pc, 5% d.r.			**297,159**	**74,935.9**

Source: Author's compilation.

a: Health benefits rise by 2.7% per year as per CCC guidelines for valuing health benefits.

b: The price of 850 HTG for a tree is net of harvesting cost and is a conservative estimate. Field observations indicate that gross price can vary widely depending of the species and the diameter/age of the tree, with the higher range up to fivefold the lower range.

We estimate the health benefits of moringa through the mechanisms of improved nutrition: reduction in under-5 mortality rate (that may be due to reduction in diarrhea, LBW and other causes) and in stunting. We should acknowledge that this intervention may improve health through a wide variety of other mechanisms, including antioxidant, tissue protective (liver, kidneys, heart, testes, and lungs), analgesic, antiulcer, antihypertensive, radioprotective, immunomodulatory and water purification (Mahmood et al, 2010; Stohs and Hartman, 2015; Waterman, n.a).

3.2 The Carbon pricing Infrastructure Intervention

Costs for this intervention include public and private costs. Public costs are linked to the carbon pricing infrastructure itself while private costs are linked to the tree planting activities in the first year. The intervention area covers about 256,000 smallholder farmers on 250,796 has and proposes to reduce GHG emissions by 2.26 million tons of CO_2 eq. The private costs for this intervention include cost to rent the land, ploughing, seedling and planting. Cost for planting trees is higher in these rocky, marginalised lands. We assume a success rate of 25% for seedlings, the cost of ploughing and planting the tree itself that is 2.5 times higher than in a typical, non-marginalised land.[18] After the first year, the land is left alone; no weeding cost is considered. Public infrastructure costs for this intervention refer mostly to costs with the VCS program. These costs are provided in the VCS program fee schedule (VCS, 2015) and are reported in Table 3. Private costs are reported per ha and sum up to 109,023 HTG for the first year and 1,923 HTG for subsequent years. For the whole intervention, these are equivalent to 27.34 billion HTG for the first year and 482.28 million HTG for subsequent years. Given that total costs are 28.89 billion and 1.52 billion respectively for the first year and subsequently, the share of private costs is highly predominant in year one (about 95%), but drops substantially in subsequent years (32%)

[18] Seedling success was 40% in a USAID (1990) project. Communication with specialists in agro-forestry confirm it is much more costly to plant trees in marginalised lands. For example, a larger and deeper hole needs to be dig.

Table 3: Breakdown of annual costs for the carbon pricing infrastructure intervention

a) Annual private costs				
Type of cost	Cost in Year 1 (HTG/ha)	Cost in following years (HTG/ha)	Total cost in year 1 (million HTG)	Total cost in following years (million HTG)
Land rental (per ha)	1,923	1,923	482.28	482.28
Labour (per ha) Ploughing Seedlings Planting	 25,000 69,600 12,500	 0 0 0	 6,269.90 17,455.34 3,134.95	 0 0 0
Total private cost	**109,023**	**1,923**	**27,342.5**	**482.3**
b) Annual social costs				
Costs with the VCS program Registration fee[a] Methodology approval process administration fee Expert application fee Verification annual fee Verified Carbon Units (VCU) issuance levy[b]	 n/a	 n/a	 0.63 0.63 0.04 0.16 13.59	 0 0 0 0.16 13.59
Costs with the Consultant Methodology development fee[c] Verification fee	 n/a	 n/a	 7.92 2.54	 0 2.54
Local expertise[d]	n/a	n/a	1.20	1.20
Ongoing payments to farmers for carbon reduction	4,073	4,073	1,021.47	1,021.47
Leakage cost	1,580	0	396.2	0
Promotion & training	400	0	100.32	0
Total social cost	n/a	n/a	**1,545**	**1,039**
Total private and social cost	n/a	n/a	**28,887.5**	**1,521.3**

Source: Author's compilation.

a: US$0.10 x estimated annual volume of emission reductions; capped at USD 10,000

b: US$0.10 per VCU for the first 1 million VCUs; US$0.09 per VCU for an additional 1 million VCUs; USD 0.08 per VCU for the subsequent 2 million VCUs; USD 0.06 per each VCU issued over 4 million. 1 VCU = 1 ton of CO_2 eq.

c: Methodology development fee and complete program documentation is estimated at US$125.000 if some local expertise is used and could be up to US$200.000 without local expertise. For the fee used in this table, we assume local expertise is used.

d: Assuming a salary of 598,000 HTG per year for a high-level professional in the Haitian public service (that was the salary budgeted for an ambulance supervisor in the MSPP) and two FTEs (full-time-equivalent).

e) n/a = not applicable

Leakage cost means farmers with existing trees on their property will be paid at the first year of the program. This leakage cost (396.2 million HTG) is necessary in the program design because it will help to prevent gaming the program. Otherwise, farmers can cut their existing trees and plant new ones to collect money later.

As for the benefits, they are considered at two levels: private and social. Just as the costs, annual private benefits are reported per ha and for the whole intervention while social ones are reported for the whole intervention. Table 4 presents these benefits that sum up to a total of 4.6 billion HTG; 2.4 and 2.2 billion respectively as private and social benefits per year.

Table 4: Breakdown of benefits for the carbon pricing infrastructure intervention (HTG/year)

a) Annual private benefits				
Type of benefits	Price per unit (HTG)	Number of units	Benefits (HTG/ha)	Total benefits (million HTG)
Leakage benefits	197.5	8 trees/ha	79 (1580/20)	19.81
Ongoing payment for carbon reduction	452.54	9 t. CO_2/ha	4,073	1,021.47
Sale of timber, after 20 yr, 5% d.r. (posts)	425	400	5,296.4	1,328.33
Total private			**9,448.4**	**2,369.6**
b) Annual social benefits				
Carbon, 3% d.r. (ton of CO_2 eq.)	1,451.29	2,257,164	13,062	3,275.8
Carbon, 5% d.r. (ton of CO_2 eq.)	*328.28*	*2,257,164*	2,955	*741.0*
Carbon, 12% d.r. (ton of CO_2 eq.)	0	2,257,164	0	0
Biodiversity (ha)	1,710.77	250,796	1,711	429.1
Regulation (ha)	4,268.25	250,796	4,268	1,070.4
Total social, 5% d.r.			**8,934.0**	**2,240.5**
Grand Total (private + social)			**18,382.4**	**4,610.1**

Source: Author's compilation.

The leakage amount (the one-time payment of 396.2 million HTG incurred by society for existing trees) is also a private benefit for marginalized landowners. It is based on the CO_2 absorption rate of a single tree per year (average of 21.82 kg)[19] during a 20 year period and on the market price of 6.41€ per t of CO_2 e.[20,21] (0.02182*20*6.41*1.114*63.38 = 197.5 HTG/tree) The pre-intervention tree density per ha was assumed to be 8 (2% of the recommended density in the agro-silviculture intervention), given the marginalised nature of the land. This private benefit is roughly equal to 19.81 million HTG/year (396.2/20).

The ongoing payment for carbon reduction is based on the observed carbon price at the ECX market. It is a social cost for the public and a private benefit for owners of marginalised lands with existing trees on their property. Therefore, it highlights the incentives to owners of these bare lands and the transfer of resources from society to them, even though it cancels itself out in

[19] Arbor Environmental Alliance. http://www.arborenvironmentalalliance.com/carbon-tree-facts.asp
[20] European Climate Exchange, Inter Continental Exchange (ECX-ICE). https://www.bloomberg.com/energy
[21] This amont was converted to US$ using the exchange rate of 1€ = 1.114 US$ in November 2016. https://www.bloomberg.com/markets/currencies

the cost-benefit calculation. Note that carbon sequestration is also included as a social benefit that is valued, not at the carbon price on the ECX market, but at the social cost of carbon as in the agro-forestry intervention. In this intervention, timber is sold as posts after 20 years. To be conservative, price per tree or post is assumed to be half of the net price of a tree in a typical land after 20 years (425 HTG). With a density of 400 trees/ha, this gives an undiscounted total of 170,000 HTG or 105,920 after a 5% discount rate is applied (5,296 HTG/ha/year). Private benefits sum up to 9,409 HTG/ha/year.

Evaluation of biodiversity and regulation benefits is done as discussed in the previous intervention. Payments to farmers for existing trees (leakage costs) are estimated at 396.2 million HTG (1,580*250,796) in year 1. The annual private benefits for this whole intervention are estimated at 2.36 billion HTG after year 1, which is (4,073 *250,796) + (5,296*250,796), respectively the value for carbon and timber.

3.3. The Biogas Scale up Intervention

Installation cost estimates are based on case studies from China found in Hojnacki *et al*. 2011 and AQPER (2014) for the case of Gaz Metro in Montreal, Canada. They were adjusted for inflation using the cumulative inflation factor between 2011 and 2015 derived from the World Bank database for Haiti (1.368). Based on these case studies, an average installation cost of 61,537 HTG/m^3 of digester was estimated. It should be noted that 1) the annual biogas potential output is 700 million m^3; 2) a digester biogas output: volume ratio of 1.5:1 was assumed. This means that the total volume of digesters requested is 467 million m^3 and that total installation cost would be about 78.7 billion HTG (61,537*467*10^6/365). The annual costs of the digesters involve capital amortization (installation cost) and operating and maintenance costs such as labour, parts replacement. The plant lifetime was assumed to be 20 years as in Lacour (2012). Operating / maintenance costs were estimated to be 3% of the installation costs. These costs were estimated at 0.4% in Lacour (2012). However, to account for the collection, transportation and final sorting of the organic waste, the much higher percentage was assumed in this study. An estimated 9 million organic waste (3 million of dry matter) was available as feedstock in 2008 at the national level (Lacour, 2012). This feedstock is made up of different types, including: household organic waste, crop residue and farm animal dung.

The cost of the NG starting kit stove was assumed to be 75% of that of LPG kit, which was estimated at 125 $US (7,923 HTG).[22] It was also assumed that the NG stove lasts seven years, which gives an annual cost of 848.77 HTG per household (a total of 336.8 million HTG). Capital and insurance costs were assumed to be respectively 1.0% and 1.2% of the installation cost. The cost of the counterfactual should be considered. It was assumed that a traditional stove costs 254 HTG, lasts three years and two are needed for a household; which translates to an annual cost of 169 HTG per household (67.1 million HTG in total). The total incremental cost in year one is estimated at 81.3 billion HTG and 6.5 billion in the following years. Table 5 provided a breakdown of these costs.

Table 5: Breakdown of annual costs for the biogas scale up intervention, million HTG

Type of cost	Cost in Year 1	Cost in following years
Land rental	0.3	0.3
Plant installation	78,739.7	0
Annual operating and maintenance cost of plants	0	2,362.2
LNG kit stove (every 7 years)	2,357.5	2,357.5
LNG Stove maintenance	0	3.4
Program promotion and training	317.4	0
Program monitoring and training	0	63.5
Insurance	0	952.0
Capital	0	787.4
Charcoal stove (every 3 years) - Counterfactual	67.1	67.1
Total incremental cost	**81,347.9**	**6,459.2**

Source: Author's compilation.

As for the private benefits, the final product to be sold on the market is natural gas (NG), which is generally about 50 to 60% of the biogas production, but could theoretically reach up to 70% (Dai *et al.* 2016).[23] To be conservative, a NG content of 50% was assumed; which gives 350 million m^3 of NG. Cooking energy need in Haiti has been estimated at 0.81 m^3 of NG/fam/day or

[22] From the web page of the store Lakayiti: https://lakayiti.com/

[23] This source suggests that methane content could theoretically reach up to 74% of the biogas content. However, NG content represents 95% of methane.

0.59 kg of LNG (Liquefied Natural Gas). This estimate is based on: 1) an approximate energy content of 37.3 mega-joules (MJ) in 1 m^3 of natural gas (NEB 2016), 2) the fact that a typical family needs about 22.5 MJ effective per day of cooking (ESMAP 2007), 3) methane efficiency of 78% (Gilson Engineering, 2010; Engineering ToolBox[24]), 4) NG content represents 95% of methane; and 4) 1 m^3 of NG is equivalent to 0.72 kg of LNG (ISU, 2014; NEB, 2016).[25]

Propane price is used as a basis for methane price. Currently, Liquefied Petroleum Gas (LPG or propane) is less expensive than charcoal, even when the latter is used with an improved cook stove (See Table 6).[26] However, the majority of the population keeps using charcoal because of the high cost of the starting kit for propane. Our field observation suggests that fairly affluent households use propane more and more. The biogas program is intended to replace charcoal and prevent the expansion of propane; an imported fuel with higher GHG emissions than methane. For these reasons, we have chosen to use propane price as a basis to set LNG price.

Table 6. Comparative cost (HTG) of the use of different substitutable fuel for cooking purpose

Fuel	Unit cost (HTG/kg)	Heating value (MJ/kg)	Efficiency (%)	Cost per effective energy (HTG/MJ)	Monthly consumption (kg)	Monthly cost (HTG)
Charcoal	24.00	31.0	25	3.11	79.52	1,909
LPG (Propane)	57.51	42.5	55	2.46	26.32	1,514
LNG	72.22	51.8	74	1.88	15.87	1,146

Source: Adapted from Angelier (2005, Table 13) and author's estimate for LNG.

This table is based on the fact that a typical family needs about 22 MJ effective per day for cooking (ESMAP, 2007). Using charcoal, this represent a gross daily need (GDN) of 88 MJ (22/0.25) when the efficiency is taken into account. This GDN is equivalent to 2.84 kg (88/31) when the charcoal heating value is accounted for; which gives a consumption of 79.52 kg valued at 1,916 HTG per month.[27,28] In the case of LPG, the GDN is 40 MJ (22/0.55) when the efficiency

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[24] Combustion Efficiency and Excess Air. The Engineering Toolbox. Available: http://www.engineeringtoolbox.com/

[25] Using these parameters, we get the 0.81 m^3 of NG/fam/day [22.5/(37.3*0.78*0.95)]. It should be noted that transformation to LNG permits to save on transportation space and cost because 1 m^3 of LNG = 588 m^3 of NG (Source: IGU, 2012).

[26] For the 1,909 HTG monthly spending for charcoal, it is assumed an improved cook stove is used. If the traditional cook stove with an efficiency of 20% is used, the monthly spending for charcoal would be higher. However, the improved charcoal cook stove takes more time to boil the water than the traditional cook stove (Booker *et al.* 2011).

[27] We assumed each household cooks 28 days in a month.

is taken into account. This GDN is equivalent to 0.94 kg (40/42.5) when the LPG heating value is accounted for; which gives a consumption of 26.32 kg valued at 1,514 HTG per month.[29],[30] Finally for LNG, the GDN is 29.73 MJ (22/0.74) when the efficiency is taken into account. This GDN is equivalent to 0.57 kg (29.73/51.8) when the LNG heating value is accounted for; which gives a consumption of 15.87 kg valued at 1,146 HTG per month. [31]

If propane is used, the equivalent consumption of 0.94 kg of LPG/fam./day costs about 54 HTG locally.[32] A reasonable price estimate for the daily LNG need of 0.59 kg (0.81 m^3 of NG) could not be higher than that for 0.94 kg of LPG (the daily propane need). We assumed that 1 m^3 of natural gas (0.72 kg LNG) will be priced at 52 HTG; this means 1 kg LNG is worth 72.22 HTG (52/0.72). For the daily LNG need, this represents a cost of 42.60 HTG, which is about 21% less expensive than the cost for the daily LPG need. If charcoal is used, the daily cost is 68.44 HTG, which means that LNG is about 38% less expensive than charcoal and shows the relative inefficiency of charcoal, both in terms of energy and cost. These situations are reflected in the last column of Table 6 on a monthly basis.[27]

The biogas process also produces slurry that can be used as an organic fertilizer. This effluent is generally estimated as the equivalent to the mass of the substrate fed to the digester (Singh and Sooch, 2004). The 10,960,000 tonnes of wet matter produce 2,960,000 tonnes of dry matter (a DM rate of 27%). A relatively low flat fee of 2,378 HTG/t. DM was set for the effluent.[33]

Social benefits include health, environmental and reduction in time for cooking. Household air pollution (HAP) is a serious health issue in Haiti. The recently released Global Burden of Disease

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[28] Cost per effective MJ from charcoal is calculated as follows. 1 kg of charcoal corresponds to 31 MJ; so 1 MJ costs 24.1/31 = 0.777 HTG. Using a traditional stove with a 25% efficiency, the charcoal gives an effective MJ at a cost of 0.777/0.25 = 3.11 HTG.

[29] Cost per effective MJ from LPG is calculated as follows. 1 kg of LPG corresponds to 42.5 MJ; so 1 MJ costs 57.51/42.5 = 1.35 HTG. Using an LPG stove with a 55% efficiency, the LPG gives an effective MJ at a cost of 1.35/0.55 = 2.46 HTG.

[30] Monthly LPG consumption in Angelier (2005) is 21.2 kg, lower than the 26.3 kg estimated in this analysis. In his study, Angelier noted that one LPG cylinder of 25 lbs last 14 days in a Haitian household. However, most households did not likely use exclusively LPG for cooking. This could be one of the reasons for his lower monthly consumption estimate for LPG.

[31] Cost per effective MJ from LNG is calculated as follows. 1 kg of LNG corresponds to 51.8 MJ; so 1 MJ costs 72.22/51.8 = 1.39 HTG. Using an LNG stove with a 74% efficiency, the LNG gives an effective MJ at a cost of 1.39/0.74 = 1.88 HTG.

[32] Based on the estimates that in Port-au-Prince, on October 2016, the 25 lbs cylinder costs 550 HTG to refill (Field Observation). Moreover, it's assumed the thank is full at 85% capacity.

[33] Manure was sold from $2.50 to $10 for a 45-50 kg bag. However, some agriculture stores in Port-au-Prince gave it for free (SOIL, 2011). In the current study, the price of $0.0375 (2.38 HTG) per kg was chosen, as in Lacour (2012).

2015 (GBD 2015) reports that an estimated 8,400 people died from HAP in 2015, making air pollution the fourth most major risk factor in the country in terms of death and disability.[34] If 50% of users are on clean cookstoves, we assumed a reasonable reduction in HAP health effects of 40% (Larsen, 2014). With the 16% energy need covered by the intervention, this suggests that the reduction in % of deaths from HAP is 6.4% (or 538 persons). The years of life lost (YLL) to the four major diseases associated with HAP sum up to 710.000.[35] The total YLL due to the top four diseases caused by HAP is 233,431.[36] This translates to an average YLL per death of 28 (233,431/8,400). Using a 5% discount rate, the DALYS avoided per life saved is 8,009 (28*0.5317*538). With a medium DALY value of 3X GDP per capita, the estimate for the health benefit is 876.2 million HTG for 2016.

Just like LPG stoves, LNG stoves tend to provide substantial cooking time savings. In this analysis, we apply a cooking time saving of 40 minutes from the use of LNG compared to an unimproved cook stove. Larsen (2014) applied this time saving from the use of LPG stove. Given the higher heating value of NG (NEB, 2016) and higher efficiency of NG stove, the 40 mn cooking time saving from NG is an underestimation. The time savings is valued at the domestic daily minimum wage of 175 HTG for an 8-hour day work or 21.88 HTG per hour (Haiti-Libre, 2016). Thus, the value of the reduction in cooking time is estimated at 14.58 HTG per day or 4,900 HTG (14.58*28*12) per household per year.

As for the environmental benefits, they are estimated based on the value of energy saved per household per year, which is (1,909 -1,146)*12 = 9,156 HTG (see Table 6). They are considered as private benefits.

[34] The top three major risk factors are: child and maternal malnutrition, unsafe sex, and high blood pressure. http://www.healthdata.org/haiti

[35] These four diseases and their respective YLL are: lower respiratory infection (284,000), stroke (260,000), ischemic heart disease (142,000) and lung cancer (24,000). Source: GBD-IHME http://www.healthdata.org/sites/default/files/files/country_profiles/GBD/ihme_gbd_country_report_haiti.pdf . The lung cancer YLL was an estimate (assumed to be the same as liver cancer).

[36] Based on the following DALYs HAP risk factors: lower respiratory infection (44.7%), stroke (23.0%), ischemic heart disease (27.0%) and lung cancer (35.0%).

Table 7: Breakdown of benefits in the first year of operation of the biogas scale up intervention

Type of benefits	Price per unit (HTG)	Number of units	Total amount (million HTG)
Private			
Sale of NG (tons)	72,222.22	252,000,000	18,200
Sale of slurry (tons)	2376.563	2,960,000	7,034.6
Repayment of NG stoves	865.75	396,793	343.5
Value of cooking time saved (Households)	4,900	396,793	1,944.3
Energy saved from switching to NG (Households)	9,156	396,793	3,633.0
Sale of charcoal before intervention (Households)	(22,902)	396,793	(9,087.4)
Social			
Carbon, 3% d.r. (ton of CO_2 eq.)	1451.29	1,893,181	2,747.5
Carbon, 5% d.r. (ton of CO_2 eq.)	*328.28*	1,893,181	*621.5*
Carbon, 12% d.r. (ton of CO_2 eq.)	0	1,893,181	0
Health, 3x GDP pc, 3% d.r. (DALYs)	109,407	10,088	1,103.7
Health, 3x GDP pc, 5% d.r. (DALYs)	*109,407*	*8,009*	*876.2*
Health, 3x GDP pc, 12% d.r. (DALYs)	109,407	4,292	469.6
Total incremental private			**22,068.1**
Total social, 5% d.r.			**1,497.7**
Grand Total			**23,565.8**

Source: Author's compilation.

a: Health benefits rise by 2.7% per year as per CCC guidelines for valuing health benefits.

b: Numbers may not multiply exactly due to rounding.

The total quantity of carbon kept locked is estimated from the reduction in quantity of charcoal consumption due to the substitution to NG, which is 378,636 tons (79.52/1000*12*396,793). Given that 5 tons of wood is needed to produce 1 ton of charcoal (FAO, 1983), the quantity of wood needed is 1,893,181 tons. With an average growth of 9 t/ha/year for tropical forest (FAO, 1983), the forest area kept with locked carbon is 210,353 ha. One ha of tropical forest also stores about 9 t. of CO_2 eq per year (SICIREC, 2009); which gives the 1.9 million of CO_2 eq.

4. Calculation of Costs and Benefits and Discussion

4.1. Main Results with Sensitivity Analysis

The benefit to cost ratios (BCR) for the series of interventions yield positive results, except for the carbon pricing infrastructure at higher discount rate of 12%. The main results are presented in Table 8, with the assumption that a DALY is worth three times the GDP per capita (medium scenario), which is projected to grow at average annual rate of 1.2% from 2015 to 2019, and at an additional point of percentage every four years.[37] They are based on a medium discount rate of 5%, with sensitivity analysis provided at 3% and 12% discount rate. The benefits and costs reported hereafter are in billion HTG for each of the three interventions during the 20 year-period. For the agro-silviculture intervention, the BCR is 2.99; in other words, for every gourde spent, the net economic benefit in its present value is 2.99 HTG. The results differ slightly for the discount rate of 3% and 12% where every gourde spent yields an economic benefit of 3.17 and 2.85 HTG respectively; meaning that the intervention is viable at any of these three discount rates. These results are not substantially sensitive to the discount rate used, in spite of the long period of 20 years (a higher discount rate produces a lower NPV of the benefits). That's because most of the benefits (sale of moringa pods and leaves as well as groundnuts) are available on a yearly basis throughout the lifetime of the program.

[37] GDP projections based on historical real growth rate of 2.7% from 1975 to 2014, (Source: CCC)

Table 8: Summary Table of the BCR (DALY at 3x GDP per capita)

Interventions	Discount	Benefit (billion HTG)	Cost (billion HTG)	BCR	Quality of Evidence
Agro-silviculture	3%	1,190.07	375.53	3.17	Medium
	5%	963.12	321.93	2.99	
	12%	595.41	208.93	2.85	
Carbon Pricing Infrastructure	3%	108.03	43.37	2.49	Limited
	5%	51.47	39.96	1.29	
	12%	23.44	32.78	0.72	
Biogas Scale up	3%	385.89	142.90	2.70	Medium
	5%	290.20	132.97	2.18	
	12%	166.27	112.02	1.48	

Source: Author's calculations

Notes:

1. The DALY valued at 3x GDP per capita is relevant for the agro-silviculture and biogas interventions which include health impacts as social benefits, but not for carbon pricing infrastructure.
2. For the agro-silviculture intervention, social costs and benefits (carbon, biodiversity, regulation and health) are included.
3. For the carbon pricing intervention, social costs and benefits (carbon, biodiversity, regulation) are included, but not health benefits.
4. For the biogas scale up intervention, social costs and benefits (carbon and health) are included.

The situation is different for the carbon pricing infrastructure where the BCR is 1.29 at 5% discount rate, but with a range of 2.49 and 0.72 at the 3% and 12% discount rate respectively. Thus, the intervention is not viable at the higher discount rate. The stronger impact of the discount rate comes from the fact that most of the benefits from this intervention (sale of timber) are available only at the end. For the biogas scale up, the impact of the discount rate is relatively important: the BCR is 2.18 at the medium scenario (NG price of 42.60 HTG/day or 52 HTG/m^3, 5% discounting, and one DALY value at 3x GDP per capita) with a range of 2.70 and 1.48 at the 3% and 12% discount rate respectively. This suggests that the intervention is viable at any of these three discount rates. It should be noted that *at the medium price scenario for NG, the* *daily cost for households using natural gas is estimated to be 38% and 21% less expensive than that for charcoal and propane respectively*.

In order to assess the strength of the body of evidence, the UK Department for International Development scale is used (DFID, 2014). This document recognized that a high rating is not always attainable and where there is a nascent field or discipline with a limited number of studies, a 'medium' rating will often be the best achievable and will be good enough.

4.2. Additional Sensitivity Analysis and General Discussion

4.2.1. Additional Sensitivity Analysis

Additional sensitivity analysis is presented in Tables 9 and 10 for avoided DALY at the low scenario (1x GDP per capita) and high scenario (8x GDP per capita) respectively.

Table 9: Summary Table of the BCR (DALY at 1x GDP per capita)

Interventions	Discount	Benefit (billion HTG)	Cost (billion HTG)	BCR	Quality of Evidence
Agro-silviculture	3%	1,157.49	375.53	3.08	Medium
	5%	944.76	321.93	2.93	
	12%	590.66	208.93	2.83	
Carbon Pricing Infrastructure	3%	86.55	43.37	2.00	Limited
	5%	30.95	39.96	0.77	
	12%	4.95	32.78	0.15	
Biogas Scale up	3%	374.12	142.90	2.62	Medium
	5%	282.38	132.97	2.12	
	12%	163.77	112.02	1.46	

Source: Author's calculations

Notes:

1. Sensitivity analysis is undertaken using a DALY valued at 1x GDP per capita. This is relevant for the agro-silviculture and biogas interventions which include health impacts as social benefits, but not for carbon pricing infrastructure.
2. For the agro-silviculture intervention, social costs and benefits (carbon, biodiversity, regulation and health) are included.
3. For the carbon pricing intervention, social costs and carbon benefits are included, but not biodiversity, regulation and health benefits.
4. For the biogas scale up intervention, social costs and benefits (carbon and health) are included.

Even at the low scenario value for DALY and the high discount rate of 12%, both the agro-silviculture and the biogas intervention remain viable, even though the BCRs are obviously smaller compared to the medium scenario. Because health benefits are not included in the carbon pricing infrastructure, DALY value does not impact the BCR of this intervention. Rather, we based the sensitivity analysis on the exclusion of some of the environmental benefits. In Table 9, carbon benefits are included, but not biodiversity and regulation benefits. As expected, the BCRs are smaller than when the full range of social benefits are considered, the intervention is viable only at the 3% discount rate.

It should be noted that, when the biogas scale up intervention is evaluated from a private perspective, without the health and carbon benefits (no account for clean cook stoves and quantity of carbon kept locked due to the intervention), the BCRs are still greater than 1 even at the higher discount rate. These BCRs are 2.10, 1.86 and 1.26 at the 3%, 5% and 12% discount rate respectively. Besides, additional sensitivity analysis based on a price of natural gas of 28.40 HTG/day (35 HTG/m^3 or 48.60 HTG/kg or almost half the daily price of LPG) suggests that, from a private perspective, the intervention is still feasible at the 3% and 5% discount rate, but not at 12% (BCR of 1.34, 1.19 and 0.81 respectively).

Table 10: Summary Table of the BCR (DALY at 8x GDP per capita)

Interventions	Discount	Benefit (billion HTG)	Cost (billion HTG)	BCR	Quality of Evidence
Agro-silviculture	3%	1,271.52	375.53	3.39	Medium
	5%	1,009.04	321.93	3.13	
	12%	607.28	208.93	2.91	
Carbon Pricing Infrastructure	3%	92.70	43.37	2.14	Limited
	5%	36.14	39.96	0.90	
	12%	8.11	32.78	0.25	
Biogas Scale up	3%	415.32	142.90	2.91	Medium
	5%	309.76	132.97	2.33	
	12%	172.50	112.02	1.54	

Source: Author's calculations

Notes:

1. Sensitivity analysis is undertaken using a DALY valued at 8x GDP per capita. This is relevant for the agro-silviculture and biogas interventions which include health impacts as social benefits, but not for carbon pricing infrastructure.
2. For the agro-silviculture intervention, social costs and benefits (carbon, biodiversity, regulation and health) are included.
3. For the carbon pricing intervention, social costs and benefits (carbon, biodiversity) are included, but not regulation and health benefits.
4. For the biogas scale up intervention, social costs and benefits (carbon and health) are included.

At the high scenario value for DALY, BCRs for the agro-silviculture and the biogas interventions are obviously the highest at a given discount rate.

For the carbon pricing infrastructure, when carbon and biodiversity benefits are included, but not regulation (Table 10), the intervention is still viable, but only at the 3% discount rates. In all scenarios, it remains the intervention with the lowest BCR at a given discount rate. In fact, *carbon pricing infrastructure is economically viable at the discount rate of 5% only when carbon, biodiversity as well as regulation are internalized* (Table 8). In these circumstances, social planners are willing to incur costs to set up a carbon market and farmers are incentivized to change their behavior and start planting trees in these marginalised lands. *If CO_2 is not internalized via a carbon market and no social benefits are considered, then the BCR that would result from the sale of timber only is less than one, regardless of the discount rate; which explain why these lands are unexploited at pre-intervention.*[38] Even though these lands stand basically idle at pre-intervention, once promotion starts for the intervention, the opportunity cost of these lands will increase. This explains why a rent is allocated during the intervention.

4.2.2. General Discussion

Virtually all the costs in the agro-silviculture and biogas scale up interventions are borne by the private sector. It is not surprising that private benefits account for about 95% of their total benefits. For the agro-silviculture intervention, private benefits come mainly from the sale of non-timber products: moringa pods and crops (groundnuts) which generate 92% of the private benefits (timber accounts for only 4%).[39] To optimize this value chain, a standard approach to marketing is needed, which is lacking in Haiti. Intermediate agents need to be trained in the transformation, packaging and labelling of the products targeted for the international market in order to ensure that the standards are met. Part of the 75.7 million HTG (300 HTG/ha) intended for promotion and training during the first year and thereafter 15.1 million per year (60 HTG/ha) could be used for this purpose. Besides, financial services in the form of credit can be provided to these agents to help them start their agro-food processing enterprises.

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[38] From a private perspective, the BCR for the marginalised land without carbon payments is 0.93, 0.79 and 0.44 respectively at the 3%, 5% and 12% discount rate. With carbon payment based on the ECX market, these BCR become 1.36, 1.17 and 0.70.
[39] The remaining 4% comes from the sale of moringa leaves.

It should be noted that, even though agricultural labour was costed in the analysis, Haitian small-holders most of the time farm their lands themselves. For the first two interventions, the major part of the costs are associated with labour (for the first intervention as an example, 87.5% in year 1 and 83.3% in subsequent years, see Table 1). This raises the question about how labour should be accounted for in the analysis. One could argue that, as smallholders, these farmers would presumably be engaged in agricultural activity in any case, the correct assessment is to consider the additional labour associated with the intervention relative to the appropriate counterfactual (i.e. existing activities including any forgone non-agricultural income). In this analysis, the labour cost reported is incremental (i.e. associated strictly with the intervention or net of the counterfactual).[40] Social benefits for agro-silviculture account for just a little over 5% of the total benefits. About 48% of these benefits come from health, specifically reduction in maternal and child malnutrition. The remaining come from regulating services (25%), carbon (17%) and biodiversity (10%).

As for the second intervention (carbon pricing infrastructure), private benefits account for just over half (51%) of total benefits (recall that private costs are about 95% in year one, but drop to 32% in the following years; i.e. social costs account for 68% of total costs after year one). The private benefits come mainly from the sale of timber (56%) while payments for non-timber product (carbon) account for the remaining 44%. Social benefits for this intervention (with a share of just under half of total benefits) come from regulating services (48%), carbon (33%) and biodiversity (19%).

Finally, for the biogas scale up intervention, the private benefits are shared with the biogas promoters (75%) and the households (25%), with most of them coming from the sale of natural gas by the promoters and energy saved by the households by switching from charcoal to NG. The social benefits in this intervention come mainly from health, specifically reduction in HAP (58%) and carbon (42%).

[40] Because of the inclusion of family labour, the resulting overall cost per ha could be considered large relative to Haitian GDP per capita.

Regarding the flow of benefits from the first intervention, the full benefits in terms of yield and income are estimated to start in year two, after seedlings of Moringa trees in year one. Even though Moringa trees grow very fast, there could be some overstatement of benefits at the beginning of the period. This assumption is also applied to the social benefits. Carbon, biodiversity and regulating services are also related to growth stage and could be overstated at the beginning of the period. However, because conservative estimates of benefits have been used throughout the whole period, this would offset this possible overstatement at the beginning.

The value estimates used for biodiversity and regulating services are drawn from existing literature (Tao et al, 2012; Schaafsma et al, 2014) for biodiversity and de Groot et al (2012) for regulating. These derived values are averages of a few potentially extreme cases. While it is beyond the scope of this analysis to undertake a comprehensive benefit transfer, care was taken in applying such values. For example, all the range of regulating services were included, income level in Haiti was considered and these values were adjusted for by applying the average share of GDP allocated to the ecosystem services of the case countries to Haitian GDP. One could still argue that it may be more appropriate to draw values from more comprehensive sources such as the Ecosystem Service Valuation Database (ESVD).[41] However, consultation of this database does not generate substantially higher cases when filtered by income level of country and type of ecosystem.

The benefits of the biogas intervention include private savings due to the cheaper and more efficient fuel source and the sale of digestate as fertiliser. Because of the latter, stricter sifting standards will be applied and thermophilic anaerobic digestion (at 50-55°C) is preferred to prevent potential barriers due to concerns over biosecurity, and contamination of waste with heavy metals or microorganisms. On the other hand, the social benefits of this intervention are estimated in terms of avoided carbon release (due to avoided deforestation) and health benefits due to reduced household air pollution. Depending on the source of the feedstock there may be

[41] http://es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database

additional greenhouse gas benefits due to reduced methane emissions. Moreover, the social benefits do not include the maintenance of existing biodiversity and regulating services benefits relative to the counterfactual of continuing deforestation. These benefits would occur in full from year 1 of the intervention or in relation to uptake by households. Consequently, the BCR of this intervention could be underestimated.

5. Conclusion

This paper suggests tackling the deforestation issue both upstream and downstream. It identifies three interventions that can boost afforestation and contribute to strengthen the agroforestry value chain in Haïti: optimal agro-silviculture; establish carbon pricing infrastructure for agro-forestry and biogas scale up for cooking. The CBA presented for each intervention takes into account a broad range of services. Thus, in the first intervention, the forest is managed not only for its timber, but also for services such as nutrition and health, carbon sink, biodiversity, regulation. It is the same for the second intervention, except that nutrition and health are not included. As for the third intervention, the CBA for biogas accounts not only for the production of biogas itself, but also the slurry, the environmental (carbon), health and social benefits. Such comprehensive CBA studies on any of these three interventions have not been done for Haiti before.

Based on the medium scenario that one DALY is worth three times the GDP per capita with a discount rate of 5%, we found BCRs of 2.99, 1.29 and 2.18 for the agro-silviculture, carbon pricing infrastructure and biogas scale up interventions respectively. Sensitivity analysis suggests that, even at the low scenario value for DALY, both the agro-silviculture and the biogas intervention remain viable at any of the three discount rates. Carbon pricing infrastructure is not impacted by DALY value because health benefits are not considered for this intervention. However, sensitivity analysis was based on the exclusion of some of the environmental benefits. This intervention is economically viable only when carbon is internalized at the discount rate of 3% and 5% and biodiversity as well as regulating services are valued. If neither regulation nor biodiversity benefits are considered, the intervention is feasible only at the 3% discount rate. Note that the lower bound for timber price has been used in this CBA. Therefore, any sensitivity analysis based on the timber price would contribute to improve the BCR for the optimal agro-silviculture and carbon pricing infrastructure interventions.

The estimated health benefits use conservative assumptions of effectiveness based on available literature for similar types of agro-silviculture intervention. However, further study is needed to show to what extent the quantity of additional nutrients from growing Moringa compares to nutritional demand in Haiti.

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Agroforestry as an alternative to the economic and environmental crisis in Haiti

Haiti Priorise

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Foreword

In Haiti, agriculture must undergo a major transformation to address the many challenges of climate change, food insecurity, malnutrition, poverty and environmental degradation. This publication aims to inspire farmers, researchers, policy-makers and NGOs to take agroforestry into account in the face of climate change and accelerate the transformation of Haitian agriculture into a more sustainable and competitive sector. Agroforestry encompasses practices and technologies that aim to sustainably increase productivity, support smallholder farmers in their adaptation to climate change, and to reduce greenhouse gas emissions. It can also help governments achieve their goals in terms of food sovereignty and poverty reduction at the national level.

Context & Rationale

The degradation of the forest cover of Haiti did not happen overnight, it has happened gradually. According to data compiled by the FAO (1995) and the MPCE (1991), from 80% when it was discovered in 1492, towards the beginning of the 20th century it was estimated at just over 60%. During the period of the American occupation, this coverage was further reduced, especially with the establishment of SHADA, which in 1943 had control of two-thirds of the pine forest, i.e 102,000 ha or 4% of the country. This institution cleared thousands of acres of land for rubber plantations to meet US rubber needs during the Second World War. Between 1977 and 1988, the wood reserve declined by more than 3.2% annually. Already in 1978, it reached 19%. Today, forest cover is estimated at less than 3%. Currently, the highest percentage of timber used by farmers in the country comes from agroforestry systems (Blanc, 2003).

Agroforestry has been practiced for centuries throughout the country. It is part of traditional methods of peasant production. As a science describing data that has been inventoried and analyzed, it is relatively new and has been seen since the beginning of the century as an alternative that can help in the fight against various environmental problems (Nelson et al., 1998). Its benefits are positive in economic, biological and environmental terms (Dupraz 2005).It is becoming an unavoidable solution due to the extensive degradation of the Haitian environment (Osei-Bonsu et al., 2002). According to studies carried out among farmers in some rural areas of the country on their main source of income, 90% admitted that they come from agriculture versus 70% who claimed that they come from the livestock (Donis 1999). This is in line with the IHSI (1996) data for the entire territory where 70% of the population practices agriculture, compared with 20% for commercial and 10% for industrial. More than two-thirds (2/3) of the rural population (FAO 1995; Weins and Sobrado 1998) are left to their own devices and unable to obtain agricultural inputs (Demetrius 1996). They are obligated to cut down the trees of the fields to achieve a surplus of revenue (Current and Scherr 1995). Agroforestry, an ancestral cultural practice whose various forms have been developed in tropical as well as temperate regions, has become a necessity to reduce the environmental problems encountered in the Haitian agricultural environment.

More trees, better livelihoods

Planting trees in the middle of crops could help preserve both the environment and livelihoods in Haiti. This method of agro-ecological farming makes it possible to strike a better balance between food crops and cash crops. To do this, it would be enough to combine the following themes: climate and livelihoods, adaptation and mitigation. Agroforestry should be an essential component of this approach. Incorporating large-scale tree crops into agricultural landscapes would create an efficient carbon well while ensuring sustainable food production, and also contributing, in other ways, to climate disruption adaptation. While the production of agroforestry systems is generally lower than that of monocultures, this method of farming offers many benefits for both farmers and the environment:

- a reduction in the amount of labor and inputs;
- diversification of resources (food, cash crops, timber, medicines, etc.);
- systems that are less vulnerable to climatic and economic uncertainties;
- many environmental services: preservation of soil fertility and water resources, erosion prevention, carbon storage and biodiversity conservation.

In some parts of the country, high population growth has led to the degradation of cultivated soils due to the abandonment of fallow practices and the increasing pressures on natural resources. The technical solutions often used by farmers to compensate for decreases in soil fertility (use of chemical fertilizers, extension of cultivated areas on land for long fallow, pastures and forestry) accelerate the destruction of natural resources. As in the rest of the country, the populations, both rural and urban, depend heavily on forest resources to live and eat. The renewal of soil fertility depends on a system of slash-and-burn crops followed by long fallows, and household energy needs that are met by collecting firewood or using charcoal in the city. Due to the lack of public investment in producing alternative energy on a large scale, this dependence on wood also affects economic activities such as brick production and prepared foods. In this context, agroforestry is seen as a solution to develop agriculture in less fertile areas, while offering an alternative to the clearing of natural forests rich in biodiversity and carbon, without condemning the wood- energy industry.

Finding a balance between food security and combating deforestation

There is a great diversity of agroforestry developments: intra-parcel alignments, hedges, pruned trees, isolated trees, edges of streams... These practices include agrosylvicultural systems but also silvopastoral, agrosylvopastoral or pre-orchard systems (animals grazing under fruit tree orchards).

Planting fertilizer trees (Leguminous trees)

A fertilizer tree is a legume like beans or peanuts. Among its other properties, a leguminous plant is used to fix atmospheric nitrogen and enrich the soil by transforming it into compounds that can be assimilated for plants. The planting of fertilizer trees therefore has the goal of making the fields autonomous in nitrogen. Fertilizer trees are used in Agroforestry as a natural and inexpensive enrichment technique for soils. It also has other advantages in terms of wood, fodder, organic matter for composting or mulching, preserving soil erosion.

A study done by the University of Essex (Great Britain) shows that the "multi-tiered" agroforestry model has gained the support of all the farmers concerned. In this model, the field has several strata: for example, on the soil of yams and cassava, at the intermediate level of bananas and cocoa trees, and in the upper stratum of large fertilizer trees. (Dupraz, 2011). Beyond the tree, all the components of the agroforestry system are its richness. The study highlights positive environmental impacts: biological diversity, improvements in groundwater and sources, as the enrichment of soils in organic matter makes it possible to reduce runoff and thus to better store water... It also highlights many economic and social benefits: reducing input costs, maintaining or increasing yields, producing domestic wood and gathering products, reducing insecurity by creating usable wood resources, reducing the hardship of female tasks because firewood and drinking water are more accessible. (Yin and Sun, 2007; Jianbo, 2006; Wenhua, 2004).

Public policies in support of the development of agroforestry sectors

Urban consumers' expectations are changing and new eating habits are emerging: the growing role of rice and wheat (bread, pasta) in connection with the desire to diversify diet, interest in processed products, easier and quicker to prepare, increased quality requirements. Demand is changing and local products are struggling to meet them in terms of price, volume, product range and quality. The existence of public policies in support of initiatives aimed at structuring, developing and improving the functioning of agroforestry sectors often determines the success of different initiatives. We must also consider those that modify the economic and institutional environment in which the various operators evolve.

Several elements determine the effectiveness of these policies: sound knowledge and expertise, clear and transparent rules, control and evaluation mechanisms, and consultations with the various participants involved. The effectiveness of these policies also depend on the capacity of the agroforestry sectors (Moringa and sisal) to structure and improve their functioning. Support measures for supply chains and policies for the protection and regulation of markets must therefore be formulated and implemented in a coherent manner. Nevertheless, urban populations remain strongly anchored in rural areas and remain particularly attached to traditional products, whether processed or not. But the urban market remains insufficiently provided for a variety of reasons: low agricultural productivity, irregular supply of raw and processed products (in quantity and quality), lack of adequate infrastructure and services for grouping, transport and processing, and marketing to urban markets.

In order to develop the agroforestry sectors, it is necessary to support the dynamics aimed at producing and developing not only basic products but also other products for which family farms are able to meet demand: dairy products, so called "secondary" products such as potatoes, onions, tomatoes, leafy vegetables and so on. These industries are in fact closely linked to the principle food industries (they are often the same operators, from production to collection and transport, sometimes to marketing), and are interdependent. The strengthening of the resilience of operators, (capacity to cope with climatic, economic or commercial contingencies) condition the sustainable development of the sectors. Various programs must be integrated, both in terms of thematic intervention and the products concerned.

Develop the transformation of agroforestry products

In order for the smallholder to benefit from agroforestry products, they must be processed and marketed. The transformation of agroforestry products is too often ignored by development policies. The participants concerned, however, represent a particularly dynamic economic fabric that plays a preponderant role in supplying our cities. This sector also represents an employment and income opportunity, especially for women and young people. Developing a range of services tailored to the specificities and needs of agroforestry products is fundamental, through several areas of intervention: training, which must be open to agro-food processing (Moringa) by encouraging young people and strengthening the professional skills of active adults.

- ✓ Moringa transformation

Sometimes called the "tree of life" or "tree of paradise" because of its exceptional environmental, medicinal and food virtues, Moringa is a multipurpose tree whose leaves, flowers, fruit, bark and roots can be eaten directly. Its nutritional qualities are increasingly recognized and could represent an effective solution in the fight against malnutrition. Transformed or not, Moringa leaves are not only a new agricultural production with high income and employment potential, but also a food of high nutritional value for families and businesses. During the 1990s, researchers, companies and NGOs contributed to the advancement of knowledge on the Moringa agronomy, the use of its leaves as food and its seeds as a source of oil and flocculants.

Moringa can be sold in the form of seedlings, seeds, powders (leaves, roots, flowers, etc.), tea, oil or fruit (pods).

- ✓ Moringa Leaf Powder

Rich in vitamins, minerals and proteins, Moringa leaves, transformed into powder, improve the nutrition of children and nursing mothers, treat diabetes as well as digestive and respiratory disorders. (Produce and transform the Moringa leaves. Moringa news, CDE, CTA). The production of Moringa leaves is also a means of generating agricultural income, developing agro-food processing activities and new markets.

To obtain the Moringa leave powder:

- Wash and dry the leaves out of the sun on the day of the harvest.
- Two days later, separate the leaflets from the petioles and then dry the leaflets for 3 to 4 days. Collect and clean the dried leaves
- Pound them in mortars or grind them in a cereal mill. A fine and deep green powder is obtained.
- Sift, put in airtight boxes or plastic bags and store in the shade in a container to avoid contamination.

The Moringa leaf powder must be accessible to the formal economy. Consumers can buy it safely and it becomes possible for local agri-food companies to use it to enrich their products. It can therefore affect a large population of people buying cheap frozen chicken carcasses from the Dominican Republic that are often lacking in proteins, vitamins and minerals and carcinogens.

One kilo of dry Moringa leaf powder sells from between 10 and 50 US dollars depending on the country.

- ✓ Flower Powder

The flower powder is produced in the same way as the leaves, the flowers being dried in a drying room away from the sun. It is used as a medication or as a nutritional supplement.

- Moringa seed oil
- Crush the Moringa seeds and boil them in water.
- Remove the foam which rises to the surface with a skimmer.
- Recover the oil that floats to the surface with a ladle.

The oil extraction can also be carried out by means of a manual hydraulic press or by solvent (example: hexane).

One liter of oil is obtained from 4 kg of Moringa seeds. This oil is used in the manufacture of cosmetics.

One kilo of Moringa seeds currently costs between 30 and 45 euros, depending on the country.

Agroforestry can meet the needs of farmers seeking an attractive rate of return combined with sustainable and socially responsible impacts.

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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.