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Technoeconomic feasibility of a sustainable charcoal industry to reduce deforestation in Haiti

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ABSTRACT

This study evaluates the technoeconomic viability of utilizing a fast-growing crop, *Pennisetum purpureum* (elephant grass), to sustainably produce charcoal in Haiti, thereby reducing the harvest of trees, slowing deforestation and driving local economy. The objective of the analysis is to determine the potential for a profitable investment in sustainable charcoal, with profitability defined by net present value (NPV) modeling over a 10-year period. Monte Carlo statistical simulation is employed in computing NPV based on variability in model inputs. Results include a probabilistic NPV that incorporates uncertainty in model inputs and yields an odds-based assessment of the likely profitability of the plant. Results indicate that the plant is likely to yield positive return on capital investment, with a 91% likelihood of the plant breaking even and an 84% likelihood of achieving a 25% return on investment within 10 years. Sensitivity analysis of the model results to model input variability show that charcoal sale price and feedstock cost are the most significant variables that affect plant profitability and profitability uncertainty. Based upon model results, suggestions for improved economic feasibility are presented. Additionally, the broader social and environmental impacts of the proposed venture to reduce deforestation and create local jobs is assessed.

Introduction

The economic value of natural resources, such as forests, has been shown to be a major cause of deforestation and forest degradation in developing countries [1]. Specifically, the demand for wood and charcoal in many countries has been shown to put significant pressure on forests, leading to degradation or deforestation without proper management [2,3]. It is estimated that about three billion people use biomass as fuel for cooking and heating worldwide, including most of the ten million people of Haiti [4]. Haiti's population growth and accompanying increase in proportion of people living in urban settings has led to an increase in demand for fuel wood and charcoal, as the latter is used extensively for cooking [5]. While other contributing factors to forest degradation have also been identified, such as agricultural techniques, the demand for fuelwood and charcoal has been confirmed to be a significant contributor which is poised to grow as Haiti's population continues to increase [6,7]. Recent estimates are that 3.4×10^7 kg of wood charcoal was produced in Haiti in 2014, which was a 22% increase in production over the previous decade [8]. Conversion of native forests for resource utilization has led to extensive forest degradation and economic and political instability [9]. Although a 2% forest cover estimate is widely circulated in media and in discourse concerning the country, a recent analysis that utilized high-resolution satellite imagery estimates forest cover at 30% [10]. Nevertheless, deforestation has been severe, and ongoing degradation poses a threat to Haiti's social stability and energy security [11].

There is significant interest in reducing the use of wood-derived charcoal, but alternative cleaner and more sustainable energy options to wood-derived charcoal, such as liquified petroleum gas (LPG), have remained limited in use due to high cost, tradition and social barriers [6]. Thus, substantial efforts focused on improving cookstoves for higher fuel efficiency [12–16] and replacing wood with other biomass sources for charcoal production in developing countries in order to slow deforestation [17–19]. Any viable alternative to wood-derived charcoal will need to be affordable to the population and satisfy the drivers of wood-derived charcoal production, however, including the economic foundation of charcoal whereby a significant fraction of a poor population derives income. The work of Luoga et al. [20] examined Tanzania with a focus on the lack of alternative livelihoods for the rural poor. Traditional charcoal-making was shown to provide income when agriculture and livestock wane. Harvesting of trees and thermal conversion in simple earthbound kilns require little cash or skilled labor, so

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Nomenclature

a	local fee multiplication factor	R	revenue
C_t	net cash flow	ROI	return on investment
F	feedstock expense	S	secondary expenses
HTG	Haitian Gourde (Currency)	t	current time period
l	land lease	T	total time period
L	labor	TCI	total capital investment
NPV	net present value	TIC	total installed cost
$OpEx$	operating expense	TOC	total operating cost
r	discount rate	USD	United States Dollar (Currency)
		x	annual feedstock produced
		X	tax

charcoal making will bring positive economic returns to the individual despite the costs of degradation to the local ecosystem. Therefore, it is important when seeking alternative options to acknowledge that it might not be possible for renewable charcoal to completely replace traditional charcoal.

Fast growing perennial bioenergy crops, such as *Pennisetum purpureum* (commonly called Napier grass or elephant grass, and henceforth referred to as elephant grass), may be a viable and sustainable alternative to trees as a source of charcoal, thereby slowing deforestation in countries such as Haiti. These crops have gained attention worldwide as an energy feedstock to replace fossil fuels for carbon emissions reduction because of their rapid growth, high yield, substantial energy density, and ability to grow in marginal soils [21]. Reviews of energy crop utilization, both from dedicated farmland and permanent grassland, in terms of environmental impacts and economics have shown the potential for substantial reduction of atmospheric carbon stores by combustion of crops instead of fossil fuels, as well potential economic viability under careful planning [22,23]. As perennial grasses, these crops do not need replanting after each harvest, reducing the energy input requirements as compared to annual crops. Of these grasses, elephant grass is particularly interesting because it grows quickly, reaching 3–5 m in height and 2 cm in diameter within 180 days [24]. Elephant grass can typically be harvested up to four times within a year in warm climates with a ratio of energy output to energy input of around 25:1, thereby making it one of the best potential energy crops for development of efficient and economical bioenergy systems [25]. Furthermore, elephant grass has minimal supplementary nutrient requirements and has been shown to grow well in similar climates to Haiti's [26]. Elephant grass and other energy crops have been shown to behave similarly to wood in the production of charcoal by pyrolysis, in which biomass is heated in an inert environment, thereby removing moisture and volatiles while concentrating carbon and increasing energy density [27]. Strezov et al. [28] studied the thermal conversion of elephant grass to produce charcoal and showed that gaseous byproducts contained sufficient caloric energy to provide the required energy for pyrolysis, suggesting minimal additional energy needs for thermal processing.

Technoeconomic analyses (TEAs) have been used to assess a wide variety of renewable energy systems, such as torrefaction of biomass residue briquettes in Brazil [29], fermentation of dedicated energy crops to produce bioethanol [30], production of other liquid fuels via upgrading of biomass pyrolysis oils [31], gasification of torrefied biomass to produce dimethyl ether fuel [32], and combustion of forest waste biomass for power generation [33]. These analyses frequently assess technical and economic feasibility in order to assess profitability, and therefore likelihood of adoption, of renewable energy systems. The majority of TEAs are deterministic, utilizing mean representative costs in economic modeling, which result in model outputs, such as net present values (NPVs), which are single point values based upon these mean model inputs. Far fewer TEAs have incorporated uncertainty and variability in model inputs into the assessment of model outputs. One such approach to incorporating model input variability is the use of Monte Carlo modeling, which draws from ranges of potential values for input variables to calculate probabilistic model outputs [34]. Over many iterations, a probability distribution of model outcomes is achieved. Paap et al. [35] used a Monte Carlo model to assess environmental and economic costs and benefits of producing ethanol or fatty acid ethyl esters from switchgrass based upon uncertainty in model inputs such as process yields and enzyme loading. Trivedi et al. [36] used a Monte Carlo simulation to assess the costs and benefits of using corn stover for production of liquid fuels and power, and results included potential ranges of greenhouse gas reductions and value of societal benefits as functions of variability in model inputs such as feedstock supply and fuel conversion costs. Di Lorenzo et al. [37] used a Monte Carlo simulation to guide financial investment in carbon reduction technologies for power production by evaluating probabilistic potential NPV, internal rate-of-return, and payback period with consideration of uncertainty in factors such as future capital, operating, and emissions costs. Hsu [38] used Monte Carlo uncertainty analysis to evaluate life cycle greenhouse gas emissions and net energy values of gasoline and diesel produced by pyrolysis of forest residue biomass, accounting for uncertainty in fuel product yield and properties. Shahrukh et al. [39] used Monte Carlo analysis to assess biomass pellet production costs, accounting for uncertainties in transportation cost, field cost, and material loss during processing. These studies demonstrate the substantial advantage of Monte Carlo modeling over deterministic modeling due to the additional insight that is gained by the inclusion of input variability to assess output uncertainty.

The present study evaluates the technical logistics and economics of using a dedicated bioenergy crop to replace trees as feedstock for charcoal production in Haiti. Elephant grass is selected as the crop of interest in this study, but the model can be readily extended to other energy crops and feedstock sources, such as food crop byproducts or waste. The objective of the analysis is to determine the potential for a self-sustaining entrepreneurship venture based on sustainable charcoal, where self-sustenance is defined as a positive return on capital investment as determined by net present value (NPV) modeling over a 10-year period. Monte Carlo statistical simulation is employed in computing NPV based on variability in model inputs. Thus, the model provides a probabilistic NPV that incorporates uncertainty in model inputs. Sensitivity analysis gives insight into plant profitability based upon each of the input variables, and strategies for improving economic viability based upon model results are discussed. Additionally, potential environmental and societal impacts of the proposed venture are evaluated. In particular, the extent to which future deforestation may be reduced by replacement of tree-based charcoal with crop-based charcoal is assessed and the potential for local job creation is discussed.

Model analysis

Plant characteristics and configuration

The technical and economic feasibility of a production plant that outputs 7.6×10^5 kg·yr^{-1} of elephant grass-derived charcoal is