2015

Resource Recovery and Reuse (RRR) Project

Socioeconomic Analysis of RRR Business Models, Lima City Report

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Data used in the analysis is from 2013 and 2014.

Denomination: 1 USD = 1 US Dollar (2014); 1 USD = 2.8 S/. (2014)

S/. : Peruvian Soles

Introduction

The report presents the socioeconomic assessment of the selected RRR business models. The socioeconomic assessment acts as a decision making tool for determining the feasibility of the business model from a societal perspective. It incorporates all the costs and benefits of the potential impacts accruing from the economic, social, health and environmental considerations. Therefore this primarily involves the derivation of the monetary values of the direct and indirect, positive and negative effects from the implementation of the business model. A comprehensive socioeconomic assessment determines whether the all the benefits of a particular business model outweigh its costs and thus supports in making decision. In this report the following business models had been assessed as shown in Table 1: Selected RRR Business Models for Lima.

Table 1: Selected RRR Business Models for Lima

RRR Business Models	Brief Description
ENERGY	
Model 2 B: Energy Service Companies at Scale – MSW to Energy (Electricity)	The business processes municipal solid waste to generate electricity which is either sold to households and business or to local electricity authority.
Model 3: Energy from own Agro-industrial waste	The business concept is applicable to existing agro-industries such as poultry, livestock, piggeries, sugar processing industry, palm oil processing industry etc., where the waste produced is used to generate electricity for internal consumption. The excess energy can be sold to the grid or neighboring communities.
Model 4: Onsite Energy Generation by Sanitation Service Providers	The business model is initiated by either enterprises providing sanitation service such as public toilets or by residential institutions such as hostels, hospitals and prisons with concentrated source of human waste. The business concept is to process and treat human waste in a bio-digester to generate biogas to be used for lighting or cooking.
WASTEWATER REUSE	
Model 9: On Cost Savings and Recovery	The business concept is to treat wastewater for safe reuse in agriculture, forestry, golf courses, plantations, energy crops, and industrial applications such as cooling plant. The sludge from the treatment plant could be used as compost and soil ameliorant and energy generated can be used for internal purpose resulting in energy savings.
Model 8: Beyond Cost Recovery: the Aquaculture example	The business concept is to cultivate aquaculture while treating wastewater generated from the city. The process of treating wastewater is through cultivation of duckweed. The treated wastewater and duckweed as fish feed is used to cultivate fish
NUTRIENTS	
Model 15: Large-Scale Composting for Revenue Generation	The business concept is to better manage Municipal Solid Waste (MSW) (service) and recover valuable nutrients (products) from the waste that would otherwise be unmanaged and disposed on streets and landfills without reuse. Compost from MSW is sold to farmers, landscaping, and plantations and so on.

Model 17: High value Fertilizer Production for Profit	Similar to Model 8 in concept but in addition to MSW, the business uses fecal sludge from onsite sanitation which is rich in nutrients as input. The business also develops enriched compost and pelletized compost which has higher nutrient content with improved and efficient delivery of nutrient to crops.
Model 21: Partially subsidized composting at district level	The business concept is similar to Large-Scale composting for revenue generation except that the operation of the business model is at smaller scale and requires subsidy to make it viable.

Methodology

The first important footstep towards a socioeconomic assessment is defining of the system boundary. This is an integration of two aspects –

- Determination of the baseline condition which becomes the benchmark for comparison of the alternative (i.e. establishment of the business model); and
- Identification of the input resources (from different waste streams) for the business models at the city level based on the availability. These constraints govern the scales of operation of the business, potential impacts and beneficiaries. Regarding the scale of operation of the businesses, the socioeconomic assessment utilized the scales of the financial models developed previously. However, it was up-scaled based on the waste resources available at the city context.

After having demarcated the system boundary the socioeconomic assessment conducted the following guided steps to evaluate the benefits and the costs.

- Step 1: Identification of socioeconomic impacts of similar business cases in Lima
- Step 2: Scoping of the potential impacts (social, environmental and health) based on the system boundary. This step leads to the defining of the parameters to be used in the socioeconomic assessment.
- Step 3: Description of the technology for the RRR business models based on the technical assessment report and as observed from the business cases in the region.
- Step 4: Identification of key input data points based on scenarios developed, type of technology used. The financial models served as the base data source for the economic data as well as some of the social data. Investments and production costs were obtained from the financial models. Data on economic indicators such as wage rates, interest rates, inflation, tax, escalation, annual write off, insurance, depreciation and debt-equity ratios were obtained from published data reports by Bank of Peru and industrial benchmarks for the region. The environmental and health data were collected from secondary sources based on the scale of the operation and assumption made under the system boundary which delineates the level of stakeholders for a particular model. For environmental data, emission rates, carbon equivalents, cost of pollution (and abatement costs) were collected from the secondary sources and likewise for the health related parameters after having scoped the potential impact and the targeted population that can be impacted, DALYs were used to measure the impact in value terms. The economic values of the DALYs were obtained from secondary data sources for Peru. In this step the parameters are also categorized as deterministic and stochastic based on literature survey and expert opinions.
- Step 5: The socioeconomic viability of an RRR business model was analyzed based on the NPV of the benefits and costs, Benefit to Cost Ratio (BCR) and the Rate of return on Investments (RoI). For each of the economic, social, health and environmental aspects, the benefits and costs were measured (in monetary terms) separately, and the cumulative figure was used to look into the

NPV, BCR and RoI. Subsequently, a Monte Carlo risk analysis method was performed for the NPV calculations using an Excel add-in, @Risk.

The Monte Carlo risk analysis involved the following steps:

- Selection of valuation criteria: The NPV of each of the business model was selected to study the stochastic variations under conditions of uncertainty of the parameters.
- Identification of sources of uncertainty and key stochastic variables. Similar sources of uncertainty as considered in the financial models were also assumed in the socioeconomic assessment. However, in addition to technical development, change in government policy, inflation, variation in input and output prices, competitors' actions and other various factors, other health and environmental parameters (like economic value of DALY and abatement costs) were also treated stochastic.
- Definition of the probability distributions of stochastic variables: Probability distributions for all risky variables were defined and parameterized.
- Running of the simulation model: Determination of the NPV for each year and the criteria (social, economic, health and environment) using sampled values from the probability distributions for project life. This process was repeated a large number of times (larger than 5000) to obtain a frequency distribution for NPV.
- Determination of the probability distribution of the simulation output (NPV): The simulation model generated empirical estimates of probability distributions for NPV which was further used for the feasibility study.

Data limitations: As had been mentioned previously in the synopsis of the financial assessment that since the RRR sector is nascent in Peru, data access and availability were limited. This was even more critical for the socio economic assessment which relied heavily on the secondary databases and the financial models. The financial models developed for the business cases served as the data source for the economic data used in the socioeconomic assessment. The data for the environmental and health costs and benefits were obtained from secondary sources and the literature survey contextualized for Peru. However, in certain cases where data was not available, data from certain reports showing global figures or assessments were utilized and actualized for the context of Lima. Since the financial model is the base for the economic model, it needs to be mentioned here that economic data not available for the businesses were mined from the different business sources operating in Asia, Africa and Latin America and were verified before their use. However, as explained before in the financial assessment, data sources for wastewater is weak and this produces a cascading effect in the socioeconomic assessment as well.

Overall approach of the socioeconomic assessment: Defining the system boundary of the models

The following matrix defines the system boundary of the socioeconomic models used in the assessment for the RRR business models. In all of these cases, the scale of the business model is so adjusted such that the entire waste can be utilized by the particular business. The socioeconomic assessment of the business models is performed taking into consideration two contrasting situations where the baseline condition refers to the present situation in Lima and the alternative scenario proposes the introduction of the business. The scale of operation for each of the businesses is based on two aspects –

- The availability of different waste streams in the perspective of Lima as derived from other reference literature, reports and documents; and
- The scale of operation is based on the scale assumed in the financial analysis. This is primarily assumed to keep a parity in the analysis performed since one of the important component of

the socioeconomic assessment includes the financial analysis of the operation. However, to achieve the entire consumption of the waste streams for the respective businesses, a linear extrapolation of the scale of the business model assumed in financial analysis is utilized.

The following table (*Error! Reference source not found.*) indicates the baseline and alternative scenarios nd also describes the scale of operation for the different business models in Lima.

Table 2: Baseline and Alternative Scenarios used for the Socioeconomic Assessment for the different Business Models

Business Models	Base case	Alternative	Remarks
System Boundary of the Energy Models			
Model 2B: Energy Service Companies at Scale – MSW to Energy	Landfill gas is not being utilized for generation of electricity	The alternative scenario assumes the utilization of the entire landfill gas for electricity production. The scale considered for the socio-economic assessment includes the entire MSW generated in Lima.	
Model 3: Energy from own Agro-industrial waste	The baseline scenario do not consider any generation of electricity from livestock wastes	The alternate situation assumes 10 pig farms with a herd size of 4,000 that generates electricity from livestock waste	In absence of the data about the number of pig farms existing in Lima it is considered that establishment of 10 big farms would be representative scale for the city
Model 4: Onsite Energy Generation by Sanitation Service Providers	Feasibility study was not undertaken		
System Boundary for the Wastewater models			
Model 9: On Cost Savings and Recovery – combined energy, water and nutrient recovery	The WWTPs existing does not have electricity production	9 WWTPs treating wastewater of more than 5000 MGD is considered for the analysis	There exists 26 WWTPs in Lima which is not being used either for aquaculture or electricity, fertilizer and irrigation. The socioeconomic study assumes that the smaller plants with than 5000 MGD is used for aquaculture and the rest plants are used for electricity, irrigation and fertilizer production (since plants with capacity less than 5000 MGD is economically not feasible for electricity generation)
Model 8: Beyond Cost Recovery: the Aquaculture example	The WWTPs are not linked with ponds where aquaculture is practiced	16 WWTPs which are smaller in capacity is assumed to be linked with ponds for aquaculture.	
System Boundary for the Nutrient Models			
Model 15: Large-Scale Composting for Revenue Generation	No Large scale composting in Lima	The alternate scenario assume 8 large scale compost plants which can take up 600 tons of organic waste to exhaust the entire organic fraction of MSW of the city.	
Model 11: High value Fertilizer Production for Profit	Feasibility study was not undertaken		

Business Models	Base case	Alternative	Remarks
Model 21: Partially subsidized composting at district level	Feasibility study was not undertaken		

Synopsis of the socioeconomic assessment of the RRR business models

The following section presents key highlights of the RRR business models in terms of the Net Present Value (NPVs) of the different components assessed under this study and for detailed assessment please refer to respective RRR business models presented in subsequent sections. The respective business models were evaluated based on the monetization of the costs and benefits pertaining to the financial/economic, environmental and social consequences of the potential impacts from the business model. The financials for the RRR business models are classified according to Energy, Wastewater and Nutrient models.

Energy Business Models

The following table (Table 3) provides key highlights of Energy business models. To iterate, the table indicates the NPV of the three components of each of the energy business model. It can be seen from the table, that the energy models have a Benefit-Cost ratio (BCR) greater than 1. However, the changes in integrating the environmental and social components has contrasting impacts for different models. It can be observed that the ESCO model has a higher return in terms of environmental and social benefits over the other two models although there are possibilities of losses based on the financial assessment of the model.

Table 3: Energy Business Models

	Model 2 B: Energy Service Companies at Scale – MSW to Energy (Electricity)	***Model 3: Energy from own Agro-industrial waste***
Scale of operation	Power generation from the landfills at the city level	10 Plants generating electricity from livestock waste targeted for farm size with 4000 pigs
NPV Financial (in USD)**	3,761,904	3,147,990
NPV Financial & Environmental (in USD)**	15,297,902	18,718,720
NPV Financial, Environmental & Social (in USD)**	50,646,571	48,795,286
B:C Ratio	9.28	6.87
ROI	321%	126%

** Calculated for life cycle term using Discount Rate of 12%

[#] 10 plants assumed since actual number of the pig farms existing in Lima were not available

K = 1,000

Wastewater Reuse Business Models

In the context of Lima, two different scenarios are considered – (i) Treated wastewater for irrigation, fertilizer and energy, and (ii) Wastewater for irrigation and ground water recharge. The following table (Table 4) provides key highlights of wastewater reuse business models. The scale was based on the input wastewater quantity in Lima which was from the waste supply and availability data based on sewer network in Lima. Both of these models exhibits higher environmental and societal benefits in terms of reduction of pollution and health benefits. Using WSPs has a lower cost which is also being reflected in the NPV of the financial benefits from the introduction of wastewater for recharge and utilization in agriculture.

Table 4 Wastewater Reuse Business Models

	Model 8: Beyond Cost Recovery: the Aquaculture example	***Model 9: On Cost Savings and Recovery***
Scale of operation	17 small scale ponds are considered for aquaculture. These ponds are linked to the WWTPs from which there is no electricity generation	9 WWTPs which have a treatment capacity of more than 5000 MGD per day is being considered for the socio-economic assessment
NPV Financial (in USD)**	152,490	(1,437,849)
NPV Financial & Environmental (in USD)**	311,988	83,747,518
NPV Financial, Environmental & Social (in USD)**	2,700,704	110,880,671
B:C Ratio	14.18	7.33
ROI	122%	146%

** Calculated for life cycle term using discount rate of 12%
K = 1,000

Nutrient Business Models

The nutrient business models have been compared in the following table (Table 5). This table provides key highlights of Nutrient business models in terms of the NPVs for the financial, environmental and societal net benefits. It can be seen from the table that High value Fertilizer production and compost derived from Sanitation Service Delivery have higher increase in societal benefits compared to the compost production from MSW. This is primarily due to the fact that sanitation infrastructure either in terms of better service delivery or treatment of faecal sludge have pertinent health benefits as well as positive environmental impacts for the society.

Table 5 Nutrient Business Model

	Model 15: Large-Scale Composting for Revenue Generation
Scale of operation	8 plants each with a handling capacity of 600 tons of MSW is assumed. Total compost production capacity in each plant is 96 tons per day
NPV Financial (in USD)**	25,258,365
NPV Financial & Environmental (in USD)**	143,483,439
NPV Financial, Environmental & Social (in USD)**	238,801,928
B:C Ratio	11.62
ROI	104%

** Calculated for life cycle term using Discount Rate of 12%
K = 1,000

Summary assessment of financial feasibility of RRR Business Models

Table 6 provides a summary overview of the criteria used for feasibility of RRR business models for Lima based on the socioeconomic assessment. Three main criteria were used to assess the feasibility of the business model - (i) Benefit-Cost Ratio (BCR), (ii) Rate of Investment; and (iii) Probability distribution of the Net Present Value (NPV). The BCR was derived as a ratio of economic, social, health and environmental benefits to the costs in monetary terms. Any project or business with a BCR greater than 1 is termed to be generating more societal benefits compared to the costs for implementing the project and therefore the BCR was used as the governing criterion for the feasibility assessment. The Rate of Investment (RoI) was determined based on all the benefits that accumulated from the business with respect to the initial investments made for the business. Along with these criteria, the probability distribution of the NPV based on the uncertainty of different parameters used in the model was used.

As mentioned earlier in the methodology, a Monte Carlo risk analysis was performed on the Net Present Value (NPV) derived from the costs and benefits from the different parameters of the socioeconomic models. These parameters which were considered as stochastic in the model were defined by a suitable probability distribution to represent uncertainty in the values used for the models. For the Monte Carlo analysis a large number of iterations were performed to obtain empirical estimates of the NPV and also derive a probability distribution of the NPV. The probability distribution obtained for the NPV was used as one of the criterion for assessing the feasibility of the business model. The mean value obtained from the probability distribution of the NPV was taken as a benchmark for determining the feasibility. The probability distribution thus generated was utilized to find out the probability of the NPV value below the benchmark (mean). The methodology used to define the feasibility is as described in Table 14 below.

Table 6: Feasibility Ranking Methodology

$P(NPV < NPV_{mean})$	B:C Ratio	Rate of Investment (RoI)	Feasibility
$0 < P(NPV < NPV_{mean}) < 30\%$	> 1	> 100%	High
$30\% < P(NPV < NPV_{mean}) < 50\%$	> 1	> 100%	Medium
50% and above	> 1	> 100%	
$0 < P(NPV < NPV_{mean}) < 30\%$	< 1	> 100%	Low
$30\% < P(NPV < NPV_{mean}) < 50\%$	< 1	> 100%	
50% and above	< 1	> 100%	
$0 < P(NPV < NPV_{mean}) < 30\%$	> 1	< 100%	
$30\% < P(NPV < NPV_{mean}) < 50\%$	> 1	< 100%	
50% and above	> 1	< 100%	
$0 < P(NPV < NPV_{mean}) < 30\%$	< 1	< 100%	Not Feasible
$30\% < P(NPV < NPV_{mean}) < 50\%$	< 1	< 100%	
50% and above	< 1	< 100%	

Using the methodology defined in Table 6, the RRR business models were assessed for their viability in the context of the Lima city (shown in Table 7). Based on the criteria of assessment, it is found that the energy models have a lower feasibility compared to that of the wastewater and the nutrient models. All the energy models have a BCR greater than 1 however, the ROI is lower than 100% indicating that the business model would not be able to reap benefits larger than the investments. Along with these observations, it was also estimated that the probability of NVP dipping down from the mean value is more than 50% or close to it. In comparison to these scenario, although the models for wastewater and nutrients had probability values close to 50%, the other criteria of BCR to be greater than 1 and RoI of more than 100% make the business models to be feasible at a medium range. It has been mentioned previously that economic costs and benefits utilize the database from the financial analysis. At the same time the financial models had been scaled up linearly to meet the waste resources from different waste streams produced in Lima. Therefore, it becomes imperative to check the convergent validity of the financial and socioeconomic model in which further we assess the social, environmental and health aspects. The results of the socioeconomic assessment for the wastewater and nutrient models conforms to that of the financial analysis while that of the energy models (excepting the Energy Service Companies) differ in the results.

Table 7: Synopsis of Socioeconomic Feasibility RRR Business Models

RRR Business Models	P (NPV< NPV_{mean})	B:C Ratio	Rate of Investment (ROI)	Feasibility
ENERGY				
Model 2B: Energy Service Companies at Scale - Agro-Waste to Energy (Electricity) – 8MW Profit Maximization Model	50.5%	9.2	321.6%	Medium
Model 3: Energy from own Agro-industrial waste	50.2%	6.87	126%	Medium
Model 8: Beyond Cost Recovery: the Aquaculture example	49%	14.18	122%	High
Model 9: On Cost Savings and Recovery – combined energy, water and nutrient recovery	49.3%	7.33	146%	High
Model 15: Large-Scale Composting for Revenue Generation - 600 tons	50.6%	8.18	104%	Medium
Model 21: Partially subsidized composting at district level				

Below is brief on key aspects that determine the feasibility of each of the business models in Lima:

Model 2 – Energy Service Companies: This business model has a lot of potential when we consider electricity generation for rural Peru where electricity is a basic need. Associated with this there is net GHG emissions saved per kWh of electricity generated is 2.724 kg CO_2eq. The highest savings in GHG emissions are mainly from avoided from the MSW which is practically untapped while the highest emissions from the business model is from the leakages from gasifier. In the present situation most of the MSW finds its way to the landfills and open dumpsites. However, as the financial analysis indicates that larger scale plants are very sensitive to price of electricity for feed-in-tariffs which when coupled with the societal benefits provides impetus for the feasibility of the model.

Model 6 – Power capture model – Livestock waste to energy: This business model has a medium feasibility based on the socio-economic assessment of the model. The societal benefits are particularly high for the model boosting the benefit-cost ratio for the business. The primary benefits accruing to the business arises from self-sufficiency in electricity and also reduction in the wastewater run-off with a high BOD content from the farms.

Model 8– Phyto-remediative wastewater treatment and fish production: In the Phyto-remediative process it is assumed that the wastewater treatment plants already exists and the ponds used for aquaculture are aerobic maturation ponds. The business model has medium feasibility, but has a high potential of employment generation particularly among the fishing communities as it provides opportunity for them to rear fish in these ponds. At the same time, the potential undesirable outputs from wastewater can be flushed off during natural treatment.

Model 9 – On Cost savings and recovery: It is being assumed that the wastewater treatment plant exists and additional investments are made to retrieve water for irrigation, sludge for compost and electricity for use in the plant. The feasibility of the business model is governed by the fact that there is lower initial investments compared and practically no operation costs, while the benefits like irrigation and groundwater recharge are more favourable. In Lima with the newly planned WWTPs coming up there is a lot of potential for electricity generation. Consideration of the health and environmental aspects shows that there is substantial amount of reduction in surface and groundwater which has indirect costs associated inter-temporally. In addition there is also a potential of earning benefits due to reduced GHG emissions and savings incurred in using compost as a soil ameliorant which reduced the fiscal burden. The socioeconomic feasibility shows that health issues among farmers which might arise due to use of wastewater is overweighed by the benefits incurred. However, application of the business model should be subjected to the research on health effects both on consumers and farmers consuming food irrigated by wastewater and producing food irrigated by wastewater respectively.

Model 15 – Large scale composting for revenue generation: The financial analysis shows that large sized compost plants of 600 tons/day is highly feasible. The socioeconomic assessment considered the 8 plants of same scale for absorbing the waste of the city. The economic feasibility of the model is similarly high mainly due to the fact that there are savings in terms of GHG emissions. This model also has societal impacts through soil amelioration and increasing the farm income in future years with higher yields when used in conjunction with chemical fertilizers and ultimately also reduces the use of the fertilizers helping the soil to retain nutrients for a longer period of time.

Socio-economic impact assessment of Energy Service Companies at scale: Municipal Solid Waste to Energy (Electricity) in Lima

Introduction

The business model is initiated by a standalone private enterprise or a public private partnership (PPP) where a private entity partners with the municipality to manage the solid waste generated by the city. The business concept considers the adaptation of a landfill into a biological reactor where municipal solid waste (MSW) is an input and gas is the main output. The organic fraction of MSW produces landfill gas (LFG) – a mix of gases with useful methane produced by anaerobic decomposition process which can be used to generate electricity. The electricity can be sold to households, business or local electricity authority. The ownership and operation of the enterprise generating electricity mostly involves a private entity partnering with municipality to form a PPP. The contractual agreement of the PPP and role of private and public entity can take many forms. Landfill Gas-to-Energy (LFGTE) projects contributes with carbon emissions reduction initiatives because the recovered gas can be readily converted into energy which very often has an immediate market. These projects have a stable up-time (as gas is produced in a relatively constant manner) and benefit from the Peruvian government supportive stance on energy generated from renewable resources.

Technology description

A gas recovery system requires three phases to be complete in order to be operational provided a landfill is already operational and is being adapted for LFG capture: Installation of vertical extraction wells; installation of high density polyethylene pipe (HDPE) piping to connect the extraction wells with the flare station and LFG control plant; and the installation of a blower and flaring station. See *Figure 1*.

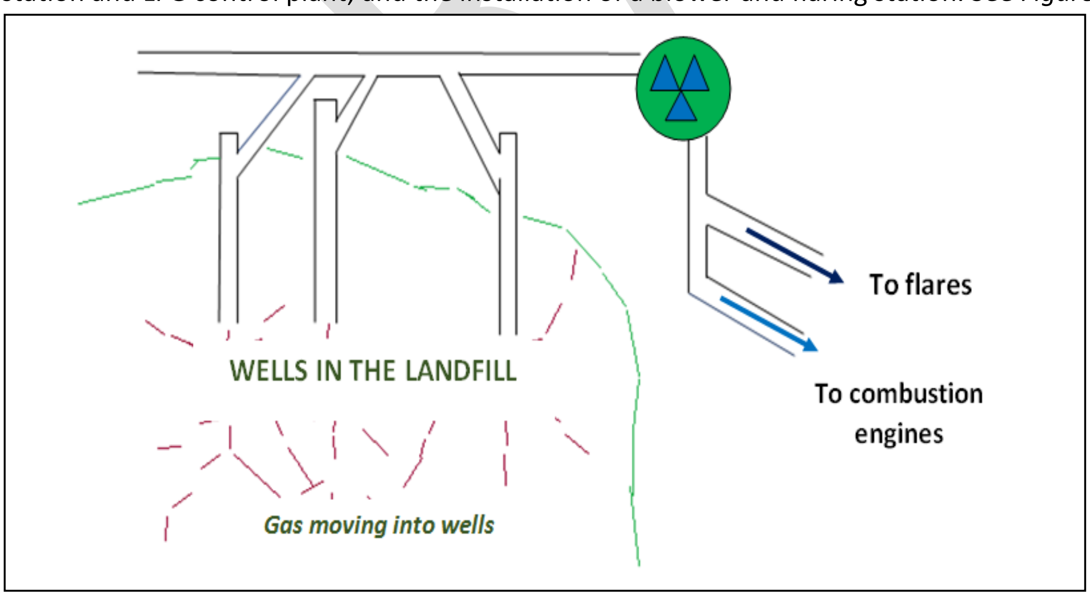

Figure 1: Process diagram of LGFTE

LFG is generally composed of 50% methane (CH4). The other 50% of the gas is mainly carbon dioxide (CO2) and water vapor, with small amounts of other gases. Methane is a known potent greenhouse gas with a warming potential 21 times that of carbon dioxide. But, methane also has high energy content which can be transformed into heat or electricity.

Overall approach to socioeconomic analysis

In this study the economic analysis of agro- waste to electricity – ESCO business model is conducted based on the valuation of socio-economic, environmental and health benefits and costs associated with the business model. Our analysis is based on a representative plant producing 11,520,000 kWh per year of electricity processing 200 tons of MSW per day. To consider the options for scaling up the operations in the context of the entire city, the socioeconomic assessment considers the entire MSW of Lima being landfilled and the landfill gas thus generated is utilized for electricity generation. Therefore, the socioeconomic assessment for the introduction of the business model at a scale to utilize the entire waste of the city considers 40 such homogenous units (each with a capacity of 200 tons) assuming constant returns to scale. This is however a major limitation of the present socioeconomic assessment which does not include different scales of operation or include increasing returns with scaling up. This socioeconomic assessment thus provides a conservative estimate based on the assumption that a linear extrapolation of a single plant to the appropriate scale such that the entire MSW of the city is being used. The electricity generated is fed into the grid which serves as a main source of revenue for the business along with the savings from the Greenhouse gases.

The economic analysis of a project is concerned with its viability from a societal perspective and answers the questions of whether it is economically rational to proceed with the project (De Souza et al., 2011). In contrast to a financial analysis, economic analysis provides a more comprehensive investigation on the effects of a proposed project, takes a broader perspective and determines the project's overall value to society (Raucher et al., 2006). The analysis, therefore, includes benefits and costs that directly affect the business entity running the project and the effects of the project on households, businesses and industries, and governments. The analysis also includes the benefits and costs that cannot be readily measured using observable market prices and costs (De Souza et al., 2011).

Environmental impact assessment

The environmental impact assessment of the plant generating electricity from landfill gas is carried out to identify the impact on the environment of using agricultural residues in biomass gasification based electricity generation systems to produce electricity and also compare these impacts with those created through the existing mode of disposal of these agricultural residues. The impacts considered under this study include climate change and acidification.

Table 8: Environmental impact categories

Environmental impact categories	Assessment criteria	unit
Climate change	Carbon dioxide CO_2 Methane CH_4 Nitrous Oxide N_2O	Kg CO_2-equivalent
Acidification	Sulphur dioxide SO_2 Nitrogen Oxide NO_x	Kg SO_2 Kg NO_x

Climate change impacts (GHG) emissions are expressed in a common unit of CO_2-equivalent. For each emission, the characterization factor with global warming potential (GWP) employed is given as: Carbon dioxide 1 CO_2-equivalent, methane (CH_4) 21 CO_2-equivalent and Nitrous Oxide (N_2O) 310 CO_2-equivalent

(IPCC, 2001). The emissions with acidification potential are given the following characterization factors: Sulphur dioxide (SO_2) 1 SO_2-equivalent and Nitrous Oxides (NO_x) 0.7 SO_2-equivalent (Kimming et al., 2011). The GHG emissions balance is estimated based on the baseline scenario i.e. the open burning of agricultural residue on farms and the use of fossil fuel based electricity generator by non-households or commercial and institutional users for their electricity needs. The climate change mitigation benefits of the agricultural residue gasification system is assessed based on the findings of a number of life cycle assessment studies (Shafie et al., 2014; Ruiz et al., 2013; Zanchi et al., 2013).

Net emissions from the MSW

The process of tapping landfill gas produces the lower GHG emissions in terms of CO_2–equivalent per KWh of electricity compared to the emissions under the baseline. Considering the scope and system boundary for this study, the net GHG emissions savings is 0.8 kg CO_2-equivalent/kWh assuming that the emissions from per ton of MSW is around 0.1523 tons CO_2 eq from 1 ton of MSW and that 192 kWh of energy can be retrieved from 1 ton of MSW. In the baseline scenario the MSW collected is either landfilled or open dumped increasing the GHG emissions. The alternate scenario on the other hand considers that the waste is landfilled where options of landfill gas collection exists and is utilized for electricity generation. Given the fact that 0.1523 tons of CO_2 equivalent is emitted from each ton of MSW, the net GHG emission saved during the alternate situation can be estimated to be 1,198 tons of CO_2 equivalent and about 359,400 tons of CO_2 equivalent if 300 days of operation the landfill is assumed.

Value of Carbon credits and other emissions

For the present socioeconomic assessment the costs and benefits are monetized to be comparable and thus to estimate the value of the GHG emissions the market price of the carbon is being used. In this study it is assumed that carbon credits will be traded in Carbon Emission Reduction (CER) units as CER is suited for large scale projects and are sold in volumes that are targeted to clients seeking small reductions to offset their footprints. The CER unit is equivalent to a reduction of 1 ton of CO_2 equivalent emissions (Reuster 2010). Based on the World Bank (2014), carbon credit prices in 2013 is about USD 3.8 (Table 2). The total annual value of carbon credit is USD 4,355,359. However value of the other emission savings that have acidification potential (NOx and SO2) were not included in the analysis.

Table 9: Annual value of GHG emission reduction from ESCO model

Item	Amount
Total GHG emission savings (ton CO_2eq)	359,400
Price of VER (USD/ton CO_2eq)	3.8
Total value of Carbon credit (USD/year)	**1,365,720**

Social impacts

Savings for end-users

Using electricity from the grid is particularly low among the rural households in Peru (about 39%). A tiny fraction of households, 0.6% (13,100 households) have generators, and 0.8% (16,700 households) has solar home systems (SHS). Small generators and SHS are commonly used in households without access to grid electricity. The household in-grid connected, which own small generators or SHS, use them due to the lack of electricity service reliability. Particularly SHS is used for lighting and communications (radio and

TV). Car batteries are commonly used as off-grid electricity sources, especially in the Coastal region of Peru, where households have more income and car battery recharging is relative easy due to the presence of good roads. It is estimated that 18% (240,000) of off-grid rural household uses it for lighting and running TV`s. Nevertheless, in rural households without electricity the most common source of energy for lighting comes from kerosene (80% of rural households) and candles (65% of rural households). Rural households in-grid connected areas consume less than 30 kWh per month (70% of households), and between 21% and 39% of their total electricity consumption is used for lighting. The remaining electricity consumption is due to the use of domestic appliances such as TV, irons and others. Less than 1% of these households own appliances such as domestic water pumps, electric pump irrigation systems or any other devices which are directly used for income-generating activities. Domestic small appliances such as radios and flashlights are powered by dry cells (74% of rural households) in both types of households, with or without access to grid electricity. Although household energy expenditure varies significantly between financially better-off households and poorer households, on average the total monthly cash expenditure for all types of energy uses is estimated to be 9.7% of the total household cash expenditures. This indicates the importance of rural electrification in Peru.
It has been estimated by the World Bank (2010) in a study with regards to rural household energy use that the net benefit (consumer surplus) from electrification in the rural areas is USD 1.23 – 1.54 per kWh on average. The alternate scenario assumes that 11,520,000 kWh is being produced per unit (40 units with a capacity of 200 tons). The total benefit (consumer surplus this arising from alternatively using electricity in the rural areas can be estimated to be USD 5,667,840 annually.

Measuring the negative externalities from open dumping and landfilling

The estimation of the negative externalities from improper landfilling and illegal open dumping takes into consideration odor and health problems associated with MSW. The net benefits accruing from the business model due to reduction of the negative externalities in the alternate scenario is estimated using the figures provided by European Commission in one of the study related to valuing the negative externalities from landfill disposal (2000). This study projects that the external costs of disposal in an old landfill site without any liner or gas collection system is 20 euros per ton of waste. This implies about USD 25 per ton of waste. In Lima, the external cost would thus amount to USD 196,775 considering the waste generation of 7871 tons per day.

Financial Analysis

This section presents the financial feasibility analysis and results of a representative plant generating about 2 MW electricity from landfill gas. The financial viability is analyzed based on Return on Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR) valuation criteria. The capital cost for the plant is estimated to be USD 3,359,000 which includes the construction and machine and equipment cost. The O&M costs are estimated to USD 470.91 per kW per year. The project life of the plant is assumed to be 15 years. The financial analysis of the representative plant shows a positive NPV of USD 470,238 with an IRR of 5.35%. The financial assessment of the 40 plants operating in the city also shows a positive net profit, with a positive NPV from the business. The rate of investment (ROI) is 7% implying that revenues are not high enough to recover all costs of the business. This is also observed that the benefit-cost ratio is less than 1 (0.69) indicating that financially the model is not viable.

Table 10: Financial results of ESCO model (USD)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Revenue															
Sale of Electricity	1,267,200	1,322,577	1,380,373	1,440,696	1,503,654	1,569,364	1,637,945	1,709,523	1,784,229	1,862,200	1,943,578	2,028,512	2,117,158	2,209,678	2,306,241
Total Revenues	**1,267,200**	**1,322,577**	**1,380,373**	**1,440,696**	**1,503,654**	**1,569,364**	**1,637,945**	**1,709,523**	**1,784,229**	**1,862,200**	**1,943,578**	**2,028,512**	**2,117,158**	**2,209,678**	**2,306,241**
Expense															
Labour and Input costs	744,200	776,722	810,664	846,090	883,064	921,654	961,931	1,003,967	1,047,840	1,093,631	1,141,423	1,191,303	1,243,363	1,297,698	1,354,407
O & M Costs	182,280	190,246	198,559	207,236	216,293	225,745	235,610	245,906	256,652	267,868	279,573	291,791	304,542	317,851	331,741
Insurance	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340	15,340
Total Expense	**941,820**	**982,307**	**1,024,564**	**1,068,667**	**1,114,697**	**1,162,739**	**1,212,880**	**1,265,213**	**1,319,832**	**1,376,839**	**1,436,336**	**1,498,434**	**1,563,245**	**1,630,888**	**1,701,488**
PBDIT	**325,380**	**340,269**	**355,810**	**372,029**	**388,957**	**406,625**	**425,064**	**444,310**	**464,397**	**485,361**	**507,242**	**530,079**	**553,914**	**578,790**	**604,754**
Depreciation	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950	87,950
Interest payment	125,963	95,963	58,463	13,463	-	-	-	-	-	-	-	-	-	-	-
Profit before tax	**111,468**	**156,357**	**209,397**	**270,616**	**301,007**	**318,675**	**337,114**	**356,360**	**376,447**	**397,411**	**419,292**	**442,129**	**465,964**	**490,840**	**516,804**
Income tax	53,504	75,051	100,511	129,896	144,483	152,964	161,815	171,053	180,694	190,757	201,260	212,222	223,663	235,603	248,066
Net Profit	**57,963**	**81,306**	**108,886**	**140,720**	**156,524**	**165,711**	**175,300**	**185,307**	**195,752**	**206,654**	**218,032**	**229,907**	**242,301**	**255,237**	**268,738**

Socioeconomic results

The socioeconomic analysis of ESCO business model is performed by putting monetary value on all quantifiable cost and benefits in order to calculate the NPV, benefit cost ratio (BCR) and ROI for the business model. The consolidated socio-economic results are presented in Table 12. The analysis looked at the potential impact of ESCO model at three levels where the levels range from including the direct benefits and costs that affect the business entity to including indirect benefits and costs to other sectors. The annual social and environmental benefits and costs from the business were discounted at a rate of 11% to obtain the present value of social and environmental impacts.

The ESCO model, when only the direct benefits are accounted for results in negative NPV and BCR of less than 1 implying that the business model is not financially feasible. The business model performs better when the financial and environmental costs and benefits are taken into account. However, the net positive incremental benefits from the environmental impacts are not high enough to make the business model feasible as the NPV is still negative and the BCR is less than 1. The business model becomes economically feasible when all externalities are included in the analysis. The NPV when all externalities are considered is USD 50,646,571 and the BCR is 9.28. Thus, major contribution to the economic feasibility of the business is from the social benefits. The total value of the social benefits of the business is USD 35 million with major benefits coming from the additional electrification in the rural areas which have a multiplied effect in terms of increase in productivity. Thus the ESCO business model is not financially feasible particularly when scaling up of the model is assumed with constant returns to scale but socioeconomically benefits accrual are large to overweigh the costs associated with the business model.

Table 11: Net socio-economic results of ESCO model

Socio-economic result (USD/year)	Financial value	Financial and environment al value	Social, environmental and financial value
Financial result:			
NPV	3,761,904	3,761,904	3,761,904
Environmental benefit:			
Value of net GHG emission saving		11,535,998	11,535,998
Social benefit:			
Total Social Benefits			35,348,669
NPV	**3,761,904**	**15,297,902**	**50,646,571**
ROI (average)	**7.5%**	**122%**	**321%**
BCR	**0.69**	**2.8**	**9.28**

Sensitivity analysis

Analyzing the uncertainty associated with the estimated socioeconomic model is an important issue since deterministic models tend to downscale the risks of the benefits which are inherent in the social processes. To do a stochastic analysis, the present study considers four different variables for the analysis – (i) capital cost of the gasifier, (ii) discount rate, (iii) value of the carbon credits, and (iv) economic value of the externalities associated with MSW disposal. For each of these relevant variables a suitable distribution was selected which helps in the iterations of calculating the probability distribution of the NPV of the benefits associated with the entire business.

Variable	Unit	Distribution specified	Source
Capital cost of the gasifier	USD/KW	*Triangular:* (2010, 2087,2890) for the smaller plant	Buchholz and Volk, 2007; IFAD, 2010
Discount rate	%	*Triangular*: (10%, 11%, 15%)	Assumed
Carbon Credit price	USD/t CO_2 eq.	*Triangular:* (0.51, 1, 3.8)	Assumed; 0.51 was the lowest value and 3.8 is the average value
Economic value of a externalities	USD	*Triangular Distribution* (20, 25,30)	Assumed.

The following figure shows the derived probability distribution of the net present value of the benefits (environmental, social and financial) arising from the business at the city level. The figure shows that the mean is 49 million USD which is achieved with 48% certainty. The 90% confidence intervals of the distribution is between 45 - 54 million showing a lower standard deviation from the mean. Overall this stochastic analysis leads use to conclude the business operating at the city level is feasible in medium range of riskiness.

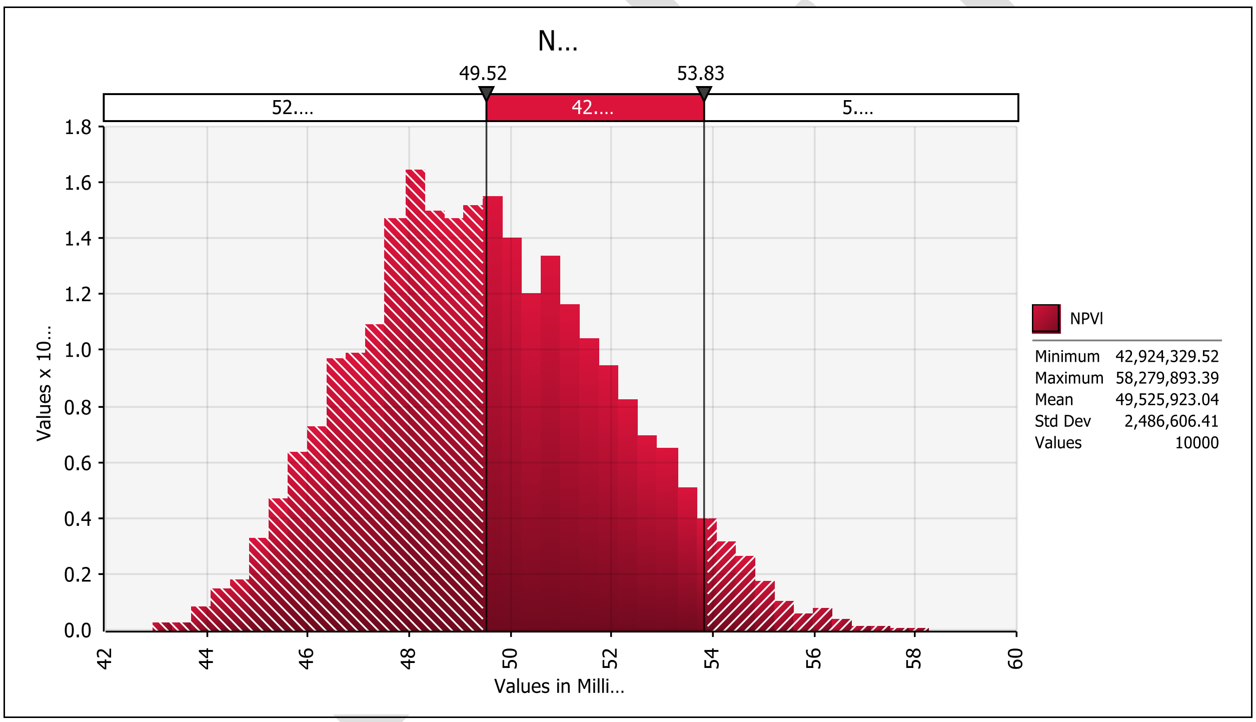

Figure 2: Probability distribution of the NPV of ESCO model at city level

Conclusion

This study assessed the socio-economic impact of energy service company (ESCO) business model in Lima, Peru. The socio-economic analysis is conducted based on the valuation of financial, environmental and health benefits and costs associated with the business model. The following conclusions can be drawn from the study:

- From the socioeconomic perspective, findings from the study indicate that the use of agricultural residue as a feedstock in a small scale biomass gasification to electricity business model is viable in Peru and has the potential of impacting positively the health, environmental and social life of the rural dwellers. The business model resulted in a BCR of 4.64 and ROI of 54% indicating that (although not all environmental and social impacts have been factored in the analysis) the business provides positive environmental and social impacts that offsets it costs.
- Net GHG emissions saved per kwh of electricity generated is 3.6 kg CO_2eq. The highest savings in GHG emissions would be mainly from substituting diesel generators for the commercial establishments while the highest emissions from the business model is from the gasifier.
- Major contribution to the economic feasibility of the business is from the social benefits. The total value of the social benefits of the business is USD 118 million with major benefits coming from the additional income to farmers and jobs created for the local community.

Socio-economic impact assessment of the business model Manure to Power in Lima

Introduction

This business model is initiated by agro industries such as piggeries, cattle farms, poultry, sugar processing factories, cassava or palm oil industrial factories and slaughter houses to generate energy from their by-products. The waste generated by these industries is used to generate electricity which is used in house for their own energy requirements. The technologies applied and the resulting energy products vary depending on the type of waste processed. These include co-generation unit to produce electricity, distillery unit to produce ethanol/alcohol and biogas unit to produce electricity and heat. Production technologies such as Covered Lagoon Bio-Reactor are also suitable for processing wastewater discharged from industrial factories such as starch and palm oil factories to produce biogas. The electricity produced by the cogeneration unit or by the covered lagoon bio-reactor is sold to the state utility on a long term power purchase agreement. The alcohol/ethanol produced from the distillery unit of sugar processing factory is sold to petroleum and pharmaceutical companies while the energy produced by the biogas unit is used onsite as input fuel to the cogeneration unit. The discharge from the biogas unit, which is high in organic matter can be distributed to farmers to be used as fertilizer.

The ownership and operation of the energy producing units take different forms. The energy production technologies are either designed, constructed, owned and operated by the agro-industrial processing factory or; are installed by an external private entity on a Build, Own, Operate, Transfer (BOOT) model. In the latter case, the private entity brings investment to set up the energy production technology while the concessionaries i.e. the agro-industrial factories provide land and inputs. The private entity designs, constructs and maintains the energy production unit until BOOT period is expired after which it assists the host company to operate the unit. The business model tested for financial feasibility targets piggeries where the pig manure is used to generate biogas and the energy from biogas is used for internal energy requirement for running piggeries.

Technology

The technology comprises of a bio-digester and an electricity generation system. The biodigester is an anaerobic reactor which captures methane gas produced by fermentation of organic material from swine production. Within the bio-digester, the manure is transformed through a process called methanogenesis, in which the methanogenic bacteria transform organic particles into methane (CH_4). From this process, biogas is produced which is subsequently captured and directed to electricity generation or CHP (combined heat and power) unit. A biogas-cleaning unit will be incorporated before the generation unit if necessary.

Equipment and infrastructure required are:

- Bio-digestors
- Substrate mixing equipment and/or machinery
- Biogas storage and cleaning equipment
- Electricity generation or CHP unit

- Complementary equipment and facilities for the modular units

Overall approach to socioeconomic impact assessment

The socio-economic analysis of a project is concerned with its viability from a societal perspective and answers the questions of whether it is economically rational to proceed with the project (De Souza et al., 2011). In contrast to a financial analysis, socio-economic analysis provides a more comprehensive investigation on the effects of a proposed project, takes a broader perspective and determines the project's overall value to society. The analysis, therefore, includes benefits and costs that directly affect the business entity running the project and the effects of the project on households, governments and other businesses outside of the business. The analysis also includes the benefits and costs that cannot be readily measured using observable market prices and costs (De Souza et al., 2011). In this study, the financial viability of the business was assessed through a cost benefit analysis and for the environmental impacts, a life cycle emissions of agricultural-residue derived briquette fuel are evaluated.

The following sections will elaborate on the assumptions made, the scenarios modeled and the data sources used for assessing the environmental, social and financial impacts associated with power capturing from pig slurry business model.

Baseline and alternative scenarios

In conducting socio-economic analysis of any project, it is important to determine the baseline scenario which will be the benchmark to compare project alternatives. This study will assess the economic viability of power generation from pig slurry model and a comparison of the costs and benefits of the business model vs. a business as usual scenario. Pig slurry from herd is often seen to be open dumped or thrown into water bodies in Lima and therefore, we have taken this as a baseline scenario for the cost-benefit analysis.

System boundary

The system boundary applied in this study contains establishment of biogas plant at the pig herd and production of electricity to self-consumption at herd and selling to households and business in rural areas. Since pig slurry is used as input in the power generation process, we assumed that under baseline, the pig slurry is open dumped or thrown into water bodies. Thus, emissions associated with this practice were accounted for when assessing the environmental impacts. There, is risk of emissions of methane in the production of electricity generation, but we ignore this aspect in this study. In per-urban areas of Lima the information about large pig farms are limited. In the financial analysis, a representative farm rearing 4000 pigs has been considered. The present socio-economic study to evaluate the societal benefits of such businesses assumes a scaling up of such farms for the city as a whole. The socio-economic assessment considers 10 such representative pig farms in the peri-urban areas of Lima.

Environmental impact assessment

Pig Slurry in the baseline scenario

In the base line scenario we evaluate the environmental impact of a pig herd consisting of 4000 pigs. Usually the pig slurry is either used as manure in the field or dumped into the water bodies indiscriminately which leads to surface and ground water pollution. Pig slurry contains pollutants like Nitrogen, Methane, Phosphorous, copper, copper, zinc, manganese, and calcium (See Table 1). Each pig produces slurry of 6.12 m^3 annually. Therefore, 1500 pigs produce pig slurry of 9180 m3 per year. We assume solid portion of pig slurry is 6 percent and density of pig slurry is 1010 kg/m^3. Hence, solid pig slurry produced annually is 556,308 kg/year. Given this one can easily estimate the emissions of pollutants from pig slurry and which is given in the last column of the Table 1. Open dumping of pig slurry produces 151,360 kg of methane.

Table 12: Chemical composition of Pig slurry

Parameter	Unit	Growing-finishing	Total Emissions (kg)
Ammonium nitrogen	mg/kg	2846	1583
Phosphorous	mg/kg	1690	940
Potassium	mg/kg	3405	1894
Copper	mg/kg	49.9	28
zinc	mg/kg	82.9	46
Manganese	mg/kg	29.85	17
calcium	mg/kg	1700	946
Magnesium	mg/kg	674	375
Methane	m^3/kg	0.243	151360

Surface and ground water Pollution under baseline

Only 6 percent of pig slurry is solid and therefore, 94 percent is liquid in nature. The pollutants contained in the liquid of pig slurry for ground water pollution are Ammonium Nitrate and Nitrate-N. Amounts of Ammonium Nitrate and Nitrate-N in pig slurry liquid are 4.25 mg/ltr and 0.33 mg/ltr respectively. Therefore, total ammonium nitrate and nitrate-N discharged by one pig heard are 37 kg and 3 kg annually. Similarly, components of surface water pollution are pH, DO, BOD, COD, NH_4, NO_3, PO_4 are 7.31, 2.72, 90, 124, 5.09, 1.85, 1.86 mg/ltr. Hence total amount of discharge of pH, DO, BOD, COD, NH_4, NO_3, PO_4 in surface water by a pig heard are 63, 23, 777, 1070, 44, 16, 16 kg annually. In the absence of abatement cost of these pollutants, the present study uses the pollution from common pollutants like nitrogen, phosphate, suspended solids, COD and BOD. It is assumed that for each of the animals 20 liters of wastewater is being generated. Based on the environmental pollution costs of the undesirable outputs as cited above (UNEP, 2010) the costs for groundwater and surface water pollution is estimated to be USD 1,101,238 annually.

Table 13: Components of ground and Surface water pollution in pig slurry

Ground water pollution	Unit		Unit	
NH4-N (Ammonium Nitrate)	Kg	37	mg/ltr	4.25
NO3-N (Nitrate-N)	Kg	3	mg/ltr	0.33
Surface water pollution				
DO	Kg	23	mg/ltr	2.72
BOD	Kg	777	mg/ltr	90
COD	Kg	1070	mg/ltr	124
NH4	Kg	44	mg/ltr	5.09
NO3	Kg	16	mg/ltr	1.85
PO4	Kg	16	mg/ltr	1.86

Environmental Benefits of Electricity generation from pig slurry under alternative

In the alternate scenario solid pig slurry produced by a pig heard i.e., 927,180 kg is being used to produce electricity. The quantity of methane produced by solid pig slurry is 0.4 m^3/kg. Hence, methane produced out of solid pig slurry is 370,872 m^3/year. Biogas constitutes 65 percent methane. Hence, total biogas produced is 570,572 m^3/year. Assuming 365 operating days, the biogas yield per day is 1563 m^3/day. Energy yield from biogas is 5700 Kcal/m^3, and conversion factor from KCal to kWh is 0.001163. Hence, we get electricity production of 10,363 kWh. We also assume that the power plant operates for 10 hrs in a day, therefore, in an hour 1,036 kW power is being generated. It is also assumed that efficiency of engine generator is 35 percent and therefore, the capacity of the power plant is 363 kWh. Therefore, total electricity which can be supplied annually in the market is 1,324,950 kWh. The average requirement of electricity per household is 120 kWh/month. Therefore, with the produced electricity only 920 households can be served. 920 households can replace the use of kerosene by electricity and thus reduces the CO_2 emissions from kerosene by 94 tons annually. By producing electricity from pig slurry we can avoid the methane emissions and therefore CO_2. Power plant helps to reduce the CO_2 emissions by 52,976 ton of CO_2 annually. In total through electricity production from pig slurry of one heard of 1500 pigs, 53,133 tons of CO_2 emissions can be avoided annually including the emissions from the kerosene used by the households for lighting. As there is a need for 10 plants to handle the problem of pig slurry in Lima, so 10 plants will help avoid emission and monetary value of that emission is 201,904 USD considering a price of USD 3.8 per ton of CO_2 equivalent.

Table 14: GHG emissions avoided due to production of electricity from pig slurry

Emission saved from production of electricity	Unit	
Emissions from CH_4	Tons of CO_2/year	52,976
Emissions from Kerosene	Tons of CO_2/year	157
Total Emissions	Tons of CO_2/year	53,133
Price of carbon credit	USD/ton CO	3.8
Value of emission from a plant	**USD**	**456,201**

Social impacts

Wage income earned under alternative

The socioeconomic evaluation of the introduction of the power generation from the large pig farms assumes only the direct effects on the employment in terms of the employed staff (both shilled and semi-skilled) for the benefits. The indirect effects of power generation and effects within the economy for households and commercial purposes are not considered within the system boundary of the study. The power plant of 425 kW can generate 10 additional employment. The monthly wage income of an employee of power plant is 225 USD. Therefore, total monthly wage income generated is 2250 and annual income of 27,000 USD. Hence, total income generated by 10 plants is 270,000 USD per annum.

Benefit from electrification

Using electricity from the grid is particularly low among the rural households in Peru (about 39%). A tiny fraction of households, 0.6% (13,100 households) have generators, and 0.8% (16,700 households) has solar home systems (SHS). Small generators and SHS are commonly used in households without access to grid electricity. The household in-grid connected, which own small generators or SHS, use them due to the lack of electricity service reliability. Particularly SHS is used for lighting and communications (radio and TV). Car batteries are commonly used as off-grid electricity sources, especially in the Coastal region of Peru, where households have more income and car battery recharging is relative easy due to the presence of good roads. It is estimated that 18% (240,000) of off-grid rural household uses it for lighting and running TV`s. Nevertheless, in rural households without electricity the most common source of energy for lighting comes from kerosene (80% of rural households) and candles (65% of rural households). Rural households in-grid connected areas consume less than 30 kWh per month (70% of households), and between 21% and 39% of their total electricity consumption is used for lighting. The remaining electricity consumption is due to the use of domestic appliances such as TV, irons and others. Less than 1% of these households own appliances such as domestic water pumps, electric pump irrigation systems or any other devices which are directly used for income-generating activities. Domestic small appliances such as radios and flashlights are powered by dry cells (74% of rural households) in both types of households, with or without access to grid electricity. Although household energy expenditure varies significantly between financially better-off households and poorer households, on average the total monthly cash expenditure for all types of energy uses is estimated to be 9.7% of the total household cash expenditures. This indicates the importance of rural electrification in Peru.

It has been estimated by the World Bank (2010) in a study with regards to rural household energy use that the net benefit (consumer surplus) from electrification in the rural areas is USD 1.23 – 1.54 per kWh on average. The alternate scenario assumes that 15, 41,254 kWh is being produced per unit (40 units with a capacity of 200 tons). The total benefit (consumer surplus this arising from alternatively using electricity in the rural areas can be estimated to be USD 7,367,450 annually.

Financial analysis

In this section, the financial analysis of the briquette is presented. The financial viability is analyzed based on Return on Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR) valuation criteria. The costs of the power plant primarily include capital investment and operating costs which include input cost, labour cost, O & M costs. The useful life of the power plant is assumed to be 15 years. Total investment cost in a single plant is USD 382,032. The production capacity of the plant is 425 kW. The selling price of electricity is 0.11 kWh. The total number of full time workers is 10 and total monthly labor cost is 225 USD. Operating and maintenance costs are assumed to be 5% for machine and equipment and 2% for building. A discount rate of 11% is assumed. A straight line method of depreciation is used for depreciable capital costs assuming a useful life of 15 years with a salvage value of 10% of total depreciable cost. (Refer to financial analysis document for details). The financial analysis of a power capturing from pig slurry is presented in Table 5. The results from a single plant shows that there is net positive profit and a positive NPV of USD 314,799 with an IRR of 13.16% making it financially viable. Results show that when this financial figures are extrapolated for 10 farms the business model resulted in a positive net profit for the 10 farms together. Assuming a discount rate of 8% and useful life of 15 years, the business model resulted in a mean NPV of USD 3,147,910 indicating that the business model is financially viable. The benefit-cost ratio for the business model is 1.01.

Table 15: Financial results of power capturing from pig slurry (USD)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
Revenue														
Sale of excess electricity	136,932	142,916	149,161	155,679	162,483	169,583	176,994	184,728	192,801	201,226	210,020	219,198	228,777	238,774
Total Revenue	**136,932**	**142,916**	**149,161**	**155,679**	**162,483**	**169,583**	**176,994**	**184,728**	**192,801**	**201,226**	**210,020**	**219,198**	**228,777**	**238,774**
Expense														
Labour and Input cost	38,105	39,770	41,508	43,322	45,215	47,191	49,253	51,406	53,652	55,997	58,444	60,998	63,663	66,445
O & M Cost	14,540	15,175	15,838	16,530	17,253	18,007	18,794	19,615	20,472	21,367	22,300	23,275	24,292	25,354
Insurance	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300	2,300
Total Expense	**54,944**	**57,245**	**59,646**	**62,152**	**64,768**	**67,497**	**70,347**	**73,320**	**76,424**	**79,663**	**83,044**	**86,572**	**90,255**	**94,099**
Profits before depreciation, interest and tax	**81,987**	**85,671**	**89,515**	**93,527**	**97,715**	**102,086**	**106,647**	**111,408**	**116,377**	**121,564**	**126,976**	**132,626**	**138,522**	**144,676**
Depreciation	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469	25,469
Interest Payments	14,326	6,826	-	-	-	-	-	-	-	-	-	-	-	-
Profit before tax	**42,192**	**53,376**	**64,046**	**68,058**	**72,246**	**76,617**	**81,178**	**85,939**	**90,908**	**96,095**	**101,507**	**107,157**	**113,053**	**119,207**
Income tax	20,252	25,620	30,742	32,668	34,678	36,776	38,966	41,251	43,636	46,125	48,724	51,435	54,265	57,219
Net profit	**21,940**	**27,755**	**33,304**	**35,390**	**37,568**	**39,841**	**42,213**	**44,688**	**47,272**	**49,969**	**52,784**	**55,722**	**58,788**	**61,988**

Socio-economic results

The consolidated socio-economic results are shown in Table 6. The analysis looked at the potential impact of power capturing from pig slurry at three levels where the levels range from including the direct benefits and costs that affect the business entity to including indirect benefits and costs to other sectors. The annual social and environmental benefits and costs from the business were discounted at a rate of 11% to obtain the present value of social and environmental impacts.

Table 16: Net socio-economic results of power capturing from pig slurry

Socio-economic result (USD/year)		Financial value	Financial & Environmental	Social, Environmental & financial
Financial result:				
	NPV	3,147,990	3,147,990	3,147,990
Environmental benefit:				
	Value of net GHG emission saving & Water pollution costs averted		15,570,730	15,570,730
Social & Health benefit:				
	Total social (employment) & Health impact			30,076,566
Total social benefit				
NPV		**3,147,990**	**18,718,720**	**48,795,286**
ROI		**18%**	**68%**	**126%**
BCR		**1.01**	**2.6**	**6.87**

The financial model generates a positive NPV and a benefit-cost ratio of 1.01. It becomes more profitable when environmental benefits are added with financial benefits and the benefit-cost ratio becomes 2.6. The largest contribution comes from social component when it was added together with financial and environment benefits. Taking into account all the components the BCR turns out to be 6.87. Thus from a socio-economic perspective, the power capturing from pig slurry model is very attractive. The social benefits primarily accrue from increased electrification particularly in the rural areas of Lima.

Sensitivity Analysis

The primary variables selected for the stochastic model are explained in the following table (Table 8). The different variables that were identified to be stochastic are – (i) discount rate, (ii) price of the carbon credit and (iii) economic value of the DALY and (iv) different range of valuation of benefits from electrification. Different values of these variables were used to assess the resulting effect on the overall socioeconomic feasibility of the business model. This was obtained through several iterations of the stochastic variables and derivation of the probability distribution of the NPV of the net benefits of introducing power generating plants within the animal rearing farms in the peri-urban areas of Lima. The primary variables selected for the stochastic model are explained in the following table (Table 8).

Table 17: Variables selected for the stochastic model – Livestock waste to electricity

Variable	Unit	Distribution specified	Source
Discount rate	%	Triangular: (10%, 12%, 15%)	Assumed

Carbon Credit price	USD/t CO_2 eq.	Triangular: (0.51, 1, 3.8)	0.51 was the lowest value reached during 2014
Benefits from electrification	USD/kWh	Uniform distribution (1.23 – 1.54)	World Bank study 2010

The following figure (figure 1) shows the probability distribution derived from the iterations of the different values of the stochastic variables and their respective distributions. The mean value estimated is 37.25 million USD and the distribution shows that 54% chance of failure exists to reach the mean value of the societal benefit. Considering the NPV and its mean, the chance of achieving the mean and the ROI, the economic feasibility is at medium level.

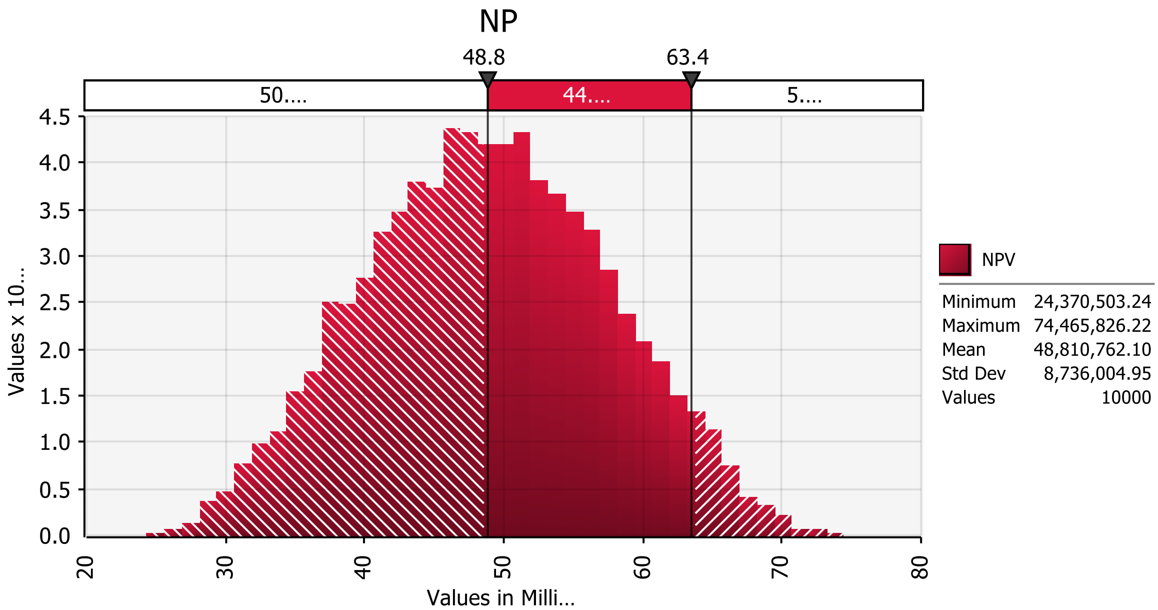

Figure 3: Probability Density function of the NPV for net benefits derived from the electricity generation form Livestock manure

Conclusion

This study assessed the socio-economic impact of a power capturing model from pig slurry in Lima, Peru. The socio-economic analysis is conducted based on the valuation of financial, environmental and health benefits and costs associated with the business model. The following conclusions can be drawn from the study:

- The environmental impacts associated with the business model were estimated based on avoided surface and ground water pollution, methane emission from pig slurry. The major contribution to GHG emission savings is from avoided methane emission from open dumping of pig slurry. Compared to the baseline scenario, the power generation business results in net GHG and other criteria emission savings.

- The power generation business model, increases the rural electrification, creates additional jobs for local residents, and enables end users to save on energy costs as well as improves the indoor environment.

- Looking at the overall socio-economic impacts, the business model is financially and economically feasible. Given the huge environmental benefit associated with it, one can safely recommend to take up this project.

Socio-economic analysis for Beyond Cost Recovery: the Aquaculture example in Lima

Introduction

Wastewater management is a major challenge in many developing countries and policy makers are constantly exploring cost effective measures to mitigate both the direct and indirect negative impact. This is important for individuals who are living below the poverty line. The social costs of poor wastewater management is high, thus innovative approaches which aimed at reducing health risks and improving the environmental conditions are imminently needed. Peru is not different from any developing country. Policy makers are engaging relevant stakeholders to explore effective and efficient options for wastewater management.

This report seeks to investigate the viability of a phyto-remediative wastewater treatment model in Lima. It is known that Lima generates 615,400 m^3 of wastewater daily (EAWAG, 2014). 40 percent of the waste water generated is being treated and the rest remains untreated and flows to waterbodies in Lima (EAWAG, 2014). The amount of waste water generated in Lima can be used for aquaculture and subsequently treated wastewater can be used for irrigation purpose.

Given the context of Lima this report investigates the socio-economic impacts of phyto-remediative waste water treatment model in which waste water stream will be used primarily for aquaculture. The potential economic, environmental, Social and health impacts of phyto-remediative waste water treatment model needs to be assessed to ensure its sustainable development. In this study, we evaluated the socio-economic impacts of treating wastewater with medium sized aerobic pond capacity (2-4 ha.) where water is being diverted from the WWTP. The socio-economic analysis is conducted based on the valuation of economic, Social, environmental and health benefits and costs associated with the business model.

Technological description of treating wastewater

Wastewater-fed aquaculture is increasingly being recognized as an innovative business-oriented reuse system. The business concept build on a public-private partnership that can be established between municipal wastewater management bodies or other public organizations with a need for wastewater treatment, and private entities proving the expertise, setting up an aquaculture business. While public entity/entities provide(s) wastewater and wastewater stabilization ponds, business entities can cultivate fish under specified safety procedures in the ponds. In this model wastewater is being treated to an advanced tertiary state and during that process produce fish for human consumption, using the same water flows. Duckweed is used to purify the wastewater. The duckweed is subsequently harvested and fed to fish fingerlings. Mature fish are caught and then sold both at pond side and to whole sellers. The advanced tertiary state treated water can be released safely in the environment, or, in areas where water is scarce and thus has value, can be sold for agricultural and other reuse. The business model has a very basic value chain in case of localized and small scale operations where fish and co-crops are sold in the local market.

The fish can be sold locally and in the export market. Profits will be divided amongst the partners depending on the partnership contracts. Usually the public entity will be responsible for maintaining, which typically is improved due to the business activity. The key players in the business set-up are the aquaculture business entity itself, local municipality and/or local public organization in need of wastewater treatment, duckweed-fish expertise provider, and of course produce buyers and consumers in the market.

Overall approach to socio-economic impact assessment

The socio-economic analysis of a project is concerned with its viability from a societal perspective and answers the questions of whether it is economically rational to proceed with the project (De Souza et al., 2011). In contrast to a financial analysis, socio-economic analysis provides a more comprehensive investigation on the effects of a proposed project takes a broader perspective and determines the project's overall value to society. The analysis, therefore, includes benefits and costs that directly affect the business entity running the project and the effects of the project on households, governments and other businesses outside of the business.

First, we have evaluated the current scenario in Lima which is denoted as baseline scenario with the help of cost-benefits analysis. The wastewater in Lima mainly comes through industrial zones. Total wastewater generated in Lima is 18.98 m^3/sec and out of which about 90 percent is being treated and 10 percent remains untreated which goes to open environment. The 90% of the wastewater is being treated in the existing 26 WWTPs while to treat the remaining 10%, WWTPs have been planned for the future. Second, in the alternative scenario we have considered aquaculture business with medium-sized pond of 2-4 ha to treat the waste water and produce fish for consumption. Third, we have increased the number of ponds to such an extent so that all wastewater generated in Lima can be handled. The cost-benefit analysis of this scenario is also being analyzed and compared with the baseline scenario. The existing WWTPs are of different capacities in terms of wastewater treatment. While conducting the socioeconomic assessment for Lima, the WWTPs which have a capacity of more than 18 million litres were assumed to be utilized for electricity generation since capacity of less than 5 MGD is economically infeasible for electricity generation. Therefore of the 26 WWTPs, 9 such plants were assumed for the cost recovery model and the other 17 WWTPs were considered for the Phyto-remediative and aquaculture business model.

Environmental Impact Assessment

Waste water generally flows directly to waterbodies without any treatment and therefore, creates a possibility of surface water pollution. The surface water pollution happens due to pollutants like Nitrogen, Phosphorous, Suspended Solids (SS), BOD, COD etc. The cost of pollution from Nitrogen, Phosphorous, Suspended Solids (SS), BOD, COD are 0.606, 0.3087, 0.00252, 0.0164, 0.083 USD/m^3 (Table 1). Hence, total surface water pollution caused by wastewater stream in Lima is 173,405 USD annually in the baseline scenario which can be avoided in the alternative scenario. Considering 12 percent discount rate, the present value of the environmental benefits stands around 1,238,582 USD.

Table 18: Surface water pollution due to wastewater - environmental value of pollution

Value for N	USD/m^3	0.606	UNEP, 2010
Value for P	USD/m^3	0.3087	UNEP, 2010
Value for Suspended Solids	USD/m^3	0.00252	UNEP, 2010
Value for BOD	USD/m^3	0.0164	UNEP, 2010
Value for COD	USD/m^3	0.083	UNEP, 2010
Total value of pollution due to undesired outputs	USD/year	**173,405**	

Social Impact Assessment

The amount of wastewater generated in Lima is 18.98 m^3/sec. Presently about 1,475,884 m^3 of water is treated while there has been a plan to set up WWTPs which would further treat 163,987 m^3 per day. All the 17 ponds assumed for aquaculture is of size 2-4 hectare. It has been assumed that on an average 4-5 fishermen are required for 1 ha of pond. Hence, total number of employment created in the alternative scenario is 136. We assume that per-capita income for fishermen is 6,661 USD annually which is based on the per capita income in the present situation in Lima. Hence, annual income of all fishermen is 905,896 USD. The present value of annual wage income for fishermen is 15,870,752 USD.

Apart from fishermen, there would also be breeding and maintenance workers and size wise employment of these workers are given in Table 4. Assuming a wage rate of 100 USD per month the value of employment for breeding and maintenance workers is 1,501,440 USD annually. The present value of which turns out to be 9,644,573 USD.

Table 19: Employment Generated

Employment Generated		
Number of workers employed in pond size of 2 - 4 ha		7
Total workers employed for the ponds		119
Wage rate per month	USD/month	220
Employment generated in terms of the fishing activities	USD/year	314,160

Health Impact

Wastewater stream can cause illness related to water, sanitation, and hygiene- which is diarrhoea. According to the latest Census total population in Lima devoid of proper sanitation and water facilities has been used for the calculation of the health benefits. The DALY/1000/per-capita annually is 14. Moreover, it is also being conservatively assumed that only 5% of the population is exposed to diarrhoea therefore, the total health expenditure in Lima annually is 197,876 USD. The present value of health costs avoided in the alternative scenario is 35,468,245 USD.

Financial Analysis

In this section, the financial analysis of the phyto-remediative wastewater treatment is presented. The financial viability is analyzed based on Return on Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR) valuation criteria. Initially we have done financial viability analysis for large, medium, and small sized ponds and then consolidated the financial analysis of three different sized firms by considering the number of plants. The initial investment costs of a medium sized firms is 21,800 USD. The revenue for medium is 46,874 USD. Total production and other costs are about 40,378, USD. A straight line method of depreciation is used for depreciable capital costs assuming a useful life of 15 years with a salvage value of 5% of total depreciable cost. Current tax for similar businesses in Lima is 20%. Table 5 presents the results of financial analysis. Since there are 6 medium sized we have scaled up the cash flows by considering these facts and the consolidated cash flow for the business and thus considering discount rate of 8 percent we obtain present value of cash-flow is 152,490 USD. The internal rate of return is 15 percent, ROI is 26 percent, however the BCR is just more than 1 (1.54). Therefore, the financial analysis of phyto-remediative wastewater treatment indicates that the business model is financially just viable at a large scale.

Table 20: Consolidated Financial Analysis of Phyto-remediative wastewater treatment ponds

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
Revenue														
Sale of fish	8,250	8,580	8,923	9,280	9,651	10,037	10,439	10,856	11,291	11,742	12,212	12,700	13,209	13,737
Total Revenue	**8,250**	**8,580**	**8,923**	**9,280**	**9,651**	**10,037**	**10,439**	**10,856**	**11,291**	**11,742**	**12,212**	**12,700**	**13,209**	**13,737**
Expense														
Labour and Input cost	4,911	5,107	5,312	5,524	5,745	5,975	6,214	6,463	6,721	6,990	7,270	7,560	7,863	8,177
Utilities and Supplies Costs	1,000	1,040	1,082	1,125	1,170	1,217	1,265	1,316	1,369	1,423	1,480	1,539	1,601	1,665
O & M Cost	347	360	375	390	405	422	438	456	474	493	513	533	555	577
Total Expense	**6,258**	**6,508**	**6,768**	**7,039**	**7,320**	**7,613**	**7,918**	**8,235**	**8,564**	**8,906**	**9,263**	**9,633**	**10,019**	**10,419**
Profits before depreciation, interest and tax	**1,992**	**2,072**	**2,155**	**2,241**	**2,331**	**2,424**	**2,521**	**2,622**	**2,727**	**2,836**	**2,949**	**3,067**	**3,190**	**3,318**
Depreciation	746	746	746	746	746	746	746	746	746	746	746	746	746	746
Interest Payments	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Profit before tax	**1,246**	**1,326**	**1,409**	**1,495**	**1,584**	**1,678**	**1,775**	**1,875**	**1,980**	**2,089**	**2,203**	**2,321**	**2,444**	**2,571**
Income tax	598	636	676	717	761	805	852	900	951	1,003	1,057	1,114	1,173	1,234
Net profit	**648**	**689**	**732**	**777**	**824**	**872**	**923**	**975**	**1,030**	**1,086**	**1,145**	**1,207**	**1,271**	**1,337**

Socio-economic Results

The consolidated socio-economic results are shown in Table 5. The analysis looked at the potential impact of aquaculture at three levels where the levels range from including the direct benefits and costs that affect the business entity to including indirect benefits and costs to other sectors. The annual social and environmental benefits and costs from the business were discounted at a rate of 8% to obtain the present value of social and environmental impacts.

Table 21: Net socio-economic results

Socio-economic result (USD/year)	Financial value	Financial & Environmental	Social, Environmental & Financial
Financial result:			
NPV	152,490	152,490	152,490
Environmental benefit:			
Value of net GHG emission saving		159,498	159,498
Social benefit:			
Total social benefit			**2,388,716**
NPV	**152,490**	**311,988**	**2,700,704**
ROI	**26%**	**38%%**	**122%**
BCR	**1.54**	**3.46**	**14.18**

The aquaculture business results in cost benefit ratio (CBR) of 1.06, NPV of USD 35,492 with medium sized plants and ROI of 7% when only direct benefits from the briquette production are taken into account. The NPV increases to 2,968,798 USD when environmental benefits are taken into account and to 6,706,600 USD when the environmental and social impacts are taken into account. The ROI taking all externalities into account is 359%. The major contribution to the economic feasibility of the business is from the social benefits. Thus from a socio-economic perspective, the aquaculture business model is highly attractive.

Sensitivity Analysis

The following variables shown in the following table has been considered for the stochastic analysis. The following figure (Figure 1) shows the probability distribution of the NPV of the net benefits from introducing the business model.

Table 22: Selected variables for the stochastic analysis of the business model

Variable	Unit	Distribution specified	Source
Discount rate	%	*Triangular*: (10%, 12%, 15%)	Assumed
Carbon Credit price	USD/t CO_2 eq.	Uniform distribution (0.51-1.5)	Assumed
Economic value of per capita loss due to diseases	USD	*Uniform Distribution* (4.49 – 9.5)	The lower range corresponds to estimates for cancer and higher range to gross national per capital income.

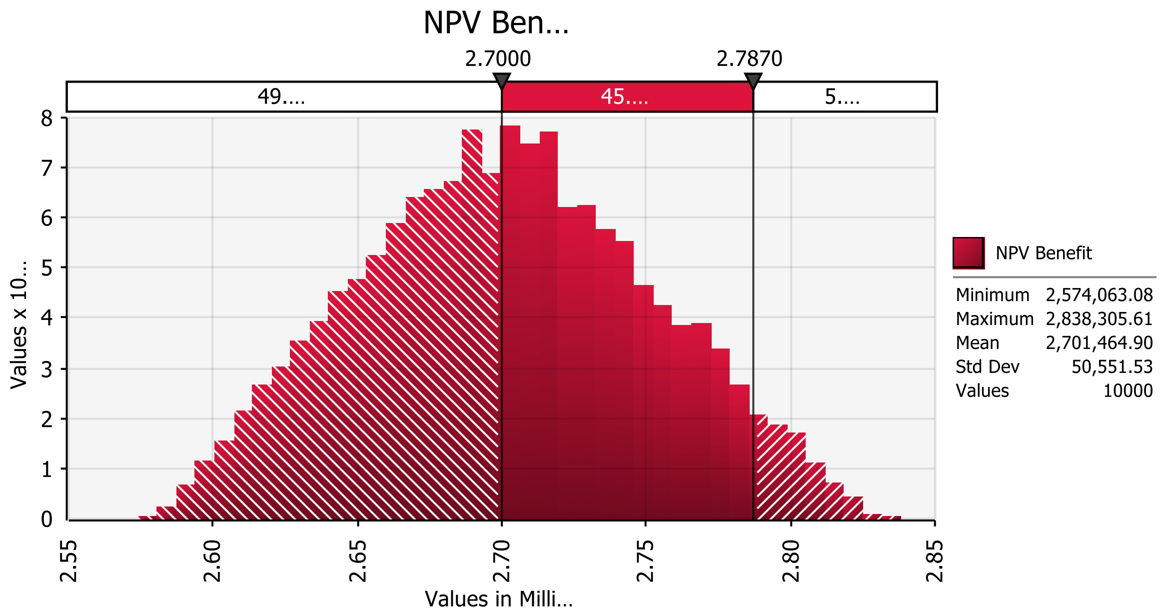

Figure 4: The probability distribution of the NPV of the net benefits derived from wastewater aquaculture

The above figure shows that the mean NPV is 7.3 million with a certainty of achieving it at 55%. Based on the ROI and the Benefit-Cost Ratio, it can be assessed that the business model of treated wastewater for aquaculture is feasible in the medium range.

Conclusion

This study assessed the socio-economic impact of phyto-remediative wastewater treatment business model in Lima, Peru. The socio-economic analysis is conducted based on the valuation of financial, environmental and health benefits and costs associated with the business model. The following conclusions can be drawn from the study:

- The environmental impacts associated with the business model were estimated based on surface water pollution from pollutants like N, P, SS, BOD, COD etc. We have seen that by treating wastewater stream in this model we can avoid the surface water pollution caused by wastewater stream in Lima.
- It helps in generating large number of employment and thus adds to the social benefits.
- Through this model we can save a large chunk of health expenditure made by residents of Lima.
- Looking at the overall socio-economic impacts, the business model is both financially and economically feasible. There is a significant increase in the economic feasibility of the business due to social and environmental benefits associated with the business.
- The major contribution to the economic feasibility of the business is from the social benefits with major benefits coming from employment generation of fishermen and breeding persons in the

business process. Thus from a socio-economic perspective, the phyto-remediative wastewater treatment business model is highly attractive.

Socio-economic impact assessment of cost savings and recovery of treated wastewater for irrigation, compost and energy in Lima

Introduction

The developing countries are facing a steep challenge of wastewater management and policy makers are constantly exploring cost effective measures to mitigate the impacts. Wastewater treatment interventions can generate significant benefits for public health, and the economic sectors such as fisheries, tourism and property markets. In developing countries with growing population and need for industrialization to cater to the economic growth the need for such interventions become more demanding. This is particularly true for individuals living below the poverty line who need provisions of safe water supply, sanitation and wastewater services. Several studies indicate that benefit-to-cost ratios for basic water and sanitation services are as high as 7 to 1 for developing countries. Thus benefits derived from such interventions are substantial in the long run for the economy.

The situation in Peru is not different from any developing country. Policy makers are engaging relevant stakeholders to explore effective and efficient options for wastewater management. Peru's urban population currently stands at 32% and is growing, due to rural urban migration. This trend has led to an increase in the production of wastewater from households and the growing manufacturing industry. Wastewater in Peru is mainly generated from domestic and municipal waste. It is estimated that about 224 million m^3 of wastewater is generated in Lima every year. In addition to this on average only about 2% of the people in 22 towns have access to sewerage systems. The dominant wastewater treatment facility existing is restricted to primary treatment and is discharged into wetlands.

One of the emerging key interventions towards wastewater management is diversion of the treated wastewater towards peri-urban agriculture and using the sludge retrieved as compost/manure for agriculture. In Peru despite a remarkable economic growth being registered in the recent years, one key set back remains the persistent food shortages and critical nutritional deficiencies often experienced in many parts of the country. This situation is partly attributed to occasional poor harvests attributed to erratic rain seasons, which have a very significant impact on the largely rain-fed subsistence farming being practiced by over 80% of the population (UN-WATER, 2006). Given the context of Lima this report investigates the socio-economic impacts of treating waste water for reuse in terms of treated wastewater for irrigation, conversion of biogas to electricity, and use of sludge as soil conditioner. This business model addresses cost recovery through three different mechanisms – (i) water sales and (ii) compost or manure sales to farming and additionally a cost saving mechanism (iii) using the treatment process to capture the biogas generated by anaerobic digestion and converting to electricity that is subsequently used to power the plant. These business interventions are pertinent for Peru given the context of lower sanitation facilities and also related scarcity of water for agriculture in the peri-urban areas.

The potential economic, environmental, and social impacts of treatment plant needs to be assessed to ensure its sustainable development. In this study, it is assumed that the Wastewater Treatment Plant (WWTP) already exists and additional investments are being made to install recovery of electricity and sludge and diverting the water to the peri-urban agricultural farm lands. The socio-economic impacts of treating wastewater for cost recovery is evaluated assuming a daily flow of 0.61 million m^3. In order to treat these amount of waste water 2 large sized plant and 3 medium sized plants are required. The socio-economic analysis is conducted based on the valuation of economic, social and health benefits and costs associated with the business model.

Technology description

In this assessment, three different technologies are being considered. Overall, wastewater is transported to the treatment plant by gravity through a conveyor pipeline. The wastewater then undergoes through secondary treatment in an activated sludge process. Sludge from the primary settling tanks and aerated tanks are covered in dissolved air flotation units. These two sludges are then pumped into anaerobic disgesters. Biogas is produced, but converted to electricty to be used on site. Also, compost is produced from the sludge. Biogas produced can be used for cooking, lighting or powering the plant. The treated wastewater and sludge are used for farming. Canal is constructed to distribute the water to the farmers. It is assumed that farmers are in the vicinity of the treatment plant. For treated sludge for farming, it is assumed that facluative ponds or the treatment plant already exisits and we only care about the additional costs of dewatering and obtaining the biosolids. Anaerobic digestion is commonly used in treatment plant for treating the sludge and to produce biogas. It stabilizes the organic matter in the sludge, reduces pathogens and odors, and reduces the total sludge quantity (EPA, 2006). The composition of biogas depends on the quality of the treatment plant, temperature and the flow of the wastewater or sludge. Typically, methane (CH_4) constitutes about 60% while 40% belongs to carbon dioxide (CO_2) (Rasi et al. 2007). Also, the efficiency of the process will be influenced by the temperature; as higher temperatures are more suitable for bacterial growth and the retention time, which is the time the process is allowed to take place. The hydraulic retention time (HRT) ranges from 15 to 25 days depending on the climatic conditions. Average HRT is 20 days at an ambient average temperature of 25 °C (Metcalf and Eddy, 2003; Degrémont, 2005). Various types of organic waste can be used to produce biogas. There are different types of biogas systems in use in developing countries. The technology employed is based on a biological activated sludge process with sludge anaerobic digestion, and includes equipment such as biogas combined heat and power engines (CHP), gas flare, standby diesel generators, biogas boilers, heat exchangers, and aeration turbo blowers for biological tanks aeration and mixing. However, only the facilities that use anaerobic digestion as part of their biosolids treatment process will be considered as the cost of building an anaerobic digester is unknown. These facilities already have an anaerobic digester onsite and are producing biogas. Capital costs and the potential electricity generation capacity will be estimated using data from existing wastewater case studies and existing literature.

Technology and processes

The electricity generation system consists of an anaerobic heated sludge digester, biogas holding tank and a gas engine connected to a generator. The compost/manure system consists of mechanical sludge thickening tanks, sludge storage tanks, mechanical sludge dewatering and drying beds. The treated water is diverted through canals or nearby waterbodies for aiding irrigation outside the urban areas.

Overall approach to socioeconomic analysis

As explained above the main focus of the study was to carry out a socioeconomic analysis of cost recovery from wastewater treatment plants in Lima. The motivation behind the socioeconomic analysis was to evaluate the net societal benefits (including the environmental and health costs and benefits) over and above the net economic benefits (which have been evaluated in the financial analysis). The economic analysis of a project is concerned with its viability from a societal perspective and answers the questions of whether it is economically rational to proceed with the project (De Souza et al., 2011). In contrast to a financial analysis, economic analysis provides a more comprehensive investigation on the effects of a proposed project, takes a broader perspective and determines the project's overall value to society (Raucher et al., 2006). The analysis, therefore, includes benefits and costs that directly affect the business entity running the project and the effects of the project on households, businesses and industries, and governments. The analysis also includes the benefits and costs that cannot be readily measured using observable market prices and costs (De Souza et al., 2011).

First, we have evaluated the current scenario in Lima which is denoted as baseline scenario with the help of cost-benefits analysis. The wastewater in Lima mainly comes through industrial zones. Total wastewater generated in Lima is 18.98 m^3/sec and out of which about 90 percent is being treated and 10 percent remains untreated which goes to open environment. The 90% of the wastewater is being treated in the existing 26 WWTPs while to treat the remaining wastewater WWTPs have been planned for the future.

The existing WWTPs are of different capacities in terms of wastewater treatment. While conducting the socioeconomic assessment for Lima, the WWTPs which have a capacity of more than 18 million litres were assumed to be utilized for electricity generation since capacity of less than 5 MGD is economically infeasible for electricity generation. Therefore of the 26 WWTPs, 9 such plants were assumed for the cost recovery model and the other 16 WWTPs were considered for the Phyto-remediative and aquaculture business model. However, the benchmark capacity is based on the financial analysis where the size of the WWTP is assumed to be 52,000 m^3. Therefore, for the bigger plant it is assumed that more than 1 unit can be established. It has been calculated that 9 such units of electricity generating units can be installed.

Environmental impact assessment

Reduced pollution of the surface sources

The environmental impact assessment of the cost recovery from wastewater treatment was carried out for the baseline scenario where the entire wastewater flows to the water courses. In the baseline scenario about 70% wastewater is being treated in fourteen WWTPs around Lima of while the rest of the untreated water is drained off towards the nearby waterbodies, streams. The alternate scenario however considers that the wastewater generated in Lima is treated before being discharged into the nearby water courses. In other words, in the 8 existing WWTPs with capacity of treatment of more than 18 million liters per day, it is assessed that electricity generation is feasible mainly because of the size of the plant.

The primary environmental impact of the wastewater is the surface water pollution of the nearby water courses as well as chances of groundwater getting contaminated. In the present study the costs of surface water pollution and ground water contamination is estimated indirectly using the shadow prices for undesirable outputs of wastewater treatment. The following table shows the environmental value of the damage avoided (surface and groundwater contamination) based on the figures provided by Hernandez-Shancho et.al. 2010.

Table 23: Environmental costs of the undesirable outputs

Parameters	**Shadow prices for undesirable outputs (USD/m^3)**
N	0.606
BOD	0.0164
COD	0.083
SS	0.00252
P	0.3087
Total Pollution load from undesirable outputs (USD/Year)	**1,572,476**

The table illustrates the reference price of water treated from different sources and also the prices of the undesirable outputs which have a potential environmental damage when wastewater is drained off to different destinations. To calculate the environmental costs averted due to wastewater treatment, the average shadow prices of the pollutants had been utilized since the baseline scenario considers the nearby water courses as the primary destination of the untreated wastewater. At the same time the table indicates the values to be mentioned at 2010 euros, hence for the final valuation these values had been inflation adjusted to the present value. The results shows that discharge of 15,649,920 m^3 of wastewater per day have environmental costs amounting to USD 1.5 million per year. The treatment of the wastewater in the alternate scenario for generating of electricity, irrigation water and compost leads to net environmental benefits associated with the removal of the different pollutants as estimated above.

Reduced GHG emissions

The alternate considers that in total 15,649,920 m^3 of waste water is being treated which is greater than the baseline scenario. It has been calculated that 1 m^3 of wastewater generates 0.853 ton CO_2 equivalent i.e., 12,519,936 ton CO_2 equivalent. The basis of this calculation that the wastewater treatment system employs an aerated active sludge unit and an anaerobic digester to reduce the quantity of sludge requiring disposal. The activated sludge unit has an average flow rate of 1 million gallons per day and an inlet BOD5 of 500 mg/L (=g/m^3) and also that the unit achieves a 95% BOD5 reduction. Given the price of CER at 3.8 USD/ton we calculated the total averted emission in the alternative scenario is of value of 47 million USD annually.

Soil Amelioration

We assume that a medium sized plant can produce compost of 445 ton/day and a large sized plant can produce compost of 4569 ton/day. Therefore, total compost production annually is 1,236,869 ton. Moreover, we assume that compost is being applied on the field as 10 ton/ha and as result of application of compost the income of the farmer will increase by 10 USD/ha. Therefore, the area covered by the compost produced is 123,686 ha. Thus total increase in income which can be considered as the proxy of soil amelioration stands valued at 1,236,869 USD annually.

The total environmental impact of 2 large and 3 medium sized treatment plants can be summarized in the table below.

Table 24: Estimation of the potential environmental impacts

Indicators	Value (USD)
Surface water Pollution	1,572,476
Reduced GHG gas emissions	47,282,345
Soil improvement	1,236,869

Social impacts

Additional income through job creation

The co-generation plant contributes to improving the local economy through job creation and hence providing additional income to workers. The financial analysis shows that the medium sized plant employs 8 workers and large sized plant employs 10 workers. Thus 3 large sized plants will employ 20 workers and 6 medium sized plants will employ 24 workers. Therefore, total number of additional jobs created by wastewater treatment plants is 204. Given a wager rate of 242 USD/month, value of additional jobs created annually is 592,416 USD. However, other indirect impacts to the local economy in terms of employment are not accounted for in this study.

Health impacts

The primary health impacts in the current situation due to partial wastewater treatment and discharge in the nearby waterbodies is diarrheal diseases make up over four per cent of the global disease burden (UNEP, 2010). The current population of Lima with poor water and sanitation facilities is considered for calculating the health benefits. WHO (2009) provides an estimate of 14 DALYs per 1000 population in terms of burden of diseases from environmental pollution (particularly water, health and hygiene) for Peru and economic values of DALY per-capita is 6,661 USD. The total health cost arises due to diarrhea is 43,898,007 USD annually. A conservative estimate that 5% population is significantly affected has been utilized to reach the 43 million USD estimate.

Financial Analysis

The financial analysis is based on three different additional costs for an existing wastewater treatment plant. In this context, there is an NPV and IRR for (a) wastewater reuse for irrigation, (b) biogas converted to electricity for onsite consumption, and (c) sludge production as soil conditioner. Finally, the combined NPV and IRR for these three values are being estimated. It is assumed that the plant will obtain a combined heat and power technology (CHP). The total cost of this technology is estimated to be $493,931. It is assumed that wastewater is treated and supplied to farmers. For simplicity, it is further assumed that the distance between farmers and the plant is 15km. It is important to stress that the total costs used in this analysis is subject to the location of the farmers. The unit cost of canal construction is estimated as $2.5 per m^3. The total treated water from the plant for reuse is assumed to be 363,700 m^3/day. It is assumed that the wastewater plant is operating already and our concern in this assessment is to estimate the additional cost of manure production or removal from the plant for farmers or other premium customers. Thus, we only considered investment cost of primary and secondary sludge treatment without the costs of facultative ponds or any exiting treatment technology. It is estimated that the additional cost of the sludge removal will be $170,000. This cost includes construction, materials, and installation costs. The cost of sludge removal for farmers or other premium customers are not included. It is also assumed that there are 3 medium and 2 large sized treatment plants.

Table 25: Capital cost of reuse components in Wastewater treatment plant

Investment type	Costs (in USD)
Cost of combined heat and power	493,931
Cost of treated water supply (canal)	15,000,000
Cost of sludge removal/production	170,000

Typically, wastewater treatment plant consumes between 0.5-2kWh per m^3 of energy (Gude, 2015). It is assumed that about 0.7kWh per m^3 of electricity will be consumed for this additional technology. The corresponding cost of electricity generation is 0.04$ per kWh (ERG (2011)). The operation and maintenance cost for the additional items is 5% of the capital costs and an escalation of 3% (based on current inflation rate in Peru). This is applied annually to inflate the price of labor, electricity and the operation and maintenance costs used to estimate the net income over the life span of the investment. It is assumed that the project has a life span of 15 years. Also, it is assumed that farmers are in the vicinity of the treatment plant. The construction of the canal will require additional 3 people. The associated labor cost is $7 per day. Now, the water must be treated to avoid any health implications for the farmers. This will cost about 0.01$ per m3 (FAO, 1997). Finally, it will cost $0.23 per m3 to pump the water to the canals.

This cost also includes the electricity cost of pumping. The operation and maintenance cost for the additional items is 5% with an escalation of 3%. It is assumed that project has a life span of 15 years. It is assumed that there will be 2 people to ensure the day-to-day operation of the sludge production. The corresponding cost is $7 per day. The largest cost is the additional labor necessary to remove the sludge to the appropriate area for the farmers. The associated labor cost is $6 per day. There is also a minor costs associated with sampling and monitoring. This cost also includes the electricity cost of pumping. The operation and maintenance cost for the additional items is 3% with an escalation of 3%. It is assumed that the total quantity of wastewater treated and reuse is about 363,700 m3 per day. This quantity of water will be transported through the canals to the farmers. Based on extensive literature review, it costs $0.05 per m^3 to supply water to the farmers ((Khouri (1992); Abu-Madi (2004)). Typically, about 2-10% of the wastewater flow is retained as sludge. In this assessment, we use 2% to obtain the sludge produced from this plant.

The financial estimates for an individual plant shows feasibility, however, when all the WWTPs are considered to operate simultaneously, it is found that they earn a negative NPV with an assumption of 11% discount rate and IRR is 8 percent. However, BCR for this financial model is less than 1 (0.86). Hence, the financial analysis suggests that model may not be financially feasible.

Table 26: Financial results of Wastewater Treatment and cost savings model (USD)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Revenue															
Treated water	633,600	658,944	685,302	712,714	741,222	770,871	801,706	833,774	867,125	901,810	937,883	975,398	1,014,414	1,054,991	1,097,190
Avoided electricity savings	521,493	542,352	564,046	586,608	610,073	634,476	659,855	686,249	713,699	742,247	771,937	802,814	834,927	868,324	903,057
Revenue from sludge	83,907	88,103	92,508	97,133	101,990	107,089	112,444	118,066	123,969	130,168	136,676	143,510	150,685	158,220	166,131
Total revenue	**1,239,000**	**1,289,399**	**1,341,856**	**1,396,455**	**1,453,285**	**1,512,436**	**1,574,004**	**1,638,089**	**1,704,793**	**1,774,225**	**1,846,495**	**1,921,722**	**2,000,026**	**2,081,534**	**2,166,377**
Expense															
Treated water for irrigation	521,700	542,568	564,271	586,842	610,315	634,728	660,117	686,522	713,982	742,542	772,243	803,133	835,259	868,669	903,416
Electricity recovery	398,693	414,640	431,226	448,475	466,414	485,071	504,473	524,652	545,638	567,464	590,163	613,769	638,320	663,853	690,407
Sludge recovery	36,720	38,556	40,484	42,508	44,633	46,865	49,208	51,669	54,252	56,965	59,813	62,804	65,944	69,241	72,703
Total Expense	**957,113**	**995,764**	**1,035,981**	**1,077,825**	**1,121,363**	**1,166,663**	**1,213,799**	**1,262,843**	**1,313,873**	**1,366,971**	**1,422,219**	**1,479,706**	**1,539,522**	**1,601,763**	**1,666,525**
Net profit	**281,887**	**293,635**	**305,875**	**318,631**	**331,922**	**345,773**	**360,206**	**375,246**	**390,920**	**407,254**	**424,276**	**442,016**	**460,504**	**479,771**	**499,852**

Socioeconomic results

The socioeconomic analysis of the business model is performed by putting monetary value on all quantifiable cost and benefits in order to calculate the NPV, benefit cost ratio (BCR) and ROI for the business model. The consolidated socio-economic results are presented in Table 12. The analysis looked at the potential impact of model at three levels – (i) financial, (ii) financial and environmental and (iii) financial, environmental and social where the levels range from including the direct benefits and costs that affect the business entity to including indirect benefits and costs to other sectors. The annual social and environmental benefits and costs from the business were discounted at a rate of 12% to obtain the present value of social and environmental impacts.

The business model, when only the direct benefits are accounted for results in negative NPV and BCR of less than 1 implying that the business model is not financially feasible. The business model performs better when the financial and environmental costs and benefits are taken into account. The net positive incremental benefits from the environmental impacts are very high enough to make the business model feasible as the NPV is positive and the BCR is substantially high 1.06. This implies that per dollar invested gives a return of more than 1 dollar. The business model becomes economically more feasible when all externalities are included in the analysis. The NPV when all externalities are considered is USD 318 million and the BCR is 29.22. Thus, major contribution to the economic feasibility of the business is from the environmental benefits. The total value of the social benefits (NPV over a period of 15 years) of the business is USD 27 million with major benefits coming from the additional income from jobs created for the local community, health benefits and savings in expenses for alternate forms of energy.

Table 27: Net socio-economic results of Wastewater treatment plant model

Socio-economic result (USD/year)	Financial value	Financial and environmental	Social, environmental and financial
Financial result:			
NPV	1,437,849	1,437,849	1,437,849
Environmental benefit:			
Value of net GHG emission saving		85,185,367	85,185,367
Social benefit:			
Total social benefit			25,695,304
Net NPV	**1,437,849**	**83,747,518**	**110,880,671**
ROI	**13%**	**46%**	**382%**
BCR	**0.86**	**1.26**	**29.22**

Sensitivity analysis

The stochastic analysis helps in determining the uncertainty of the socioeconomic model based on deterministic assumption. For the present study the following variables have been considered as stochastic with the respective distributions as described in the following table.

Table 28: Selected variables for the stochastic analysis

Variable	Unit	Distribution specified	Source
Discount rate	%	*Triangular*: (10%, 12%, 15%)	Assumed

Carbon Credit price	USD/t CO_2 eq.	*Uniform* (0.51- 3.8)	Assumed
Yield per hectare of rice	tons/ha.	*Uniform :* (5.34, 6.5)	Present scenario in Lima, upper limit is the amount produced from hybrid rice
Net income from per hectare of land in paddy cultivation	USD/ha.	*Uniform:* (40, 49.5)	The lower range is the conservative estimate, the upper range is base case scenario
Increase in income due to application of compost	USD/ha.	*Uniform:* (5, 10)	The lower range is the conservative estimate, the upper range is base case scenario
Economic value of per capita loss due to diseases	USD	*Uniform Distribution* (4.49 – 9.5)	The lower range corresponds to estimates for cancer and higher range to gross national per capital income.

The following figure (figure 1) shows the probability distribution of the NPV estimated through numerous iterations of the stochastic variables. The derived stochastic mean is 110 million which can be achieved with a success rate of 49%.

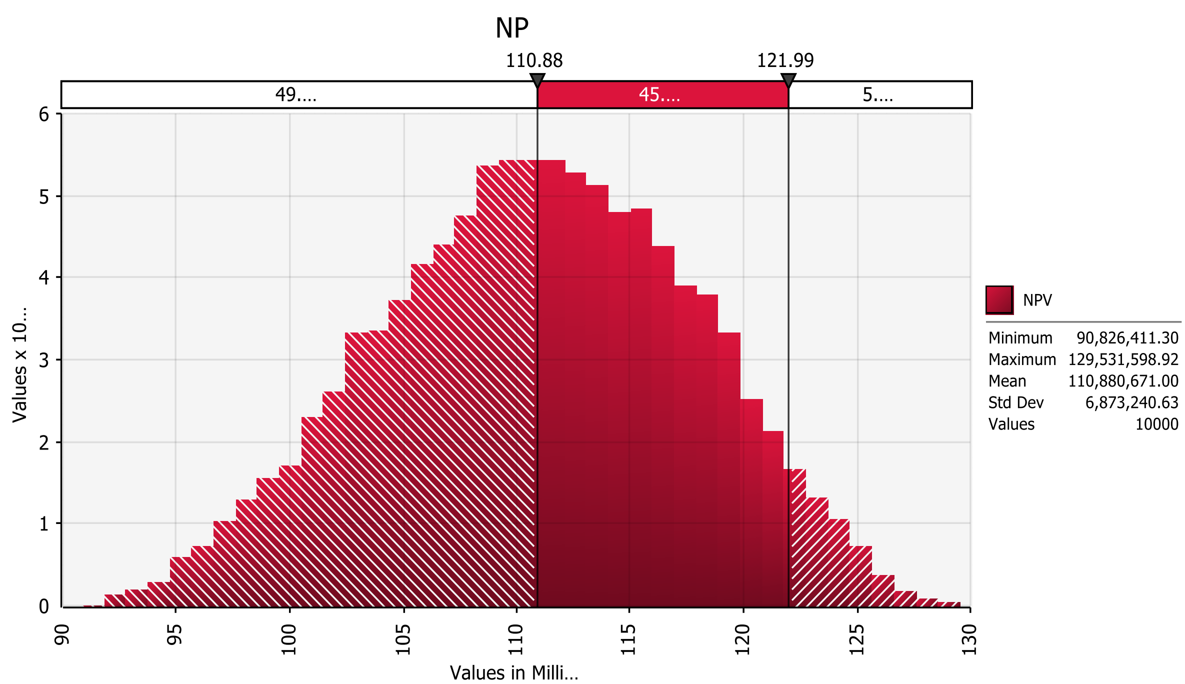

Figure 5: Probability Density Function of the NPV derived for Wastewater treatment and cost savings business model

Conclusion

The efficient implementation of policies to prevent the degradation and depletion of water resources requires determining their value in social and economic terms and incorporating this information into the decision-making process. A process of wastewater treatment has many associated environmental benefits. However, these benefits are often not calculated because they are not set by the market, due to inadequate property rights, the presence of externalities, and the lack of perfect information. Nevertheless, the valuation of these benefits is necessary to justify a suitable investment policy and a limited number of studies exist on the subject of the economic valuation of environmental benefits. In this paper, we propose a methodology based on the estimation of shadow prices for the pollutants removed in a treatment process. This value represents the environmental benefit (avoided cost) associated with undischarged pollution. This is a pioneering approach to the economic valuation of wastewater treatment. The comparison of these benefits with the internal costs of the treatment process will provide a useful indicator for the feasibility of wastewater treatment projects. This study assessed the socio-economic impact of cost savings from wastewater treatment in Lima, Peru. The model includes the water for irrigation and digester sludge for compost. The socio-economic analysis is conducted based on the valuation of financial, environmental and health benefits and costs associated with the business model. The following conclusions can be drawn from the study:

- From the socioeconomic perspective, findings from the study indicate that the most pertinent benefits accrues from treatment of water reducing the environmental burdens. The benefits from wastewater treatment offsets the marginal financial benefits and the net returns amount to USD 21 from per dollar invested. The business model resulted in a BCR of 27.63 and ROI of 443% indicating that (although not all environmental and social impacts have been factored in the analysis) the business provides positive environmental and social impacts that offsets it costs and is highly feasible.
- Net GHG emissions saved per kwh of electricity generated is 1.4 kg CO_2eq. The highest savings in GHG emissions would be mainly from substituting diesel generators for the commercial establishments while the highest emissions from the business model is from the gasifier.

Socio-economic impact assessment of Large Scale Composting for revenue generation of Municipal Solid Waste Lima

Introduction

The increasing quantity of urban waste in urban towns of developing nations coupled with inadequate sanitation services is of a growing concern to the deteriorating urban environment (Oyoo, 2010). In Lima 7800 tons of Municipal Solid waste is generated daily and out of this about 55 percent is collected and the remaining uncollected waste is normally burnt and/or dumped in unauthorized sites, causing health and environmental problems. However, the organic fraction of domestic waste can provide an opportunity to improve livelihoods and incomes through fertilizer and energy production (Komakech, 2014).

The potential economic, environmental, social and health impacts of composting plant needs to be assessed to ensure its sustainable development. In this study, we evaluated the socio-economic impacts of composting of MSW business with plant capacity of handling 600 tons of MSW in Lima daily. The socio-economic analysis is conducted based on the valuation of financial, environmental and health benefits and costs associated with the business model.

Technological description for Large Scale Composting from MSW

There are two fundamental types of composting techniques – open or windrow composting and enclosed or in-vessel composting method (Dulac, 2001). Open composting processes are simpler, require less capital, and use less energy. This generally rely more on land and labour and less on machinery. In comparison enclosed or in-vessel composting is more technology driven and require complex equipment and also utilizing substantial amounts of energy. The aerobic process or the windrow composting is arguably the most suitable technology for developing countries. While operating costs usually start at US $ 40 per ton, for the least expensive variant; more expensive systems can cost up to US $ 100 per ton, operational costs for windrow composting is comparatively lower around US $ 5 to US $ 20 per ton.

Windrow composting comprises of – (i) Pre-processing (segregation/sorting), (ii) Shredding, (iii) Piling of the waste, (iv) Turning of the windrows, (v) Maturing, (vi) Sieving, and (vii) Storage and Bagging. MSW comprises of different wastes from different sources and sorting is important since left over inorganic materials might contaminate the final product. The segregation and sorting can be done manually or using a conveyor belt. Manual sorting is labour intensive but can achieve a good result if done carefully while conveyor sorting is subject to maintenance and requires power supply to operate. Shredding primarily involves shredding of the raw materials (organic waste) and can be done manually by crushing or chopping or by using mechanized milling machine. However, this depends on the source of waste. Wastes generated from the horticulture and agriculture as well as the agro-industries requires shredding before they are composted. The shredded raw material is then loosely heaped (called windrow) to an appropriate height of about 2 meters. However, it should be noted that the size of the heap should be suitable to build up the heat and also retain it to achieve pathogen inactivation. Windrow composting involves aerobic decomposition and hence passive diffusion of oxygen into the centre of the heap is a prerequisite.

This aerobic degradation is exothermic in nature which generates heat within the pile. To ensure that aerobic degradation can continue a sufficient supply of oxygen must be ensured. Turning of the windrows also enhances oxygen supply. In the first weeks of the process it is recommended that the heap be turned 3 times weekly as temperatures such that higher temperatures are avoided as it will inhibit microbial activity. In such cases, turning can be an appropriate measure to cool the heap. After the first 2 weeks the turning frequency can be reduced to weekly turning and the pile can then be turned once every ten days. High temperatures and microbial activity during the thermophilic phase will lead to moisture losses. When moisture levels fall below 40 % additional water must be added to the heap with each turning. The moisture content should be maintained ideally between 40 and 60%.

It takes about 5-6 weeks from the day piling takes place for the temperature of the pile to fall below 50°C and the maturation phase to set in. The material is characterized by a soil like colour. Mesophilic microorganisms become active and further stabilize the immature compost within approximately 15 days. Turning is no longer necessary and only little watering is required if the piles are very dry. After a total of about 8 weeks the mature compost material is characterized by a dark brown colour, an earthy smell and a crumbly texture. The final mature compost can then be sieved to obtain the required particle size which depends on the customer requirements. Sieving can help remove still remaining inorganic particles in the compost. The coarse rejects form sieving can be added to the fresh incoming waste. Sieving can be performed using a flat frame sieve operated with manual labour or using mechanical rotating drum sieves. Depending on the marketing and sales strategy, the final compost product can be either stored or sold in bulk or else be packaged in bags of different volumes. The moisture content should be below 40% before bagging and the final product should be stored in a dry and sheltered location.

Overall approach to socio-economic impact assessment

The socio-economic analysis of a project is concerned with its viability from a societal perspective and answers the questions of whether it is economically rational to proceed with the project (De Souza et al., 2011). In contrast to a financial analysis, socio-economic analysis provides a more comprehensive investigation on the effects of a proposed project, takes a broader perspective and determines the project's overall value to society. The analysis, therefore, includes benefits and costs that directly affect the business entity running the project and the effects of the project on households, governments and other businesses outside of the business.

In emerging economies like Peru, cities experience generation of urban waste at a steadily increasing rate. This poses a serious challenge to the policy makers on how to deal with them effectively so that it would not cause any steady deterioration of urban environment (Oyoo, 2010). In Peru, Lima generates on an average, 7800 tons of solid waste per day, of which about 70% is generally collected by the local personnel, and the remaining 15% waste is either dumped in an un-authorised manner discretely or burnt conveniently by households and/or enterprises in open spaces, both of which can cause health hazards and environmental problems, apart from creating unpleasant surroundings and 15% is being recycled. If an appropriate system for the collection and disposal of municipal solid waste is put in place, it can be an important source of fertilisers and energy production (Komakech, 2014). Of the two, collecting and converting waste into composting is a widely practised system with immense potential for positive socio-economic impacts.

The urban waste can be systematically collected for composting either in a centralised location or in a de-centralised manner in different locations. If the socio-economic potential of de-centralised composting of municipal solid waste (MSW) has to be exploited adequately for sustainable development, an assessment of compositing feasibility has to be made in terms of composting plants and their capacity. Accordingly, we have evaluated the socio-economic impacts of compositing of MSW business with an annual capacity of handling 225,936 tons of MSW in Lima. The socio-economic analysis is done based on the evaluation of financial, environmental and health benefits and costs associated with the business model.

In the baseline scenario it is assumed that about 85% of the municipal solid waste is collected and landfilled. This assumption is used to make the calculations simplistic and would help in providing an idea about the waste that is being open-dumped without landfilled further or burned. The alternative scenario in contrast considers establishment of 10 composting plant which can handle 200 tons of MSW and can produce compost up to 50 tons daily. It has been assumed that the entire waste in the baseline scenario which is being presently landfilled can be utilized for composting. Therefore in the alternate situation organic fraction of 4000 tons of waste is utilized which is accommodated in 10 composting plants since each has a capacity of 200 tons. Thus the socioeconomic assessment of the centralized compost business model considers upscaling of the project for the entire city based on providing an alternative solution to the bassline situation.

Environmental Impact Assessment

The alternate situation considered in the case of centralized large scale composting is contrasting to the baseline scenario since the entire waste which is being landfilled in the baseline scenario is being composted in the alternate scenario the main environmental impacts of which are as follows –

- Avoided GHG emissions due to open dumping in the landfills,
- Cost of leachate treatment that can be averted, and
- Increase in soil fertility since compost acts as a soil conditioner

Avoided GHG emissions

In the baseline scenario (business as usual), the waste generated in the city is usually open dumped or burned which had been explained in the system boundary previously. This leads to GHG emissions from landfilling and open-dumping as well as burning. In the situation where the entire waste is send to the landfill site, segregated and the organic fraction of the waste is used for composting and the recyclables sold back, the chances for GHG emissions are averted. The price for Carbon Emission Reductions (CERs) following the CDM mechanism is USD 3.8 (ton Co_2 equivalent). Utilizing the above procedure and also considering the emissions from open-dumping of waste as 0.1532 tons Co_2-eq/ton, the annual savings in terms of GHG savings is calculated to be 631,009 ton Co_2 equivalent which implies a monetary benefits of USD 2,397,834 annually.

Cost of leachate treatment

The leachate potential from a MSW landfill primarily depends on the precipitation and thus is influenced by the climatic conditions such as rainfall and evaporation. On an average leachate produced per tons of MSW is considered to be 87.2 - 100 lts which depends on the climatic factors and the characteristics of the waste. Therefore, the total amount of leachate produced annually can be calculated to be 150,903 lts. Considering the treatment cost of leachate to be USD 20 per litre (Johannessen, 1999; which on average ranges between 9 -30 USD/m^3), the annual cost of leachate treatment can be estimated to be USD 3,018,063. In the alternate scenario, the entire amount of waste is bereft of the organic fraction and the recyclables which constitute the major fraction of the waste (more than 96%). The remaining inert material is considered to be landfill which also reduces the chances for production of leachate in the landfill.

Increase in soil fertility/amelioration

To provide a value for the increase in soil fertility the increase in yield due to application of the compost in the context of Peru had been considered. The application of compost at the rate of 5 ton per ha will increase the income of the farmers by 10 USD/ha. The area which can be covered by applying compost is 45,187 ha. Therefore, the increase in income due to increase in productivity is 451,873 USD.

The following tables provide the net benefits obtained in terms of averting environmental costs for composting the organic fraction of the MSW and utilizing them for agricultural production enhancement –

Table 29: Estimation of the net Environmental Impacts of large scale composting

Environmental Benefits	**Valuation (USD/annually)**
Avoided GHG emissions	2,397,834
Cost of leachate treatment averted	3,018,063
Soil amelioration	451,873
Total environmental benefits	**5,867,770**

Social Impact assessment

Employment

The alternative situation considers that the whole of the MSW would be utilised for the compost business. This implies that 50% of the waste which comprises the organic fraction would be required for the compost and the rest landfilled (about 715 tons after sorting of the recycables). In the alternative scenario thus the labour employment by each plant is 47 which is quite high as compared to the baseline scenario as it adds additional labourers. Thus, as there are 10 plants the total amount of employment that will be created is 470. The average wage rate per worker is 217 USD/month. Therefore, income generation from additional employment is 733,211USD annually which accumulates to USD 4,949,081 over the life-cycle of the project.

Saving of Landfill area & disposal cost

The other costs related to the landfill which can be saved is by increasing the life of the landfill since there would be a restricted use of the landfill. In the baseline scenario since the entire waste is being landfill, there is a greater requirement of land compared to the alternate scenario where about 60% of the organic fraction of the waste is utilized for compost production and additionally 20% is being recycled. It is being assumed here that the recycling business which is quite a dominant informal sector engagement is being kept intact and the same amount of waste which can be recycled in the baseline scenario is being recycled in the alternate scenario. Therefore, the remaining 20% of the MSW find its way to the landfill in the alternate scenario reducing the amount of land required. In other words, while about 5500 tons of waste is landfilled every day in the baseline scenario, in the alternate scenario only 20% of the waste is being landfilled (about 715 tons per day).

The land required for landfilling 1 ton of waste per day for a period of one year ranges from 0.01 – 0.03 hectares (Rawat and Ramanathan, 2011). The cost of landfill operations as estimated by Johannessen 1999 is around 10-15 USD per ton annually. Given these figures it is easy to estimate the amount of costs that are being averted by reducing the amount of waste that is being landfilled. The amount of land saved due to reduced landfilling is about 40 ha. the estimated savings of which is around USD 7,548,000 based on the fact that land prices in Lima is USD 15 per m^2. However, this is considered as savings on initial investment and is not discounted annually. The additional costs of operation and maintenance costs saved due to reduced amount of waste being landfilled amount of USD 30,000 per day assuming USD 12.5 is spend per day on waste disposal and landfilling. Thus the amount of landfill and disposal costs saved is estimated to be around USD 12,849,245 over and above the land savings as mentioned above.

Reduction in externalities

The health cost per ton of MSW is estimated to be 11 USD. It has been assumed that in the alternative scenario externality can only be reduced to 25 percent of the MSW landfilled. Therefore, the amount of health expenditure avoided in the alternative scenario is 4,842,843 USD.

Other Social & Environmental costs which are not considered in the Social Impact

In the socioeconomic assessment the following costs and benefits are not being considered for the assessment –

- GHG emissions from transportation

The alternate scenario provides an alternate in the sense that the waste of 4000 tons produced per day which is being collected and landfilled is being collected in the alternate scenario and is send to the 6 compost plants instead of the landfill. Only about 15-20% of the inert waste which cannot be composted is send to the landfill. In the socio-economic assessment a simplistic assumption is being made that compost plants and the landfill used for disposal are at the same distance from the primary/secondary transfer stations in the city and hence the disposal cost and the GHG emissions from transportation in the baseline and alternate scenario does not vary much. This serves as the rationale for not considering the benefits in the social assessment of introducing large scale composting for Lima.

Financial Analysis

This section presents the financial feasibility analysis and results of business model considering production of from large scale centralized compost plant. As explained previously, to utilize the whole waste of the city, 8 large scale plants of 600 tons each had been considered. The financial analysis incorporated in the socioeconomic analysis escalates linearly the economic and financial costs presented in the financial analysis of the 600 tons plant in the financial report. The financial viability of the 8 compost plants is analyzed simultaneously based on Return on Investment (ROI), Net Present Value (NPV) and Internal Rate of Return (IRR) valuation criteria. The capital cost for each of the compost plant considered is taken to be USD 6141 per ton. The capital costs includes the following entities –

- construction and building,
- machine and equipment,
- Environment Impact Assessment,
- Investments for CDM

The project life of the plant is assumed to be 15 years. The financial assessment of the 6 plants operating in the city shows positive net profit excepting for the first year. The IRR of the proposed business is 15% which is above the discount rate and the Rate of Investment (ROI) is 15% implying that revenues are high enough to recover all costs of the business. This is also observed that the benefit-cost ratio is more than 1 (1.317) indicating that financially the model is viable. For the entire city when the 8 compost plants run simultaneously the NPV is USD 5,629,178 which shows that the large scale composting at the city level is viable.

Table 30: Financial results of Large Scale Centralized Compost Business Model (USD)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Revenue															
Sale of compost	114,592	127,120	148,731	154,680	160,867	167,302	173,994	180,954	188,192	195,720	203,549	211,690	220,158	228,964	238,123
Sale of carbon credits	8,171	20,041	29,248	36,510	42,332	47,073	50,989	54,265	57,037	59,407	61,452	63,229	64,786	66,157	67,373
Sale of recyclables	2,154	2,240	2,329	2,422	2,519	2,620	2,725	2,834	2,947	3,065	3,188	3,315	3,448	3,586	3,729
Tipping fees	25,857	26,891	27,966	29,085	30,249	31,459	32,717	34,026	35,387	36,802	38,274	39,805	41,397	43,053	44,775
Total Revenue	**150,773**	**176,292**	**208,274**	**222,697**	**235,968**	**248,454**	**260,425**	**272,078**	**283,563**	**294,994**	**306,462**	**318,040**	**329,789**	**341,761**	**354,000**
Expense															
Labour and input costs	73,200	76,128	79,173	82,340	85,634	89,059	92,621	96,326	100,179	104,186	108,354	112,688	117,196	121,883	126,759
Sales and Marketing costs	19,190	19,957	20,755	21,586	22,449	23,347	24,281	25,252	26,262	27,313	28,405	29,541	30,723	31,952	33,230
Supplies, Utilities & Other costs	17,559	19,083	20,940	21,929	22,871	23,786	24,686	25,583	26,483	27,394	28,321	29,267	30,236	31,231	32,256
O & M cost	18,899	19,655	20,441	21,259	22,109	22,994	23,913	24,870	25,865	26,899	27,975	29,094	30,258	31,468	32,727
Total Expense	**73,276**	**128,847**	**134,823**	**141,309**	**147,113**	**153,063**	**159,185**	**165,502**	**172,031**	**178,789**	**185,792**	**193,055**	**200,590**	**208,412**	**216,535**
Profits before depreciation, interest and taxes	21,926	41,470	66,965	75,584	82,904	89,269	94,923	100,047	104,774	109,201	113,407	117,450	121,377	125,226	129,028
Depreciation	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867	34,867
Profits before interest and taxes	**(12,941)**	**6,603**	**32,098**	**40,717**	**48,038**	**54,402**	**60,057**	**65,181**	**69,907**	**74,335**	**78,541**	**82,583**	**86,510**	**90,359**	**94,161**
Interest	23,550	19,800	11,550	-	-	-	-	-	-	-	-	-	-	-	-
Profit before tax	**(36,491)**	**(13,197)**	**20,548**	**40,700**	**48,021**	**54,385**	**60,040**	**65,164**	**69,890**	**74,318**	**78,524**	**82,566**	**86,493**	**90,342**	**94,144**
Income tax	-	-	9,863	19,536	23,050	26,105	28,819	31,279	33,547	35,673	37,691	39,632	41,517	43,364	45,189
Net Profit	**(36,491)**	**(13,197)**	**10,685**	**21,164**	**24,971**	**28,280**	**31,221**	**33,885**	**36,343**	**38,645**	**40,832**	**42,935**	**44,977**	**46,978**	**48,955**

Socioeconomic Assessment of the business model

The socioeconomic analysis of large scale compost business model is performed by putting monetary value on all quantifiable cost and benefits in order to calculate the NPV, benefit cost ratio (BCR) and ROI for the business model. The previous sections have estimated the net benefits from the different impact assessments considering both the costs and benefits associated with the business at a city scale (the entire waste is consumed by the 10 large scale plants of 200 tons to produce compost). The consolidated socio-economic results are presented in Table 12. The analysis looked at the potential impact of compost business model at three levels where the levels range from including the direct benefits and costs that affect the business entity to including indirect benefits and costs to other sectors. The annual social and environmental benefits and costs from the business were discounted at a rate of 8% to obtain the present value of social and environmental impacts.

The large-scale compost model, has a positive NPV following the financial model when the direct economic/financial benefits are accounted and also has BCR is more than 1 implying that the business model is financially feasible. The business model additionally performs better when the social and environmental costs and benefits are taken into account. The business model becomes economically feasible when all externalities are included in the analysis. The NPV when all externalities are considered is USD 113,261,861 and the BCR is 6.94. Thus, major contribution to the economic feasibility of the business is from the social benefits - employment generation, and health expenditure saved. Thus the large scale compost business model is socially feasible along with financial feasibility.

Investment for the land made by the local body to ensure operations of the compost plants has also been included in the costs to derive the benefit-cost ratio for the socio-economic assessment.

Table 31: Net socio-economic results of Large-Scale Compost model

Socio-economic result (USD/year)	Financial value	Financial & environmental	Social, Environmental & Financial
Financial result:			
NPV	5,629,178	5,629,178	5,629,178
Environmental benefit:			
NPV of environmental benefits		98,152,986	98,152,986
Social benefit:			
Total social benefit			67,418,892
NPV	**5,629,178**	**103,782,163**	**171,201,055**
ROI	**15%**	**91%**	**104%**
BCR	**1.32**	**6.3**	**8.18**

Sensitivity Analysis

The following table shows the stochastic variables with their respective distribution used for determining the probability distribution of the NPV derived from benefits in introducing the compost model. The variables used for the analysis includes – (i) discount rate, (ii) application rate of the compost, (iii) leachate production, (iii) treatment costs of the leachate, (iv) average increase in income due to application of compost, (v) investments and operational costs of the landfill.

Table 32: Selected variables for stochastic analysis

Variable	Unit	Distribution specified	Source
Discount rate	%	*Triangular*: (5%, 8%, 10%)	Assumed
Application of compost	ton/ha	*Uniform Distribution*: (5, 10)	Assumed
Leachate production	m^3/ton	*Triangular distribution:* (80, 85, 100)	Safari and Baronian (undated)
Cost of leachate treatment	USD	*Triangular*: (9, 20, 30)	Johannessen 1999
Average increase in income due to application of compost	USD/ha	*Uniform*: (5, 10)	Conservative estimate based on
Landfill area saved per unit	ha/ton	*Uniform*: (0.01 – 0.03)	Johanssen , World Bank
Investments and operational costs of landfill	USD/ton	*Triangular:* (10, 12.5, 15)	Johanssen , World Bank
http://www.worldbank.org/urban/solid_wm/erm/CWG%20folder/uwp5.pdf			

The figure below shows the probability distribution of the NPV with a mean of 178 million and a certainty of 50% to achieve the mean NPV. The combination of certainty of the NPV, benefit-cost ratio and a lower ROI makes the feasibility of the business low socioeconomically.

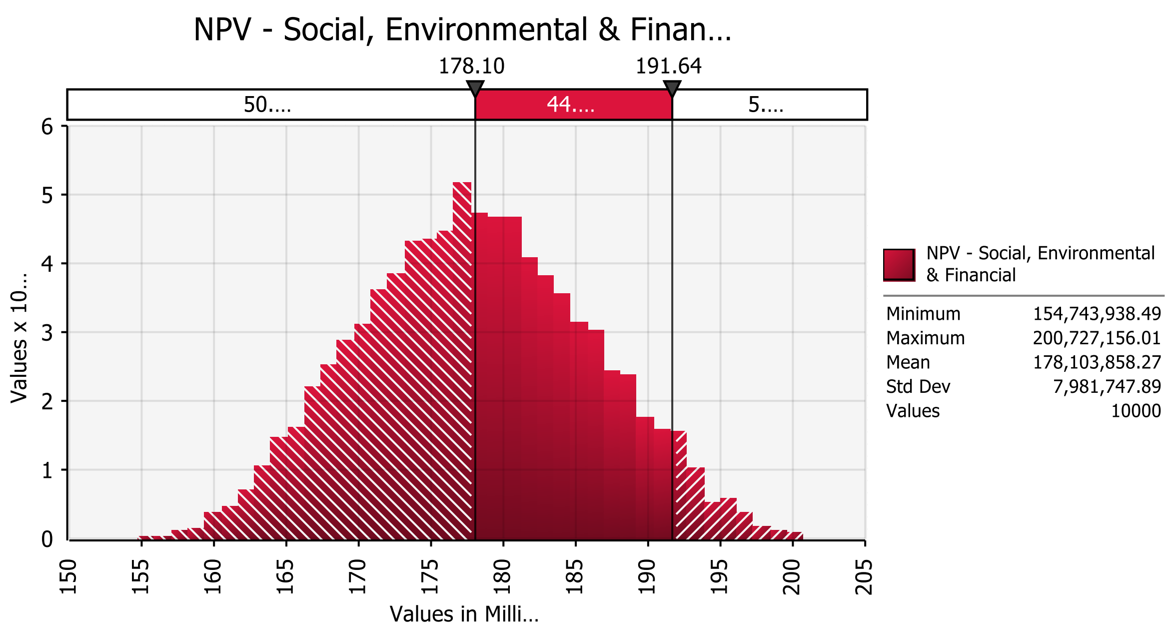

Figure 6: Probability density function of the NPV of large scale composting

Conclusion

This study assessed the socio-economic impact of a composting business model in Lima, Peru. The socio-economic analysis is conducted based on the valuation of financial, environmental and health benefits and costs associated with the business model. The following conclusions can be drawn from the study:

- Composting plant can reduce the GHG gas emissions and leachate production and thus reduces the chances of air pollution, water pollution and soil pollution.
- Composting plant can produce sufficient revenue from collection of MSW and selling of compost.
- Use of compost may increase the soil productivity.

- Composting of MSW can reduce the health risks sufficiently as we increase the amount of composting.
- Composting can reduce the import of inorganic fertilizer and thus save foreign exchange.
- Composting plant can also raise the price of land in the adjacent area to landfill site or open dumping space.

However, even with a greater than 1 benefit-cost ratio, the certainty of achieving the mean level of NPV is lower which makes the business less feasible for Lima.

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