Waste-based power generation supply chain of Pabna city, Bangladesh: An approach of game theory

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Abstract

The purpose of this paper is to test the feasibility of a co-opetition organic waste supply strategy for waste based power plant at Pabna where the broker, household and moholla (area) methods are co-exist. To fulfill the research objective, we use game theory, Monte Carlo simulation and sensitivity analysis to check the efficiency of co-opetition and its comparison with the competition and cooperation strategies. Estimated result shows that the co-opetition strategy supplies sufficient organic waste for a plant of one year's operation, while it is not possible under the other strategies. In addition, the co-opetition strategy maintains the highest equilibrium level of organic waste in terms of quantity and price for power generation and ensures the highest profit followed by the cooperation and the competition strategies. The findings of this study will provide a robust basis for policy makers to develop a specified policy to lessen the emission of GHGs from organic waste, building a resilient and sustainable waste management technique and establish a low carbon society.

Keywords: Waste management, Pabna municipality area, Energy economics, Game theory

1 Introduction

Waste is a part of the natural environment, but it is becoming a serious issue in urban areas of all over the world except developed countries. Rapid population and economic growth are the concern issues of waste generation. Generally, the greater quantities of waste and its characteristics and composition create more complexity in the city. More specifically, as societies become more affluent and urbanized, communities become more congested and waste composition becomes more complex with greater portions of plastics and other mixed and processed materials which make it problematic to continue dumping or burying waste (Klar et al.,2014). Landfills by solid waste are from of mixed streams and not sorted, allowing for chemicals and harmful metals to mix with organic degradable materials. Heavy metals, pathogens and other hazardous substances can also contaminate the environment. Most disposal sites released untreated and potentially toxic leachate directly into the waterways or soil and harmful greenhouse gases (GHGs) like methane and carbon dioxide (AUS Aid, 2011).

The environmental degradation in the city is expressed by the contamination of surface and ground water through leachate, soil contamination through direct waste contact or leachate, air pollution by burning of waste. Generally households dumped their waste indiscriminately on the street or road side or through it in the drain. This is also a common practice in the Pabna city.

Solid waste management in the Pabna city is facing serious challenges. In particular, the practice of landfilling is unsustainable and no longer an adequate solution because of its negative impacts on society and the environment. Waste based power generation is the potential solution to get rid of this unexpected situation. Waste based power generation provides long-term sustainable waste management, reduces GHGs emissions from waste enhance income generation capacity, promote feed-in tariff[1] system and be a new source of renewable energy for the Pabna city.

To implement the waste based power generation project in the Pabna city, a new waste collection strategy is needed for the power plant. Game theory guided strategies play an important role in this regard. Game theory is used in the study to test the efficiency of the co-opetition strategy, compared with the competition and cooperation strategies A large number of studies focused on

[1] Feed in tariff creates rapid growth in new generation of electricity from renewable energy sources. It is a payment mechanism made to households for generating their own electricity the use of methods that do not contribute to the depletion of natural resources, proportional to the amount of power generation.

modeling and analyzing the biomass feedstock supply system with the approach of game theory (Nasiri & Zaccour, 2009; Luo & Miller, 2013; Sun et al., 2013; Wen, 2015), which made good examples of using game-theoretical modeling in biomass supply systems (Zhang et al., 2017).

There are several types of strategy in the game theory: competition, co-opetition and co-operation. The economics literature has laid more emphasis on co-opetation strategy. It is a kind of game behavior which will make the player gain more benefits (Brandenburger & Natebuff, 1996). It is a strategy combining co-operation strategy with competition strategy. Co-opetation strategy is suitable for renewable energy and supply chain management (Wang et al., 2014; Zhang et al., 2017).

The purpose of this paper is to test the feasibility of a co-opetition organic waste supply strategy for waste based power plant at Pabna where the broker, household and moholla (area) methods are co-exist. Under this strategy, the waste collection from the broker method and the areas (moholla) committee (salaried committee by Municipality) method co-exist. The moholla committee is a concern body of monitoring waste collection and management and influences the households' to maintain the supply chain of waste. More specifically, this committee is responsible to cooperate with households for waste collection and delivery waste to the plant, improve the waste mismanagement and provide public welfare.

2. Analytical Approach

2.1 Game theory

Game theory is a powerful tool that can suggest the best strategy or outcome in many different situations. It can be used to study of parlor games, political negotiation and economic behavior. In addition, it is suitable for aggression, cooperation, hunting and collection. Under this approach, we consider three strategic options: Competition, Co-opetition and Cooperation. In the following part, we will briefly explain these fascinating building blocks of game theory.

2.1.1 Competition

Strategic interaction can involve many players and many strategies, but we'll limit ourselves to area (moholla) committee games with a finite number of strategies. Under this strategy, equilibrium is reached with the competition among households, brokers and the energy generation plant. Households are assumed as a single game player, player f and its payoff function is shown in equation (1). with the two committee members' payoff as equation (2).

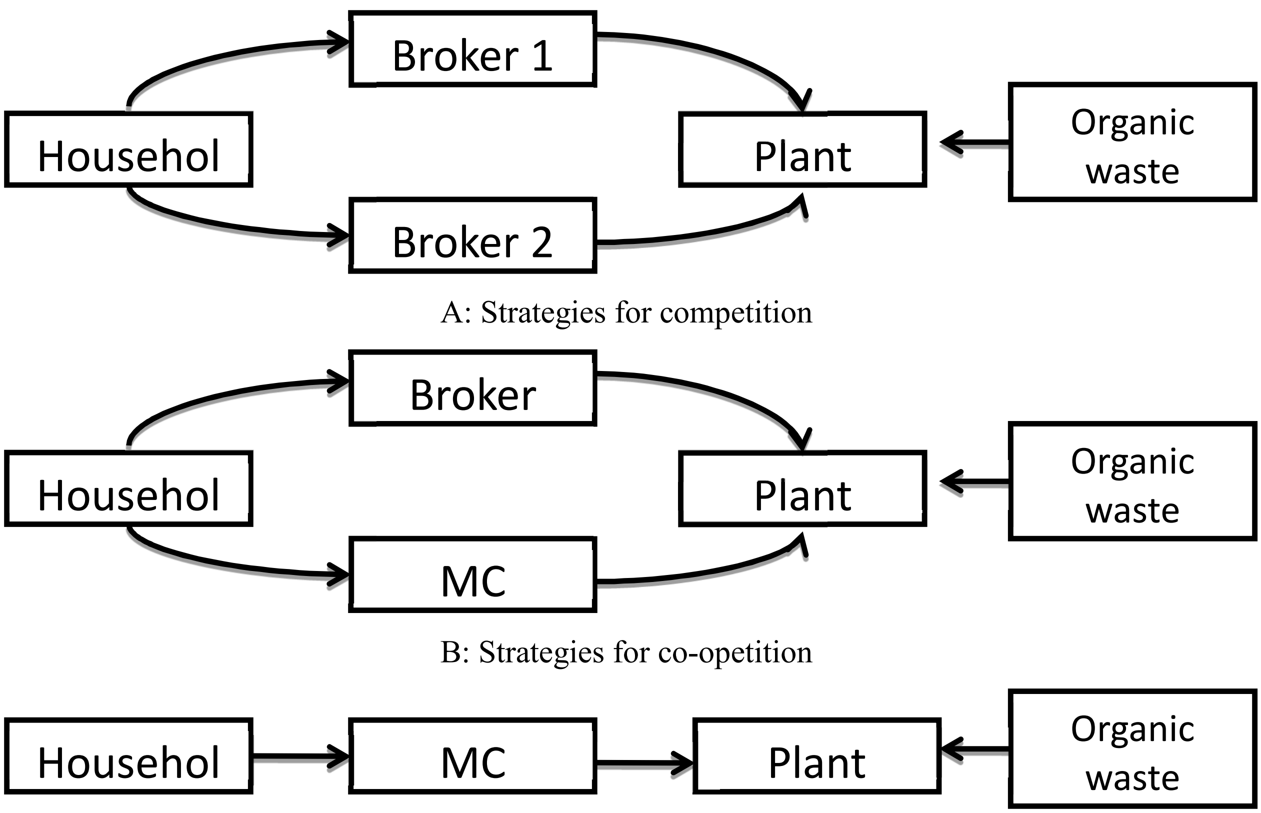
$$\pi_f(a) = aq_a \qquad (1)$$

where, a denotes the unit profit of the household from per days organic waste; q_a is the total organic waste purchased by brokers, subject to $q_a = q_1 + q_2$.

$$\pi_i(q_i) = (p_2 - p_1 - c_1 d)q_i, \qquad i = 1,2 \qquad (2)$$

When we deal with more than single game player, the equation 1 will be turn into equation 2 where, q_i denotes the organic waste purchased by broker *i*; p_2 is the procurement price for the plant's; P_1 is the procurement price for brokers', subject to $p_1 = a + b\sqrt{q_1 + q_2}$; C_1 is the unit transportation cost; *d* is the transportation distance; *b* is the coefficient of organic waste collection cost subject to $b = 2\sqrt{2c_1}/3\sqrt{\pi y}$ and *y* is the unit of collected organic waste.

Figure 1. Supply chain architectures with different strategies



C: Strategies for cooperation

Note. MC= Moholla Committee

(**Source:** Prepared by the authors based on Zhang et al., 2017)

Under these strategies farmers prefer unit profit and brokers prefer to purchase the organic waste. The equilibrium condition is calculated by the approach of Nash equilibrium[2] and the prisoners' dilemma[3] under the oligopoly market structure which is given as equation (3).

$$a^E = \frac{p_2 - c_1 d}{2}; \qquad q_1^E = q_2^E = \frac{32(p_2 - c_1 d)^2}{225b^2} \tag{3}$$

where E denotes the equilibrium level of the corresponding variable.

2.1.2 Co-opetition

Under this strategy, it is possible to maintain organic waste supply chain to generate energy. Broker and moholla methods are the main building blocks under this strategy. Households play also an important role to implement the strategy because households are cooperating with the mohollas' committee, they make decisions as one played with the payoff function as equation (4).

$$\pi_{f+2}(a, q_2) = aq_1 + (p_2 - b\sqrt{q_2} - c_1 d)q_2 \tag{4}$$

The Brokers' payoff function[4] holds the same characteristics like equation (2) with $i = 1$. Under this circumstance, we can calculate the equilibrium condition as equation (5).

$$a^e = \frac{p_2 - c_1 d}{3}; \; q_1^E = \frac{12(p_2 - c_1 d)}{27b^2}; \; q_2^E = \frac{4(p_2 - c_1 d)^2}{6b^2} \tag{5}$$

2.1.3 Cooperation

Under this strategy, only the mohollas' committee methods are mostly activated. Its payoff function and the equilibrium condition are shown in equations (6) and (7).

$$\pi_{f+2}(q_0) = (p_2 - c_1 d - b\sqrt{q_a})q_a \tag{6}$$

$$q_a^e = \frac{4(p_2 - c_1 d)^2}{9b^2} \tag{7}$$

The payoff function of all the strategies of the organic based power plant is identical as equation (8).

$$\pi_p(q_w) = p_e(q_o + q_w) - p_2 q_a - p_w q_w - c_p \tag{8}$$

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[2] Nash equilibrium is a situation in which economic actors interacting with one another each choose their best strategy given the strategies that all the other actors have chosen (Mankiw, 2008).

[3] Prisoners' dilemma is a particular "game" between two captured persons that illustrates why cooperation is difficult to maintain even when it is mutually beneficial (Mankiw, 2008).

[4] Payoff function in the game theory is a mathematical function describing the award given to a single player at the outcome of a game.

where, q_w is the organic waste the plant purchase; $p_e = (p_e - c_0)\tau$ is the feed-in tariff for waste based electricity; c_0 is the unit operation cost of the energy plant of the conversion of organic waste to electricity (τ); p_w is the price of the organic waste subject to $p_w = \alpha + \beta q_w (\alpha, \beta > 0)$; c_p is the annual fixed cost of the plant.

All the equilibrium conditions of different strategies are obtain partial differentiate of profit with respect to strategy and seting them equal to zero.

2.2 Simulation

Simulation helps us to identify the required physical level of organic waste for energy or power plant. The main objective of the simulation of the study is to identify daily physical average level of organic waste from the household for energy plant. The parameters hold the different characteristics under the simulation process which is shown in Table 1. Data are collected from the households and the Pabna Municipality Office. Expected amount of household organic waste and its price are collected from the households and total amount of collected waste in daily, distance of the waste collection area from the Pabna Municipality Office are collected from the Pabna Municipality Office.

Table 1. Parameter assumptions

Parameter (unit) parameters	Distribution parameters	Parameter (unit)	Distribution
α, β	Constant: 137, 0.302	$P_2(Tk / ton)$	Mean=201, SD=17
$p_e(Tk / kWh)$	Constant: 0.45	$Q_m(hundred\, ton)$	Constant: 117
$c_0(Tk / kWh)$	Constant: 0.17	$c_1(Tk / ton * km)$	Mean=3.3, SD=1.9
$c_p(million\, TK)$	Constant: 7	$y_r(ton / km^2)$	Constant: 21.75
$\gamma(kWh / ton)$	Constant: 557	$d(km)$	Max: 21, Min: 0

Note. Tk stands for Taka (Bangladeshi currency) and its rate of exchange US$1: BDT82.27 at 2 February 2018.

(Source: Estimated by the authors 2018)

2.3Sensitivity Analysis

The sensitivity (cost-benefit) is taken into account both the financial and environmental considerations. Financial costs include both capital and operational costs, whereas environmental costs are the valuation of net emissions for each scenario. Financial benefits include revenue received through taxes and sales of electricity while environmental benefits are the net emissions reduction for each of the scenarios. The costs and benefits of organic waste under different strategy are shown in Table 2.

Table 2. Cost-benefit of waste based power plant

Cost	Benefit
Construction and capital	Electricity sales
Operational costs	Avoided landfilling
Debt service	Avoided land and capital expansion
Interest paid	Avoided emissions

3. Results and Discussion

Based on the estimated result, we can say that co-opetition strategy maintains the highest equilibrium level of organic waste with respect to quantity and price for power generation and ensure the highest profit ($\pi_{pw}^{E} = (p_e - \alpha)q_{qw}^{E} - \beta(q_w^{E})^2$), followed by the cooperation and competition strategies. Table 3 shows the details equilibrium positions of different strategies of waste based power generation.

Table 3. Equilibrium positions of different strategies of waste based power generation

Strategy	Equilibrium amount of organic waste	Equilibrium level of profit
Competition	$0.1984\frac{(p_2-c_1d)}{b^2}$	$0.0080\frac{(p_2-c_1d)^3}{b^2}+0.0917\frac{(p_2-c_1d)^2(p_e-p_2)}{b^2}+\pi_{pw}^{E}-c_p$
Co-opetition	$0.5136\frac{(p_2-c_1d)}{b^2}$	$0.3916\frac{(p_2-c_1d)^3}{b^2}+0.5073\frac{(p_2-c_1d)^2(p_e-p_2)}{b^2}+\pi_{pw}^{E}-c_p$
Cooperation	$0.4143\frac{(p_2-c_1d)}{b^2}$	$0.2892\frac{(p_2-c_1d)^3}{b^2}+0.1407\frac{(p_2-c_1d)^2(p_e-p_2)}{b^2}+\pi_{pw}^{E}-c_p$

(**Source:** Estimated by the authors 2018)

Simulation results also support that the co-opetation strategy is the best strategy for organic waste based power generation compared to those of other strategies (see Table 3 for more details).

Table 4. Simulation results

Strategy Tk	Amount of organic waste/ton	Total profit/million Tk	Plant profit/million
Competition	80	16.70	11.37
Co-opetition	120	51.02	32.49

Cooperation	92	37.96	26.71

(**Source:** Estimated by the authors 2018)

From the table, we see that the estimated amount of organic waste under competition strategy is 80 tons daily and it is 120 and 92 tons daily when we have co-opetation and cooperation strategies. Thus, it is clear that co-opetation strategy is the best strategy to collect organic waste for power generation in the Pabna city. Similarly, highest yearly total profit of households and brokers, and total profit of plant are estimated as 51.02 million and 32.49 million Taka under the co-opetation strategy which is also greater than the other two strategies.

It is also possible to evaluate these strategies for waste based power generation in terms of sensitivity analysis: financial internal rate of return (FIRR) and economic internal rate of return (EIRR). Table 5 shows the sensitivity analysis under different strategies for waste based power generation. Highest FIRR and EIRR are estimated under the strategy of co-opetation and it is 1.38 % and 1.63 % respectively.

Table 5. Sensitivity analysis of waste based power generation

Strategy	FIRR	EIRR
Competition	0.89%	0.82%
Co-opetition	1.38%	1.63%
Cooperation	1.07.%	0.17%

(**Source:** Estimated by the authors 2018)

4. Policy Implications

Waste based energy has the potential to provide sustainable waste management and solve other challenges in Bangladesh including the reduction of GHGs emissions and development of renewable energy supply. It requires effective implementation strategy. Based on the estimated results, we propose co-opetition strategy for waste based energy or power plant. Households, brokers and moholla committee are the main building blocks of the co-opetition strategy. Results show that co-opetition strategy ensure the maximum amount of organic waste, maintain the supply chain and bring the highest profits for the households, brokers and energy plant.

The findings of the study generate the body of new knowledge in the energy sector and ensure to establish low carbon society. It is expected that other urban areas or cities generate more waste based electricity and promote green growth from the findings of this study.

Due to the time limitation, budget constraints and other logistic supports, this study is not free from certain lacunas. Pabna municipality is the study area of this study. It is not possible to include all cities of Bangladesh Bangladesh and large respondents to participate questionnaire survey. Thus, this study recommends for further study to avoid such shortcomings and get better findings to formulate waste based energy policy.

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