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SUPPLY CHAIN OPTIMIZATION OF AGRICULTURAL BIOMASS WASTE FOR CENTRALIZED POWER GENERATION

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ABSTRACT

Pre-treatment and storage of agriculture residue are crucial for its supply chain. To investigate the effect of pre-treatment methods (i.e. torrefaction and compaction), the number of storage depot, and power generation technology on supply chain model, this work compared 7 scenarios in order to optimize supply chain model for power generation in China using corn stalk as feedstock. Furthermore, the influential roles of supply chain parameters on power generation profitability will be investigated through sensitivity analysis. It was found that combined heat and power based power generation shows significant profitability compared with electricity generation. The results approved that supply chain model reaches the highest profitability with compaction as pre-treatment method and 9 storage depots. According to sensitivity analysis results, the capital investment cost of power plant is the most influential parameter for supply chain profitability, the followed by is the purchasing price of corn stock residues

Keywords: Agriculture residues, pre-treatment, supply chain model, CHP

1. INTRODUCTION

Biomass, as an eco-friendly and sustainable source, has made great effect in energy industry worldwide. EU had set a renewable target that the renewable energy should account 20% of final energy consumption by 2020, while 42% share of related biomass energy in total renewable energy [1]. It is estimated 90TWH electricity will be generated based on biomass by 2020 in China. What's more, China has set an ambitious target to raise renewable energy generation from 22% in 2015 to 34% of total energy generation in 2040[2-4].

Biomass-based power generation shows a tendency for further expansion; however, previous research have reported financial problem. Nearly 70% of biomass-based power plants in China were facing the crisis of financial difficulties [5]. Due to the dispersal of agriculture resides resources, logistical system limitation and imperfection of energy conversion technology, the industrialization of biomass utilization in China is behind European countries, such as Denmark and Sweden. To promote the utilization of agriculture residues for energy and generate profitability, two advices are provided: 1) Optimizing agriculture residues supply chain model; 2) Applying Combined Heat and Power (CHP) into power generation, in order to improve waste reuse efficiency. CHP could reuse waste energy that produced by power generation, which could achieved efficiency from 65% to 80% comparing with 20%-25% in electricity[6-8]. The generic supply chain of agriculture residues from fields to power plants includes agricultural residues collection, processing (pre-treatment), transportation, storage, and conversion to bioenergy [9, 10], as demonstrated in Figure 1. Among them, pre-treatment could play a significant role in supply chain, because pre-treatment may affect further stages of supply chain, such as transportation and storage. Therefore, optimizing pre-treatment has great potential in the improvement of supply chain model and cost reduction.

Various research has attempted to optimize supply chain model and evaluate supply chain performance by either cost minimization or profit maximization, or even environment impact. Morales et al.[11] proposed a Multiple Objective Mixed Integer Linear Programming for agriculture residues supply chain model, which achieved flexible and sustainable supply chain structure for economic consideration. Badri et al.[12] developed a supply chain model based on profit maximization. How and Lam[13] optimized supply chain model by a mathematical programing, they evaluate supply chain model by various environmental indicators. Woo et al.[14] Identified the optimal candidate wood land location by Geographical Information systems (GIS) to balance economic, environmental, and social criteria in biomass supply.

However, researchers are mostly focusing on the supply chain of wood as power generation fuel, while studies on agriculture residues are rarely reported. Besides, previous studies did not consider the transportation distance in collecting phase, either assumed power plant located in the middle of a circular area or homogeneously distribution collection points, [15-17]. Moreover, biomass pre-treatment technologies are well developed in the field, which, however, are barely applied in biomass supply chain for power generation, for example, considered torrefaction and pelletization into wood co-firing supply chain to evaluate logistic cost, and concluded that torrefaction is competitive for long distance transportation. Thus, in this study, the transportation distance in collection phase and pre-treatment method (torrefaction) are considered into supply chain model.

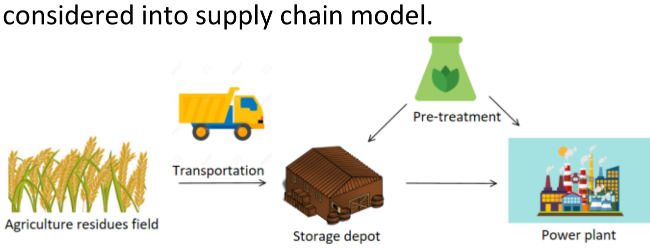

Fig 1. Sketch of biomass supply chain

A supply chain model will be built up in this work. The profitability index (PI) value of between CHP and traditional power generation (electricity only) will be compared based on the supply chain model, in order to figure out a better scheme of biomass-fired power generation system. Most importantly, the effect of pre-treatment method on supply chain model will be investigated to determine an optimal pre-treatment method for corn stalk supply chain. To reduce risk for influential parameters in the supply chain model profitability, a sensitivity analysis will be performed.

2. MATERIAL AND METHODS

The supply chain model is based on a 20MW CHP generation system, and annual operating time set as 7600 hours. The efficiency of electricity generation is 22.5% and CHP total generation efficiency is assumed as 72.5%, which is the average value of reference data.

A huge amount of agriculture residues is generated in China. Based on the grain production data from National Bureau of Statistics of China [18], it is estimated that china has approximate 812.94 million tons of agriculture residues, while corn stalk contributes the largest part of agriculture residues, ca. 36%. Therefore, corn stalk will be considered as the main feedstock in this work, which contains 20% moisture by weight and has a lower heating value of 15.59 MJ/Kg and bulk density of 0.087 ton/m^3. Compaction and torrefaction are considered as two pre-treatment methods in this study. Compaction can be done either at storage depot or power plant, while torrefaction has to locate in power plant for heating reuse and energy cost consideration. The torrefaction data was acquired from torrefaction experiments. It was found that corn stalk undergoing 300 °C torrefaction has the optimal performance, where the trade-off between the increasing in rate of weight loss against that in HHV, the lower heating value of torrefied material is 23.55 MJ/KG.

Table 2. The properties of scenarios

Scenario	Pre-treatment method	Number of storage depots	Generation technology
1	Compaction bulk density 0.4 ton/m^3	3	CHP
2		9	CHP
3		1	CHP
4	Torrefaction and compaction with bulk density 0.4 ton/m^3	1	CHP
5		5	CHP
6	Non pre-treatment with bulk density 0.087 ton/m^3	1	CHP
7 (ref)		1	Electricity Power generation only

There are totalling 7 scenarios investigated to evaluate the profitability of CHP and traditional power generation with or without pre-treatment methods. The number of storage depots is determined based on the working capability of pre-treatment equipment and the amount of residues to be used for power generation. A detailed scenarios properties are given in table 2.

In scenario 1, 2 and 3, residues are equally collected at each storage depot and compacted to a bulk density of 0.4 ton/m^3. Depending on compaction equipment working capability, the number of storage depots is classified as 3, 9 and 1 respectively. In both scenario 4 and 5, similar as scenarios1-3, residues will be compacted at storage depot to a bulk density of 0.4 ton/m^3 before being delivered to power generation plant; those residues will be subsequently torrefied in power plant using available waste heat resource. Both scenario 6 and 7 will be studies as reference, there will be no pre-treatment to be applied so that the bulk density of residues will remain as 0.087 ton/m^3 through the whole supply chain..

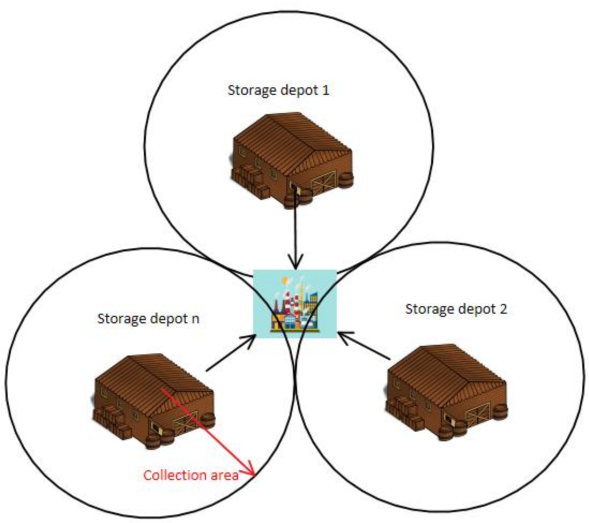

Fig. 2. The supply chain model collection pattern.

The supply chain collection pattern shows in Fig. 2, each storage has its corresponding collection area. The residues are collected and sent to depots for pre-treatment (compaction), and transported to power plant from designated storage depots. Each collection area does not overlap or influence each other. It should be noticed that, if there exists only one depot, the depot is located in power plant.

3. RESULTS AND DISCUSSION

3.1 Investment analysis

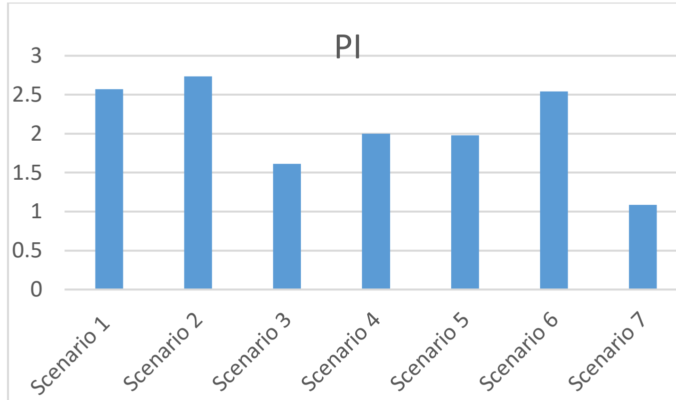

Fig. 3. PI value of supply chain model scenarios

The evaluation of PI is a critical for…. In other words, the capital gain depends on the value of PI [19]. According to Rentizelas and Li [20], a PI value above 1 indicates the project is profitable investment. Fig. 3 illustrates that all 7 scenarios supply chain models are profitable. It suggests that corn stalk residues to be collected to 9 depots and compacted with density of 0.4 ton/m^3 (scenario 2) is a highly profitable investment, which achieves the highest PI value of 2.73, followed by scenario 1 and scenario 6. It was observed that scenario 3 has a relative lower PI value above CHP based power generation supply chain, because the loose residues transport and compacted in power plant, resulting in high transportation cost. It is no surprise, scenario 7, representing traditional power generation supply chain, has the lowest PI value, which is just above the baseline of profitability.

The PI value in scenario 4 is lower than that in scenario 2, one of the main reasons is the expensive investment of torrefaction unit, which raises its capital expenditure. For the same reason, the profitability of scenario 4 and scenario 5 are lower than that of scenario 6. Overall, the average PI value of compaction as pre-treatment based supply chain system is higher than that of torrefaction based supply chain system.

In addition, it was found that for one storage depot CHP based supply chain with torrefaction or compaction (scenario 3 and 4) are less competitive against the scenario 6 without pre-treatment, because the pre-treatment saves only storage cost rather than transport cost, where the transport cost saving plays a crucial role in increasing supply chain profitability. While for multiple storage depots, supply chain with compaction holds a competitive advantage with a PI of 2.73 (scenario 2), raised 7% from 2.54 in scenario 6. Same trend was observed in scenario 2 (PI value 2.73) and scenario 1 (PI value 2.57). Therefore, it can be summarized that, when the PI value of CHP based supply chain undertaking the same pre-treatment condition, the larger number of storage depots the greater profitability could be obtained, due to the cost saving for the transportation from residues field to storage depots. However, such a trend is insignificant in supply chain model when considering both torrefaction and compaction as pre-treatment (scenario 4 and 5). A possible reason could be inferred that, when compared with torrefaction equipment, the capital cost of compaction equipment is less significant, which has less impact of supply chain system profitability.

As expected, the PI value in scenario 7 as a traditional electricity power generation has the lowest value when compared with all other CHP scenarios. Comparing with CHP based power generation (scenario 6, PI=2.54), traditional power generation supply chain model has less profit capability, which approximate half PI value (1.08) of that of CHP supply chain model. In other word, the PI value of scenario 7 evidenced that the supply chain model has less profitable in biomass power generation market.

3.2 Sensitivity analysis

Various input parameters are considered as variable, because they are independent and cannot be manipulated by the system inspection. Thus, it is necessary to analyse and evaluate the performance of financial yield sensitivity on the changes of those influential parameters. In this section, 16 most influential parameters are identified and subjected from lower value (-25%) to higher value (+25%) of its baseline value, as suggested in accordance with other biomass supply chain analysis [20]. Comparing the changed PI value with baseline PI value. Those identified uncertain parameters are conducted sensitivity analysis and the resulting PI values are indicated in Fig. 4, in which the baseline of PI value was 2.73 from the scenario 2. The fluctuation of PI value depends on parameters alterations, the larger value range, the greater sensitivity is.

The main capital expenditure of power plant appears to be the most influential parameter. With the power plant capital cost reducing 25%, the PI value has significant fluctuation, which raise 33.3%. Meanwhile, profitability is less sensitive for the increase of capital cost, which is only 20% decrease against 25% capital increase. With the development of power generation technology, the power plant capital cost is expected to decrease in the future, which gains further profitability for the project. Residues purchasing price becomes the second most influential parameter. In spite of less sensitivity of residues purchasing price, securing long terms and low cost residues resources are crucial for power plant profitability in order to against purchasing price increase year by year.

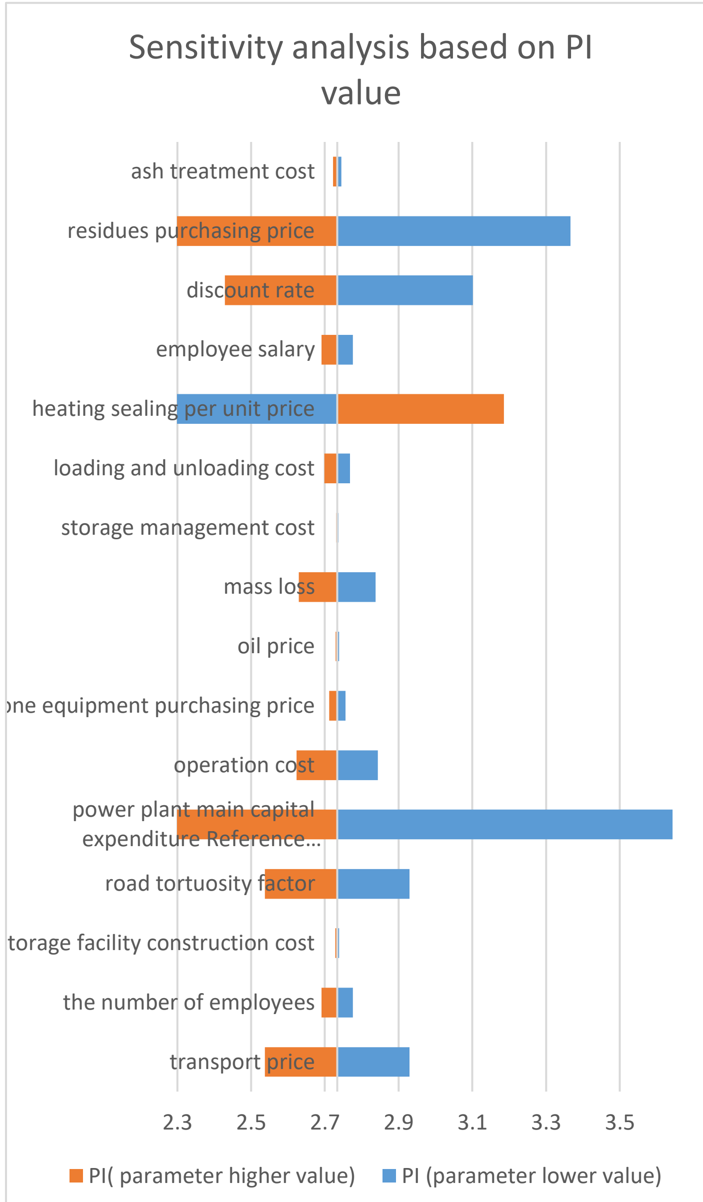

Fig 4. Sensitivity analysis for scenario 2.

4. CONCLUSIONS

This work evaluated a feasibility of pre-treatment in supply chain for CHP power plant. It has compared 7 scenarios, considering the effect of storage depot, pre-treatment method and power generation technology on the power plant profitability. By balancing the disadvantage of capital investment for pre-treatment and the advantage of advanced high efficiency power generation technology, the resulting conclusions could help power plant sectors to avoid potential unexpected risks.

The results showed that CHP based power generation (scenario 6) has a great advantage than electricity generation (scenario 7) in profitability, which has over twice profitability performance. It indicated that traditional power generation no longer suits for the pressure of cost fluctuation in agriculture residues supply chain. By undertaking same pre-treatment conditions (i.e. compaction), supply chain profitability can be increased with an increasing of the number of storage depots; while such a trend becomes less significant when torrefaction and compaction are applied. CHP based power generation with compaction as pre-treatment method indicated the optimal profitability performance. The suggestion made based on supply chain profitability above is that the power generation operator should accept CHP as power generation technology and residues should compaction in multiple storage depots to transport in order to fit in the maximum profitability.

Considering the effect of uncertainty parameters on supply chain profitability, the most influential parameters are the main capital expenditure of power plant and residues purchasing price. A positive view is that the power plant investment will cut down in the future and a stable cooperation relationship of long terms residues resources collection could help increase supply chain profitability. While storage manage cost has insignificant impact for supply chain profitability.

Despite of the fact that the findings of this supply chain model cannot apply to all types of biomass such as wood; awareness can be learned from the sensitivity analysis with influential parameters to supply chain. Moreover, CHP will be the trend of power generation in the future.

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