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Research paper

Logistics cost analysis of rice straw pellets for feasible production capacity and spatial scale in heat utilization systems: A case study in Nanporo town, Hokkaido, Japan

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ABSTRACT

Rice straw is a promising renewable energy source because it is abundantly available in Asia. This study conducted a case study of logistics cost analysis for rice straw pellets by considering all stages in the supply chain to define the main factors affecting the selling price of rice straw pellets: collection (job-commission or employment of part-time workers), transportation, storage (vinyl greenhouses or storage buildings with larger capacity), pelletizing, and delivery to users with biomass boilers. The selling price was found to be strongly dependent on the production capacity because the investment cost for the pellet production facility had a significant effect of economies of scale. A production capacity of larger than 1500 t y^{-1} is required for rice straw pellets to compete with wood pellets and fossil fuels in the studied Japanese context if the subsidy rate for the investment is 50%, part-time workers conduct the collection, and rice straw is stored in the storage buildings. Our sensitivity analysis also showed an economically feasible spatial scale: for example, rice straw should be collected within a 20 km radius and the users should be within a 38 km radius when the production capacity is 1500 t y^{-1}. In addition, other critical factors related to the collection of rice straw from the paddy fields and transportation of rice straw rolls to storage were identified as planning factors to further reduce the total logistics cost of rice straw pellets.

1. Introduction

Agricultural residues, such as wheat straw, rice straw, and rice husk have been investigated as promising renewable energy sources. In most Asian countries, rice straw is abundantly available as unused biomass. About 90% of paddy production is from Asian countries [1]. Japan generates about 9 million tons of rice straw annually [2].; some of this rice straw is already used as an amendment and bulking agent for the composting of livestock manure [2]. However, 60% of the rice straw is incorporated into paddy fields [2] and naturally degrades into the paddy soils, following the 1997 ban of open field burning of rice straw because of air pollutant emissions. Incorporation of rice straw has advantages to build up organic matter, N, P and K in soils, and the disadvantage is the immobilization of inorganic N [3], which might increase the protein content of in rice and result in low quality rice for eating [4]. The degradation of rice straw results in methane gas emissions [5]. Therefore, incorporation of rice straw in some Japanese paddy fields with peaty soil or rich organic content is not recommended.

Rice straw can be used as a renewable energy source to reduce the use of fossil fuels and the emission of methane as a greenhouse gas. Existing technologies can use the energy in rice straw, such as direct combustion, densification of rice straw to pellets or briquettes, gasification, pyrolysis, anaerobic digestion and bioethanol production [6]. Rice straw has already been successfully used as a renewable energy source for power and heat production (direct combustion) in Denmark, UK, Spain and India [7]. However, in Japan, large-scale biomass power plants for woody biomass, such as forest residue, have been constructed, but have not yet been used for straw-based fuel. In addition, bioethanol production is also economically difficult in Japan. Therefore, the present study focuses on the pelletization of rice straw for the straw-based fuel because (1) rice straw with low density needs to be transported effectively [8] and stored for a prolonged period as it can only be collected

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during a short period, and (2) rice straw pellets can be used in popular stoves and boilers for wood pellets. In this case, the selling price of rice straw pellets should be competitive with other fuels.

Rice straw pellets were produced commercially in Nanporo town, Hokkaido, Japan [9]. Rice straw is collected in early November and stored during the winter to dry. Rice straw pellets are used as a heat source at a public bathhouse, which operates a pellet boiler customized for using both rice straw and wood pellets. The proper production conditions of rice straw pellets were studied regarding their heat value, yield ratio, and durability, which are important indices for the quality of rice straw pellets [10]. Another issue remains to be solved, concerning the reduction of the logistics cost of rice straw pellets.

The scatter spatial distribution of agricultural residues with low density and their seasonal characteristics significantly affects the logistics cost of biomass fuel [11,12]. Therefore, the complete logistics system, including the collection, storage, transportation, production of rice straw pellets, and delivery of pellets to users, should be integrated to reduce the logistics cost of rice straw pellets [13,14]. The logistics cost is also determined by local factors, such as the cost of biomass fuel and labor. Therefore, the project feasibility should be assessed based on the localized conditions in the region of interest [15,16]. Many case studies of the development of local biomass power-generation systems and assessments of the feasibility of the system have been performed in Thailand [17,18], India [19], Malaysia [1], China [20], and Ghana [21].

Several studies of the logistics cost of biomass have been performed: e.g., transportation of cotton-stalk [22,23], herbaceous biomass [24–26], and forest biomass [27,28].

Kadam et al. [29] reported that the most effective rice straw collection method is baling. They noted the moisture content of bailed rice straw because the decreasing rate in moisture content of rice straw is small. Igathinathane et al. [30] analyzed aggregation logistics of baled straw in fields. Storage of rice straw, which depends on its seasonal availability, should be considered to ensure a continuous fuel supply [31,32]. Rentizelas et al. [31] revealed that selection of the lowest cost storage method is the most efficient solution and that an approach using multi-biomass with different harvesting periods has more advantages when combined with relatively expensive storage methods. However, the biomass fuel has to be transported twice, from fields to storage places and from storage places to conversion places, which results in a higher delivery cost than a system in which there is only one transportation movement [32]. The option of setting the storage facility next to the conversion places has been investigated [23,33].

A large portion of the operational cost for a biomass energy generation facility is its fuel costs because a much large number of vehicle movements are required for transportation of straw biomass with low bulk density compared with woody biomass fuel [17,31,32].

Jenkins [34] pointed out that a positive effect of economies of scale is found in bioenergy investment and operation costs as the facility size increases. Delivand et al. [17] analyzed the cost relationships among rice straw collection, field hauling, road transport, and storage, and how the cost of rice straw supply processes would change in relation to the capacity of the power plant. The scale of the bioenergy facility affects the spatial distribution of biomass over the area, and the fraction of transportation costs to the total logistics cost cannot be negligible [35–37].

Many optimization studies to reduce the logistics cost of biomass have been conducted [19,38,39]: Ba et al. [40] comprehensively reviewed optimization models, Delivand et al. [41] attempted to determine the optimal locations of bioenergy facilities using geographic information system and multicriteria analysis.

Technoeconomic analysis of biomass energy using various conversion routes have been performed in many studies, and different aspects of the analysis such as net present values, internal rate of returns, pay back periods, and benefit-to-cost ratios have been investigated [15,31,36].

Although there are many studies on logistic biomass supply, there will be a need for specific local study in the specific region because the spatial distribution of agriculture residue is varied [42]. Based on case studies, economically feasible production capacity and spatial scale should be determined and measures for cost reduction should be considered.

The aim of the present study is to conduct a case study of the logistics cost analysis of rice straw pellets for local heat utilization in Nanporo town, Hokkaido, Japan. The specific objectives of this study are as follows:

1) To conduct a logistics cost analysis of rice straw pellets considering all stages from collection of rice straw to delivery to users in the supply chain management.
2) To investigate measures for reducing the selling price of rice straw pellets by sensitivity analysis for the production capacity, spatial scale, subsidy, and methods of collection and storage.
3) To identify other planning factors that might affect the logistics cost significantly.

2. Strategy for promoting use of rice straw pellets in Japan

Rice straw pellets were first commercially produced in Nanporo town, Hokkaido, Japan [10]. As shown in Fig. 1, rice straw is baled and collected in November, and transported and stored in vinyl greenhouses during the winter. The number of rice straw rolls collected in 2014 was about 120 and their moisture content was reduced to less than 10% during storage. Rice straw pellets are produced (EF-BM-370, capacity: 200 kg h^{-1}; diameter of die: 6 mm; Earth Engineering Co., Ltd. in Japan) and then burned in a biomass boiler (with a 400 kW capacity) at a public bathhouse. The high silica content in the ash as a by-product after burning causes clinker problems and the wood pellets are mixed with the rice straw pellets at the ratio of 1:1. This ash is applied to agricultural fields as a snow-melting and soil-improving material, which results in no treatment fee for the ash.

In 2015, the result of rice straw pellets production was still small at about 20 t y^{-1}, because the number of users was still small. Based on its heat value, the actual transaction price (selling price) of rice straw pellets was also higher than that of fossil fuels such as heavy oil and heating oil. The investment costs for replacing boilers that use fossil fuels with biomass boilers that use woody and rice straw pellets are more expensive than for those that use fossil fuels. In addition, a lot of effort will be needed for the operation of biomass boilers, which results in high maintenance and management costs because rice straw burning produces a lot of ash that causes clinker problems. Considering the above disadvantage, the selling price of rice straw pellets should be reduced to at least a price equivalent to the fossil fuels based on its heat value in order to compete with heavy oil and heating oil. This is a minimum requirement for promoting the utilization of rice straw pellets. The difference between both investment costs for oil boilers and biomass boilers can be supported by a government subsidy.

In Nanporo town, rice straw is already sold to be used for cow manure composting. However, most of the produced rice straw is incorporated into the paddy fields. The characteristic of the soil in this area is peaty. Therefore, the incorporation of rice straw into the soil is not recommended. Most farmers want to remove rice straw from the paddy field, if possible, with no treatment fee. This study