

## **SCENARIO ANALYSIS OF RENEWABLE ENERGY BUSINESSES: A CASE STUDY OF WOODY BIOMASS IN A JAPANESE RURAL COMMUNITY**

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*Keywords: scenario analysis, energy business, renewable energy,  
woody biomass, rural community*

### **1. Introduction**

With the aim to realize a low-carbon society, more attention is being paid to renewable energy sources, such as solar, wind, and woody biomass, than ever. Some countries have introduced feed-in tariff (FIT) schemes for increasing electricity generation from renewable energy. For example, in Germany, the FIT scheme increased the cumulative photovoltaic (PV) capacity up to 32.6 GW as of 2012, which accounts for 32% of the total installation in the world (102 GW) [European Photovoltaic Industry Association 2013]. While the diffusion of renewable energy contributes to reducing CO<sub>2</sub> emissions, economic sustainability must be satisfied to make renewable energy businesses feasible in a long run (*e.g.*, 10-20 years). In other words, renewable energy businesses relying solely on governmental subsidies or the FIT scheme are not necessarily considered sustainable because even a small change in the business environment may lead to their bankruptcy. In this paper, a renewable energy business refers to economic activities where various actors (*e.g.*, business provider, consumer, government, and non-governmental organization (NGO)) exchange materials, energy, money, and information that are associated with renewable energy.

When attempting to design sustainable renewable energy businesses, one critical problem is that there are many unpredictable factors that may drive or inhibit the business, such as national energy policies (*e.g.*, FIT schemes and nuclear power policies), consumers' lifestyles, global economic situations, and technological advancements. In the domain of engineering design, one of emerging research topics for enhancing sustainability would be the design of sustainable renewable energy businesses, which ensure economic feasibility and less environmental impacts compared with conventional businesses, by taking not only technological components but social aspects into account.

This paper takes a simulation-based approach to designing sustainable renewable energy businesses. By undertaking scenario analysis with the simulation (*i.e.*, changing assumptions of the simulation), we aim to clarify conditions for sustainable renewable energy businesses and to extract key factors that might affect the economic feasibility of the businesses. For this purpose, we propose a method for modeling renewable energy businesses based on the life cycle simulation [Umeda et al. 2000]. In a case study, we focus on a woody biomass energy business in Maniwa City, which is a rural community in Okayama Prefecture, Japan. This is because such a biomass energy business has a large potential to reduce CO<sub>2</sub> emission for tackling global climate change problems as well as to promote the local economy of the community.

The remaining part of the paper is structured as follows. Section 2 mentions the Japanese current status of renewable energy businesses. Section 3 describes a method for modeling renewable energy businesses. Section 4 illustrates a case study of the woody biomass energy business in Maniwa City. Section 5 gives discussions based on the case study results. Finally, Section 6 concludes the paper.

## 2. Current status of renewable energy businesses

### 2.1 Japanese current situations of renewable energy businesses

Since the Great East Japan Earthquake on the 11th of March, 2011 and the Fukushima nuclear power plant accident as the aftermath, national energy policies have been actively discussed across the world with a particular emphasis on nuclear power. In Japan, post-Fukushima energy policies have been discussed as well, during which the Japanese government presented several scenarios of nuclear power reduction [McLellan et al. 2013]. For reducing both nuclear shares in the Japanese electric power supply and CO<sub>2</sub> emission, the Japanese government enacted the law regarding feed-in tariff (FIT) in July of 2012 [METI 2013]. The law says that, for example, the electricity generated from photovoltaic (PV) systems of households, which are mostly installed on the rooftop, can be sold to the electrical grid at the price of about 38 JPY/kWh, while the grid electricity price in Japan is about 25-26 JPY/kWh as of 2013. As a result, renewable energy businesses are booming in Japan, including large-scale solar power generation and regional biomass energy businesses. Moreover, technology roadmaps describe the advancement of renewable energy technologies in the future, which may accelerate the renewable energy business. For example, the conversion efficiency of PV systems is projected to increase from 16% in 2012 to 25% in 2030 [NEDO 2013].

### 2.2 Literature review

In an effort to design future energy systems, much work has been conducted so far, such as the smart grid project in Europe [European Commission 2011] and renewable electricity generation in the United States [NREL 2012]. However, to the best of our knowledge, few studies have dealt with the design of renewable energy businesses although many researchers proposed methods for designing general sustainable businesses [Kondoh and Mishima 2010], [Boons et al. 2013]. Related to biomass energy businesses, Murphy et al. [2014] conducted the life cycle assessment of forest biomass supply chains in Ireland and Lauri et al. [2014] discussed long-term woody biomass supply. Zhang et al. [2010] mentioned that there are many biomass conversion technologies available, which include gasification [Brown et al. 2009], [Fiorese et al. 2014] and biorefining [Näyhä and Pesonen 2014]. Despite useful studies as shown above, methodologies for designing sustainable renewable energy businesses are insufficient. Moreover, conditions for sustainable biomass energy businesses in terms of economic sustainability have not been discussed enough. One of the most critical problems here is that there are many unpredictable factors surrounding renewable energy businesses in the future, including the FIT scheme, grid electricity price, and initial costs of renewable energy facilities.

## 3. A method for modeling renewable energy businesses

### 3.1 Approach

In order to help design sustainable renewable energy businesses considering future unpredictable factors, we carry out scenario analysis by taking a simulation-based approach. We employ the concept of the life cycle simulation (LCS) [Umeda et al. 2000], [Kishita et al. 2009] to evaluate various scenarios of renewable energy businesses.

LCS is a generalized method to analyze the flow of a material/product, money, and information throughout a product life cycle based on a discrete event simulation technique. In LCS, a process flow is modeled as a network of various process types, such as material production, product assembly, transportation, usage, and disposal. Each process is defined as the formulas of input-output relationships between neighboring processes. LCS evaluates the balance of a product life cycle from both environmental and economic perspectives. When compared to the life cycle assessment (LCA), advantages of LCS include evaluating the dynamic balance of inlet and outlet flows of products over the simulation period.

To examine conditions for sustainable renewable energy businesses, we define the procedures for scenario analysis using the concept of LCS in five steps as follows:

1. Setting the problem to be solved (e.g., time frame, region, and evaluation boundary of interest)

2. Constructing causal networks for extracting factors associated with biomass energy businesses and understanding the relationships among them
3. Describing scenarios of renewable energy businesses based on the causal networks constructed in Step 2
4. Evaluating each scenario in terms of profitability based on of the concept of LCS, by which we model the scenario as a process network (see Section 3.2)
5. Undertaking scenario analysis by changing assumptions of each scenario with the aim to clarify conditions for sustainable energy businesses

### 3.2 Modeling renewable energy businesses

To evaluate the costs and sales of various scenarios of renewable energy businesses, we define five categories of process types as shown in Table 1 – material extraction, production, collection/distribution, selling, and end-of-life (EOL). The basic process model is illustrated in Figure 1. We define equations for each process type to represent the relationship of inlet and outlet flows between neighboring processes. The annual costs and sales in each process type are commonly calculated by the following equations:

$$\text{annual costs} = \text{unit variable cost} \times \text{annual processed amount} + \text{annual fixed cost} \quad (1)$$

$$\text{annual sales} = \text{unit price} \times \text{annual sold amount} \quad (2)$$

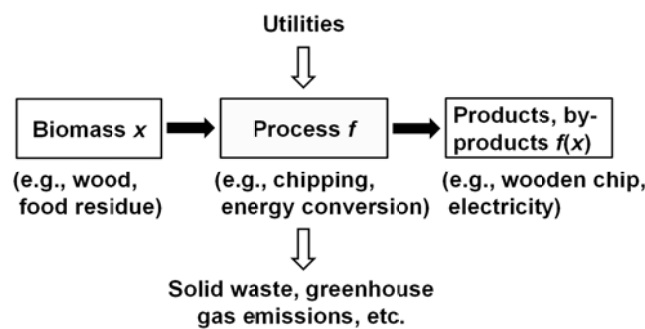


Figure 1. Basic process model [updated from Moriguchi 1999]

Table 1. Definition of process types

Category	Definition	Process type defined in the case study
Material extraction	Raw materials are extracted from the earth.	Wood extraction
Production	Materials, products, or energy are produced using facilities and technologies.	Laminated timber production, chipping, pelletizing, energy conversion
Collection/Distribution	Materials or products are collected in one place or are distributed from one place to another.	Collection, land transportation, marine transportation, export, import
Selling	Materials, products, or energy are sold from one actor to another.	Selling
End-of-life (EOL)	Solid wastes are discarded at a certain cost.	Disposal

The annual costs consist of annual variable costs (e.g., utilities cost, transportation cost, and procurement cost), which are calculated by multiplying unit variable costs by annual processed amount, and annual fixed costs (e.g., initial and maintenance costs of facilities and labor cost).

Several actors are, in general, involved in a renewable energy business, such as business providers, consumers, and governments. In this paper, we evaluate the annual profit of business providers over

the simulation period in order to analyze the economic feasibility of the business. The annual profit is calculated by subtracting the total costs from the total sales of the business for every year. In the case study, we define 12 process types described in Table 1 for evaluating scenarios of woody biomass energy businesses.

#### 4. A case study of biomass energy business in Maniwa City, Okayama, Japan

##### 4.1 Problem settings

We carried out a case study of the woody biomass energy business in Maniwa City, Okayama Prefecture, Japan, of which the population and the area are 47,096 and 828.4 km<sup>2</sup>, respectively. The city is a typical rural community with 79% of the whole area being occupied by forests. The economy is mainly led by forestry industry, where about 30 timber mills are currently running business by manufacturing wooden products including laminated timber. The purpose of the case study is to analyze conditions for economic sustainability of the woody biomass energy business. The period covered ranges from 2013 to 2032 (*i.e.*, 20 years, specified in the current FIT scheme in Japan). In the business, we assumed that woody biomass is converted to two types of energy – “wood pellet,” which is used as a fuel to supply hot water, and “electricity.” In particular, the electricity generated from woody biomass can be sold to the electrical grid at the price of 25.2-33.6 JPY/kWh based on the current FIT scheme, which is about 1-1.3 times higher than the grid electricity price [METI 2013].

##### 4.2 Constructing a causal network

Figure 2 describes a part of the causal network that we constructed regarding the biomass energy business by PEST (political, economic, social, and technological) analysis [O’Brien 2004]. Each link means a causal relationship between two factors. The link types of “positive” and “negative” represent a positive and negative effect from one factor to its descending factors, while “related” represent an undetermined effect in terms of polarity (*i.e.*, positive or negative).

The causal network shows a number of factors that will affect the profit of the biomass energy business. For example, the FIT scheme influences Factor (i) “sales of electricity generated from woody biomass,” while it also has a positive impact on (c) “grid electricity prices.”

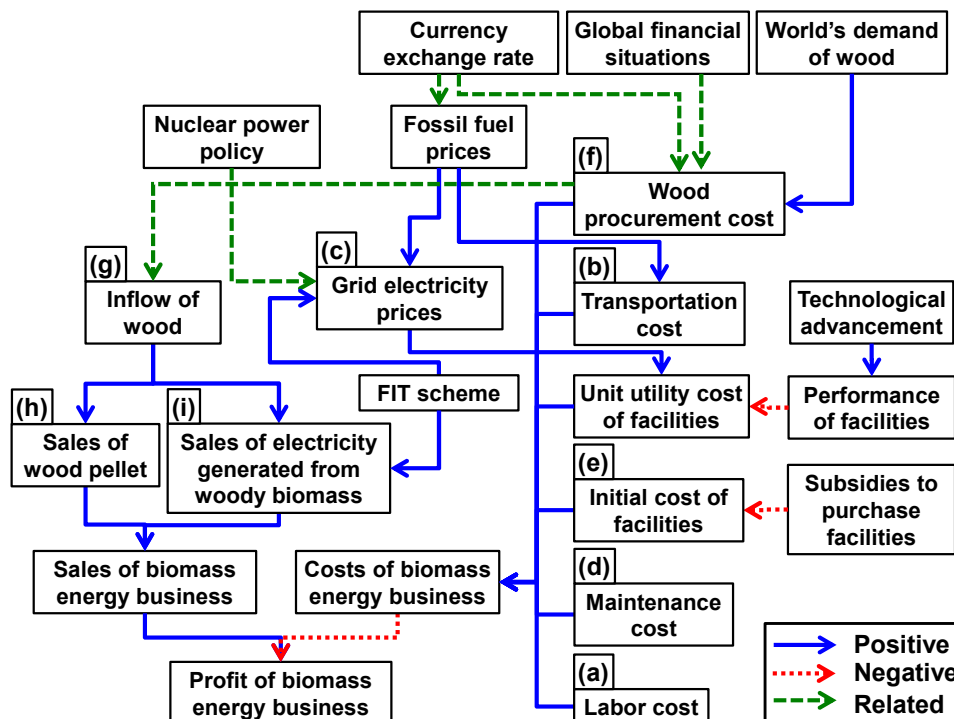
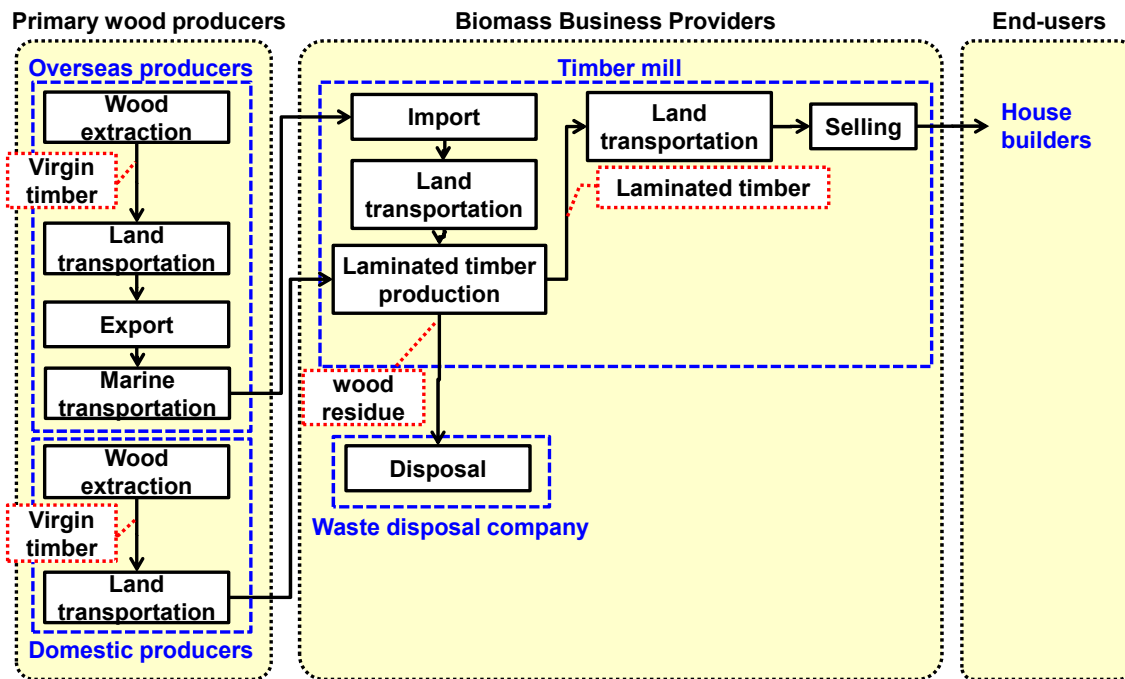
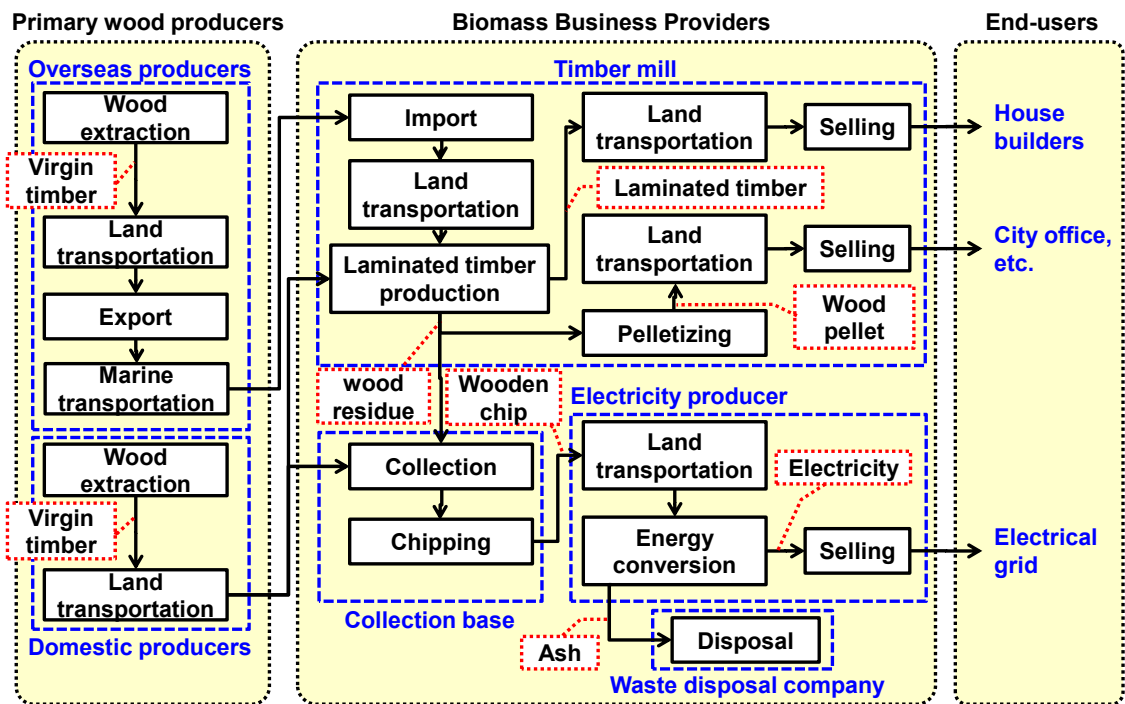


Figure 2. Causal network of the biomass energy business (not exhaustive)



a)



b)

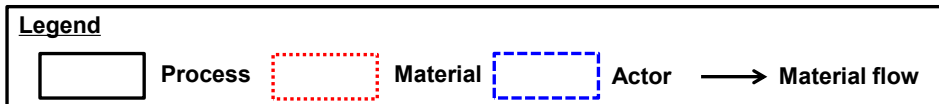


Figure 3. Process flows of woody biomass in Maniwa City: a) Conventional Business Scenario, b) Biomass Energy Business Scenario

#### 4.3 Assumed scenarios

We described two scenarios for analyzing the profit of the biomass energy business as follows:

- (A) Conventional Business Scenario: The wood residues (e.g., shaving and bark, 76 thousand ton/year) from the timber mills are simply discarded in landfill sites.
- (B) Biomass Energy Business Scenario: The wood residues from the timber mills are used for producing wood pellets (18 thousand ton/year) and electricity (58 thousand ton/year) that is sent to the electrical grid based on the FIT scheme. In addition, a larger amount of virgin timber (90 thousand ton/year) is collected from domestic wood producers for generating electricity. This is because, according to the Japanese FIT scheme, the electricity generated from domestic virgin timbers can be sold at a higher price (33.6 JPY/kWh) than that from wood residues (25.2 JPY/kWh) [METI 2013]. The difference of the FIT rate for virgin timbers and wood residues comes partly from the difference of their water content. In other words, wood residues contain less water, enabling to produce more electricity than virgin timbers.

**Table 2. Collected data used in the case study (not exhaustive)**

<i>Process type</i>	<i>Item</i>	<i>Value</i>	<i>Unit</i>	<i>Remarks</i>
General	Labor cost	4.0	million JPY/year	Obtained from the interview with Maniwa City.
	Grid electricity price	23.8	JPY/kWh	Obtained from the website of Chugoku Electric Power Co., Ltd.
Disposal	Disposal cost	6.0	JPY/kg	To landfill wood residue in Scenario A.
		40.0	JPY/kg	To landfill the ash of wood after the energy conversion process in Scenario B.
	Annual amount of discarded wood residues	76	thousand ton/year	The amount of the wood residues to be landfilled in Scenario A.
	Annual amount of discarded ash	1.48	thousand ton/year	The amount of the ash to be landfilled in Scenario B.
Land transportation	Gasoline price for trucks	134	JPY/liter	Obtained from the website of Agency for Natural Resources and Energy, Japan.
	Transportation distance	20	km	Authors' assumption.
Collection	Wood procurement cost	4.0	JPY/kg	Obtained from the interview with Maniwa City.
	Annual amount of collected wood for electricity generation	148	thousand ton/year	The collected wood is classified into wood residue (58 thousand ton/year) and domestic virgin timber (90 thousand ton/year).
	Annual amount of collected wood for pellet	18	thousand ton/year	Obtained from the interview with Maniwa City.
	Initial cost of the collection base	17.5	million JPY/year	The depreciation period of the collection base is 20 years.
Chipping	Initial cost of chipping machines	7.5	million JPY/year	The maximum amount of wood that is processed in chipping machines is 150 thousand tons a year. The depreciation period of the chipping machines is 8 years.
	Maintenance cost of chipping machines	1.5	million JPY/year	
Pelletizing	Initial cost of pelletizing machines	50.0	million JPY/year	The maximum amount of wood that is processed in pelletizing machines is 36 thousand tons a year. The depreciation period of the pelletizing machines is 8 years.
	Maintenance cost of pelletizing machines	2.0	million JPY/year	
	Material loss in the process	20	wt%	Authors' assumption.
Energy conversion (power)	Initial cost of the power generation plant	207	million JPY/year	Obtained from the interview with Maniwa City. The depreciation period of power generation plant is 20 years.
	Maintenance cost of	124	million	

generation)	the power generation plant		JPY/year	
	Power conversion efficiency	17.2	%	Authors' estimation based on the interview with Maniwa City.
Selling	Price of wood pellet	20	JPY/kg	Obtained from the interview with Maniwa City.
	Price of electricity from wood residue to the grid	25.2	JPY/kWh	According to the Japan's FIT scheme [METI 2013].
	Price of electricity from virgin timber to the grid	33.6	JPY/kWh	

The process flows of the scenarios are illustrated in Figure 3. While we divided the actors involved into three categories, *i.e.*, primary wood producers, biomass business providers, and end-users, the profit of the biomass business providers was evaluated in the case study. The biomass business providers consist of timber mills, collection base, and electricity producer. For the sake of simplicity, we calculated the costs and sales of the processes after the wood residues arise in the “laminated timber production” process since the upstream processes before “laminated timber production” are the same in Scenarios A and B. In Scenario B, the wood pellets are sold to the city office, city pool, hotels, etc., whereas the generated electricity is sent to the electrical grid.

To calculate the costs and sales in each process, we collected much data based on interviews with Maniwa City and experts and many literature reviews. A part of the collected data is summarized in Table 2. The first two items (labor cost and grid electricity price) are used for calculating costs in several process types.

#### 4.4 Evaluation results

Figure 4 depicts the annual costs and sales in Scenarios A and B. The annual profit of Scenario A is -456 million JPY, which is equivalent to the disposal cost. In contrast, the annual profit of Scenario B is 1,060 million JPY. The annual electricity and pellet sales are 2,100 million JPY and 360 million JPY, respectively. The annual costs of Scenario B amounts to 1,400 million JPY, where the three largest costs are wood procurement cost (26%, 360 million JPY), electricity cost (22%, 310 million JPY), and initial cost (20%, 280 million JPY). On the other hand, disposal cost (4%, 59 million JPY), labor cost (5%, 76 million JPY), maintenance cost (9%, 130 million JPY), and land transportation cost (13%, 190 million JPY) are less significant.

Obviously, the electricity sales based on the FIT scheme is the most significant to make it economically feasible to run the biomass energy business in Scenario B. The comparison of Scenarios A and B shows that another strength of the biomass energy business is to save the disposal cost of wood residue, resulting in reducing solid waste to be landfilled.

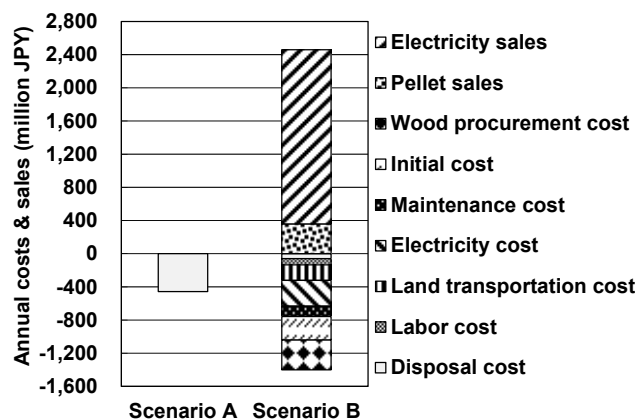


Figure 4. Annual costs and sales in Scenarios A and B

#### 4.5 Scenario analysis of the biomass energy business

Given there are uncertainties in various factors associated with the biomass energy business, we conducted scenario analysis of Scenario B. Figure 5 shows the result of sensitivity analysis, describing the annual profit when each parameter of (a)-(i) in Figure 2 is increased 10%. The result indicates that less sensitivity is observed in the cost factors (a)-(f) compared with the factors (g) and (i), which are related to the sales of the business. The most critical factors for the economic sustainability of the business are (i) “price of electricity generated from woody biomass” and (g) “inflow of wood for wood pellet and electricity generation.” In other words, the business might be bankrupt if the value of (i) or (g) decreases.

Based on the result in Figure 5, we examined the marginal condition of economic feasibility for clarifying conditions for a sustainable business. Figure 6 describes the marginal line of the profit when we changed the values of (g) “inflow of wood” and (i) “price of electricity generated from woody biomass” in Scenario B. In the original condition of Scenario B, the inflow of wood (annual amount of collected wood) for electricity generation is 148 thousand ton/year (wood residue: 58 thousand ton/year, domestic virgin timber: 90 thousand ton/year) and the price of electricity generated from woody biomass is 25.2 JPY/kWh (wood residue) or 33.6 JPY/kWh (domestic virgin timber). The result indicates that, if we assume that the current FIT scheme is maintained in the upcoming 20 years (*i.e.*, the price of electricity from woody biomass is the same as Scenario B), it is required to collect more than about 40 % of inflow wood for electricity generation (74 thousand ton/year of wood, consisting of 29 thousand ton/year of wood residue and 45 thousand ton/year of domestic virgin timber) to ensure economic feasibility. The business will be economically unfeasible if the current FIT scheme is amended and the price of the electricity produced from woody biomass drops to below 50% of that in Scenario B.

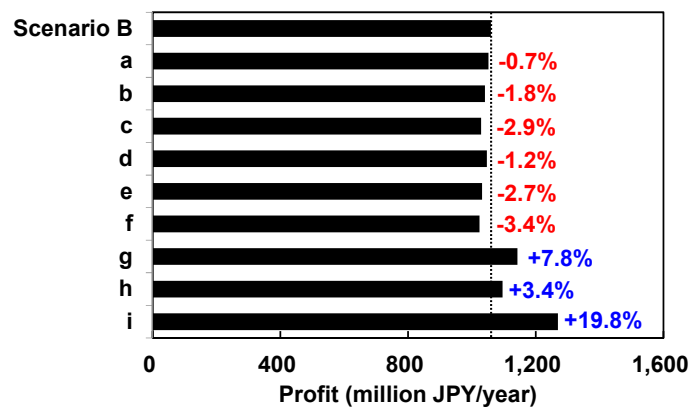


Figure 5. Sensitivity analysis in Scenario B when increasing each parameter by 10%

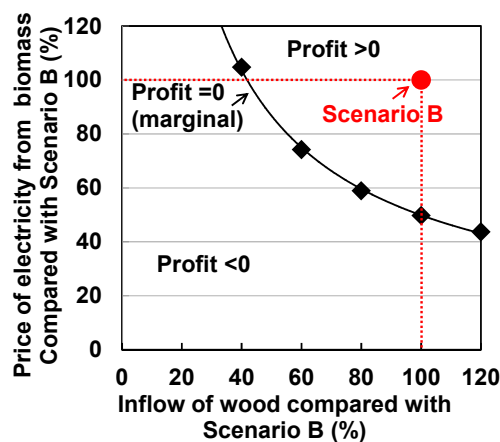


Figure 6. Economically marginal condition of the biomass energy business



## 5. Discussions

The result of the case study showed that critical factors of driving the business include (g) “the amount of inflow wood” and (i) “the price of electricity from woody biomass” (see Figure 5). For the biomass business providers, Factor (i) is an external variable since it depends on the FIT scheme, which is a part of the Japan’s national energy policies. Figure 6 pointed out that the business becomes economically unfeasible if the price of the electricity produced from woody biomass decreases to below 50% of the price as of 2013. Regarding Factor (g), the biomass business providers need to collect more than 74 thousand ton/year of wood for electricity generation. In particular, domestic virgin timber should be collected of higher priority because the price of the electricity generated from virgin timber (33.6 JPY/kWh) is higher than that from wood residue (25.2 JPY/kWh). One promising measure for increasing the amount of collected domestic virgin timber is to incentivize domestic wood producers by paying more procurement cost (see Factor (g) in Figure 2). Figure 7 describes the influence of wood procurement cost on the annual profit when the annual amount of collected domestic virgin timber for electricity generation is fixed at 90 thousand ton/year. While the wood procurement cost in Scenario B is 4.0 JPY/kg (see Table 2), the marginal wood procurement cost is 15.8 JPY/kg to keep the business profitable.

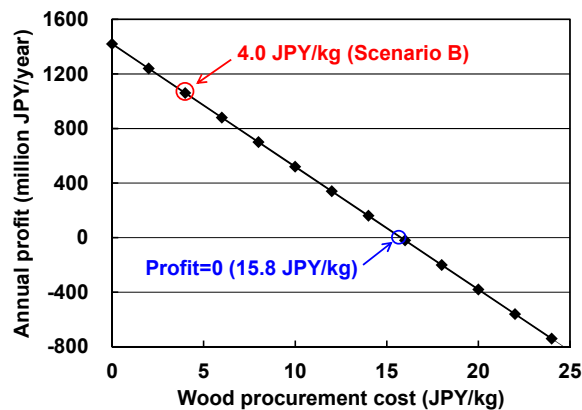


Figure 7. Influence of wood procurement cost on the annual profit

In this way, the proposed method is useful for identifying key driving and inhibiting factors, which helps business providers come up with possible actions for realizing an economically sustainable business. We believe that the 5-step procedures for conducting scenario analysis, which are shown in Section 3.1, are applicable to other renewable energy businesses for clarifying conditions for sustainable energy businesses, if necessary data is available. The method and the case study regarding the design of renewable energy businesses, which were demonstrated in this paper, would contribute to expanding a new academic field in design for sustainability.

However, in order to design sustainable renewable energy businesses in a holistic way, it is needed to combine quantitative analysis and narrative stories because not all the factors of the businesses can be quantified in our model. For example, there are many possible ways to increase the annual amount of collected domestic virgin timbers other than paying additional wood procurement cost. These include indirect and delayed factors, such as developing forest roads to carry wood more efficiently and teaching forest management skills especially to younger generations. Describing such narrative scenarios based on quantitative analysis using the simulation model developed in the paper is one of our future issues.

## 6. Conclusions

Toward designing sustainable energy businesses, we proposed a method for modeling renewable energy businesses based on the concept of life cycle simulation (LCS). The case study of the woody biomass energy business in Maniwa City revealed that the energy business using wood residues and domestic virgin timbers becomes economically feasible if the current FIT scheme is maintained and an abundant amount of wood is collected for producing wood pellet and electricity. In addition, the usage

of wood residues for producing wood pellet and electricity results in reducing the disposal cost compared to directly landfill them. Future issues include collecting more data for improving the accuracy of the evaluation results.

## Acknowledgement

The authors are grateful to Maniwa City for providing indispensable dataset to carry out the case study described in the paper.

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