P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol. 26 No.1 January - March 2021
Page: [18-29]

Original research article

Multi-Period Inventory Models with Synchronized Stages of Bamboo Biomass Planning for Small Power Plant

Praephun Pongtaveesub[1], Prachya Boonprasurt[2,*]

[1]*Department of Organization Transformation, Carabao Group Public Co., Ltd., Bangkok 10500, Thailand*
[2]*Department of Mathematics and Statistics, Faculty of Science and Technology, Thammasat University, Pathum Thani 12120, Thailand*

Received 30 October 2019; Received in revised form 8 June 2020
Accepted 4 December 2020; Available online 16 March 2021

ABSTRACT

The use of renewable energy sources is becoming the Thailand government's mainstream policy. Energy production from biomass is one of the efficient choices in the policy framework due to the agricultural geography advantage and its high-energy outputs to replace the conventional fossil fuel energy sources. However, some problems in this industry have been found such as raw material shortage in some periods, moisture content, or price fluctuation. This paper is focused on inventory management dealing with a moisture content affected by seasonal variation, so the multi-period inventory models with synchronized stages are proposed. This consists of two sub models: 1) the periodic production lot-size model at the pre-drying stage providing the biomass feedstock for gasification and 2) the periodic EOQ (the economic order quantity model) for raw material management which is related to support the demand from the gasification drying stage. Nevertheless, the scope of the study is focused on the small local biomass power plant with capacity up to 3 MWh (megawatt-hour), and the raw material, bamboo-biomass, is considered for the study. The test problem shows the results of the inventory management and the character of synchronized stages inventory movement including the total economic cost.

Keywords: Biomass; Bamboo; Gasification; Periodic inventory; Seasonality

1. Introduction

For the past decade, electricity consumption has been rapidly increasing due to the economic growth, especially in Asia, but in the opposite direction, the power supply is still limited. Oil, gas, or coal are conventionally used for power generation. However, the fluctuation of oil and gas prices, including the decrease of the world's oil reserves, is highly volatile and tends to

*Corresponding author: prachya@tu.ac.th
doi: 10.14456/scitechasia.2021.3

gradually increase. Thus, the development of renewable energy generation from solar, wind, or biomass is a very important approach and their applications have been steadily growing.

Biomass used for energy production is the most common form of renewable energy that can be derived from the agriculture waste such as rice hulls or from agriproduct processing. Biomass can provide high-energy outputs to replace conventional fossil fuel energy sources, and it is widely used in the developing countries but less often in the western countries due to the limited natural resources. Therefore, utilization of biomass in bioenergy production is the beneficial alternative to support the increase of energy demand and the global warming policy.

To drive the economic growth in Thailand, energy security and sustainable economic development must be built in parallel. In accordance with the framework for determining the proportion of fuel in electricity production of the power development plan of Thailand (2015-2036) [1], it is stated that the proportion of electricity produced from renewable energy is between 15% to 20% by 2036. It is also noted that the group of power producers from renewable energy, especially in solar and biomass, is currently receiving high interest with a gap of 3,343.74 and 2,565.32 megawatts (MW), respectively [2].

In Thailand, electricity production from biomass has also been promoted domestically for renewable energy since there is the potential to bring natural resources from the remaining agricultural material or waste such as rice husk, bagasse, palm bunch, rice straw, etc. [3]. However, problems such as material quality, price jump, uncertain supply (due to seasonal growth or changing type of crops according to market demand), or high moisture content have restrained the investment in the biomass power generation industry. Furthermore, the industry has been confronted with the lack of stationary zones that causes the competition for raw materials in the area including the cost of biomass raw materials which have been rising over the past several years.

One of the crucial parts in biomass operations is the requirement of the raw material treatment prior to feeding into power generation processes. The moisture content of raw materials affects the efficiency of biomass power operations, especially for biomass gasification systems that require low moisture content (not more than 20%). Basically, the productivity depends on the moisture content which affects the energy conversion process and the form in which the energy is required. It is noted that any biomass power plants are practically supposed to respond the consistent rate of electricity supply.

Furthermore, much attention has been focused lately on identifying suitable biomass species which significantly affect the energy output. In this research, bamboo is properly selected as the main raw material in the study. It is a marvelous plant that can be grown in any season and provides a high heating value. There are varieties which provide large quantities of biomass, and all parts of the tree are suitable for use in producing biomass energy. Additionally, it is environmentally friendly and slows soil erosion.

The government policy which encourages each subdistrict community to generate electricity from biomass for local use will increase household revenues from local biomass agriculture and decrease domestic fossil fuel consumption. However, the efficiency of the biomass power generation processes is affected by the moisture content of biomass. Not only are raw materials required to reduce moisture to reach a specific value, but there is a material weight loss during the treatment. Furthermore, the treatment requires a processing area, time, and inventory management, so the interrelationship of inventory management between the period of the raw material procurement and the moisture reduction is crucial for the 24-hour operations.

Consequently, this research is interested in studying the inventory planning for a small biomass power plant (not more than 3 MWh) with the gasification system. Basically, managing raw materials for a small biomass power plant is more agile than a midsize or large biomass power plant. Furthermore, the advantages of the local management are the sufficiency of raw material supplies from the local planned crop, lower transportation costs, and better raw material quality control. Additionally, the research intention is to develop the inventory models for two synchronized management stages namely, the moisture treatment and the preparation of the raw material supply.

Firstly, the inventory planning is for the treatment period to remove the excess moisture from the biomass (called the pre-drying process) which is the pre-process requirement before the gasification. The moisture treatment is required to adequately prepare the raw material that is suitable for each type of gasification and leads to a high conversion efficiency and high heating value of syngas product [4]. Note that the first process of gasification system is called the drying process which requires the proper moisture content (about 5%-20%) of the treated materials derived from the pre-drying process.

Next, the other inventory planning is for the raw material supply period by the time the raw material is fed to the pre-drying process for the moisture treatment. The treatment output and the raw material inventory is proportionally increased and decreased, respectively, at the same time.

However, due to the weather conditions in the tropical zone, raw materials have moisture variation according to the weather period. Thus, the objective of the research is to propose multi-period inventory models with the synchronized stages to manage the raw material preparation in the small biomass power plant with the gasification system by using bamboo biomass as the case study. It is noted that the principles of the economic production lot-size model and EOQ (the economic order quantity model) are applied to develop the models in the pre-drying stage and the raw material supply stage, respectively.

The results of the study are expected to indicate the significant details of the local inventory management which affect the investment planning for community enterprise or SME investors, especially in the tropical zone countries.

2. Bamboo-Biomass Inventory Planning for Biomass Gasification

2.1 Bamboo-biomass: basic information

Biomass is an organic matter that can be processed to become energy. Energy production can be derived from the agriculture waste or from agriproduct processing. Common examples are food crops, energy crops (e.g., switchgrass or prairie perennials), crop residues (e.g. corn stover), wood waste, and animal manure [5]. The biomass-based applications in Asia such as India and Southeast Asia have been increasing significantly due to the advantage of agricultural geography. There is a review of the biomass supply chain in Asian and European countries which summarizes the potential of various categories of biomass [6].

In addition, there are many varieties of biomass that provide different heating values, sizes, moisture content, and chemical composition. Some properties of biomass samples [7] are shown in the table below.

Bamboo is the fast-growing grass-family evergreen with the large stem. In tropical countries, it is easy to cultivate bamboos and they are very well adaptive to every area. Furthermore, the biomass weight of bamboo per area unit yields more than other plants compared to the same growing period [8-9].

Furthermore, the water consumption rate of bamboo is lower when compared with the rice crop. In an environmental view, bamboo produces 35% more oxygen than any other plants [10]. From the above table, Beechey bamboo and Rough Giant bamboo have the relatively high heating value. Furthermore, the average growth rate is 30 centimeters per day which is faster than the other biomass growth rates [11].

By using bamboo-biomass type for power generation with the gasification system, the research in India shows that the testing bamboo sample yields 16 MJ/kg (megajoule per kilogram) of the heating value at 13% moisture content [12]. This means that bamboo is the good raw material when compared to others. Furthermore, there is about 5% of ashes remaining after processing. Some properties of the bamboo parts [7] are shown in Table 1.

Table 1. Properties of the bamboo parts.

Bamboo part	Moisture (H_2O%)	Production (O_2%)	Absorption (CO_2%)	Ashes (%)	Heating Value (MJ/kg)
Tip stem	13.7	79.6	15.6	5.2	16.2
Middle stem	13.5	80.5	15.6	3.9	15.5
Bottom stem	13.0	80.6	14.9	4.5	15.8
Under soil part	11.1	79.8	15.9	4.3	-

2.2 Basic information of biomass gasification systems

There are two main processes for transforming agriculture raw material or waste into biomass for energy production: biological and thermochemical [13].

1. The biological process is based on microbes used by the operator to covert raw materials into biomass. The process is complicated in both operation control and management of microbe circumstances. It is claimed to be less efficient than another one.

2. The thermochemical process is the conversion process of solid biomass via gasification. It is mainly composed of pyrolysis, combustion, and gasification.

In this section, the concepts of energy conversion technologies are briefly reviewed for the particular gasification technologies. The biomass gasification is a process of converting solid biomass into a gaseous combustible gas through a sequence of thermo-chemical reactions. The product is so-called synthesis gas or syngas which mainly are carbon monoxide, hydrogen and carbon dioxide. Syngas can be used to generate heat and power. This is achieved by reacting the material at high temperatures (> 700 °C).

The advantage of syngas from the gasification is being more efficient than the direct combustion due to the higher temperature combustion. Thus, it is considered as a key technology for the current bioenergy production due to the technological consistency, high efficiency, and cost effectiveness [14].

The downdraft gasifier system is considered in this paper because the producer gas is a proper usability for an engine combustion. Thus, it is of interest for biomass syngas power plants in generating electricity. It is noted that the main advantage of this system is in the possibility of producing a tar-free gas which is suitable for engine applications. However, low moisture biomass is required, while ashes produced from the processes are at the low level. The quality of producer gas resulting from these processes is clean [15].

The main processes of gasification can be separated into 5 stages, namely 1) drying: driving off water with heat, 2) pyrolysis: heating without air to make charcoal, 3) combustion and 4) cracking: adding air to burn and crack tar gases, and 5) reduction: converting charcoal to flammable gas [16]. After that, the produced gas is burned inside and drives a generator to generate electricity.

2.3 Seasonal factors and inventory management

Due to the seasonal variation, the moisture content is one of the key factors for the periodic raw material or inventory management. As demand and supply are seasonally fluctuated in the food industry, the dynamic (two-phase) inventory model is devised to prepare the material according to climate variation [17]. The demand seasonality also affects retailers. The study provides the insight impact of incorporating demand seasonality in a retail replenishment system [18]. Inventory management for a seasonal agriculture product is challenging. A wholesaler has to decide the optimal purchase and the quantity to retrieve from the control storage in each period to sell to the market; thus, a multi period dynamics programming model is proposed for the study [19].

However, few articles are proposed for biomass inventory management. The deficiency of debottlenecking biomass supply chain resources is considered as an optimization modelling which concerns the fluctuation of supply availability. It shows the integration of element targeting in supply chain and multi-period analysis. The model application improves process feed selection and biomass utilization [20]. The multi-lot-size production inventory is also developed for deteriorating items with constant production and demand rate [21]. Yet, there is only one case study of bamboo biomass periodic inventory management found [22].

To design and operate a biomass supply chain, the simulation model is developed for two inventory systems, incorporating demand fulfillment and order quantity in a complex and dynamic natural environment [23]. In addition, an example of practical application of raw material management can be found in the case study of a small power plant in Prachin Buri province (Thailand) [24].

Moisture content of raw material is the biomass gasification crucial point. The original moisture content must be decreased to at least 20% for being the proper feedstock in the next process. It is noted that in this research the wet weight refers to the fresh weight of raw materials, and the product from the pre-drying process (the raw material that lost some weight) is called the dry weight.

In the industrial application, it is convenient to report the moisture content (%) on the basis of wet weight (or total weight). In practical terms the moisture content referred to in this research is the extrinsic moisture content whose value is the influence of prevailing weather conditions after the harvest.

In addition, in finding the mass of materials, the formula is presented as the difference ratio between the wet weight and the dry weight (the remaining weight after drying) [25]. For instance, if there is a 1 kg of wet weight where the moisture content is at 60%, the weight after drying with all moisture loss is 0.4 kg. As follows, if 20% of moisture content of dry weight is required (40% loss of moisture content), so the new dry weight is 0.6 kg.

Basically, the material supply for gasification is the weight after the pre-drying process. It is also definitely required at the constant rate supply to generate the electricity accordingly. However, the moisture content of the material is varied by season, so this affects the mass of the material.

Let d_r be a drying ratio for which 1% moisture loss from a kilogram of a wet weight input (hour /% moisture loss/kg), so it can be shown that a time spent to repel some moisture content to reach at the fixed moisture percentage is $d_r(h-H)$ where h is a moisture percentage of the raw material (wet weight) and H is a specified moisture percentage of dry weight required for gasification. Therefore the production rate (kg/hour), P_H^h , of h% initial moisture content of wet weight input with H% required moisture content output is introduced as follows:

$$P_H^h = \frac{1}{d_r}\left(\frac{1}{h-H} - 0.001\right) \qquad (1)$$

It is also noted that the value of the drying ratio (d_r) depends on a technical capacity in a pre-drying process. The examples of the drying contents are shown in Table 2 below.

Table 2. Sample of drying contents at specified 15% moisture of dry weight output for 1 kg (wet weight) input with $d_r = 0.007$.

Initial moisture (%)	Moisture loss (%)	Dry weight (kg/1 kg input)	Drying time (hour)	Production rate (kg/hour)
16	1	0.99	0.007 (25.2 sec.)	141.43
40	25	0.75	0.175 (10.5 min.)	4.29
67	52	0.48	0.364 (21.8 min.)	1.32

Based on the average of heat value of a kilogram of dry wood-biomass (moisture content about 13-17%) which is 18.6 MJ/kg, it can be converted to 1 kilowatt-hour (kWh) [26]. However, referring to this ratio, about 1.1847 kg of Beechey bamboo (heating value = 15.7 MJ/kg from Table 3) can be converted to 1 kWh.

Table 3. Example of biomass properties.

Biomass type	Moisture (H_2O%)	Ashes (%)	Volatile (%)	Fix carbon (%)	Heating Value (MJ/kg)
Beechey bamboo	14.30	3.70	63.10	18.90	15.70
Rough giant bamboo	5.80	2.70	71.70	19.80	17.59
Rice husk	12.05	12.73	56.98	18.88	14.64
Rice straw	10.12	10.42	60.87	18.80	13.28
Hevea wood	45.32	1.70	45.67	7.71	10.11
Corncob	40.11	0.95	45.55	13.68	11.20
Eucalyptus bark	60.09	2.33	28.02	9.56	6.72

Note: MJ/kg is megajoules per kilogram

Assume that the bamboo biomass has 60% of moisture content while waiting for supply to the pre-drying process. The output from the process specifically requiring the 15% of moisture content and 100 kWh of electricity must be generated from a biomass power plant.

It can be calculated that 118.47 kg/hour is produced to supply the gasification, or (the production rate) $P_H^h = 118.47$ kg/hour.

According to this sample value, it can be also noted that 171.78 kg/hour is the requirement for the raw material input (wet weight). Furthermore, the production rate relatively depends on the drying ratio, so the minimum proper drying ratio which is related to drying capacity in this example can then be presented as $d_r = 7.12x10^{-5}$.

3. Problem Formulation

Due to the pre-process of gasification in the meaning of moisture treatment (pre-drying process) and economic order quantity dealing with suppliers, two models related to these processes are developed. The first model is introduced as the periodic economic production lot-size model. A set of raw material from a warehouse having a high moisture content is fed into the evaporation process. It is completed when the moisture content of materials has reached a certain value. This is specifically before continuing to the first step of the gasification. Thus, the holding cost of the treated materials, the set-up cost, and the production cost of the pre-drying process are considered as the total cost in this stage.

Next, the second model is involved with the raw materials planning which is sufficiently supplied to the pre-drying stage during each production in every period. Therefore, the synchronized periodic EOQ is introduced for a biomass utilization during both production and non-production runs in each period. The holding, ordering, and raw material costs are considered as the total cost of this model.

Furthermore, bamboo is considered to be the main biomass in this research for power generation by the gasification processes. However, its moisture content is rather high. Basically, the higher the moisture content the higher the material consumption rate that is required to reach the same target. It is also noted that the moisture content at period i is presented by an average value of its interval.

To develop the models, the average values are introduced with some of the factors, and the assumptions are stated as follows:

1.Supply for raw material is unlimited and constant.

2.The raw material cost has seasonal variation.

3.The demand for gasification is constant at all times.

4.Moisture content of the raw material at period i is constant and is determined by the ordering date.

5.The transportation cost per unit weight is constant.

6.The number of a lot-sized cycle time at period i is not necessary to fit in that period date due to the 24-hour operations, and it can be crossed to the beginning of the next period.

In addition, when considering the relation in a period between a raw material remaining quantity in model 2 and treated product (dry weight material) increment in model 1, it is reciprocal. Fig. 1 shows the relationship as mentioned.

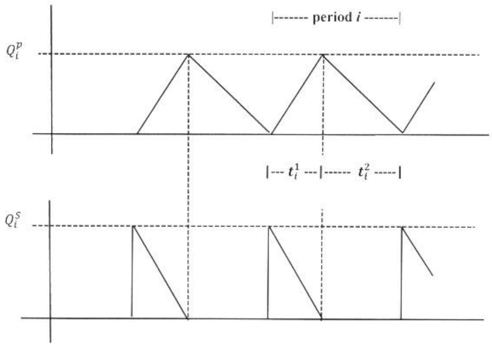

Fig. 1. Synchronized periodic inventory for pre-drying lot-size production and EOQ.

3.1 Model 1: The periodic economic production lot-size model at the pre-drying stage

Parameters:

t_i^1 number of days during a production run at period i

t_i^2 number of days during a non-production run at period i

p_i daily production rate at period i (kg/day)

d^p daily demand (dry weight) at pre-drying stage (kg/day)

T number of working days per year

T_i number of working days at period i

h_i moisture content of the raw material (wet weight) at period i (%)

H fixed moisture content of dry weight required for gasification (%)

n the number of periods in a year

C_h^p annual holding cost (Baht/unit)

C_o^p set up cost per production run (Baht)

C_i^p production cost at H% moisture required at period i (Baht/kg)

Variable:

Q_i^p the production lot size quantity (dry weight) at period i (kg)

Referring to the production rate in the lot-size inventory model, the maximum inventory level at period i can be shown as $(1-d^p/p_i)Q_i^p$. The annual holding cost can be formulated as

$$\frac{1}{2T}C_h^p\sum_{i=1}^{n}(1-\frac{d^p}{p_i})Q_i^pT_i \tag{2}$$

Since the setup cost per production run is assumed to be constant for every period and the number of production runs (or the number of cycle time) at period i is d^pT_i/Q_i^p, so the annual setup cost is represented by

$$d^pC_o^p\sum_{i=1}^{n}\frac{T_i}{Q_i^p} \tag{3}$$

Finally, the production cost, which is varied by the moisture content for each period, is considered. Basically, more moisture content means a longer treatment time is used to receive a dry weight material at the same certain moisture content per weight unit. As follows, the production cost at period i is the multiplication of the dry weight material and the production cost per unit. Thus, the total production cost is

$$d^{p}\sum_{i=1}^{n}T_i C_i^{p} \qquad (4)$$

In this paper, only the holding, ordering, and production cost are considered as variable costs. Thus, the total inventory cost can be derived from the summation of (2) through (4). The objective of this model is to find the minimum total cost. It means that the minimum periodic production lot-size quantity denoted by Q_i^{p*} is required. By using the differential calculus, the economic production is formulated as follows,

$$Q_i^{p*}=\sqrt{2d^{p}\,TC_o^{p}\Big/\left(1-\frac{d^{p}}{p_i}\right)C_h^{p}} \qquad (5)$$

3.2 Model 2: The periodic EOQ model for raw material management

Parameters (addition):

- d_i^s average daily demand for raw material (wet weight) at period i (kg)
- C_h^s annual holding cost (Baht/kg)
- C_o^s ordering cost per production run (Baht)
- C_i^s raw material cost of at period i (Baht/kg)

Variable (addition):

- Q_i^s the order quantity of raw material at period i (kg)

The cycle time at period i for the raw material order quantity is derived from the pre-drying stage as shown in Fig. 1 above. A raw material quantity in a cycle at period i should conform to the production time in model 1, and the non-production time is related to a stock-out period in a cycle.

As a result of these, the average inventory level at period i for this model is $\frac{t_i^1}{2}\left(\frac{Q_i^s}{t_i^1+t_i^2}\right)$. Therefore, the annual holding cost is presented as

$$\frac{1}{2T}C_h^s\sum_{i=1}^{n}\left(\frac{t_i^2}{t_i^1+t_i^2}\right)T_iQ_i^s \qquad (6)$$

Next, finding the ordering cost is to consider the number of orders for each period. However, the raw material demand is converted from dry weight after the pre-drying process which is referred to the demand in model 1. Since h_i-H is a percentage of moisture loss, then $1-\left(\frac{h_i-H}{100}\right)$ is the ratio of dry weight to the wet weight. It is noted that H could be set as the minimax percentage value of the acceptable moisture level for the gasifier system. Since $d_i^s=d^{p}t_i^1\big/(t_i^1+t_i^2)$, the annual ordering cost is presented as

$$C_o^s\sum_{i=1}^{n}\frac{d_i^sT_i}{Q_i^s}\left(1-\frac{h_i-H}{100}\right)^{-1} \qquad (7)$$

Finally, the raw material cost is also considered in this model, and the seasonal humidity affects the variation of materials cost. The higher the moisture content of the material the lower the price is dealt at the same weight, but it is not at the exact ratio.

Basically, the raw material cost at period i is the multiplication of the number of an order quantity and the material cost per unit at period i, so the annual raw material cost is

$$\sum_{i=1}^{n}\left(\frac{T_i}{t_i^1+t_i^2}\right)C_i^sQ_i^s \qquad (8)$$

In conclusion, the total annual cost under the research assumption is the summation of (6)-(8). Furthermore, let Q_i^{s*}

be the optimal order quantity at period i, the formula is also given by

$$Q_i^{s*} = \sqrt{\frac{d_i^s T_i C_o^s \left(1 - \frac{h_i - H}{100}\right)^{-1}}{\left(\frac{T_i}{t_i^1 + t_i^2}\right)\left(\frac{t_i^1}{2T} C_h^s + C_i^s\right)}} \qquad (9)$$

4. Numerical Results and Discussion

The seasonal periods in Thailand, which are winter, summer, and rainy season, are assumed in the test problem. The biomass power plant up to 1 MWh capacity in the biomass gasification system with 24-hours operation is discussed for the multi-period inventory models with synchronized stages. Furthermore, the moisture content of the material required for the gasification in this paper is fixed to 15%.

Assume the daily dry weight demand (d^p) of bamboos to feed the 1 kWh biomass with constant rate is 1.19 kg/hour or theoretically 28.56 ton/day for 1 MWh. Therefore, the capacity of the pre-drying process must support enough fresh raw material (wet weight) for feeding into the gasification processes. It is also assumed that maximum moisture content of bamboos is not more than 70%, so the maximum drying capacity supporting the sufficient productivity is related to the drying ratio (d_r) and is set to be $4.52x10^{-6}$ for this test problem. Note that, to receive 1.19 kg/hour of dry weight, the minimum capacity of the production rate (P_H^h) to reduce the moisture content related from 70% down to 15% to the drying ratio theoretically requires 1,810 kg/hour of wet weight.

The holding cost for both models is 25% of material cost used in its stage. The ordering cost to order the fresh raw material is 500 Baht per order. However, in the pre-drying stage, the set-up cost is 800 Baht per production run. The additional data is also shown in the Table 4.

Table 4. Technical data for 1MWh power plant in the biomass gasification system.

No.	content	seasonal period		
		winter	summer	rainy
1	number of day in season*	122	90	153
2	raw material cost (Baht/kg)	0.87	1.00	0.62
3	moisture content of raw material (%)	55	50	67
4	delivery lead time (day)	10	8	15
5	production (pre-drying) rate (kg/hour)	3,319	4,109	2,043
6	(wet) raw material required (kg/hour)	4,646	5,547	3,105
7	production (pre-drying) cost (Baht/kg)	0.135	0.121	0.162

Note: * refer to Meteorological Department of Thailand

Based on the equations in the previous section, the results are summarized in Tables 5 and 6. The economic order or production quantities which are related to the number of cycle time (the amount of raw material ordered or the number of production runs) and affected by seasonal moisture content are presented. The number of cycles in each season is also different and may be a non-integer because of the 24-hour operations. However, the number of cycles is set for the daily unit, so a cycle is counted when the operations period is started.

In addition, summer is set as the baseline for the comparison due to the lowest moisture content. It is found that the number of cycle time in each period is nearly the same range, but the production run times are much different between winter-summer and rainy season (about 2 times difference).

In winter-summer season period, the total holding and setup cost is decreased by 26.5% but increased by 50.8% in summer-rainy season period, whereas the total holding and ordering cost at the raw material order stage is decreased by 18.3% and increased by 34.5% respectively.

It is noted that the production cost of the pre-drying process is varied by the time to evaporate moisture from the raw material and its cost is varied by the market tradition at each region. However, based on this test problem, the overall costs are 13,475,299.60 Baht. When considering the partial total cost between summer and rainy seasons, the increase is 27.7%.

Table 5. Results of seasonal inventory planning at pre-drying stage.

No.	content	seasonal period		
		winter	summer	rainy
1	economic production quantity Q_i^{p*} (kg)	877,768	881,008	993,426
2	the number of production runs	4.0 (4)	2.9 (3)	4.4 (5)
3	cycle time (production time)(day)	30.73 (11.0)	30.85 (8.9)	34.78 (20.3)
4	total cost (Baht)	476,734.44	315,686.51	714,925.91
	(holding + setup)	(6,351.24)	(4,668.11)	(7,037.75)
	(production)	(470,383.20)	(311,018.40)	(707,888.16)

Table 6. Results of seasonal inventory planning for raw material order stage.

No.	content	seasonal period		
		winter	summer	rainy
1	economic quantity order Q_i^{s*} (kg)	1,228,874.92	1,189,360.72	1,510,007.64
2	reorder date in the cycle (reorder point)	20 (0)	22 (0)	19 (36,119)
3	total cost (Baht)	4,290,555.28	3,508,157.16	4,169,240.29
	(holding + ordering)	(46,653.52)	(38,117.16)	(51,253.86)
	(raw material)	(4,243,901.76)	(3,470,040.00)	(4,117,986.43)

5. Conclusion

Tropical countries such as Thailand are dominated by the highly humid weather conditions. The advantage is that there is abundance of agricultural resources (including agricultural waste) for biomass, but it comes with high moisture content due to seasonal variation. To generate power from biomass, the gasification system is the efficient technology widely used in biomass power generation industry. However, the processes require biomass with low moisture content (not more than 20%).

The bamboo-biomass is considered as the raw material in the research because of its high heating value, high growth rate, moderate cost, and relatively small cultivated area. These factors are suitable for the inventory planning of a small biomass power plant (3 MWh or less). The research proposes multi-period inventory models which are related to bamboo-biomass supply and production lot- size pre-drying treatment which are simultaneously operated.

The sufficient and constant supply of dry material (output from pre-drying stage) is strictly demanded to feed the gasification for 24-hour operating power generation. The noteworthiness of the study is the variation of the material moisture content for each period (or season). The study result is useful as concerned issues for moisture variations in the tropical zone countries such as inventory cost analysis, sufficient material supply, and proportional area of warehouse to benefit for an investment planning in the industry.

Furthermore, if the community enterprise or the cooperative platform applies with the investment in the small local biomass power plant, the sustainable community economy and the household revenue are the crucial strategic points that could be developed by good management planning and the best practices. Thus, it is expected that the contribution of this article may be considered as the guideline of the local raw material management which directly affects the production efficiency in the long run.

In a future study, more factors will be considered to develop more sophisticated models such as the transportation cost and condition related to the cultivated perimeter, or the limited inventory area.

Acknowledgements

This research study is academically supported by Faculty of Science and Technology, Thammasat University, Thailand.

References

[1] Ministry of Energy. Power development plan [internet]. [cited 2020 Jan 5]. Available from: http://www.eppo.go.th/images/POLICY/PDF/PDP_TH.pdf.

[2] Government Savings Bank. Sunrise-Sunset Industry 2018 [internet]. [cited 2020 Jan 5]. Available from: https://www.gsb.or.th/getattachment/982fc458-e1c8-4c25-aabe-7e3844481865/IN_eco_61_detail.aspx.

[3] National Reform Steering Assembly. Fast-growing tree promotion to supply biomass power energy production: Local economy stimulation for agriculturist, Reforestation, and Energy security [internet]. [cited 2018 Apr 3]. Available from: https://www.parliament.go.th/ewtcommittee/ewt/drive_energy/download/article/article_20171017151441.pdf.

[4] Gasification: user manual. Bioenergy and food security rapid appraisal (bees Ra). FAO 2014 [cited 2018 Apr 5]. Available from: http://www.fao.org/3/a-bp852e.pdf

[5] Bracmort K. Biomass: Comparison of definitionsin legislation. Congressional Research Service [Internet]. [cited 2018 Dec 19]. Available from: http://www.nationalaglawcenter.org/wp-content/uploads/assets/crs/R40529.pdf

[6] Raychaudhuri A, Ghosh S K. Biomass supply chain in Asia and European countries. Procedia Environmental Sciences 2016; 35:914-24.

[7] Sritong C. Management innovation of bamboo as raw material for small power plants in Thailand [Ph.D. thesis]. Bangkok: Chulalongkorn University: 2013.

[8] Phuangchik T. Activated Carbon from Bamboo: Does the Market have a High Demand? Journal of Science and Technology, Thammasat University; 2015; 23(6):945-54.

[9] Bunnag S, Phuangchik T, Boonyuen S. The energy quality of Kim Sung bamboo (Bambusa beecheyana) at different growing ages. Thai Journal of Science and Technology 2019; 8(3):250-57.

[10] Phuangchik T, Ruensuk P, Jirakiattikul Y. Study on growth of four bamboo varieties. Thai Journal of Science and Technology 2015; 4.3:302-09.

[11] Shanmughavel P, Francis K. Above ground biomass production and nutrient distribution in growing bamboo (Bambusa bambos (L.) Voss). Biomass and Bioenergy 1996; 10.5-6: 383-91.

[12] Arunachalam A, Arunachalam K. Evaluation of bamboos in eco-restoration of 'jhum' fallows in Arunachal Pradesh: ground vegetation, soil and microbial biomass. Forest Ecology and Management 2002 ; 159.3:231-39.

[13] Chutichai B, Arpornwichanop A. Electric power from biomass gasification. Technology Promotion and INNOMag 2013; 39.227:45-8. [cited 2020 May 20]. Available from: http://www.tpa.or.th/publisher/pdfFileDownloadS/tn227a_p045-48.pdf.

[14] Heidenreich, S, Foscolo P U. New concepts in biomass gasification. Progress in energy and combustion science 2015; 46: 72-95.

[15] Teri: The energy and resource institute. Biomass gasifier for thermal and power applications [internet]. [cited 2019 Jan 23]. Available from: https://www.teriin.Org/technology/biomass-gasifier-for thermal-and-power-applications.

[16] All Power Labs: Carbon Negative Power & Products. How Gasification Works [internet]. [cited 2019 May 7]. Available from: http://

www.allpowerlabs.com/gasification-explained.

[17] Shin M, Lee H, Ryu K, Cho Y, Son Y J. A two-phased perishable inventory model for production planning in a food industry. Computers & Industrial Engineering 2019; 133; 175-85.

[18] Ehrenthal J C F, Honhon, D, Woensel T. Demand seasonality in retail inventory management. European Journal of Operational Research 2014; 238.2; 527-39.

[19] Liu H, Zhang J, Zhou C, Ru, Y. Optimal purchase and inventory retrieval policies for perishable seasonal agricultural products. Omega 2018; 79: 133-45.

[20] Lim C H, How B S, Ng W P Q, Lam H L. Debottlenecking of biomass element deficiency in a multiperiod supply chain system via element targeting approach. Journal of Cleaner Production 2019; 230:751-66.

[21] Yang P C, Wee H M. An integrated multi-lot-size production inventory model for deteriorating item. Computers & Operations Research 2003; 30.5: 671-82.

[22] Logistic Management NIDA: Periodic inventory management for bamboo biomass power plant [internet]. [cited 2019 Oct 2]. Available from: http://logistics.nida.ac.th/biomass/.

[23] Akhtari S, Sowlati, T, Siller-Benitez, D G, Roeser D. Impact of inventory management on demand fulfilment, cost and emission of forest-based biomass supply chains using simulation modelling. Biosystems engineering 2019; 178:184-99.

[24] Sangnin S, Kantangkul P. Raw material management for very small power producer biomass power plant: a case study in Prachin Buri province. Kasetsart Engineering Journal 2017; 30.102: 37-46.

[25] Cornell composting science & engineering. Moisture content [Internet]. [cited 2018 Oct 3]. Available from: http://compost.css.cornell.edu/calc/moisture_content.html

[26] Mckendry P. Energy production from biomass (part 1): overview of biomass. Bioresource Technology 2002; 83.1: 37-46