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Feedstock Security Analysis for Wood Pellet Production in Thailand

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Abstract: Thailand is one of the upcoming wood pellet exporters in the Southeast Asia region. Wood pellet production has been gradually increasing in Thailand; however, the recent trend is more rapid. Therefore, the objective of this study is to analyze the feedstock security for wood pellet production in Thailand. The important issue of feedstock security analysis relates to availability and diversity of feedstock (Shannon index) to meet the increased demand for the wood pellets in the future. The results present that the feedstock supply (from waste wood and fast-growing tree wood) in Thailand is 5.32 million tonnes of wood pellets per year. However, increasing 25% of wood pellet export and 50% of wood pellet domestic use causes a deficit in fast-growing tree wood because para-rubber waste wood is not distributed uniformly in all regions of the country. The present diversity of feedstock supply is quite low (Shannon index 0.17). Increasing the fast-growing tree plantation area in the wastelands could help increase diversity. Recommendations on policy from this study focus on encouragement for the increase in domestic use of wood pellets, cultivation of fast-growing trees in wasteland and optimized logistics management.

Keywords: feedstock security; fast-growing tree; para-rubber tree; wood pellets; Thailand

1. Introduction

The use of biomass as renewable energy is broadly accepted for substituting fossil fuels [1]. Wood pellets are solid fuels made from biomass, especially waste wood. The wood pellets are bio-based products utilized for heat and electricity production in several countries [2]. Future forecast of global wood pellet demand predicts a significant increase up to 54 million tonnes in 2024 (40% demand for the heating pellet market and 60% demand for the industrial pellet market) [3]. The wood pellet demand depends on policies, weather and the price of fossil fuels. In 2018, about 52.7 million tonnes of the wood pellets were produced, including 17.7 million tonnes from China [4]. The growth rate average of the global wood pellet market is 11.6% annually (in 2012–2018) [3]. In Asia, South Korea and Japan have a huge potential demand for the wood pellet industry. South Korea presented a wood pellet demand of around 2.88 million tonnes for electricity production in 2020 [5]. The wood pellet demand in Japan will increase to 5.8 million tonnes in 2030 because the Japanese government plans to partially substitute coal with industrial wood pellets [6]. The main supplier of Japan was Vietnam in 2019 (Canada in 2018) [3].

Thailand exported 172,441 tonnes of wood pellets in 2019. The major importers of wood pellets from Thailand are South Korea and Japan. The wood pellet production of Thailand is expected to rise because of increasing import from Japan [7]. The trend of domestic use in Thailand became enhanced with encouragement from the Thai government, with policies such as supporting 30% to 50% of the cost of modifying existing factory boilers to be able to utilize wood pellets [8]. The Thai government presented the goal of biomass use in the Alternative Energy Development Plan (AEDP2015) of Thailand to produce 5570 MW of renewable energy [9]. However, the Thai government does not support using wood pellets for electricity production because biomass power plants in Thailand use wood chips or other biomass substitutes [10]. Wood chips are cheaper than wood pellets in Thailand; however, there is often a shortage of wood chips in the rainy season.

The raw material for wood pellet production of Thailand is waste wood from para-rubber and economic wood (EW), including fast-growing trees (FGTs). Most of the raw material is para-rubber wood, which is abundant in the south of Thailand. Rubber trees are cut at the age of 25 years because the yield of latex is reduced. About 8 million tonnes (dry weight) of para-rubber waste wood is collected from cultivation and the furniture industry every year [7]. Previously, the FGTs were grown in Thailand largely for the paper industry and pillar wood for buildings. At present, they are used for renewable energy by the Forest Industry Organization (which supports 3500 THB (based on the exchange rate 31.1 THB per USD) per 0.16 ha per 3 years for plantation) [11], and Thai entrepreneurs persuade farmers to grow them in contract farming.

Feedstock security is one of the important factors for the sustainability of renewable energy from biomass [12]. Several studies have dealt with the issue of feedstock security of biofuel and bioenergy. A study was conducted regarding the potential of biomass in terrestrial ecosystems for energy production in China to solve shortage of biomass, which is barrier for the development of China's bioeconomy and bioenergy industry [13]. Thai researchers studying the security of feedstock supply for future bio-ethanol production in Thailand indicated that high-yield improvement of feedstock is necessary to satisfy the long-term demands for bio-ethanol [14]. In addition, a study on the quantification of biomass potential in India for energy and biofuel production found that energy crop and agroforestry residues are significant potential feedstock [15]. Several studies advise that the use of residues is better than the harvesting of standing trees from the point of view of environmentally friendliness [16]. The increase in yields and good management will improve short-rotation willow energy performance [17]. The findings from a study revealed that the agrotechnical factors, the type of plants and the harvest cycle affect not only the yield, but also the qualitative features of short-rotation coppice willow biomass [18]. The use of pellets and briquettes could decrease the effects of limited trucking, however, the total fuel cost could increase when compared to using only wood residues [19]. The suitable feedstock supply pattern can increase the profits of biomass plants, biomass supply amounts, and farmers' participation [20]. The pattern of different harvests affects the efficiency from an the energy yield perspective; the whole tree harvest type is significantly higher in efficiency than the stem wood without debarking harvest type [21]. Moreover, short-rotation woody crops can accomplish greenhouse gas (GHG) emission savings of over 80% when substituting conventional fossil fuels in heat and power applications [22].

Considering the above reasons, the main objective of this study is to analyze the feedstock security for wood pellet production in Thailand. The important issue of feedstock security analysis relates to availability and diversity of feedstock to be stocked enough for the increased demand of wood pellets in the future, following the domestic target and exports. Furthermore, the potential of biomass feedstock relates to energy security if the goals of energy use are focused on the decrease in fossil use. The outcome of this study will provide a new reference to future development of the renewable energy industry. Even though this study is based on the case of Thailand, the findings and insights of this study will support the management of feedstock for wood pellet production in other regions with similar climate and production conditions.

2. Materials and Methods

Important indicators for evaluating feedstock security are quantity and diversity of wood feedstocks that are sufficient to produce wood pellets to meet the demand.

2.1. Evaluation of Wood Pellet Production

Statistical data of wood pellet production in Thailand have not yet been compiled at an organized level. However, the quantity of production can be estimated considering wood pellet export and domestic use. The data of wood pellet export can be obtained from the website of the Thai customs (https://www.customs.go.th). Interviewing entrepreneurs revealed that they sell only 20% of the entire wood pellet production for domestic use. Hence, it is assumed that 80% of the wood pellet production is for export.

2.2. Sensitivity Analysis

Sensitivity analysis is a tool to analyze how the different values of an independent variable affect a specific dependent variable under certain exact assumptions. In general, its aims are to analyze the data for the decision problem and to create a necessary decision model. It is used in several fields, for example, economics, biology, geography and engineering [23,24]. In this study, sensitivity analysis is used for testing the assumptions related to the wood pellet production in Thailand. The quantity of wood pellet production can refer to the quantity of feedstock, which is one of the indicators of sustainable wood pellet production. Domestic use and exports govern the demand of wood pellet production. Hence, domestic use and export of wood pellets are important factors to evaluate the quantity of wood pellets per year. Sensitivity analyses help to calculate the minimum and maximum values of wood pellet production under demand from domestic use and export. The variation in wood pellet demand was evaluated by increasing (+10%) the export and domestic use (tonne). The maximum quantity of wood pellet production helped to evaluate the sufficiency of raw materials. However, the wood pellet demand was also evaluated based on the policy of importers and the Thai government. Two-way sensitivity analysis is identified as the interaction effect between the increase in wood pellet export and domestic use. The increases in wood pellet export and domestic use were determined with a maximum of +150% to present the quantity of feedstock.

2.3. Evaluating the Potential Amount and Proportion of Feedstocks

The potential amount of wood (main feedstock) was analyzed because it is important for increasing the wood pellet production. The potential amount of wood or waste wood in the past was considered to prepare and plan for an increase in wood pellet production in the future, which is forecast by sensitivity analysis. The potential amount of feedstock was converted from the product by a conversion factor which was subtracted from the total amount of feedstock. The net feedstock balance was calculated by subtracting the projected feedstock requirements in the future from the estimated available feedstock resource. The available feedstocks for wood pellet production were estimated from the following equation [14,25]:

$$PQ_i = TQ_i - \sum_j CF_{i,j} \times D_{Domestic\ i,j} - \sum_j CF_{i,j} \times D_{Export\ i,j} \quad (1)$$

where PQ_i is the potential amount of feedstock i for wood pellet production in the country (tonne/year), TQ_i is the total amount of feedstock i in the country for a period (tonne/year), CF_{ij} is the conversion factor to convert amount of feedstock i for producing product j, $D_{Domestic\ i,j}$ is the total demand of product j for domestic consumption (tonne/year), and $D_{Export\ i,j}$ is the total demand of product j for export (tonne/year). Quantity of wood and waste wood data were collected from the related organizations. The data of wood pellet production were surveyed by questionnaires from farmers and wood pellet manufactures. The average conversion factor was calculated from five wood pellet factories having different processes and raw materials (Table 1).

Table 1. Conversion factor from five wood pellet factories.

Factories	A	B	C	D	F
Raw material (tonne)	23	150	217	112	60
Product (tonne)	14	110	128	70	40
Conversion factor (Raw material/one tonne of wood pellets)	1.64	1.36	1.70	1.60	1.50
Average of conversion factor			1.56 ± 0.13		

2.4. Shannon Index—The Diversity of Supply

The diversity of feedstock supply relating to the feedstock security was calculated by the Shannon–Wiener index [26]. This index, applied to evaluate the long term security of supply and the diverse distributions of energy flows in a system, can open up more possibilities and channels for cooperation and interdependency in energy utilization [27]. Moreover, the diversity of the demand side, which is critical for an energy system because increasing variance and balance of the energy consumers enhances efficiency and adaptability, can be calculated by the Shannon–Wiener index as follows [26]:

$$H = -\sum_i (p_i \, ln \, p_i) \quad (2)$$

where H is the feedstock supply security indicator, p_i is the share of fuel i in the energy mix or the market share of supplier i and, i is the feedstock source index.

3. Results and Discussion

3.1. Wood Pellet Production in Thailand

Thailand has 44 wood pellet factories, most of them set in the south and central region [28]. The wood pellet factories in the south of Thailand use para-rubber waste wood as raw material and in the other regions use whichever waste wood is available. Quantity of wood pellet export from Thailand decreased in 2015–2016 (as shown in Figure 1) because the price of wood pellets was higher than that in Vietnam [29]. Since 2017, the quantity of wood pellet export continued to grow. South Korea and Japan are the major importers. Japan increased the import of wood pellets from Thailand in 2019 (Figure 2). From interviewing entrepreneurs who produce the wood pellets, it was found that in 2018, 80% of the wood pellet production was exported, and only 20% was for domestic use. Hence, the production of wood pellets in Thailand can be estimated at 361,600 tonnes in 2018 and 215,600 tonnes in 2019.

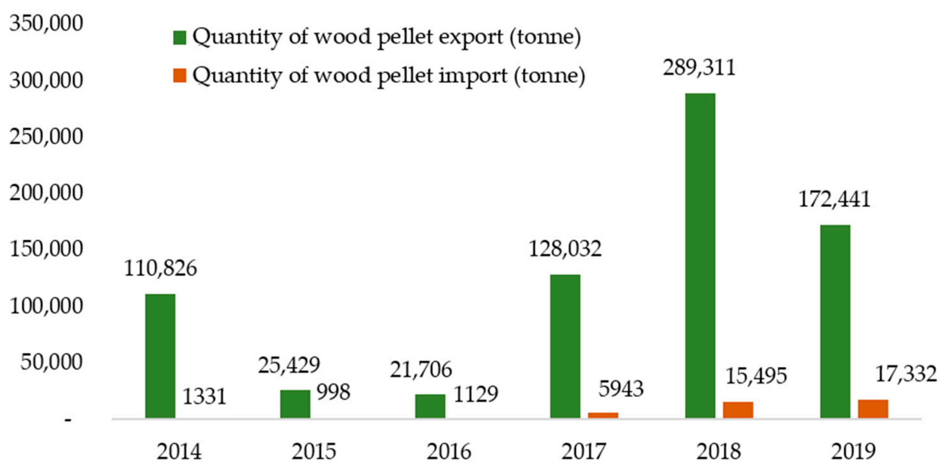

Figure 1. Quantity of wood pellet export and import of Thailand in 2014–2019 [29].

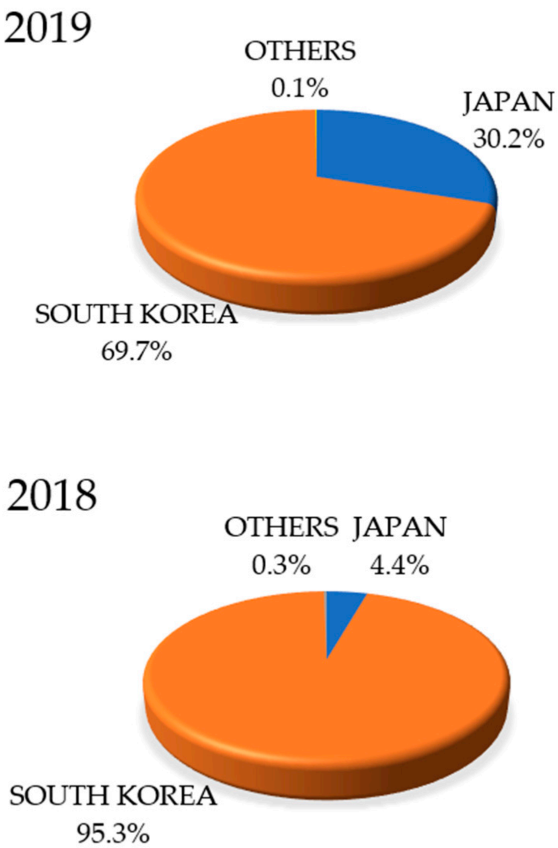

Figure 2. Proportion of importers of wood pellets from Thailand in 2018–2019 [29].

3.2. *Evaluating of Wood Pellet Demand in Thailand*

To evaluate the potential of feedstock for wood pellet production, sensitivity analysis is used for forecasting the wood pellet demand. The wood pellet demand in Thailand consists of demand from export and domestic use. Evaluating of wood pellet demand when export and domestic use increase is shown in Table 2. The results show that if the export increases by 100% of export in 2018 and domestic use increases by 100% of the domestic use in 2018, the wood pellet demand will become 723,000 tonnes. Although the wood pellet demand in Thailand fluctuates depending on several factors (policy for domestic use, the demand of importer and competition of other countries), it can be predicted to be within a range of 398,000 to 904,000 tonnes.

Table 2. Evaluating of wood pellet demand by increasing export and domestic use (tonne).

Wood Pellet Production	**Increasing of Domestic Use**						
Increasing of Export	**10%**	**25%**	**50%**	**75%**	**100%**	**120%**	**150%**
10%	398,000	409,000	427,000	445,000	463,000	477,000	499,000
25%	441,000	452,000	470,00	488,000	506,000	521,000	542,000
50%	514,000	524,000	542,000	561,000	579,000	593,000	615,000
75%	586,000	597,000	615,000	633,000	651,000	665,000	687,000
100%	658,000	669,000	687,000	705,000	723,000	738,000	759,000
120%	716,000	727,000	745,000	763,000	781,000	796,000	817,000
150%	803,000	814,000	832,000	850,000	868,000	882,000	904,000

However, the trend of wood pellet demand in Thailand can be estimated from exports in the future related to the industrial demand of the main importers, South Korea and Japan (99% of wood pellet export), as shown in Figure 2, and the domestic use in Thailand (Table 3). In 2022, the wood pellet demand in Japan will become higher than South Korea by about 200,000 tonnes owing to new power plants coming into operation. The domestic use in Thailand focuses on heat production because the Thai government supports using wood pellets only for heat. The results indicate that the wood pellet demand for Thailand in 2025 will surge to 582,000 tonnes.

Table 3. Evaluation of wood pellet demand based on policy of importers and Thai government (tonne).

	2020	**2021**	**2022**	**2023**	**2024**	**2025**
Forecast of Wood Pellet Industrial Demand in South Korea and Japan [3]						
Japan	2,200,000	3,100,000	4,300,000	5,100,000	6,600,000	6,800,000
South Korea	3,400,000	3,700,000	4,100,000	4,500,000	5,200,000	5,500,000
Japan [7]						
Total Import	1,870,000	1,870,000	4,870,000	4,870,000	4,870,000	4,870,000
Import from Thailand [1]	89,000	89,000	232,000	232,000	232,000	232,000
South Korea [30]						
Total Import [2]	3,230,000	3,520,000	3,900,000	4,280,000	4,940,000	5,230,000
Import from Thailand [3]	129,000	141,000	156,000	171,000	198,000	209,000
Demand from main exporters	218,000	230,000	388,000	403,000	430,000	441,000
Demand from domestic use [4]	87,500	96,300	106,000	116,000	128,000	141,000
Total wood pellet Demand in Thailand	305,500	326,300	494,000	519,000	558,000	582,000

[1] Japan import from Thailand at a market share of 4.75% of all imports to Japan; [2] total wood pellet import of South Korea is about 95% of wood pellet demand; [3] South Korea import from Thailand at a market share of 4% of all imports to Japan; [4] domestic use (only for heat) of Thailand is determined to increase by 10% every year.

3.3. Feedstock Supply for Wood Pellet Production

The main raw materials of wood pellets are waste wood from economic wood and para-rubber wood, including wood from FGTs. In 2017, economic and FGT wood production (for domestic use) in Thailand was about 506,350 tonnes (excluding para-rubber wood)—see in Table 4. Some wood was imported from other countries at 30,254 tonnes, that is, only 5.64% of domestic use. Economic wood is timber that can be processed to products, including both direct and indirect benefits for growers such as furniture wood, construction wood, firewood or wood for extracting essential substances. It is valuable and expensive wood and provides farmers with income. It is harvested from trees that grow over three years old, such as, *Tectona grandis*, *Pterocarpus macrocarpus*, *Samanea saman*, *Dalbergia cochinchinensis*, *Dalbergia oliveri*, *Hopea odorata*, *Afzelia xylocarpa*, *Shorea obtuse*, *Shorea roxburghii*, *Swietenia macrophylla*, *Azadirachta indica*, *Michelia champaca* and *Anthocephalus chinensis*. The waste from economic wood is at 45% of total wood (198,500 tonnes).

FGTs can grow well and are popular in Thailand, for instance, *Eucalyptus globulus*, *Acacia* spp., *Leucaena leucocephala*, *Melaleuca cajuputi* and *Casuarina junghuhniana*. FGT production in Thailand was about 84,000 tonnes; these were used for several industries, not only renewable energy. The calculation of feedstock from FGTs is different from economic wood; the trunks of FGTs are used, whereas for economic wood, only waste wood is used to produce the wood pellets. Hence, the total waste wood from economic wood and FGT wood available for producing wood pellets is about 305,000 tonnes.

The para-rubber trees are an economic crop of Thailand for natural rubber production. The para-rubber wood is harvested when the yield of para-rubber reduces (over 25 years old). Thailand had a para-rubber plantation area of about 3.62 million hectares in 2018 [31]. Most of the plantation area (60%) is in the south of Thailand (see in Figure 3). The yield of para-rubber wood per hectare is about 285 tonnes. Waste wood from the para-rubber wood industry is around 8,000,000 tonnes per year [7].

Table 4. Wood consumption in Thailand in 2017, excluding para-rubber wood (tonne).

	Wood	Waste Wood [3]
Domestic use [1]		
1. Forest Industry Organization		
-Economic wood	69,820	36,400
-Fast-growing trees	57,430	-
2. Private sector		
-Economic wood	352,500 [2]	158,600
-Fast-growing trees	26,600 [2]	-
Total	**506,350**	**195,000**
Import [4]		
-Economic wood	7769	3500
-Fast-growing trees	22,485	-
Total wood for wood pellet raw materials		
-Economic wood	**-**	**198,500**
-Fast-growing trees	**106,515**	**-**

Note: The underlined numbers show the quantity of wood and waste wood that is suitable for wood pellet production. [1] Secondary data from Royal Forest Department. [2] Calculated from 25% of the plantation area. [3] Calculated from 45% of all wood. [4] Secondary data from Thai customs.

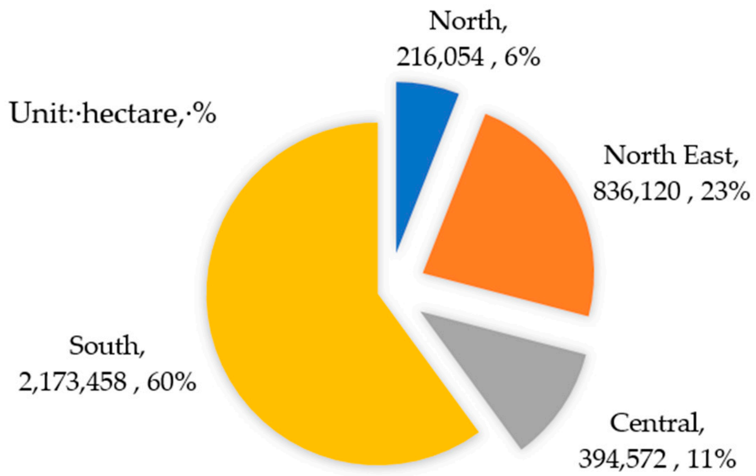

Figure 3. Para rubber production areas by regions of Thailand: 2018 (unit: hectare, %) [31].

The feedstock supply of wood pellets in Thailand from para-rubber waste wood, economic waste wood and FGT wood is 8.31 million tonnes, which can produce 5.32 million tonnes of wood pellets (CF 1.56). However, the proportion of feedstock type can be calculated by weighting in terms of the number of wood pellet factories and the volume of wood in each region (Table 5). The results show that the proportions of para-rubber waste wood, economic waste wood and FGT wood are 0.65, 0.15 and 0.20, respectively. The potential amount of feedstock (PQ) in 2018 (Table 6) remains enough for wood pellet production. Nevertheless, a lot of the para-rubber waste wood is concentrated in the south of Thailand; hence, the distribution of feedstocks is not suitable.

The potential amount of feedstock relates to the wood pellet demand in Thailand in the future. The maximum wood pellet demand is about 904,000 tonnes (Table 2), whereas the overall potential amount of feedstock can produce 5.23 million tonnes of wood pellets. Therefore, Thailand has a substantial potential to produce wood pellets. However, the feedstock, especially para-rubber waste wood, is not distributed evenly in all regions of the country. If the Thai government supports using wood pellets in domestic use conscientiously, the cost of raw material transportation will increase. The results in Table 7 indicate that increasing 25% of wood pellet export and 50% of wood pellet domestic use will lead to a lack of FGT wood (PQ of fast-growing woods becomes −3480 tonnes).

Table 5. Estimating the proportion of feedstock by type.

Region	Number of Wood Pellet Factories [1]	Para-Rubber Tree Plantation Area [2] (%)	Economic Wood Plantation [2] (%)	Proportion of Raw Material (%)		Para	FGT	EW [5]
South	19	70	30	Para [3]	100	1900	0	0
North	5	34	66	Para + FGT [4] + EW	35/15/50	175	75	250
North-East	3	90	10	Para + FGT [4] + EW	90/5/5	270	15	15
East	5	40	60	Para + FGT [4] + EW	45/15/40	225	75	200
Central	12	20	80	Para + FGT [4] + EW	25/40/35	300	480	420
Total	44	-	-			2870	645	885
					(%)	65	15	20

[1] Primary data from surveying; [2] secondary data from the Office of Agricultural Economics; [3] primary data from interviewing entrepreneurs; [4] proportion of fast-growing trees (FGTs) estimated from interviewing entrepreneurs, and their plantation areas; [5] Economic wood (EW).

Table 6. Evaluating feedstock for wood pellet production in 2018.

	Quantity
Export [1] (tonne)	289,300
Domestic use [2] (tonne)	72,300
Wood pellet production [3] (tonne)	361,600
Conversion factor [4] (CF)	1.56
Total amount of feedstock; **TQ** (tonne)	**8,305,000**
-Para-rubber waste wood [5]	8,000,000
-FGT woods [6]	106,500
-Economic waste wood [7]	198,500
Potential amount of feedstock; **PQ** (tonne)	**7,741,000**
-Para-rubber waste wood (65%)	7,633,300
-FGT wood (15%)	22,000
-Economic waste wood (20%)	85,700

[1] Secondary data from Thai customs; [2] 20% of wood pellet production (primary data from surveying factories); [3] export + domestic use; [4] average from five wood pellet factories, as shown in Table 1; [5] para-rubber wood from forecast of the Kasikorn Research Center; [6,7] FGT and economic woods from the Royal Forest Department.

Table 7. The potential of feedstock for 470,000 tonnes of wood pellets (+25% of wood pellet export and +50% of wood pellet domestic use).

	Quantity (tonne)	**CF**	**TQ (tonne)**	**PQ (tonne)**
Wood pellet production	470,000	1.56	8,305,000	7,572,000
Para wood (65%)	305,500	1.56	8,000,000	7,523,000
Fast-growing tree wood (15%)	70,500	1.56	106,500	−3500
Economic wood (20%)	94,000	1.56	198,500	52,000

3.4. Diversity of Feedstock Supply

The diversity of feedstock supply (in 2018) for wood pellet production is shown in Table 8. The result indicates that the types of feedstocks for wood pellet production is small (the Shannon–Wiener index is 0.17). In 2018, Leucaena wood production was 0.45% of FGTs, which is rather small. However, Leucaena can be harvested faster than others (in only 2 years) and continuously every year because of regeneration. Hence, to support wood pellet production in the area which does not have para-rubber trees, Leucaena should be planted in the wasteland (areas unsuitable for agriculture, without irrigation systems, not for housing, not conservation area and not government areas). In this study, the increase in FGT production is set at 15%, 25%, 50%, 75% and 100%, as shown in Table 9. Production of Eucalyptus wood was 89.3% of all FGTs, with most of the Eucalyptus wood being used in the paper industry. Even though the weather of tropical countries is highly suitable for the rapid growth of Acacia without requiring any major agricultural input [32], Acacia can be harvested only after 3–4 years. However, the Shannon–Wiener index can be increased by having a variety of feedstock with equal proportions. If the FGT plantation area in wasteland is increased, the Shannon index will increase (Table 9). Evaluation of FGT production in wastelands is determined by assuming an average yield of

FGTs at 3 tonnes per 0.16 ha per year and allowing for the harvest of only 25% of the plantation area annually [33].

Table 8. Shannon–Wiener index of raw materials for wood pellet production in 2018.

	Quantity (tonne)	(1) p = n/N	(2) Ln p	(1) × (2)	Shannon–Wiener Index (I)
Para-rubber waste wood	8,000,000	0.955720	−0.03	−0.0337	
FGT					
Leucaena	376 (0.45%)	0.000045	−10.00	−0.0005	
Acacia	7980 (9.49%)	0.000963	−6.95	−0.0067	0.17
Eucalyptus	75,055 (89.3%)	0.009060	−4.70	−0.0426	
Other FGTs [1]	636 (0.76%)	0.000077	−9.47	−0.0007	
Economic waste woods	199,928	0.024134	−3.72	−0.0899	
Total	**8,386,303**				

Note: [1] Other FGTs are Casuarina equisetifolia, Casuarina junghuniana and bamboo.

Table 9. Shannon–Wiener index forecast and increase in the fast-growing tree plantation area in the wasteland.

	% Increase in FGT Plantation Area in Wasteland				
	15%	**25%**	**50%**	**75%**	**100%**
Wasteland (ha)	16,800	28,100	56,200	84,200	112,300
Quantity of FGTs (tonne)	79,000	131,700	263,200	394,900	526,400
Leucaena [1]	7900	13,200	26,300	39,500	52,600
Acacia [1]	7900	13,200	26,300	39,500	52,600
Eucalyptus [2]	62,400	104,000	208,000	312,000	415,900
Other FGTs [3]	800	1300	2600	3900	5300
Shannon–Wiener index	**0.16**	**0.20**	**0.27**	**0.33**	**0.38**

[1] Leucaena and Acacia wood production increases at 10% of all FGTs. [2] Eucalyptus wood production is about 79% of all FGTs. [3] Other FGT wood production is about 1% of all FGTs.

Although wasteland is selected without an irrigation system, which is a main factor for plantation, this area was identified considering the suitability of soil (in term of texture, depth, electrical conductivity, pH and slope) and rainfall. These results presented that FGT can grow in wasteland [34]. However, agriculture in wasteland needs more investment than an abandoned area, while the yield may be less. If agriculture management is not suitable, problems in relation to disease and insects will occur and affect other crops. Therefore, the farmers should increase the diversity of genus and species of FGT.

Increasing the trend of domestic use and export of wood pellets in Thailand will enhance the value added of waste wood, especially para-rubber waste wood. Thailand will earn more income from wood pellet export. Moreover, the promotion of fast-growing trees plantation in wasteland will also contribute to the utilization of the wasteland and generate income for agriculture. The wood pellet production will support the security of energy production in Thailand because the feedstock is domestically available. Therefore, wood pellet production is essential to the economy and energy supply of Thailand.

3.5. Recommendations for Enhancing Long-Term Security of Feedstock Supply

3.5.1. Encouragement for Increasing the Domestic Use of Wood Pellets

Although the Thai government has encouraged using the wood pellets only for heat production, by supporting 30–50% of the fund to change to new burners, some factories joined this project. Thailand has 8005 units of boilers (526 coal boiler units, 4760 liquid fuel boiler units and 2719 gas boiler units which can be changed to renewable energy [35]). However, promotion of wood pellet use in Thailand should be performed urgently because Thailand has the potential to become a more important producer and consumer on wood pellet markets if effective policy encouragement and a suitable regulatory framework are formulated. Furthermore, the Thai government should have a plan to raise the confidence of entrepreneurs for the acquisition of wood pellets and support a subsidy to control the price of raw materials.

3.5.2. Encouraging Cultivation of Fast-Growing Trees in Wasteland

Even though the feedstock from para-rubber waste wood is enough to produce a lot of wood pellets, the results from Sections 3.2 and 3.3 indicate that the distribution and quantity of feedstock supply in other regions are less in comparison to the south of Thailand. Moreover, the wood pellet factories are also concentrated only in the south of Thailand (Figure 4A) [35]. Meanwhile, there is about 702,000 ha of wasteland in Thailand which is suitable for the growth of FGTs, most of which is in the north-east (40%) (Figure 4B) [36]. The Thai government, through the Forest Industry Organization, tried to support only 3100 ha FGT plantation in 39 provinces in 2019 [11]. Hence, an increase in FGTs in the wasteland can help in the expansion of wood pellet production and higher diversity of feedstock. However, two cases can be set for comparison in terms of job opportunity, GHG emissions and increase in wood pellet cost. Case 1: the para-rubber wood pellets produced in the south of Thailand are sent to other regions (distance for sending to user: 1600 km (south to north or north-east)). In this case, there is no cultivation of FGTs for wood pellet production. Transportation of wood pellets to the north or north-east is by trains or trucks. Case 2: FGTs are encouraged to be planted in the wasteland areas of the northern or north-eastern regions. The wood pellet factories are set in the same area to minimize transportation requirements (100 km around the fast-growing tree cultivation area). The results in Table 10 indicate that Case 2 creates job opportunity of 0.13 person-year per ha from FGT cultivation and 0.0019 person-year per tonne from FGT wood pellets [37], which is higher than for Case 1. However, the employment from para-rubber wood cultivation is excluded, as it is latex, not para-rubber wood, that is the main product of this. Thus, the employment from cultivation should be considered for latex (rubber) rather than wood pellet production.

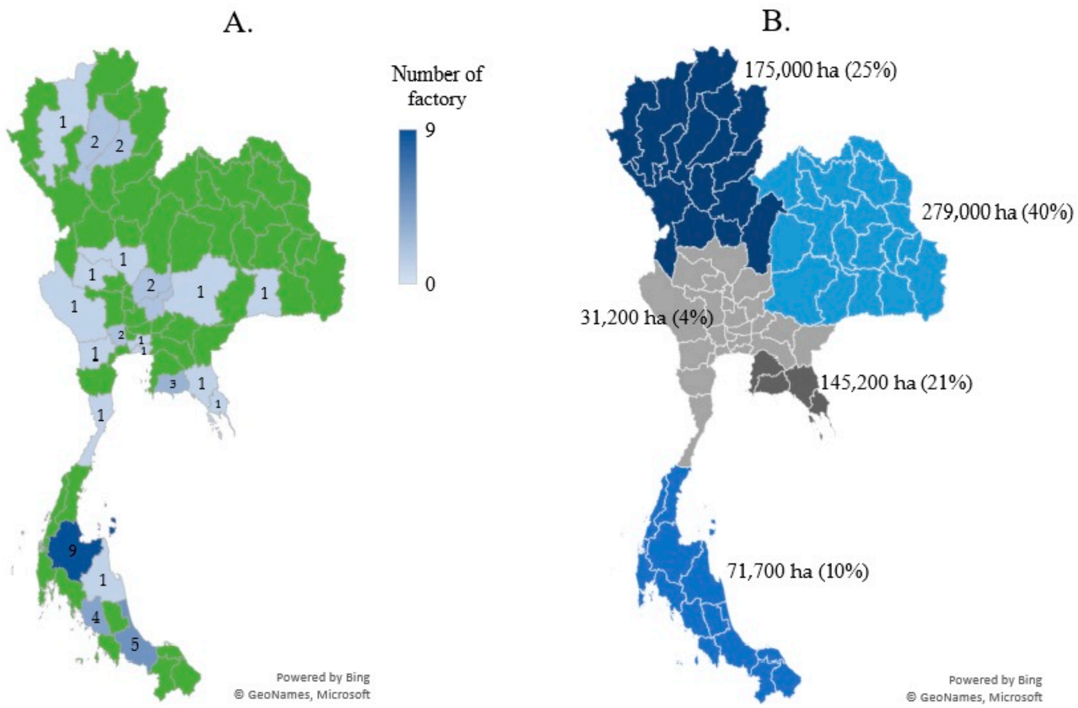

Figure 4. Comparing number of wood pellet factories and wasteland by region in Thailand. (**A**) Number of wood pellet factories [35], (**B**) Wasteland by region [36].

The GHG emissions per tonne of para-rubber wood pellets (144 kg CO_2 eq) are higher than the FGT wood pellets (88.8–94.4 kg CO_2 eq) because of the use of chemical fertilizers [38]. The para-rubber cultivation consumed 220 kg of chemical fertilizers per ha per year, whereas FGTs cultivation used only 30 kg per ha per year [38]. Even though a higher proportion of environmental impacts from para-rubber cultivation were allocated to latex, which is the main product, the chemical fertilizers allocated to para-rubber wood were still higher than those for FGT cultivation. The FGTs can grow for 1–5 years before harvest and utilization. In terms of the environmental burdens, the FGTs are a suitable feedstock for wood pellet production, especially in the wasteland where economic crops cannot be grown. If the para-rubber wood pellets are sent to the north or north-east, GHG emissions from transportation by trains or trucks will increase by 62.2 kg CO_2 eq per tonne and 458.0 kg CO_2 eq per tonne, respectively. Furthermore, the cost of transportation to user by trains or trucks will increase by 660 THB/tonne/1600 km and 3150 THB/tonne/1600 km, respectively. Therefore, if there is encouragement for increasing the domestic use of wood pellets in Thailand, FGT cultivation in the wasteland is a solution of choice for distribution and quantity of feedstock supply, including lower GHG emissions and cost from transportation.

However, the FGTs which are planted in different regions should be selected properly considering the specific factors of each region, such as type of soil, quantity of rain, etc. The Thai government should consider offering a guaranteed price which can help stimulate immediate short-rotation coppice adoption [39]. Furthermore, importers still request a certificate for good forestry management due to concerns about the raw material being from natural forest or poor cultivation. Hence, to address the issue of good forestry management, the increase in FGT cultivation should be managed by good forest management or sustainable cultivation which is safe for farmers and environmentally friendly. Moreover, the research on breeding to increase their yield should be encouraged by the Thai government.

Table 10. Comparison of Cases 1 and 2 in terms of job opportunity, GHG emissions and increase in cost.

	Case 1	**Case 2**	
	Para-Rubber Wood Pellets [1]	**FGT Cultivation**	**FGT Wood Pellets**
Job opportunity [37]	0.0019 person-year per tonne	0.13 person-year per ha	0.0019 person-year per tonne
GHG emissions (kg CO_2 eq) per tonne of wood pellets	144.4 [40]	-	88.8–94.4 [4] [37]
+Train 1600 km	+62.2	-	-
+Truck 1600 km	+458.0	-	-
Increase in cost			
+Train [2] 1600 km	+660 THB/tonne	-	-
+Truck [3] 1 km	+2 THB/tonne	-	-
+Truck [4] 1600 km	+3150 THB/tonne	-	-

[1] Job opportunity of para rubber cultivation is not considered because the main product is para-rubber. [2] The data are from the State Railway of Thailand. [3] The data are from the Bureau of Standards and Evaluation, Department of Highways, Thailand. [4] This value is for the 100 km transportation around the FGT cultivation area.

3.5.3. Logistics Management

Logistics management is a considerable issue which relates to transportation of raw materials and products. Transportation of feedstock and wood pellets consumes fossil fuel such as diesel, which has a significant impact on the environment. Hence, setting the locations of feedstock cultivation, wood pellet factories and wood pellet users should be optimized to reduce the time and use of fuel. If the Thai government encourages wood pellet production for domestic use, the wood pellet factories should be distributed in all regions of Thailand to respond to the demand of industry and power plants. Although there are no factories in the north-east, this region has the most amount of wasteland suitable for cultivating FGTs (Figure 4). Therefore, if the wood pellet factories are set in the north-east or other areas which have high abundance of feedstocks and high demand of wood pellets, the environmental burdens are anticipated to reduce.

4. Conclusions

The trend of wood pellet demand, with export and domestic use increasing by 10–150% from the values in 2018, was forecast to be within a range of 398,000 to 904,000 tonnes. Evaluating the wood pellet demand following the requirements of the main importers and increasing 10% of domestic use as in 2018 showed that the wood pellet demand of Thailand in 2025 would surge to 582,000 tonnes. The feedstock supply of wood pellets in Thailand from para-rubber waste wood, economic waste wood and fast-growing tree wood is 8.31 million tonnes per year, which can produce 5.32 million tonnes per year of wood pellets. Therefore, Thailand has sufficient feedstock to produce the wood pellets following the forecasted wood pellet demand. However, increasing 25% of wood pellet export and 50% of wood pellet domestic use will result in a deficit of the fast-growing tree wood because para-rubber waste wood is not the distributed across all regions. The diversity of feedstock supply suggests that the type of feedstocks for wood pellet production is less (Shannon–Wiener index: 0.17) because it is predominated by para-rubber wood. By increasing the fast-growing tree plantation area in the wasteland, the Shannon–Wiener index will increase. GHG emissions from the para-rubber wood pellets are higher than those from the wood pellets of the fast-growing trees because of the higher use of chemical fertilizers. Recommendations for policy from this study focus on encouraging increasing domestic use of wood pellets, cultivation of fast-growing trees in wasteland and optimized logistics management.

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