Environmental and socio-economic assessment of wood pellet production from fast growing trees in Thailand

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Abstract. Sufficient quantity of raw materials is a critical factor for wood pellet production. The recommendations from past research on biomass have indicated that the cultivation of fast growing trees should be encouraged in wasteland. Leucaena and Acacia are the popular fast growing trees in Thailand because they are resistant to drought and can grow in low quality soil. Wood from them has a high heating value and entrepreneurs invite farmers to grow these varieties on contract farming for renewable energy. The purpose of this study is to assess the environmental and socio-economic of wood pellet production from Leucaena and Acacia. The environmental impacts were evaluated by cradle to gate life cycle assessment, covering fast growing tree cultivation (sprout preparation, plantation, cutting), transportation and wood pellet production. The ReCiPe2016 Midpoint method (version 1.02) was used to evaluate the environmental impacts of one tonne wood pellet production from Leucaena and Acacia. The indicators of socio-economic considered in this study were the profit from cultivation, economic assessment of wood pellet production (net present value, internal rate of return, payback period, discount payback period and benefit cost ratio) and opportunity of employment. The environmental results showed a better performance of wood pellets made from Leucaena are better than Acacia. The production capacity of 110 tonnes per day of wood pellet factory would return a profit when the price of raw material is less than 1,300 THB per tonne. Finally, Leucaena and Acacia cultivation increase the opportunity of employment at 0.16 and 0.10 person-year per ha, respectively. The wood pellet production increases the opportunity of employment at 0.0019 person-year per tonne. Considering the results of the environmental and socio-economic assessment, Leucaena is seen to be better than Acacia and should be supported as an alternative raw material for wood pellet production.

Keywords: Wood pellet, Fast growing tree, Thailand

1. Introduction
Biomass is a source of renewable energy gathering the energy from the sun. Wood pellets are a solid biomass that is a popular substitute to fossil fuels for heat and electricity production. Preference of wood pellets compared with fossil fuels is that wood pellet combustion, being of biogenic origin, can...
be considered carbon neutral. The main exporters are US, Canada, Latvia, Estonia, Russia and Vietnam [1]. Fast growing trees or short rotation crops are interesting raw materials for wood pellet production. The short-rotation woody crops (SRWC) plantations should be grown on poor soils and harvested in one or two stages for 3 to 4 year rotations. Variety of species, cultivar, clone, soil, weather conditions, planting density, agricultural procedures, cultivation, protection measures, and harvest cycle directly affect the yield of SRWC [2]. There are several studies about fast growing trees like Poplar and Willow which are availed in the Mediterranean basin, Northern Europe and North America [3,4]. The study about the environmental, energy and economic analysis of a biomass supply chain based on a poplar short rotation coppice in Spain showed that harvesting was the most significant life cycle phase for environmental impacts and economic costs [4]. Fast growing tropical trees such as Leucaena and Acacia widely studied for wood pellet production [5–8].

In 2018, Thailand increased the production and export of wood pellets by around 56% from 2017 [9]. The forecast of the wood pellet export to Japan in 2020 is about 80,000-100,000 tonnes or 4.2-5.3% market share of Japanese import [10]. In term of domestic use, heat production from wood pellets is supported by the Thai government; entrepreneurs get 30% to 50% of the fund for adjusting their factory boilers with ones capable of utilizing wood pellets [11]. Electricity production in Thailand is currently only from wood chips or other biomass due to lower prices.

Para-rubber wood, mainly concentrated in the south of Thailand, is the main feedstock for wood pellets in Thailand. Although Thailand has about 8 million tonnes per year (dry weight) of waste wood from para-rubber trees; however, as it is not distributed across other regions of the country [10], cultivation of fast-growing trees in wasteland is being considered for energy. The objective of this study is evaluating the environmental and socio-economic of wood pellet production from the fast growing trees (focusing on Leucaena and Acacia).

2. Methods

2.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is the tool used to evaluate the environmental impacts of wood pellet production; it has been extensively used for product development, product improvement, strategic planning, public policy making, and marketing and communication [12]. The SimaPro software (v. 8.5.2.0) and the ReCiPe2016 Midpoint (version 1.02) life cycle impact assessment method have been used for this study [13]. The 17 midpoint impact categories included are Global warming potential, Stratospheric ozone depletion, Ozone formation (Human health), Ozone formation (Terrestrial ecosystems), Fine particulate matter formation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Land use, Mineral resource scarcity, Fossil resource scarcity, and Water consumption.

2.1.1 Functional Unit and System boundary

The functional unit is one tonne of wood pellet production from Leucaena and Acacia wood. The results of this study can be used to choose suitable raw materials by entrepreneurs and farmers. Also, the Thai government can consider them for policy decisions. A cradle to gate approach was applied, i.e. from cultivation through wood pellet production and transportation. The system boundary is shown in Figure 1.

2.1.2 Life Cycle Inventory

Cultivation: Fast growing tree plantation and cutting

Fast growing trees are quite popular with the entrepreneurs anticipating to manage their feedstock by themselves. Leucaena and Acacia are of interest because they can grow very well in Thailand [14].
Firstly, farmers prepare for a sprout of Leucaena or Acacia. The data of sprout preparation were surveyed from a farm in Uthaithani province. In the next step, the sprouts are cultivated with chemical fertilizers being applied every year until harvesting. Leucaena will be cultivated for ten years per crop but will be cut every year. Only 85% of the plant is harvested each year, the remaining 15% being left to regenerate. Acacia will be cultivated for five years after which the entire tree is harvested. The cultivation data of Leucaena and Acacia were cited from [15]. Yield of Leucaena was 37.84 tonnes per ha per year as the yield of Acacia was only 11.36 tonnes per ha per year.

Wood pellet production
There are six processes of wood pellet production; pretreatment, drying, comminution, pelletization, cooling and storage. The log or trunk of a tree will be sent to a factory where it is chopped and dried before pelletization. The data of wood pellet production were collected from a factory in the south of Thailand which uses para-rubber wood for the main raw material of wood pellet production. As there are currently no factories only using wood from fast growing trees, wood pellet production for this setup was calculated by actual characteristics of the one factory in the south of Thailand. This factory has a chopper, a hammer mill, a screener, a rotary drum dryer, three pellet mills, a cyclone and a cooler. The performance of this factory can produce wood pellets at about 88 tonnes per batch from 150 tonnes raw material.

Electricity was used in the production process of about 800 kWh. About 5 tonnes of firewood was used per batch for drying. Moreover, transportation within this factory (forklits) consumed 32 liters of diesel per batch. Air emissions from firewood combustion were referred from the U.S. Life Cycle Inventory Database.

Transportation
Transportation between wood pellet factory to farm about 100 kilometers apart is provided by 10-wheel trucks, with 0% loading on the trip to the farm and 16 tonnes of wood (100% loading) on the return trip.

2.2 Socio-economic assessment
2.2.1 Analysis of employment
Employment is an indicator of sustainability wood pellet production because it presents the spending of additional wages and profits from both biomass production and bioenergy plant activities [16]. Direct employment is calculated from wages for crop cultivation, construction, operation and
maintenance of conversion plants and transportation, etc. It is computed as labour costs in feedstocks production divided by the average annual working-hours in agriculture sector as in equation (1) [17]:

\[
\text{Employment}_{\text{agri}} = \frac{PC_{\text{feedstock}} \times \text{Labour share}}{AWG_{\text{agri}}} 
\]

where \(\text{Employment}_{\text{agri}}\) is the agriculture employment (person-year/ha), \(PC_{\text{feedstock}}\) is the production cost of feedstock (THB/ha), Labour share is the share of labour cost in \(PC_{\text{feedstock}}\) and \(AWG_{\text{agri}}\) is the average annual wage per person employed in Thailand’s agriculture sector (THB/person).

2.2.2 Analysis of economics

This study evaluates the economics of Leucaena and Acacia cultivation (cost, income and profit), and wood pellet production (cost, interest and capital repayments, Internal Rate of Return: IRR, Benefit Cost Ratio: BCR, Net present value: NPV (THB), Payback period: PBP (year), and Discounted payback period: DPB (year).

2.2.3 Analysis of Sensitivity

The results of the economic analysis are controlled by several factors. Therefore, sensitivity analysis was performed on the various factors such as yield of trees and price of wood. The yield of Leucaena was varied in the range of 19-38 tonne per ha per year and Acacia between 32-125 tonne per ha per year. The price of wood was varied in the range of 800-1,300 THB per tonne.

3. Results and discussion

3.1 Environmental assessment

Contribution of the life cycle phases for wood pellets made from Leucaena and Acacia are similar (Figure 1). The contribution of cultivation to Stratospheric ozone depletion, Land use, Mineral resource scarcity, and Water consumption is more than 65% and the contribution of transportation more than 50% to Terrestrial ecotoxicity, Freshwater ecotoxicity and Marine ecotoxicity. The contribution of wood pellet production to Freshwater eutrophication and Human non-carcinogenic toxicity is more than 50%. The contribution of Leucaena transportation is over 50% also to Global warming potential, Ozone formation (Human health) and Ozone formation (Terrestrial ecosystems). Environmental impacts of wood pellets made from Acacia are higher than from Leucaena for all the categories considered as seen in Figure 1. The lower yield of Acacia is an important contributing factor. One tonne of Acacia wood pellet consumes about thrice as many resources as Leucaena.

3.2 Socio-economic assessment

3.2.1 The employment in cultivation and wood pellet production

The employment generated by Leucaena and Acacia cultivation is about 0.16 and 0.10 persons-year per ha. The employment for Leucaena is higher than Acacia because Leucaena is harvested every year whereas Acacia only once in 5 years. The employment for wood pellet production is about 0.0019 person-year per tonnes of wood pellets. Haruthaithanasan et al. evaluated that there is around 704,000 ha wasteland in Thailand which can be used cultivating fast growing trees [18]. Hence, the employment increased by fast growing tree cultivation in the wasteland can be estimated at least seven million persons-year. In the same way, if the Thai government continuously encourages the production of wood pellets for domestic use, the employment for wood pellet production will increase.

3.2.2 Economic assessment of cultivation

The results vary according to the yield of Leucaena and Acacia which can fluctuate depending on soil type, climate and agronomic management options. The 19 tonnes per ha per year of Leucaena can make a profit at 1,846 THB per ha per year. On the contrary, Acacia can make a profit when its yield is 100 tonnes per ha per five years (currently it is only 63 tonnes per ha per five years).
### Table 1: Environmental Impacts of Leucaena and Acacia Wood Pellets Life Cycle Phases

| Impact Category                              | Leucaena  | Acacia  |
|----------------------------------------------|-----------|---------|
| Global warming (kg CO₂ eq)                   | 6.86E+01  | 8.35E+01|
| Stratospheric ozone depletion (kg CFC11 eq)  | 3.70E-05  | 9.43E-05|
| Ozone formation, Human health (kg NOx eq)    | 6.71E-01  | 7.71E-01|
| Fine particulate matter formation (kg PM2.5 eq) | 9.87E-02  | 1.27E-01|
| Ozone formation, Terrestrial ecosystems (kg NOx eq) | 6.74E-01  | 7.74E-01|
| Terrestrial acidification (kg SO₂ eq)        | 3.09E-01  | 3.80E-01|
| Freshwater eutrophication (kg P eq)          | 2.40E-03  | 2.58E-03|
| Marine eutrophication (kg N eq)              | 1.33E-04  | 1.84E-04|
| Terrestrial ecotoxicity (kg 1,4-DCB)         | 9.05E+01  | 1.05E+02|
| Freshwater ecotoxicity (kg 1,4-DCB)          | 5.60E-02  | 6.54E-02|
| Marine ecotoxicity (kg 1,4-DCB)              | 1.43E-01  | 1.67E-01|
| Human carcinogenic toxicity (kg 1,4-DCB)     | 1.35E-01  | 1.57E-01|
| Human non-carcinogenic toxicity (kg 1,4-DCB) | 6.32E+01  | 9.41E+01|
| Land use (m²a crop eq)                       | 8.47E-02  | 1.46E-01|
| Mineral resource scarcity (kg Cu eq)         | 2.33E-02  | 6.46E-02|
| Fossil resource scarcity (kg oil eq)         | 1.94E+01  | 2.62E+01|
| Water consumption (m³)                        | 9.71E+01  | 6.46E+02|

Figure 2. The environmental impacts and contribution of Leucaena and Acacia wood pellets life cycle phases to various environmental impact categories.

#### 3.2.3 Economic assessment of wood pellet production

The economic assessment of wood pellet production is shown in Table 1. The results indicate that the wood pellet production and transportation of this factory can make a profit. They already start to receive some profit when they operate for less than a year (about 0.68 years) at a raw material price of 800 THB per tonne, and wood pellets being sold at 2,900 THB per tonne. The cost of raw material is an important factor for the sustainability of wood pellet production. Consequently, the price of raw material was varied at 800-1,300 THB per tonne in a sensitivity analysis. The results of various raw material prices show that if the price is more 1,344 THB per tonne, the factory will suffer a loss; this is in fact already apparent at 1,300 THB per tonne (Table 1) where the payback period is as high as almost 9 years which would normally be unacceptable to investors.
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Table 1. Economic assessment of wood pellet production

| Cost (THB)                                     | 800       | 1,000     | 1,200     | 1,300     |
|-----------------------------------------------|-----------|-----------|-----------|-----------|
| Initial investment cost                        | 20,000,000| 20,000,000| 20,000,000| 20,000,000|
| Operation cost                                 | 57,600,000| 68,400,000| 84,600,000|           |
| Maintenance cost                               | 1,000,000 | 1,000,000 | 1,000,000 | 1,000,000 |
| Salary and administration                      | 8,229,600 | 8,229,600 | 8,229,600 | 8,229,600 |
| Fuel                                          | 6,258,862 | 6,258,862 | 6,258,862 | 6,258,862 |
| **Internal Rate of Return: IRR (%)**           | 156.5     | 102.5     | 48.0      | 19.9      |
| **Benefit Cost Ratio: BCR**                    | 24.81     | 15.95     | 7.09      | 2.67      |
| **Net Present Value: NPV (THB)**               | 224,294,262| 135,934,534| 47,574,805| 3,394,941 |
| **Payback Period: PBP (year)**                 | 0.68      | 1.08      | 2.58      | 8.49      |
| **Discount Payback Period: DPB (year)**        | 0.61      | 1.12      | 3.05      | 10.65     |
| **Cost of wood pellet production (THB/tonne)** | 2,085     | 2,385     | 2,685     | 2,835     |

4. Conclusions

The environmental impacts of wood pellet production from Leucaena are lower than Acacia. Leucaena can make a profit as its yield is more than 19 tonnes per ha per year for harvesting format every year in a crop (10 years). Acacia can make a profit if its yield over 100 tonnes per ha per 5 years (currently it is only 63 tonnes per ha per five years). The economic results for production capacity of 110 tonnes per day of wood pellet factory will return a profit when the price of raw material is less than 1,300 THB per tonne. The results of the employment of Leucaena and Acacia cultivation increase the opportunity of employment at 0.16 and 0.10 person-year per ha, respectively. The wood pellet production increases the opportunity of employment at 0.0019 person-year per tonne. Considering the results of the environmental and socio-economic assessment, Leucaena is seen to be better than Acacia and should be supported as an alternative raw material for wood pellet production. If the fast growing trees can be cultivated in the 704,000 ha of wasteland in Thailand, the opportunity of induced employment will be at seven million persons-year. The Thai government can consider supporting fast growing tree plantation in wasteland. However, cultivation of fast growing trees must be controlled for high yield, low cost of operation, and good agricultural practices. Moreover, entrepreneurs can plant their feedstocks from fast growing tree in their land or contract farming with farmers who are close to the wood pellet factory.

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