Research article

Biomass Blending Approach: Availability and Potential of Agricultural Residues as an Energy Source in Thailand

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Abstract Blending different agricultural residues for pellet production can address the problem of seasonal availability of materials and improve biomass pellet quality and efficiency. With widely available agricultural residues in Thailand, our previous research took the blending approach to produce biomass pellets from five residue types, including Rice Stubble (RB), Rice Straw (RW), Sugarcane Leaves (SL), Cassava Leaves (CL), and Cassava Rhizome (CR). By combining high and low energy residues, it is possible to enhance the energy density, durability, and other desirable properties of the pellets. To gain a better understanding of agricultural residue availability, this study investigated farming practices and crop/residue characteristics by considering several factors, including the plantation process (site, area, growing crops, production, and harvesting), crop residue production, and crop residue utilization and the management. Using a sub-district in Mahasarakham Province as a case study, a questionnaire survey was conducted on 100 households to collect data on rice, sugarcane, and cassava crops and their associated residues. The Surplus Availability Factor (SAF) was estimated using survey data to assess the ratio of residues available for energy use to the total residue produced. This factor indicates the portion of the residue that can be collected for energy as a surplus after basic local usage. The study showed that RB and RW are the most commonly produced residues in Mahasarakham Province, but only RB has the greatest potential for energy use. SL and CR exhibited substantial volumes in the area despite the lower production of cassava and sugarcane. Regarding seasonal availability, RB and RW are available for a longer duration, whereas SL, CL, and CR are only available for four to five months. The results show that SL and CL were not used at all, and their SAFs were 1.00. Meanwhile, CR and RB had relatively lower SAF values (0.913 and 0.875, respectively). As rice straw may be sold and utilized for various applications, it had the lowest SAF (0.134). An estimated 5,509 tons of biomass pellets could be produced annually in Mahasarakham Province using the agricultural residues that are currently available. The biomass blending technique can offer an alternative use of agricultural waste to generate energy and value-added products. Using agricultural waste as an energy source has numerous environmental benefits, including minimizing harvesting burning, providing a carbon-neutral fuel supply, and encouraging the circular economy by using waste as an input for new products.

Keywords agricultural residues, biomass blending, renewable energy, energy potential, surplus availability factor

INTRODUCTION

Agricultural residues are an important source of renewable biomass energy because the process of using biomass feedstock can contribute to carbon neutrality. Approximately 5.5 billion metric tons of crop residues are produced annually. However, several activities use only a portion of the total production and require collection, bundling, and transportation (Shinde et al., 2022). Approximately

22.7 million hectares, or 42% of Thailand's total land area, are used for agriculture (NSO, 2023). The annual production of agricultural residues is 294.3 million tons. Approximately 136.5 million tons were used annually, whereas 159.8 million tons were either openly burned by farmers or left in the fields after harvest (DEDE, 2020).

The Alternative Energy Development Plan 2024-2037 (also known as AEDP 2024), currently under public hearing, aims to increase the share of renewable energy consumption in Thailand to 36% by 2037 (Kurovat, 2024). The Power Development Plan (also known as PDP 2024) complements this by targeting 50% renewable energy generation (electricity and heat) for the same year (EPPO, 2024). This represents a significant shift from the previous target of 36%. In these plans, biomass is targeted as the third-most important renewable energy source for power generation after hydropower and solar power. Agricultural residues are a significant biomass source, offering various opportunities for sustainable energy production and economic benefits for the agricultural sector. However, this has become a limitation for commercial production from agricultural residues because of the wide range of material properties, compositions, and seasonal availability.

Biomass blending has been proposed as a promising strategy for producing biomass fuel from agricultural residues (Hanaki and Portugal-Pereira, 2018; Anukam et al., 2016; Sasongko et al., 2017; Martinez et al., 2019). This strategy can mitigate the impact of seasonal availability-related material shortages and high costs. Additionally, blending can improve the energy efficiency of biomass feedstocks (Luesopa and Singhirunnusorn, 2023). It is difficult to control the use of agricultural residues throughout the year. It may be limited or available depending on the current alternative applications, such as animal feed, domestic use, and ecological uses (Daioglou et al., 2016). Therefore, it is necessary to evaluate the residue availability of various crops. Several studies have evaluated the potential and availability of agricultural residues using various methods, such as the residue-to-product ratio (RPR), Residue Recovery Factor (RRF), Surplus Availability Factor (SAF), and Residue Dryness Factor (RDF) (Akter et al., 2024). Furthermore, the potential of biomass as a source of energy production is also impacted by geological factors and site differences (Lozano-García et al., 2020; Zyadin et al., 2018). The SAF was used in this study to determine the crop residue potential for bioenergy. It is the ratio of residues available for energy purposes to the total number of residues produced. This factor indicates the portion of the residue that can be collected for energy as a surplus after basic usage.

OBJECTIVE

The purpose of this study is to assess the local potential for applying the biomass blending approach to manufacture biomass pellets from agricultural residues, including rice stubble (RB), rice straw (RW), sugarcane leaf (SL), cassava leaf (CL), and cassava rhizome (CR). The study investigates the farming practice and crop/ residue characteristics by considering a number of factors, including plantation process (sites, area, growing crops, production, and harvesting), crop residue production, and crop residue utilization and management.

METHODOLOGY

Case Study

All districts and subdistricts were clustered based on their similar growing crops. For this study, a sub-district with all three major crops—rice, sugarcane, and cassava—was chosen at random. The Tha Song Kon subdistrict area was randomly selected as the case study, and 100 households cultivating rice, sugarcane, and cassava were randomly sampled.

Questionnaire Survey

To examine the availability of crop residues after harvesting, this study conducted a questionnaire survey with 100 household heads through in-person interviews. The sample comprised 56 rice-farming, 24 sugarcane-farming, and 20 cassava-farming households. The questions were grouped into three sections: 1) plantation process (sites, area, growing crops, production, and harvesting), 2) crop residue production, and 3). Crop residue utilization and management.

Surplus Availability Factor (SAF)

The Surplus Availability Factor (SAF) is an important factor used to estimate the bioenergy potential of crop residues. It is the ratio of residues available for energy purposes to the total residue produced. The SAF of five materials (RB, RW, SL, CL, and CR) was evaluated based on the surveyed data. The availability potential of crop residues for energy production or Volume of Agricultural Residues (VOR) was then calculated according to the following equation (Eq. 1):

$$\text{VOR} = \text{Cultivation Area (ha)} \times \text{Biomass Load (ton/ha)} \times \text{SAF} \quad (1)$$

Energy Potential

Energy potential of biomass pellet produced from the agricultural residues was calculated using the following Equations [Eqs. (2), (3), (4)].

$$\text{ENU} = \text{VOR} \times \text{RNUr} \times \text{HHV} \quad (2)$$

where ENU: energy not used (10^{12} J), VOR: volume of agricultural residue (10^3 kg), RNU_r : residues not used ratio (%), HHV: higher heating value (MJ/kg).

$$\text{TOE} = \text{ENU} / (42.244 \times 10^9) \quad (3)$$

where TOE: tons of oil equivalents energy (10^3) and 1 TOE is 42.244 x 10^9 (J) , ENU: energy not used (10^{12} J).

$$\text{POE} = (\text{ENU} \times PE_{hour}) / 3{,}600 \quad (4)$$

where POE: potential of energy (10^9 Wh), PE_{hour}: power of electric per hour (Wh).

RESULTS AND DISCUSSION

Availability Potential of Agricultural Residues

The 100 examined households included 56 rice, 24 sugarcane, and 20 cassava farming households. Because most of their agricultural land is outside government irrigation districts, they can only produce one crop each year. They usually use machines for planting and harvesting. Rice Stubbles (RB) and Rice Straw (RW) were the most commonly generated residues in the area. However, research revealed that 76.34% of RB was typically abandoned in the field without being used, 11.16% was burned before the following crop began, and only 12.5% was used to feed livestock. In contrast, RW was considered more valuable and adaptable. The majority of RW was used to feed animals (72.32%), whereas 14.29% was sold. Only 13.39% of the waste had the potential to be exploited as an energy source (Fig. 1).

Cassava and sugarcane were the second and third most productive crops in the area. They can also grow once a year. These crops were picked manually by hired workers. It was discovered that leaf leftovers from sugarcane fields have great potential for energy production. All sugarcane leaves were discarded. Farmers typically left sugarcane leaves in the fields (70.83%) without use, while another 29.17% were burned during or immediately after harvesting (Fig. 2). This also occurred with cassava leaves; farmers had not used the materials for any purpose. The majority of them (95%) were abandoned in the fields, with barely 5% being openly burned immediately after harvest. Only 8.75% of the cassava rhizome (root component) was used for traditional home fuel, with the remainder being left in the fields (53.75%) and burned (37.50%) (Fig. 3). Although cassava and sugarcane were produced in significantly lower quantities than rice, their crop residues had a better potential for energy production than RB or RW.

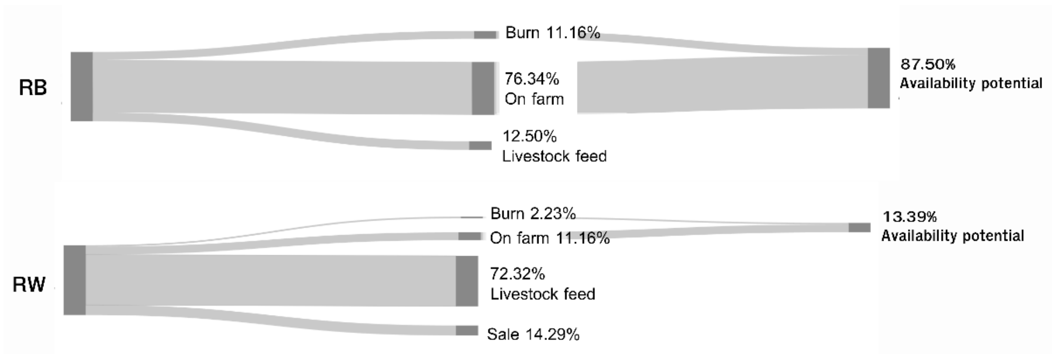

Fig. 1 Residue availability from rice cultivation

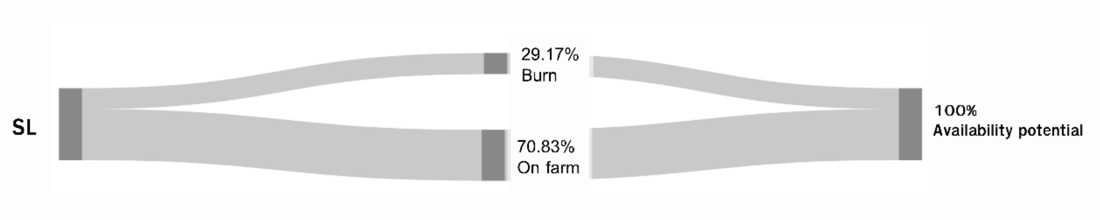

Fig. 2 Residue availability from sugarcane plantation

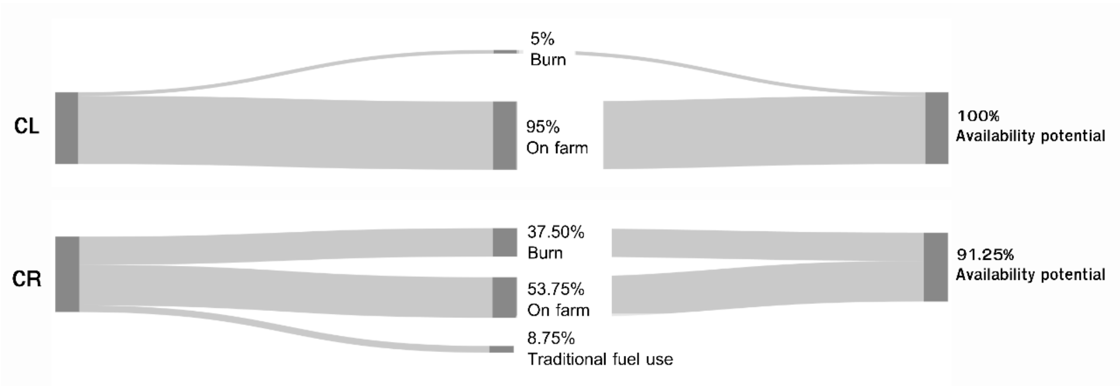

Fig. 3 Residue availability from cassava plantation

Table 1 Crop residue calendar of rice, sugarcane and cassava

Types	Residue production and availability											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice stubble (RB)	■	■	■	■	■	■					■	■
Rice straw (RW)	■	■	■	■	■	■					■	■
Sugarcane leaves (SL)	■	■	■	■	■							
Cassava leaves (CL)	■	■	■	■								
Cassava rhizome (CR)	■	■	■	■								

Crop Residue Calendar

Using agricultural residues as a source of energy production is quite complex. The quality and quantity of feedstock vary greatly, as does its seasonal availability. Table 1 depicts the periods of the year when various types of crop residues were produced and made available. Rice had traditionally been harvested between November and early December. RW was handled and stored for subsequent use and sales. Farmers normally leave RB in the fields until June, then burn or plow it into the soil before planting the next crop. SL, CL, and SR have been available for a shorter time of 4-5 months.

Farmers must burn or plow all remains before beginning the next crop rotation. This information is beneficial for residue-use planning and management.

Surplus Availability Factor (SAF)

The SAF is an important factor for estimating the bioenergy potential of crop residues. The residues produced are not only used for energy generation but also for other purposes. The study data showed that among the five crop residues, SL and CL had not been used at all, and their SAFs were 1.000. Meanwhile, CR and RB had relatively lower SAF values (0.913 and 0.875, respectively). Rice straw had the lowest SAF (0.134) because it can be sold and used for many purposes (Table 2).

Table 2 Surplus availability factor (SAF) of agricultural residues

Agricultural residues	Surplus availability factor (SAF)
Sugarcane leaves (SL)	1.000
Cassava leaves (CL)	1.000
Cassava rhizome (CR)	0.913
Rice stubble (RB)	0.875
Rice straw (RW)	0.134

To estimate the available potential of five crop residues in Mahasarakham Province, we used crop residue data estimated by the cultivation area from our previous work (Singhirunnusorn et al., 2017) and SAF values from this study. Table 3 demonstrates that RB has the highest potential for energy production, followed by SL and CR.

Table 3 Estimate crop residues available for energy production

Types	Cultivation area[a] (ha)	Crop residue[b] (ton/ha)	SAF	Potential availability (ton/year)
Rice stubble (RB)	3,530.16	0.75	0.875	2,316.67
Rice straw (RW)	3,530.16	1.25	0.134	591.30
Sugarcane leaves (SL)	81.04	15.44	1.000	1,251.26
Cassava leaves (CL)	480.87	0.5	1.000	240.44
Cassava rhizome (CR)	480.87	2.75	0.913	1,207.34

[a] Data were adopted from the Land Development Department (2019), [b] Data adopted from Singhirunnusorn et al. (2017).

Pellet Heating Values

In our previous study (Luesopa and Singhirunnusorn, 2023), we employed a blending approach to produce pellets from RB, RW, SL, CL, and CR and investigated the heating values of the pellets. The data showed that CL, SL, and CR were among the biomasses with the highest Higher Heating Value (HHV) of 19.29, 17.49, and 16.92 MJ/kg, respectively. In contrast, RB and RW showed low HHVs of 14.20 MJ/kg and 14.31 MJ/kg, respectively, which are below the heat standard limit of biomass pellets. Blending techniques for biomass pellet manufacture have been suggested to improve the energy properties of pellets. The two-type blending technique revealed that the SL: RW ratio of 80:20 had the maximum heat value of 16.08 MJ/kg. Three-type blending revealed that SL:RW: RB in a 60:20:20 ratio had the maximum heat value (15.68 MJ/kg). Energy quality can be increased by using greater HHV as supplementary materials, such as CL and CR. For example, the RW: CL (50:50) ratio produced the greatest heat value of 16.25 MJ/kg (Luesopa and Singhirunnusorn, 2023).

Energy Potential

A blending strategy for biomass pellet manufacture was suggested in a previous study. The energy potential was calculated based on this scenario. The findings indicate that all available crop residues in Mahasarakham may be used to produce 5,509 tons of pellets each year, accounting for 2.5 Ktoe of biomass (Table 4). The utilization of pellets might generate approximately 5,910 MWh.

Table 4 Energy Potential from different scenarios

Production period	Biomass blending	Biofuel pellet production (Ton)	Energy Potential TOE (Ktoe)	Energy Potential POE (MWh)
Jan- Mar	RB:SL (20:80)	1,173	0.49	1,157
	RB:CR (90:10)	843	0.32	741
	RW:CR (90:10)	235	0.09	209
	CL (100)	240	0.12	272
	CR (100)	1,100	0.48	1,113
April	RB:SL (20:80)	391	0.16	385
	RB:RW (20:80)	88	0.33	776
	RB (100)	235	0.09	209
May	RB:RW (20:80)	265	0.10	229
Nov - Dec	RB (100)	939	0.35	819
Annual Energy Potential		5,509	2.53	5,910

CONCLUSION

The study showed that in Mahasarakham Province, rice stubbles and straw are the most produced residues, but only rice stubbles show the highest availability potential for energy use. Although the production of cassava and sugarcane residues is low, sugarcane leaves and cassava rhizomes show high residue volumes in the area. In terms of seasonal availability, rice production residues are available for a longer period, whereas cassava and sugarcane residues are available for only four to five months. The biomass blending approach can provide a solution to the seasonal variation of materials proposed as an alternative use of agricultural residues to produce energy fuels and reduce material shortages and storage costs. Blending different agricultural residues for pellet production is a strategy to improve pellet quality and efficiency. This strategy allows for the efficient use of both high- and low-energy residues, potentially enhancing the overall energy density and other desirable properties of the pellets.

In the AEPD 20224 and PDP 2024 plans, biomass is targeted as the third-most important RE source for power generation, after hydropower and solar power. Agricultural residues are a significant source, offering various opportunities for sustainable energy production and economic benefit for the agricultural sector. The government’s policies aim to utilize agricultural residues for multiple purposes by using them as a source of industrial energy, co-firing them with fossil fuels in power plants, generating renewable energy at the local level, and creating income opportunities for farmers through biomass collection and processing.

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