Environmental and economic potential of rice husk use in An Giang province, Vietnam

Tiềm năng kinh tế và môi trường của việc sử dụng trấu tại tỉnh An Giang, Việt Nam

Research article

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To evaluate CO₂ emission mitigation potential and cost effectiveness of rice husk utilization, Life Cycle Analysis was conducted for 9 scenarios. The results showed that, gasification is the most efficient CO₂ mitigation. From cost analysis, the cost mitigation can be achieved by replacing the current fossil fuels in cooking scenarios. Among the power generation scenarios, it was found that 30MW combustion and 5MW gasification power generations were the most economically-efficient scenarios. The briquette combustion power generation appeared less cost-competitive than direct combustion, whilst the large-scale gasification scenarios and the pyrolysis scenarios give the increase in cost from the baseline. From the viewpoints of both CO₂ and cost, it was indicated that the win-win scenarios can be the rice husk use for cooking, for large-scale combustion power generation, and for small-scale gasification.

Để đánh giá tiềm năng giảm thiểu phát thải CO₂ và hiệu quả chi phí của việc sử dụng trấu, phương pháp đánh giá vòng đời sản phẩm đã được thực hiện cho 9 kịch bản. Kết quả cho thấy, khí hóa trấu để sản xuất điện có tiềm năng giảm phát sinh khí CO₂ nhiều nhất. Kết quả phân tích chi phí cho thấy việc giảm thiểu chi phí có thể đạt được khi thay thế sử dụng nhiên liệu hóa thạch trong kịch bản dùng trấu cho nấu ăn. Giữa các kịch bản về sản xuất điện, hiệu quả kinh tế cao nhất trong trường hợp đốt trực tiếp trấu để sản xuất điện ở quy mô công suất lớn (30MW) và khí hóa ở quy mô trung bình (5MW). Trường hợp dùng cùi trấu không mang lại hiệu quả kinh tế so với dùng trực tiếp trấu để phát điện. Hai trường hợp dùng trấu để sản xuất dầu sinh học và khí hóa gas công suất lớn (30MW) cho thấy chi phí tăng cao so với điều kiện biên. Kịch bản cho kết quả khả thi về hiệu quả kinh tế và giảm phát thải CO₂ là dùng trấu để nấu ăn, đốt trực tiếp để phát điện công suất lớn và khí hóa công suất trung bình.

Keywords: cooking, combustion, gasification, pyrolysis, life cycle assessment

1. Introduction

Rice husk is one of the most widely available agricultural wastes in many rice producing countries. In Vietnam, rice husk has been utilized for various local needs such as organic fertilizer, cooking fuel, and building material, however, the traditional use is decreasing. In the Mekong River Delta, there are many rice mills distributing and generating husks are not appropriately treated. The estimation conducted by the local authority shows that 3.6 million tons of rice husks are annually produced, some of which are dumped into the dense canal and river systems [1]. The discharged rice husks decrease the dissolved oxygen seriously by covering the water surfaces. In addition, it is seen that

mill owners burn the excess rice husks in the open air. This causes not only respiratory diseases but also severe fire accidents. However, there have not been shown any policies and supports by the Vietnamese government to treat or use them so far.

Rice husks are defined as renewable energy resource. Converting rice husks into heat, steam, gases or liquid fuels would bring benefit to countries that have no conventional energy resources [2]. It is also a good chance to expand the energy resources as well as to reduce the environmental burden derived by the disposal of rice husks. In this study, the CO₂ mitigation potential and economic effectiveness by rice husk utilization was evaluated by using Life Cycle

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Assessment to propose possible strategies for rice husk usage from the viewpoints of both CO₂ and cost.

Figure 1. Map of An Giang province

2. Methodology

2.1 Study area

An Giang province (Fig. 1) situated in the Mekong River Delta region was selected as the study area, because it has the largest paddy area in Vietnam with 520,000 ha in use

[2] and, therefore, it can be a potential market place for rice husk energy production. There are more than 1,000 rice mills, of which more than 200 have larger capacities above 100 t/d [2]. The total quantity of rice husks in An Giang province for 2015 was estimated at 620,000 tons per year (t/y).

2.2 Scenario setting

Based on rice husk supply and current local demands, the following scenarios were set up (see Table 1). The total supply was fixed at 620,000 t/y.

S0 is baseline scenario, in which current demands for cooking (8.6%) and brick making (25.8%) were maintained, and the excess (65.6%) was considered treated by open burning. In **S1**, all excess rice husks are used for cooking to replace coal, LPG, and finally, fuel wood. In **S2** and **S3** scenarios, the excess rice husks (65.6%) were assumed to be used for power generation through combustion (S2) or gasification (S3). **S4** is scenario for bio-oil production by pyrolysis that current demand was maintained. In **S1B**, we were assumed to replace coal and LPG in rural areas with briquettes. In **S2B**, excess rice husks were allocated to briquette production and then used for power generation as with S2.

Table 1. Fuel allocation in each scenario (*: baseline)

		[10 ³ t/y]	S0*	S1	S2	S3	S4	S1B	S2B
Cooking	RH		53	460	53	53	53	53	53
	RHB		0	0	0	0	0	388	0
	Coal		5.2	0	5.2	5.2	5.2	0	5.2
	LPG (urban)		22.6	22.6	22.6	22.6	22.6	22.6	22.6
	LPG (rural)		34.0	12.5	34.0	34.0	34.0	0	34.0
	Fuel wood		434	0	434	434	434	393	434
Brick making	RH		160	160	160	160	160	160	160
	RHB		0	0	0	0	0	0	0
	Coal		0	0	0	0	0	0	0
Power combustion	RH		0	0	407	0	0	0	0
	RHB		0	0	0	0	0	0	388
Gasification	RH		0	0	0	407	0	0	0
Pyrolysis	RH		0	0	0	0	407	0	0
Open burning	RH		407	0	0	0	0	0	0

Note: a: 5MW; b: 30MW, B: briquette

2.3 Preparations for life cycle inventory analysis

2.3.1 Data preparation for Life Cycle CO₂ Inventory Analysis

(i) Direct combustion in cooking and brick making

It is assumed that rice husks or briquettes can replace liquid petroleum gas (LPG), coal and fuel wood for household cooking and brick making. Emission from rice husk transportation for domestic use is negligible because people usually obtain the rice husks from neighborhood mills using bicycles or wood-boats. In the case of brick making, the furnace efficiency for each fuel – coal, fuel wood, rice husk, briquette – was not available, therefore, the requisite amount of fuel for the production of one brick was used instead: 0.3 kg of coal [3] or 0.18 kg of fuel wood [4]. The

default CO₂ emission factors for stationary combustion stated by the Intergovernmental Panel on Climate Change IPCC (2006) were summarized and used as shown in Table 2.

The total CO₂ emission from household cooking and brick making in An Giang province was estimated with the equation as follows:

$$Em_{CO_2} = \sum (F_i \times Ef_i)$$

Where: Em_{CO_2} : CO₂ emission [tCO₂/y]; F_i : consumption of fuel i [t/y] (i : coal, LPG, fuel wood, rice husk, and briquette); Ef_i : CO₂ emission factor of fuel i [tCO₂/t fuel] (with Global Warming Potential, tCO₂/t GHG (CH₄: 21; N₂O: 310 - IPCC, 2006)

Table 2. CO₂ emission factors for stationary combustion in residential areas, [unit: kgCO₂/kg fuel], [5]

Fuels	Combustion	Production phase	Total CO ₂ emission
LPG	2.990	0.230 [6]	3.220
Coal	2.160	0.110 [7]	2.270
Fuel wood	0.118	0	0.118
RH	0.100	0	0.100
RHB	0.123	0.060	0.183

(ii) Power generation by combustion or gasification

The CO₂ emission from the combustion process is derived from three components: (1) use of residual oil in the combustion start-up process, (2) N₂O and CH₄ emissions during combustion and (3) transportation by motor boats. Replacing national-grid electricity with electricity generated from rice husk and briquette was counted as a CO₂ reduction. The CO₂ emission factors applied for the power generation plants are listed in Table 3.

Table 3. CO₂ equivalent emission factors for power generation plants, [unit: kgCO₂/kg], [5]

Categories	Emission factors
Operation	RH combustion
	0.024
	RHB combustion
Transportation	0.031
	Residual oil
	3.272
Replacement	Diesel oil
	3.382
	Grid electricity*
	0.459

* kgCO₂/kWh*(iii) Fuel production by pyrolysis*

In the pyrolysis process, CO₂ emission is derived from (1) nitrogen gas for fluidizing, (2) zeolite as a catalyst, (3) electricity use and (4) transportation, and CO₂ mitigation can be achieved by replacing diesel oil with the produced oil.

For production of nitrogen gas and the zeolite catalyst, the inventory data offered by JLCA (Life Cycle Assessment Society of Japan, Japan Environmental Management Association for Industry) were summarized and adopted in this study. The electricity input to nitrogen gas production is 0.271kWh/kg, which is equivalent to 0.114 kgCO₂/kg based on carbon intensity in Vietnam. To produce 1 kg of fluid catalytic cracking (FCC) catalyst, 0.180kWh electricity, 0.476 m³ natural gas and 17.7 kg steam are needed. The total CO₂ emission for 0.935kg of FCC offered by JLCA was applied for the following calculations.

Taking into account the difference in LHVs between bio-oil (28.15 MJ/kg) [8] and diesel-oil (43 MJ/kg) [5], 1 kg of bio-oil can replace 0.65 kg of diesel oil. CO₂ emission factors, 0.74 kgCO₂/kg [9] and 3.24 kgCO₂/kg (IPCC 2006) for, respectively, diesel-oil production and combustion were used in calculations. The yield of liquid oil from rice husks was set at 20% with catalytic treatment [8].

2.3.2 Data Preparation for Life Cycle Cost Analysis

In order to calculate the life cycle costs for the developed scenarios, data were prepared through interviews, statistics

and literature reviews. All cost figures were adjusted to US dollars by converting currency in 2015 (1 US\$ = 21,000 VND).

(i) Direct combustion in cooking and brick making

In the case of household cooking, the investment cost of cooking equipment (cook stove) and fuel cost should be considered. As shown in Table 4, the lifetime cost of a rice husk stove is not so high comparing to the other stoves. As fuel cost, the market price including transportation cost was used except for rice husks. For rice husks, the price of rice husks without transportation cost obtained through interviews with rice mill owners was applied here.

Table 4. Fuel and stove costs in An Giang province

Fuel type	(a) Stove		(b) Fuel	
	Price, US\$	Life-time, year**	Life-time cost, US\$/y	Price, US\$/kg
LPG	58.8	5	11.8	1.1
Coal	2.9	1	2.94	0.04
Fuel wood	2.9	1	2.94	0.03
RH	11.8	3	3.92	0.01
RHB	2.9	1	2.94	0.06

* market price in An Giang province obtained on Sept. 15, 2015

** data obtained through interviews with An Giang households on Sept. 16, 2015

(ii) Power generation by combustion or gasification

The lifetime cost for a power generation plant (LCG) was estimated following the equation shown by Bergqvist *et al.* (2008). The LCG [US\$/kWh] is

$$LCG = \frac{I_0 + CRF + OM + F - RHA}{P_{net} \times \tau} \quad CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Where I_0 is investment cost [US\$/y]; CRF is capital recovery factor; i is interest rate; n is lifetime; OM is operation and maintenance costs [US\$/y]; F is fuel cost including transportation cost [US\$/y]; RHA is the sale of rice husk ash [US\$/y]; P_{net} is power plant capacity [kW]; τ is operation time (5,000 hours per year).

The all cost data applied to the power generation scenarios are summarized in Table 5.

Table 5. Applied data for cost analysis of power plants

Category	Item	Data	Reference
Investment [US\$/kW]	Com (RH-5 MW)	1,937	[1]
	Com (RH-30 MW)	2,045	
	Com (RHB-5 MW)	2,600	[10]
	Com (RHB-30 MW)	2,045	[11]
	Gas (RH-5 MW)	1,200	
	Gas (RH-30 MW)	2,437	[12]
Operation and maintenance [US\$/kW/y]	Com (RH-5 MW)	62	[1]
	Com (RH-30 MW)	60	
	Com (RHB-5 MW)	104	[13]
	Com (RHB-30 MW)	82	

Category	Item	Data	Reference
	Gas (RH-5 MW)	96	[13]
	Gas (RH-30 MW)	195	
Transportation	RH	0.10	Interview
[US\$/km.t]	RHB	0.12	
Fuel including	RH	5.88	Interview
storage	RHB	29.4	Interview
[US\$/t]			
National	grid electricity	0.10	2015 price
[US\$/kWh]			
RH ash [US\$/t]		50	[14]

Com: power generation by combustion, Gas: power generation by gasification

(iii) Bio-oil production by pyrolysis

In the pyrolysis process, the cost arises from (1) capital, (2) operation and maintenance, (3) nitrogen gas, (4) catalyst, (5) electricity use, and (6) transportation, while it can be avoided by replacement of diesel oil by produced oil.

Table 6. Applied data for cost analysis of pyrolysis plants

Category	Item	Data	Reference
	Annualized capital cost [US\$/y]	55,063	[8]
	Operation and maintenance (incl. Labor) [US\$/plant]	30,450	[8]
	Transportation (incl. Labor and diesel oil) [US\$/km.t]	0.10	Interview
Fuel	RH (incl. Storage)	5.88	Interview
	[US\$/t]		
	Nitrogen gas	0.8	[8]
	[US\$/m ³]		
	Catalyst [US\$/kg]	100	[8]
	Electricity	0.10	2015 price
	[US\$/Kwh]		
	Diesel oil [US\$/kg]	0.74	2015 price

3. Results and discussions

3.1 Life cycle CO₂ assessments

Table 7 shows the estimated CO₂ emissions for the baseline scenario (S0) and scenario considering the domestic uses of rice husks and briquettes. Table 8 shows the total CO₂ increase from the baseline in power generation scenarios.

The maximum mitigation potential is derived from briquette combustion (S2Bb) and followed by direct gasification (S3b). Even the scenario S2a, which shows the lowest CO₂ reduction, can still gain CO₂ reduction with the involvement of construction and decommissioning CO₂ emissions. In the case of bio-oil production (S4), it is also reported that the CO₂ emission can be reduced by diesel oil replacement.

Table 7. CO₂ emissions in baseline and scenarios related to local uses, [unit: 10⁵ t/y]

Emission sources		S0	S1	S1B
	RH	0.05	0.46	0.05
	RHB	0	0	0.48
Cooking (combustion)	LPG	1.82	1.13	0.73
	Coal	0.12	0	0
	Fuel wood	0.58	0.58	0.53
Brick making (combustion)	RH	0.16	0.16	0.16
	RHB	0	0	0
RHB production		0	0	0.23
Open burning		0.40	0	0
Total emission		3.13	2.33	2.16
Difference from the baseline		-	-0.80	-0.95

Table 8. CO₂ change from the baseline in power generation scenarios, [unit: 10⁵ tCO₂/y]

Technology		Combustion				Gasification	
Capacity		5 MW		30 MW		5 MW	30 MW
Feedstock		RH	RHB	RH	RHB	RH	
Scenario		S2a	S2Ba	S2b	S2Bb	S3a	S3b
Cooking (combustion)		0	0	0	0	0	0
Brick making (combustion)		0	0	0	0	0	0
Power generation	Combustion	0.098	0.120	0.098	0.120	0	0
	Start-up	0.0008	0.0015	0.0002	0.0003	0	0
	Transportation	0.012	0.007	0.023	0.015	0.012	0.021
	Electricity re-placement	-0.91	-1.81	-1.52	-2.18	-0.97	-1.82
Briquette production		0	0.23	0	0.23	0	0
Open burning		-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
Total difference from S0		-1.20	-1.85	-1.80	-2.21	-1.36	-2.20

Table 9. CO₂ change from the baseline in pyrolysis scenarios, [unit: 10⁵ tCO₂/y]

Scenario	S4
Cooking (combustion)	RH, RHB, LPG, coal, Fuel wood
Brick making (combustion)	RH
	0
	0

Scenario	S4
Electricity	0.15
Bio-oil generation	Transportation 0.0030
	Nitrogen 0.0011
	Catalyst 0.0015
Diesel oil replacement	Combustion -1.169
	Production -0.075
Diesel oil combustion	0.0026
Open burning	-0.40
Total difference from S0	-1.49

3.2 Life Cycle cost analysis

Table 10 shows the estimated costs of the baseline (S0) and the scenarios promoting the domestic uses. Comparing to S0, the fuel cost decreases significantly when LPG, coal or fuel wood are replaced by rice husks or briquettes. Even though the price of a briquette is six times higher than that of rice husk, the cost mitigation can be achieved by replacing the current fossil fuels into briquettes.

Table 10. Costs in baseline and scenarios related to local uses, [unit: 10⁶ US\$/y]

		S0	S1	S1B
Fuels	RH	0.5	4.6	0.5
	RHB	0	0	23.3
	LPG	60.0	37.2	24.0
	Coal	0.2	0	0
	Fuel wood	14.5	14.5	13.2
Cook stove	RH	0.1	0.3	0.1
	RHB	0	0	0.3
	LPG	1.4	1.0	0.8
	Coal	0	0	0
	Fuel wood	0.8	0.8	0.8
Brick making (combustion)	RH	1.6	1.6	1.6
	RHB	0	0	0
Total cost		79.2	59.9	64.5
Difference from the baseline		-	19.2	14.7

Table 11 presents the total cost changes in power generation scenarios. It was found that the scenario S2b and S3a used for 30 MW combustion and 5 MW power generations were the most economically-efficient scenarios, while the large-scale gasification scenario showed increase in cost from the baseline. The small-scale gasification could be a promising technology especially in remote areas unconnected with the grid power. The briquette combustion power generation appeared less cost-competitive than direct combustion due to its higher investment and fuel costs.

Table 11. Cost change from the baseline in power generation scenarios, [unit: 10⁶ US\$/y]

Technology		Combustion				Gasification	
	Capacity	5 MW		30 MW		5 MW	30 MW
	Feedstock	RH	RHB	RH	RHB	RH	
	Scenario	S2a	S2Ba	S2b	S2Bb	S3a	S3b
Cooking		0	0	0	0	0	0
Brick making		0	0	0	0	0	0
Power generation	Investment	10.0	26.8	17.7	25.3	6.6	25.3
	O&M	2.7	9.1	4.0	8.6	4.1	15.5
	Fuel	2.4	11.4	2.4	11.5	2.4	2.4
	Trans-portion	1.1	0.6	2.1	1.4	1.1	1.9
	Electricity- sale	-19.9	-39.5	-33.1	-47.4	-21.2	-39.7
	ash sale	-4.1	-3.9	-4.1	-3.9	-4.1	-4.1
Total difference from S0 (without ash sale)		-3.6	8.4	-7.0	-0.7	-7.0	5.3
Total difference from S0 (with ash sale)		-7.7	4.6	-11.1	-4.5	-11.1	1.2

Fuel (RH + catalyst)	18.7
Transportation	0.27
Diesel oil replacement	-39.2
Total difference from S0	3.0

Table 12. Cost change from the baseline in pyrolysis scenarios [unit: 10⁶ US\$/y]

Scenario	S4
Cooking	0
Brick making	0
Bio-oil production	Investment 7.2
	OM 16.0

As shown in Table 12, the pyrolysis scenarios give the increase in cost from the baseline. The large number of requisite labors for operation and high cost of catalyst led to the marked increase in the cost of bio-oil production. This huge cost would be a barrier of expansion of pyrolysis so far.

3.3 Scenario evaluation based on CO₂ and cost

The estimated cost changes from the baseline are plotted in Figure 2 with the CO₂ mitigation potentials shown in this study. The scenarios showing the largest CO₂ mitigation potentials, such as large-scale gasification (S3b) and large-scale briquette combustion (S2Bb), were not better options from the view point of cost reduction. The pyrolysis scenarios (S4) also show cost increase from the baseline, although they give relatively larger CO₂ mitigation potentials. The win-win scenarios achieving both large CO₂ mitigation and cost reduction are cooking (S1), large-scale rice husk combustion (S2b), and small-scale gasification (S3a). Prioritizing cost over CO₂, S1 where all rice husks are used for cooking can be the best scenario. S2b where rice husks are allocated to large-scale combustion power generation keeping the current domestic use is the most recommended scenario emphasizing CO₂ mitigation potential. The scenario S2a, where rice husks are allocated to small scale combustion power generation, shows the smallest CO₂ mitigation potential with relatively smaller cost reduction turning out not to be an attractive scenario.

Figure 2. Positions of all scenarios in terms of CO₂ generation from the baseline

◆: Cooking, ■: Rice husk combustion, ✱: Rice husk gasification, ✱: Briquette combustion, ▲: Rice husk pyrolysis

4. Conclusions

The life cycle cost analysis was conducted to evaluate the developed rice husk use scenarios not only from the view-point of CO₂ mitigation potentials but also from the view-point of cost savings. Substitution of current fuels, such as coal, LPG and fuel wood, by rice husks or briquettes, involves CO₂ mitigation potential and cost saving potential. Replacing grid electricity or diesel oil with generated by rice husk involves higher CO₂ mitigation potential. Similarly, sale of generated electricity to the national grid can lead large cost savings. The win-win scenarios can be the rice husk use for cooking, for large-scale combustion power generation, and for small-scale gasification.

5. References

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