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ORIGINAL RESEARCH

Sustainability of a rice husk recycling scheme

Ryoko Sekifuji[1], Chieu Le Van[2], Masafumi Tateda[1*], Hiroshi Takimoto[3]

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Abstract

Purpose To ensure the sustainability of rice husk recycling schemes, there are essential conditions that should be considered. In this study, a system in which a fertilizer was obtained after rice husk heat treatment, which also produces hot water as a heat recovery strategy, was considered, and its financial sustainability, based on different conditions in place, was then evaluated.

Method Based on a previous study, three essential conditions that are necessary for the sustainability of the system were identified (i.e., free or low-cost rice husk collection and hauling, production of silica in the amorphous state, and complete recycling of rice husk ash). The necessity of these conditions was confirmed based on the sustainability of the financial balance of the system.

Results A 24-h d^{-1} operated system is more profitable than one that is operated at 6-h d^{-1}. The pelletizing process is costly; however, the fertilizer in the pellet form can be sold at a relatively higher price. The system was unsustainable when rice husk collection and hauling as well as ash disposal fees were charged.

Conclusion Therefore, the cost of rice husk collection, hauling, and ash disposal as well as the amorphous state of the ash were confirmed as conditions that are necessary to ensure the sustainability of a rice husk recycling scheme.

Keywords Rice husk recycling, Amorphous silica, Collection and hauling, Silica fertilizer, Financial balance, Pellet ash

Introduction

To evaluate the performance of a scheme, sustainability is key, and sustainable development is evaluated on the basis of economic, environmental, and social growth (Ameer and Othman 2012; Banerjee 2008). A scheme may persist if it is beneficial to the environment; thus, in academia, the scheme is considered sustainable. On the other hand, financial sustainability is often the simplest and most convincing economic parameter. Hence, a financially healthy scheme is also considered beneficial to the environment (Ameer and Othman 2012; Banerjee 2008). With respect to its contents, rice husk is considered a bio-ore of silica (Tateda 2016a). However, most stakeholders simply dispose of it as waste, a wasteful practice that is frequently encountered globally. Many researchers have studied rice husk recycling in terms of material (Rufai et al. 2012; Saceda et al. 2011; Uddine et al. 2018; Sekifuji et al. 2019) and chemical (Minh et al. 2018) recycling as well as thermal recovery (Alhinai et al. 2018; Arnaldo et al. 2018; Azat et al. 2019; Eiamsa-ard et al. 2019; Fernandes et al. 2016; Martínez et al. 2011; Quispe et al. 2017). Since rice husks are combustible, they have been investigated in energy generation-related studies. Recycling rice husk into silica fertilizer has been proposed by some researchers (Ma and Takahashi 2002; Tateda 2016b). Ash from incinerated rice husks can be used as a fertilizer after heat collection, leading to the ideal agricultural loop shown in Fig. 1 (Sekifuji and Tateda 2019).

✉ Masafumi Tateda
tateda@pu-toyama.ac.jp

[1] School of Environmental Engineering, Toyama Prefectural University, Toyama, Japan
[2] Project Management Department, Vietnam National University, Hanoi, Vietnam
[3] Faculty of Bioresources and Environmental Sciences, Ishikawa Prefectural University, Japan

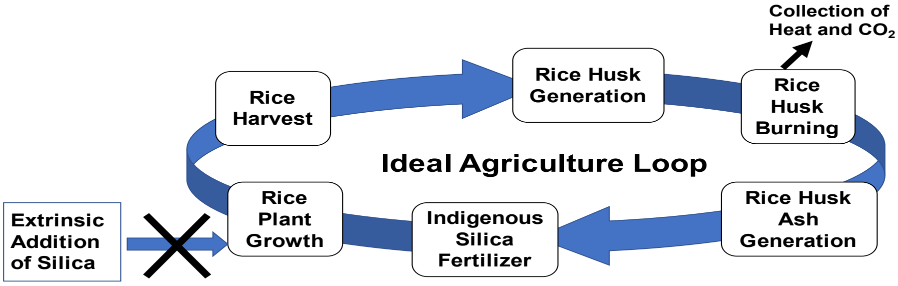

Fig. 1 Ideal agriculture loop based on rice husk recycling

The fundamental concept of the loop is to recover both heat and silicate resources from the combustible rice husk. In a previous study, the usefulness of rice husk in electricity generation and hot water production was compared, and it was found that hot water production makes the loop sustainable (Sekifuji and Tateda 2019). It was also observed that there are three essential conditions for loop sustainability: free or low-cost rice husk collection and hauling, the silica in the incinerated rice husk ash should be in the amorphous state, and the complete recycling of the ash. Rice husk collection and hauling fees negatively affect the sustainability of the loop. The importance of collection and hauling has been investigated in several studies. In terms of solid waste management (i.e., collection, transportation, and disposal), 50–70% of the total management cost can be attributed to the collection phase (Tchobanoglous et al. 1993). Demir et al. (2017) stated that minimizing the solid waste disposal cost minimizes the cost of collection and transportation. In a case study, a 37 kg CO_2 week^{-1} emission reduction was expected, as per the results obtained from the optimization of sludge hauling routes (Passos et al. 2018). If the silica ash is in the crystalline state, it must be completely disposed of without recycling because of its potential carcinogenicity (WHO 1997). On the other hand, Prasara and Gheewala (2017) noted the importance of ash transportation when discussing the recycling of crystalline rice husk ash for products, including thermal insulators and refractory bricks. The incinerated ash obtained after heat recovery must be recycled given that large amounts are generated (20% of the rice husk weight becomes ash). There is no specific order for the three conditions necessary for sustainability. However, the loop cannot be sustainable if any one of the three conditions is not fulfilled. In this study, the sustainability of the loop scheme was evaluated by financially balancing annual income and expenditure. If the loop scheme results in a negative balance, it implies that the scheme is unsustainable, and vice versa if the scheme results in a positive balance (Tateda and Sekifuji 2019). The results of this study will be valuable and useful to stakeholders in rice-growing countries.

Materials and Method

Fundamental information for the ideal agricultural loop recycling scheme

The same boiler plant and associated conditions discussed in Sekifuji and Tateda 2019 (2019), as summarized in Table 1, were employed in this study.

Table 1 Basic data for calculating annual balance

Category	Item	Value	Unit
Operation fundamentals	Boiler capacity	250	kg (rice husk as-obtained) d^{-1}
	Boiler operation	6	h day^{-1}
		220	d yr^{-1}
Operation, maintenance, labor cost	Boiler cost	200000	USD system^{-1}
	Operation cost	1000	USD mon^{-1}
	Maintenance cost	800	USD mon^{-1}
	Pelletizer cost	200000	USD system^{-1}
	Operation cost	1000	USD mon^{-1}
	Maintenance cost	1000	USD mon^{-1}
	Labor cost	35000	USD yr^{-1} capita^{-1}
Miscellaneous	Kerosene price	0.9	USD L^{-1}
	Greenhouse area	3240	m^2
	Ash generation	20	% in weight of rice husks

Equation for calculating the financial balance of incomes and expenditures

$$\underbrace{\boxed{\text{Kerosene saving for rice drying}} + \boxed{\text{Kerosene saving for greenhouse heating}} + \boxed{\text{Fertilizer sale}}}_{\text{incomes}} = \underbrace{\frac{\boxed{\text{Price of the boiler system}}}{\boxed{\text{Depreciation years: 8 yr}}} + \boxed{\text{Yearly boiler cost}} + \boxed{\text{Yearly pelletizing cost}} + \boxed{\text{Rice husk hauling and collection fee}} + \boxed{\text{Ash disposal tipping fee}}}_{\text{expenses}} \tag*{Eq. (1)}$$

In this study, “Incomes” also included the “cost of saving necessities”. For example, the cost of purchasing kerosene was compensated for by heat recovery, which was then considered as an income. Additionally, in this study, “Sustainability” was defined as a net zero balance in Eq. (1).

The data detailed in Table 1 correspond to a case without incurring “Rice husk collection and hauling” and “Ash disposal tipping” fees. The necessary information on income and expenses is shown in Table 2. In a previous study, the basic scheme was considered sustainable even though the final balance was -2949 USD yr^{-1}. This was because this negative balance was not significant and could easily be made up by implementing minor improvements/changes.

Table 2 Previously reported annual balance for a 6 h d^{-1} operated system (USD yr^{-1})

Incomes			Expenditures		
Item	Value	Remarks	Item	Value	Remarks
Rice drying	61875	25 L h^{-1} kerosene consumption	Boiler yearly cost	25000	8 yr depreciation
Greenhouse heating	32076	11 L m^{-2} yr^{-1} kerosene consumption	Yearly operation	12000	
Fertilizer sale	46200	0.7 USD kg^{-1}	Yearly maintenance	9600	
			Yearly labor	35000	1 person
			Pelletizer yearly cost	20000	10 yr depreciation
			Yearly operation	12000	
			Yearly maintenance	12000	
			Yearly labor	17500	0.5 person
Total	140151		Total	143100	

1 USD = 100 yen

Various scenarios to consider for evaluating sustainability

To evaluate sustainability, scenarios with different conditions based on a 6-h d^{-1} operation were considered (Table 3). Regarding rice husk collection and hauling, cases with rice husk collection and hauling free of charge or below 35 USD m^{-3} were considered. Regarding ash usage, 100% usage, 50% usage, and no usage (0%) as fertilizer were considered. With respect to application as fertilizer, prices in the range 0–1 USD kg^{-1} were considered, while 0.7 USD kg^{-1} was considered as the basic price based on a previous study (Sekifuji and Tateda 2019). A price of 0 USD kg^{-1} indicated that the ash could not be sold as a fertilizer and was disposed of as waste. For ash disposal tipping fees, a fee in the range of 0–35 USD kg^{-1} was considered. A tipping fee of 0 USD kg^{-1} (free) under 50% and 0% use of ash was also considered, even though this is an unlikely occurrence.

Table 3 Various scenarios for system operation

Scenario	Rice husk collection and hauling fee (USD m^{-3})	Percentage of ash (%) sold as fertilizer	Fertilizer price (USD kg^{-1})	Ash disposal tipping fee (USD m^{-3})	State of ash (pellet or as-obtained)
0	0	100	0–1	0	pellet
1	0	100	0–1	0	as-obtained
2	0	50	0.7	0–35	pellet
3	0	50	0.7	0–35	as-obtained
4	0	0	0	0–35	as-obtained
5	0–35	100	0.7	0	pellet
6	0–35	100	0.7	0	as-obtained
7	0–35	100	1	0	pellet
8	0–35	0	0	15	as-obtained

According to a previous study, the pellet state (Fig. 2b) is preferred for ash fertilizer over the initial state (Fig. 2a) (Sekifuji and Tateda 2019). However, scenarios in which the as-obtained ash was used were also considered, given that the pelletizing process is costly. For Scenarios 4 and 8, only the as-obtained ash was considered because the stakeholders did not need to produce pellets for ash disposal. Therefore, “pellet ash” and “pellet fertilizer” as well as “as-obtained ash” and “as-obtained fertilizer” were considered synonymous. As shown in Table 3, the 24-h d^{-1} operation was also considered for some scenarios, and the basic data for this 24-h d^{-1} operation are shown in Table 4. The same greenhouse areas for the 6-h d^{-1} operation were used for the 24-h d^{-1} operation, given that there was no extension plan for the greenhouses. Rather, to limit kerosene consumption, the excess heat generated in the 24-h d^{-1} operated process was used for rice drying. Boiler operation and maintenance costs were multiplied by 3, since 24 hours is 8 hours multiplied by 3. The labor costs associated with the operation of the boiler system were also multiplied by three persons, and 1.5 persons were applied to the labor cost of the 24-h d^{-1} operated pellet production system.

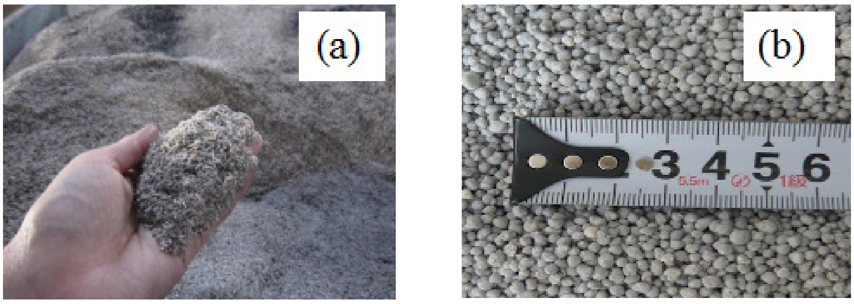

Fig. 2 Fertilizers (a) As-obtained and (b) In a pellet state

Table 4 Previously reported basic data for a 24-h d^{-1} operated system (USD yr^{-1})

Incomes			Expenditures		
Item	Value	Remarks	Item	Value	Remarks
Rice drying	247500	25 L h^{-1} kerosene consumption	Boiler yearly cost	25000	8 yr. depreciation
Greenhouse heating	32076	11 L m^{-2} yr^{-1} kerosene consumption	Yearly operation	36000	
Fertilizer sale	184800	0.7 USD kg^{-1}	Yearly maintenance	28800	
			Yearly labor	105000	3 persons
			Pelletizer yearly cost	20000	10 yr. depreciation
			Yearly operation	36000	
			Yearly maintenance	36000	
			Yearly labor	52500	1.5 person
Total	464376		Total	339300	

1 USD = 100 yen

Results and Discussion

Comparison of annual financial balance with respect to differences in daily operation hours

Fig. 3 shows the difference in the annual balances of the 6 and 24-h d^{-1} operations. A fertilizer price of 0.7 USD kg^{-1} corresponded to the basic operation cost, as shown in the data presented in Tables 2 and 4. The 24-h d^{-1} operated system was sustainable at a fertilizer price of ~0.22 USD kg^{-1} compared with a fertilizer price of 0.7 USD kg^{-1} for the 6-h d^{-1} operated system. Therefore, an increase in daily operation hours enhanced sustainability, even though operation, maintenance, and labor costs increase when operation time increases. The fertilizer could be sold at a price 70% cheaper if the boiler was operated for 24 h each day.

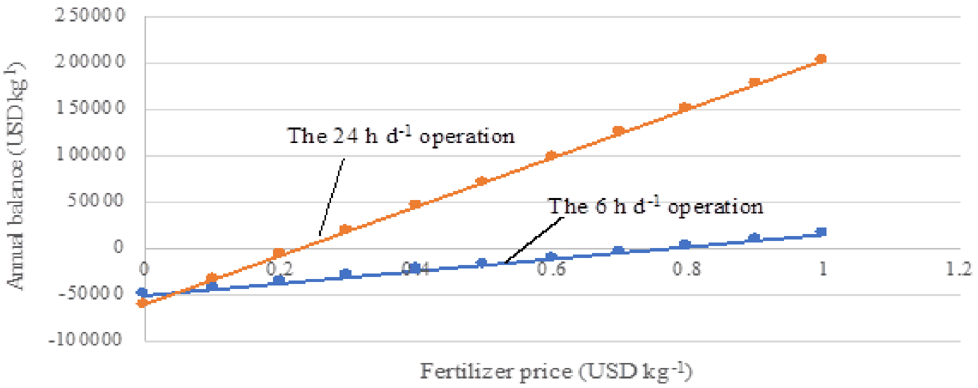

Fig. 3 Comparison of the 6- and 24-h d^{-1} operated systems

Comparison of the annual financial balance of pellet ash vs. as-obtained ash for 6 h d^{-1} operations

As previously reported, the fertilizer was pelletized because a significant number of farmers (80%) preferred the fertilizer in pellet form. However, pelletizing is costly and requires high operation, maintenance, and labor costs. Fig. 4 shows a comparison of the two fertilizer states. As previously mentioned, the system was deemed "sustainable" when the fertilizer price was 0.7 USD kg^{-1} for the fertilizer in the pellet state (Scenario 0). On the other hand, the system could also be "sustainable" if the fertilizer was free of charge (Scenario 1). Given that it is very difficult to use the as-obtained fertilizer owing to the fact that it disperses and can be inhaled by farmers (Fig. 5), its use by farmers was unlikely.

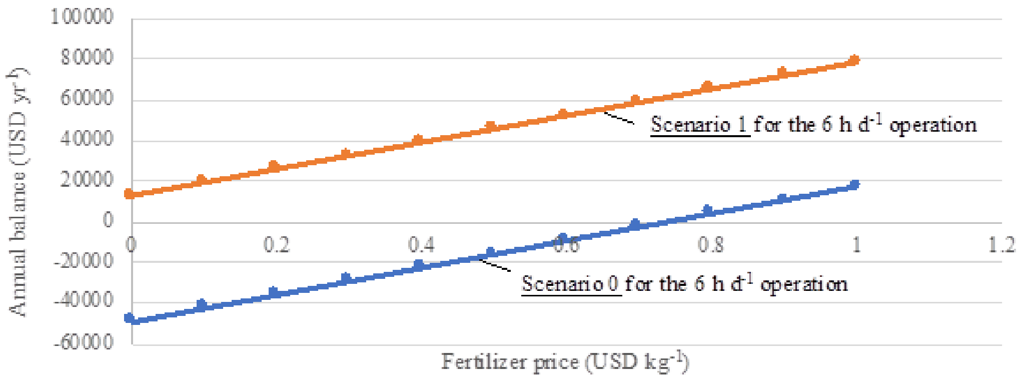

Fig. 4 Comparison of as-obtained ash and pelleted ash

Comparison of annual financial balance when collection and hauling are charged for 6 h d^{-1}

During the calculations, it was considered that the specific gravity of rice husk was 0.1 t m^{-3}. According to Fig. 6, when the pellet fertilizer was used, the annual financial balance became negative once a fee was charged for rice husk collection and hauling (Scenario

Fig. 5 Scene showcasing application of as-obtained fertilizer

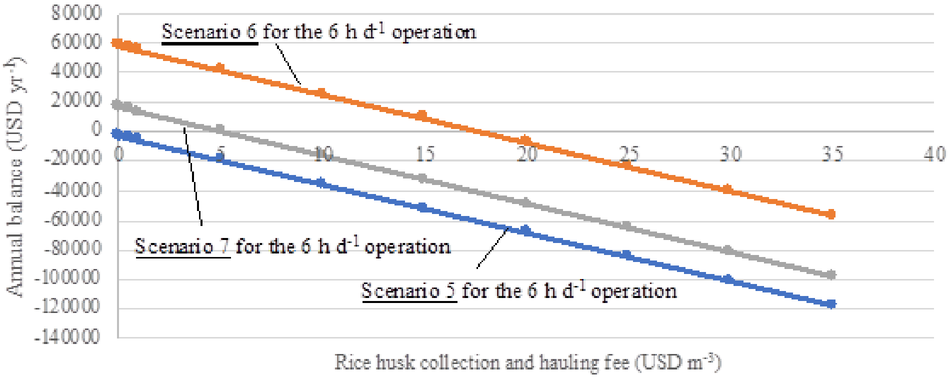

Fig. 6 Comparison of financial balance when rice husk collection and hauling are charged

5). On the other hand, when the as-obtained fertilizer was used, the system was "sustainable" until the rice husk collection and hauling fee reached 17 USD m^{-3} (Scenario 6). However, it is still unlikely that the as-obtained fertilizer would be sold or used by farmers. If the pellet fertilizer could be sold and accepted by farmers at 1.0 USD kg^{-1} instead of 0.7 USD kg^{-1}, financial sustainability could be expected until rice husk collection and hauling fees reached 5 USD m^{-3} (Scenario 7).

When fertilizer cannot be sold and when 50% can be sold, while disposing the rest

In the calculations, a fertilizer price of 0.7 USD kg^{-1} was used, and the specific gravities of the pellet ash and the as-obtained ash were considered to be 1.1 and 0.07 t m^{-3}, respectively. As shown in Fig. 7, pellet fertilizer under a 6-h d^{-1} operation resulted in a significant negative financial balance, despite the fact that the ash disposal was free of charge (Scenario 2, 6 h d^{-1} operation). However, the scenarios became very profitable when the as-obtained ash was used during the 6 h d^{-1} operation (Scenario 3) and when the pellet fertilizer was used during the 24 h d^{-1} operation (Scenario 2).

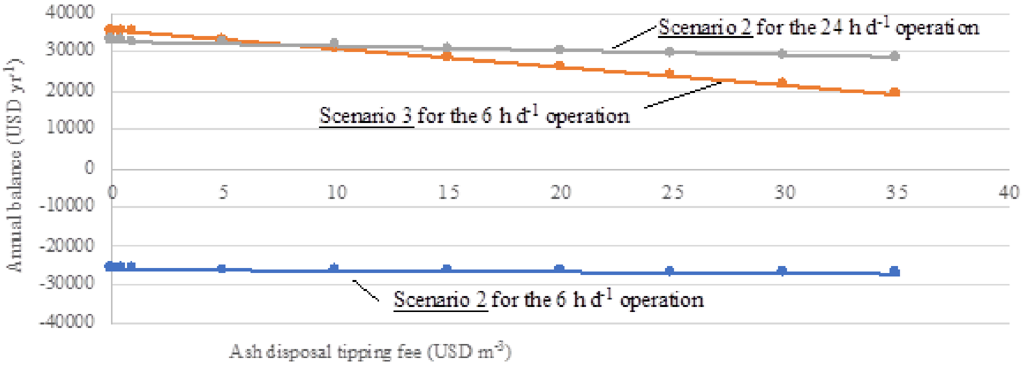

Fig. 7 Comparison of financial balance when ash disposal is charged

When all the ash must be disposed, it can not be sold as a fertilizer

When all the ash must be disposed of, only the as-obtained ash state was considered. According to Fig. 8, the system showed sustainability until the ash disposal tipping fee reached 15 USD m^{-3} (Scenario 4, 6 h d^{-1} operation). However, a tipping fee of 15 USD m^{-3} is unrealistic and too low, considering the 30 USD m^{-3} solid waste disposal fee in Japan. In Turkey, the cost of solid waste collection falls in the range of 30–40 USD t^{-1} (Demir et al. 2017). In Japan, it is higher, and is in the range of 42–56 USD m^{-3} for solid waste with a specific gravity of 1.4 t m^{-3} (Yesiller et al. 2014). The 24-h d^{-1} operated system remained sustainable until the tipping fee reached 22 USD m^{-3} (Scenario 4, 24 h d^{-1} operation). This indicated a financial improvement relative to the 6-h d^{-1} operation; however, the fee was still lower than it would be accepted in practice. Therefore, the system is unrealistic. Self-consumption is usually the last and best resort to solve the challenges associated with recycling. However, the ash could not be used because the constituent silica was crystalized and became carcinogenic.

When rice husk collection and hauling are charged with ash disposal at 15 USD m^{-3}

The worst-case scenario is when stakeholders have to pay for both rice husk collection and hauling, and ash disposal (Fig. 9). Even though this is unrealistic, a 15 USD m^{-3} ash disposal tipping fee was chosen because it allowed for financial sustainability (see previous section). The annual balance became more negative for the 6-h d^{-1} operation as rice husk collection and hauling cost increased (Scenario 8, 6 h d^{-1} operation). A slightly positive annual balance was observed for the 24-h d^{-1} operation; however, it became negative after rice husk collection and hauling fees reached 3 USD m^{-3} (Scenario 8, 24 h d^{-1} operation). A 3 USD m^{-3} fee for rice husk collection and hauling was unrealistically low; thus, the system was unsustainable under both 6- and 24-h d^{-1} operated systems when the ash disposal tipping fee was set at 15 USD m^{-3}. It was easy to ascertain the annual financial balance with an ash disposal tipping fee of 30 USD m^{-3}, which is the normal minimum.

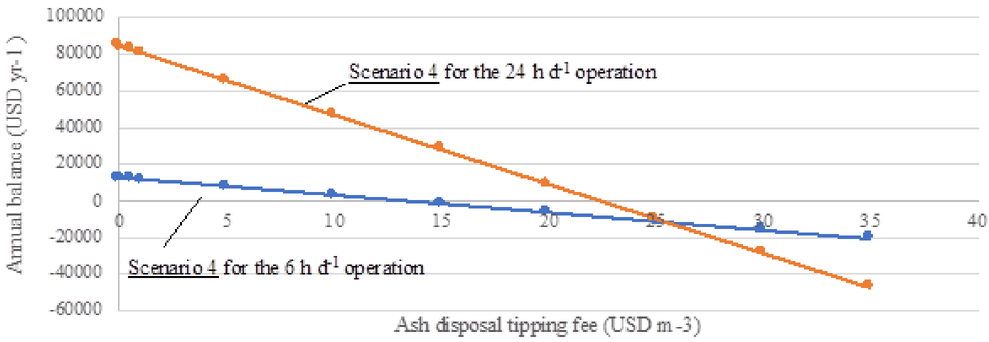

Fig. 8 Comparison of the 6- and 24-h d^{-1} operations when all ash must be disposed of

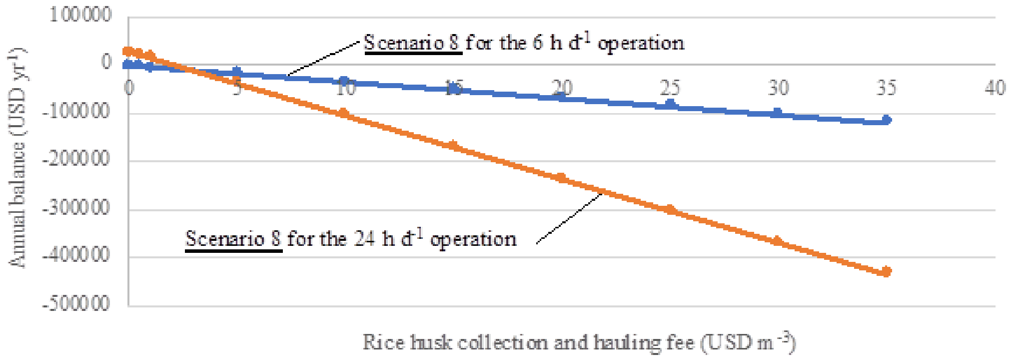

Fig. 9 Cases when both rice husk collection and hauling and ash disposal are charged

Sustainability of the system

Many financially "sustainable" scenarios were observed where income outweighed expenses. However, the conditions necessary to ensure sustainability were very limited, and most often, the scenarios were impractical. For example, the as-obtained fertilizers could not be sold, and a high ash disposal tipping fee hindered sustainability.

Considering all the results obtained (Table 5), it can be concluded that the following conditions are necessary to ensure sustainability: free or low-cost rice husk collection and hauling, the silica in the incinerated rice husk ash should be in the amorphous state, and the complete recycling of the ash. An example of a checklist for system sustainability is summarized in Fig. 10. Any of the three conditions can be the starting condition, i.e., "Collection and hauling" must not be the initial step as shown in the figure. The figure depicts only the cases that guarantee system sustainability; a system was considered unsustainable even if only one of the three conditions was not met.

Table 5 Results of sustainability evaluation for Table 3

Scenario #	State of ash	Varying factor	Sustainability evaluation	Remarks
0	pellet	Fertilizer price	Sustainable @ $\geq$ 0.7 USD kg^{-1} for fertilizer price	Basic operation @ 0.7 USD kg^{-1} for fertilizer price
1	as-obtained	Fertilizer price	Sustainable	Difficulty of ash sale as fertilizer
2	pellet	Ash disposal tipping fee	Sustainable @ the 24-h d^{-1} operation	-Fertilizer price 0.7 USD kg^{-1} fixed Half sold of fertilizer-
3	as-obtained	Ash disposal tipping fee	Sustainable	-Fertilizer price 0.7 USD kg^{-1} fixed -Half sold of fertilizer -Difficulty of ash sale as fertilizer
4	as-obtained	Ash disposal tipping fee	-Sustainable @ $\leq$ 15 USD m^{-3} for the 6 h d^{-1} operation for ash disposal tipping fee -Sustainable @ $\leq$ 22 USD m^{-3} for the 24-h d^{-1} operation for ash disposal tipping fee	-Difficulty of ash sale as fertilizer -Ash disposal tipping fee is usually $\geq$ 30 USD kg^{-1}
5	Pellet	Rice husk collection and hauling fee	Unsustainable	-Fertilizer price 0.7 USD kg^{-1} fixed
6	as-obtained	Rice husk collection and hauling fee	Sustainable @ $\leq$ 17 USD m^{-3} for rice husk collection and hauling fee	-Fertilizer price 0.7 USD kg^{-1} fixed -The less rice husk collection and hauling fee is, the more sustainable it is.
7	Pellet	Rice husk collection and hauling fee	Sustainable @ $\leq$ 5 USD m^{-3} for rice husk collection and hauling fee	-Fertilizer price 1 USD kg^{-1} fixed -The less rice husk collection and hauling fee is, the more sustainable it is.
8	as-obtained	Rice husk collection and hauling fee	-Unsustainable for the 6-h d^{-1} operation -Sustainable @ $\leq$ 3 USD m^{-3} for the 24-h d^{-1} operation and for rice husk collection and hauling fee	-The less rice husk collection and hauling fee is, the more sustainable it is. -Ash disposal tipping fee 15 USD m^{-3} fixed. -Ash disposal tipping fee is usually $\geq$ 30 USD kg^{-1}

Free collection and hauling, which is part of a typical Japanese agricultural business system, was discussed in our previous study (Sekifuji and Tateda 2019). Additionally, in Japan, most farmers belong to a local agricultural association (Fig. 11), and they take their agricultural products to the shops operated by these local associations. At times, members of these associations receive agricultural advice regarding the purchase of

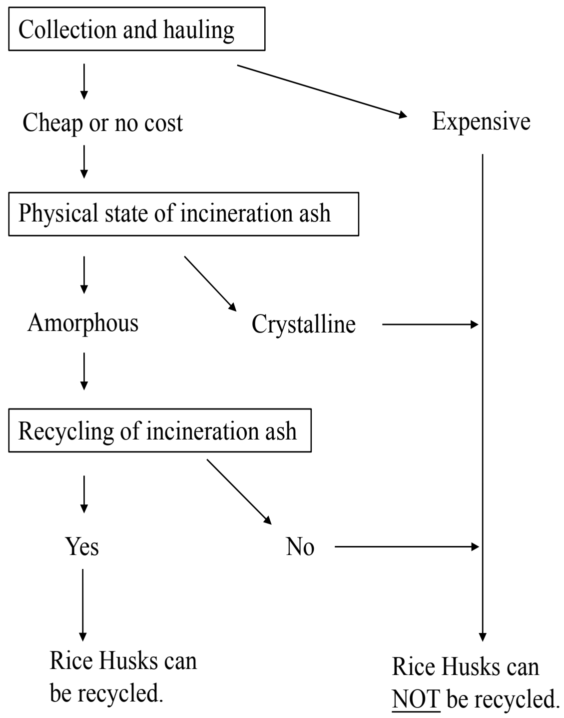

Fig. 10 Sustainability Flow chart

materials, such as fertilizers and machinery. Additionally, they can borrow money and even request funeral services. A local agricultural association is part of the famers' lives. Farmers bring their harvested paddies to the rice centers operated by these local associations, where the rice is milled and sold. Under the association scheme, rice husk is gathered at the community rice center free of charge and is used by the association for energy recovery; further, the fertilizer developed from the incinerated rice husk ash after recovery is sold. The association can sell the silica fertilizer to members, given that these members also buy agricultural materials from the association.

Obtaining silica in the amorphous state after incineration of the rice husk is essential. As previously reported (Sekifuji and Tateda 2019), controlled rice husk incineration is essential to keep the silica in the amorphous state, which has a wide variety of applications, including fertilizers, solar panels, insulators, refractories, high-performance concrete, waterproofing chemicals, food, healthcare, and cosmetics (Pode 2016). For a local agricultural association, selling the ash as fertilizer is tremendously advantageous over selling it as a raw material for other products because it can be sold to farmers, who are members of the association. If the fertilizer cannot be sold and the silica is still amorphous, it is essential that the ash be disposed outside the local association's jurisdiction or to be freely given to users. In this study, to better reflect the costs considered by Armington and Chen (2018), administrative costs were not considered. Therefore, the results obtained are not an adequate reflection of the system given that administrative costs, which often represent an additional expenditure, were not considered.

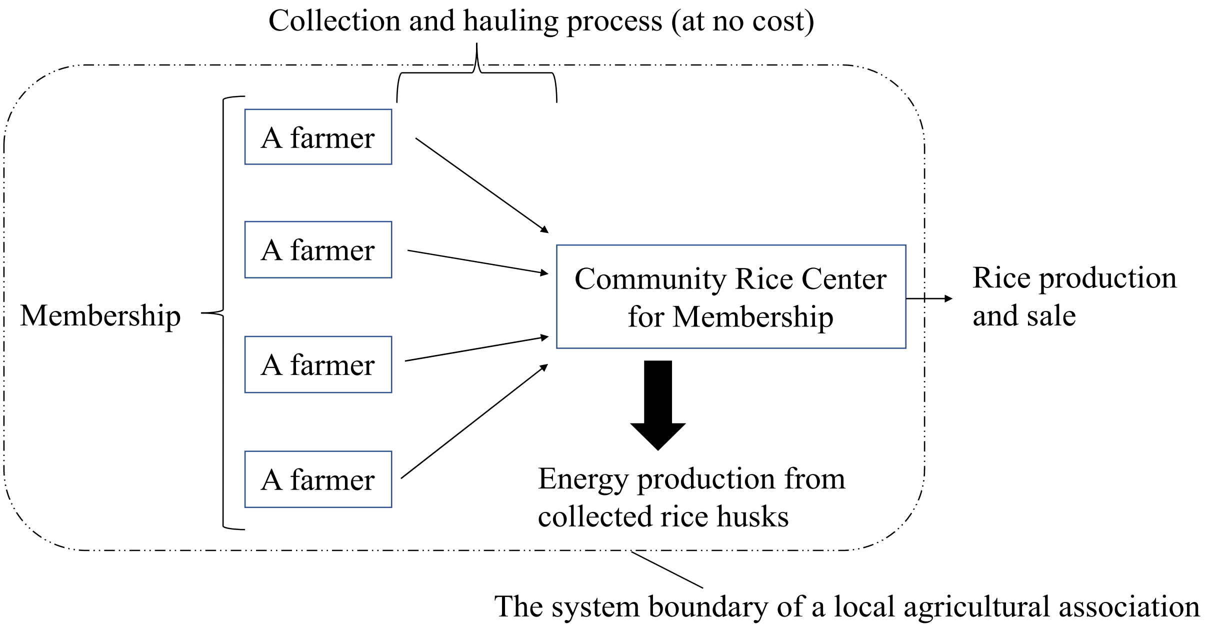

Fig. 11 System boundary of a local agricultural association

Given that a considerable amount of ash is generated, it is necessary for the ash to be completely used—20% of the weight of rice husk is converted to ash compared with only 0.1% for wooden biomass. Moreover, with respect to returning the silica to its original source, a paddy field is ideal for recycling. Silica is applied between the soil and the rice plants continually, resulting in an ideal agricultural loop. Notably, the essential conditions described herein are extremely important with respect to pursuing a sustainably ideal agricultural system.

Conclusion

The following conclusions were drawn from this study:

- A 24-h d^{-1} operated system is more profitable than one that is operated at 6-h d^{-1}.

- The pelletizing process is costly; however, the fertilizer in the pellet form can be sold at a relatively higher price.

- The as-obtained fertilizer is considerably cheaper in terms of production cost; however, selling puts sustainability at risk because it cannot be sold at a high price.

- The system becomes unsustainable when rice husk collection and hauling are charged.

- The system becomes unsustainable when ash disposal is charged.

- To ensure recycling, the silica content of the ash must be in the amorphous state.

- All the ash must be recycled in order to make the system sustainable.

Based on the results, the following are essential considerations to ensure sustainability: free or low-cost rice husk collection and hauling, the silica in the incinerated rice husk ash must be in the amorphous state, and the complete recycling of the ash.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

References

Alhinai M, Azad AK, Bakar MSA, Phusunti N (2018) Characterisation and thermochemical conversion of rice husk for biochar production. Int J Renew Energ Res 8(3): 1648–1656

Ameer R, Othman R (2012) Sustainability practices and corporate financial performance: A study based on the top global corporations. J Bus Ethics 108: 61–79. https://doi.org/10,1007/s-1063-011-10551y

Armington W, Chen RB (2018) What to do with all this food? Examining the emerging food waste hauling network in Western New York State. In: 97th Annual Meeting of the Transportation Research Board, Washington, DC; 2018 Jan 7–11

Arnaldo J, Costa S, Paranhos CM (2018) Systematic evaluation of amorphous silica production from rice husk ashes. J Clean Prod 192: 688–697. https://doi.org/10.1016/j.jclepro.2018.05.028

Azat S, Korobeinyk AV, Moustakas K, Inglezakis VJ (2019) Sustainable production of pure silica from rice husk waste in Kazakhstan. J Clean Prod 217:352–359. https://doi.org/10.1016/j.jclepro.2019.01.142

Banerjee SB (2008) Corporate social responsibility: The good, the bad and the ugly. Crit Sociol 34(1): 51–79. https://doi.org/10.1177/0896920507084623

Demir G, Ozcan HK, Karakus PK, Bakis Y (2017) Solid waste collection route optimisation by geographical information system in Faith, Istanbul, Turkey. Int J Glob Warm 11(3): 263–272

Eiamsa-ard S, Wongcharee K, Chokphoemphun S, Chuwattanakul V, Promvonge P (2019) Investigation on rice husk combustion in a fluidized with longitudinal vortex generators. Earth Environ Sci 265: 1–8. doi:10.1088/1755-1315/265/1/012008

Fernandes IJ, Calheiro D, Kieling AG, Moraes CAM, Rocha TLAC, Brehm FA, Modolo RCE (2016) Characterization of rice husk ash produced using different biomass combustion techniques for energy. Fuel 165:351–359. http://dx.doi.org/10.1016/j.fuel.2015.10.086

Ma JF, Takahashi E (2002) Soil, fertilizer, and plant silicon research in Japan. Elsevier, Amsterdam

Martínez JD, Pineda Tatiana, López JP, Betancur M (2011) Assessment of the rice husk lean-combustion in a bubbling fluidized bed for the production of amorphous silica-rich ash. Energy 36: 3846–3854. doi:10.1016/j.energy.2010.07.031

Minh TN, Xuan TD, Ahmad A, Elzaawely AA, Teschke R, Van TM (2018) Efficacy from different extractions for chemical profile and biological activities for rice husk. Sustainability. https://doi.org/10.3390/su10051356

Passos J, Lourinho G, Alves O, Brito P (2018) A heuristic solution based on Clarke and Wright's saving algorithm for the optimization of sludge hauling: The case of a Portuguese company. Repositório Comum. Accessed: May 15, 2020. http://hdl.handle.net/10400.26/25185

Pode R (2016) Potential applications of rice husk ash waste from rice husk biomass power plant. Renew Sust Energ Rev 53: 1468–1485. https://doi.org/10.1016/j.rser.2015.09.051

Prasara AJ, Gheewala SH (2017) Sustainable utilization of rice husk ash from power plant: A review. J Clean Prod 167: 1020–1028. http://dx.doi.org/10.1016/j.jclepro.2016.11.042

Quispe I, Navia R, Kahhat R (2017) Energy potential from rice husk through direct combustion and fast pyrolysis. Waste Manag 59: 200–210. http://dx.doi.org/10.1016/j.wasman.2016.10.001

Rufai IA, Uche OAU, Ogork EK (2012) Biosilica from rice husk ash a new engineering raw material in Nigeria. In: National Engineering Conference Exhibition and Annual General Meeting "Harmony 2012." 2012. p. 1–20

Saceda JJF, de Leon RL, Rintramee K, Prayoonpokarach S, Wittayakun J (2011) Properties of silica from rice husk and rice husk ash and their utilization for Zeolite Y synthesis. Quim Nova 34(8): 1394–1397. https://doi.org/10.1590/S0100-40422011000800018

Sekifuji R, Le VC, Tateda M (2019) Investigation of negative effects of rice husk silica on komatsuna growth using three experiments. Int J Recycl Org Waste Agric. 8 (Suppl 1): S311–S319. https://doi.org/10.1007/s40093-019-00303-w

Sekifuji R, Tateda M (2019) Study of the feasibility of a rice husk recycling scheme in Japan to produce silica fertilizer for rice plants. Sust Environ Res 29: 11. https://doi.org/10.1186/s42834-019-0011-x

Tateda M (2016a) Bio-Ore of silicon, rice husk: Its use for sustainable community energy supply based on producing amorphous silica, Session Environmental Sciences (2). In: International Congress on Chemical, Biological and Environmental Sciences (ICCBES) Osaka, Japan 2016 May 10–12

Tateda M (2016b) Production and effectiveness of amorphous silica fertilizer from rice husks using a sustainable local energy system. J Sci Res Rep 9(3): 1–12. https://doi.org/10.9734/JSRR/2016/21825

Tateda M, Sekifuji R (2019) Trial calculation for knowing the upper limit price for an electricity generation whole system from waste burning, In: 34th International Conference on Solid Waste Technology and Management. Annapolis, MD; 2019 Mar 31- Apr 3

Tchobanoglous G, Theisen H, Vigil S (1993) Collection of solid waste. In: Integrated solid waste management; engineering principles and management issues. McGraw-Hill, Boston, pp 193–245

Uddin MN, Rashid MM, Taweekun J, Techato K, Roy R, Rahman MA (2018) Investigation on producing silica from rice husk biomass. Int J Renew Energ Resour 8: 7–12. https://ejournal.um.edu.my/index.php/IJRER/article/view/14806

WHO (World Health Organization) (1997) Silica, some silicates, coal dust and dust and para-aramid fibrils. IARC Monographs on the Evaluation of Carcinogenic Risks to Human 68. Accessed: May 15, 2020. https://publications.iarc.fr/86

Yesiller N, Hanson JL, Cox JT, Noce DE (2014) Determination of specific gravity of municipal solid waste. Waste Manag 34: 848–858. https://doi.org/10.1016/j.wasman.2014.02.002