Technical-economic Studies of Bio-Waste Valorisation for Local Multi-Energy System

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Abstract. Globally, substantial volumes of bio-waste are generated every day, causing severe environmental concerns, occupying soil, and demanding financial support for its management. An ingenious way of handling this bio-waste challenge is the expansion of modern and original methods focused on the alteration of these raw materials into value-added fuels. This work was conducted in the European Institute for Energy Research - a facility dedicated to energy subjects as well as the environment, and was motivated in order to research economic opportunities for investment in markets where energy costs and waste disposal costs are relatively high and where valorisation of bio-waste could be introduced. The work presents a choice of biogas digester for rural areas of French Guiana based on the MCA and the unit size based on the number of family members depending on the used feedstock. In addition, a business model of the pre-feasibility study for electricity production through rice husk gasification, was performed. Two models based on length of the rice mill operating hours were investigated and analysed.

1. Introduction

Solid waste and the factor of its rising generation is one of the significant problems' societies have to face. This challenge can be addressed as a result of the linear economy being used as a putative pattern for many centuries, where the take-make-dispose approach has been applied. On the contrary, the closed-loop Circular Economy (CE) approach has gained much attention in the recent decade. The leading difference CE presents to the prior, adversarial concept, is using materials value and potential indefinitely, recycled of their properties, or returned to the natural environment without damage to the ecosystem [1]. Re-evaluating the structure of our economic system and enforcing CE can contribute to alleviating the problem of Waste Management (WM) both in the case of urban and rural areas. It also provides an answer to the limited availability of resources [2]. In the light of the gradual depletion of non-renewable resources of energy with a limited stock of reserves and fuel import dependence, alternative fuels represent a compelling substitute to fossil fuels, notably in countries lacking their resources. Moreover, using and re-using a variety of waste available locally, namely, bio-waste, can contribute to streamlined WM support in energy systems transformation [3].

1.1 State of art

This work was motivated in order to research economic opportunities for investment in markets where energy costs and waste disposal costs are relatively high and where valorisation of bio-waste could be introduced. To achieve this aim, several topics were investigated, including energy resources, means of energy conversion, energy transportation and consumption in three different regions - domestic use of micro prefabricated biodigester in French Guiana, and application of waste-to-energy systems in the agricultural industry of Indonesia. Technological features and local constraints of the territories were investigated and analysed.

1.2 Goals

This research combines technical and economic evaluation of various waste-to-energy systems for bio-waste valorisation and pre-feasibility studies. Those systems are characterized by different unit sizes, varying technologies, distinct economic environments, and diverse actors involved (household, industry, and regional authorities). The first case is the evaluation of most suitable biogas digester for remote, rural areas of Amazon French Guiana, taking into consideration regional and climate characteristics. Moreover, research should find the appropriate size of the digester and the number of family members able to offset LNG utilisation used for cooking through the valorisation of household organic waste based on implemented biomass feedstock and aim to examine the energy relationship of substituting LPG and solid, traditional biomass by biogas for cooking. Results of the study should allow to duplicate the project in various locations and settings. The second case is the energy recovery from MSW in Kumasi, Ghana. The aim is to find the right size of neighbourhood or district which can self-sustain communal parts in electricity generation. The research should find a suitable technology for waste valorisation, define required actors, and conduct necessary calculations for a pre-feasibility study. The third, and the last case of bio-waste valorisation exercised in this study, is to identify an agro-industry based in Indonesia which could be able to self-sustain electricity generation from production waste of this industry. The exercise should contain a technical-economic analysis which will indicate the feasibility of such a project.

2. Formal model and assessment

Firstly, the methods used to determine the appropriate type of biogas digester, as well as its' size and produced biogas potential, were described. The initial reports adopted in this chapter are records from the EIFER projects concerning biogas production in South America and the Caribbean. Secondly, the methods used to assess rice husk potential and the components of technical-economic analysis were presented. Methods were adopted from a study on rice husk utilization in Cambodia and India. In order to verify the figures, data from the Central Agency on Statistics of Indonesia. The third project, for Kumasi, Ghana, was not analysed in this work due to terminated cooperation with the stakeholders. Nevertheless, various recommendations and possible solutions for that region were outlined in the last section of this work.

2.1 Digester evaluation

Multi-criteria Analysis (MCA) was applied for the comparison of possible choice of digester. For French Guiana AD project fixed dome digester, prefabricated digester, and floating drum digester were examined. The guidelines for the examination were chosen subsequent to a literature review related to the expected common properties of biogas digesters for obtaining reliable operation. The chosen digester is required to be:

- operating at optimum temperatures, from 20 to 35 Celsius degrees,
- lightweight, easy to transport and self-assemble,
- able to contain the volume of waste generated by a typical-size family in rural French Guiana.

In the first part of the MCA analysis, biogas digesters were investigated with regards to four criteria: durability, technical expertise and skills, and capital cost. The MCA findings and parameters' summary were depicted in the performance matrix (Table 1). In order to finalize the matrix, the weight for every criterion was assigned. The measuring was performed by distributing 100 units among the criteria. Durability and Technical knowledge were assigned 30 units out of the 100, whereas capital cost received 40 units. The linear additive model determined the cumulative scores described in Chapter 3. The most significant score from the MCA determines that the technology adjusted the best to the requirements of rural and remote areas of French Guiana is the prefabricated digester.

2.2 Biogas yield and biodigester size

This part introduces the evaluations of biogas volumes which can be produced by handling the bio-waste applying the prefabricated digester. The evaluations were made to establish the volume of the digester, as well as the size of a family and used feedstock biomass to offset LNG utilisation through the valorisation of organic waste. The conclusions of the digester’s capacity were attributed to two criteria: size and the biogas production rate. The former was essential to define its potential to be applied in the prefabricated version, while the biogas production was significant to discover how beneficial introduction of the digester was to substitute LNG to meet the family’s cooking fuel demand. The significant fraction of bio-waste presented a human waste but considering that each family holds their food leftovers, and those leftovers hold a rate of biogas production, those scraps were combined with the overall waste to analyse the advancement in the production of biogas.

Table 1 Outcomes of the MCA

Type of digester	Durability 0,3	Skills 0,3	Cost 0,2	Size 0,2	Score
Fixed dome	33	0	0	0	**10**
Prefabricated	100	100	50	100	**80**
Floating drum	0	50	100	50	**45**

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The significant fraction of bio-waste presented a human waste but considering that each family holds their food leftovers, and those leftovers hold a rate of biogas production, those scraps were combined with the overall waste to analyse the advancement in the production of biogas. It was assumed that each family member produces 400 grams of faecal waste per day and the retention time is 60 days.

The digesters' volume relying on household waste and the different size of family is displayed in Figure 1; the one that utilises a mix of human and food waste holds the most significant size, and it remains remarkably close to the one handling human waste alone. As the number of family members rises, the difference in respective digester size becomes more notable. Figure 1 further reveals that the digesters' volume processing solely food waste was the lowest.

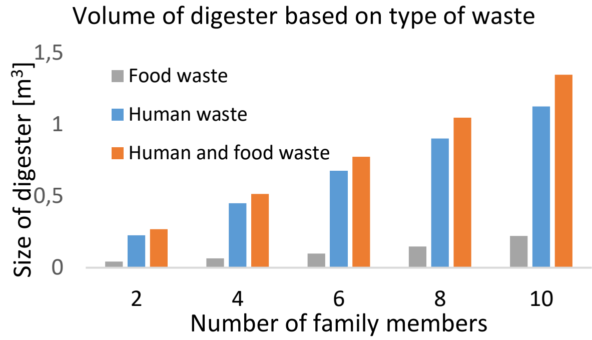

Figure 1 Size of digester as per bio-waste type

The findings of biogas gas production from digesters are provided in Figure 2, which shows that adopting the human and food waste blend as a feedstock supplied 120% more gas demand for cooking concerning a family of five. In parallel, the employment of only human waste or only food waste as feedstock contributed to 67% and 45%, respectively. As for the individual digester, food waste alone could supply the entire LPG cooking gas demand, whereas a digester applying only human waste fails to cover it. With the increase of the family size, the number of food residues increases as well; therefore, digester loses its efficiency and capability to meet the LPG cooking demand. Figure 2 presents that

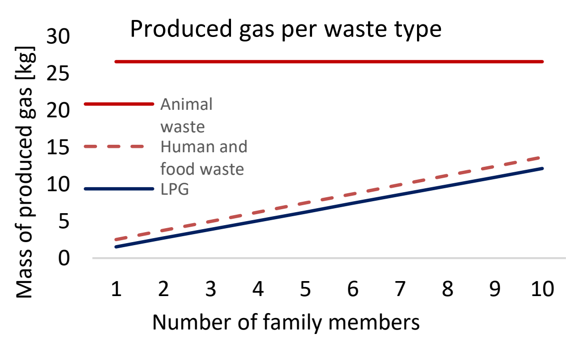

Figure 2 Mass of produced gas as per waste origin

digester based only on human waste meets only 38% of the five-person-family's requirement for LPG. Ultimately, the converging lines representing LPG and the food–human waste will meet, indicating that an expansion of the family members will limit the digester from satisfying the family's need for LPG. The last digester feedstock design used animal manure, which was considered fixed despite the family size. The adopted type, number of animals, and daily produced waste were as follow: one cow (10 kg of waste), two sheep (2 kg), and seven chickens

(0,08-0,01 kg) [4]. Table 2 presents the estimated biogas production as per the feedstock origin. Figure 3 shows the volume of produced biogas from domestic animals' waste associated with food-human waste and LPG demand as a reference. In comparison to a family of five, digester fed with only animal manure can meet the cooking gas demand four times. The surplus of fuel can be applied for lighting, whereas the food and human waste digester satisfied 120% of fuel demand.

The overview of the findings of the three examples of the biodigester size and capacity of gas production was given in Table 2. The family size, on average, was assessed to constitute five, based on the Insee - National Institute of Statistics and Economic Studies of France [5]. The gas vessel was compared to the typical LPG cylinder used for cooking purposes that, as stated by *Société Anonyme de la Raffinerie des Antilles* - French company operating in West Indies-Guiana region, holds 12,5 kg of liquefied petroleum gas.

Table 2 indicates that human waste satisfies 67% of the requirement for cooking gas per month and can be improved by food waste to meet 120% of needed gas. On the contrary, animal waste is able to satisfy the cooking gas need more than four times; however, the obstacle was, to a large extend, enlarged digester size.

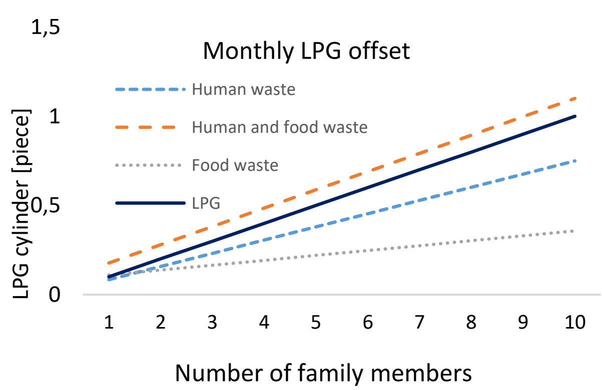

Figure 3 Compensation of LPG cylinders per type of bio-waste

2.3 Rice husk valorisation analysis

- **Electricity generation**

Supply of feedstock: This model was based on a theoretical solution, describing a small-scale rice mill concerning what could be established, including rice husk as fuel. It was assumed that rice mill was provided with rice husk from its' production, and it, for at least, provided electricity for itself. Considering the intended capacity for stable operating conditions (6 h/day) was 1 500 tons per month, needing 18 000 tons per year of raw material. Suppose the estimated projected operating time increased to 12 hours per day, the amount of processed raw material increases to 36 000 tons/year. Smaller mills with lower milling capacity located in the neighbourhood could turn into potential partners as feedstock suppliers. Nevertheless, as rice husk is considered a potential biofuel, the cumulative CO_2 emission is equal to zero as a result of CO_2 consumption by rice paddy. As all the CO_2 in rice production is recycled, the share of emissions would be added through transport, which contributes to over 60% emissions related to paddy processing [6].

Table 2 Outcomes overview for five-person family size

Type of digester	Size of digester [m³]	LPG replacement [%]
Human residues	0,5	67
Food waste	0,09	45
Food-human waste	0,55	120
Animal dung	2,11	>400

No comprehensive investigation of demand fluctuations during the year or day was done. Alternatively, a comparable amount of a total load of operating hours was applied for calculations. As reported by a feasibility study conducted in Cambodia and practice from already available projects, it was plausible to presume 1800 h per year of the full load performance for rice mill. Considering that rice husk is released through the milling process, rice husk as a fuel for power generation is accessible through an identical period as the electricity demand exists, which means that plant utilising rice husk has the same number of operating hours as those mills.

Electricity: It was assumed that the total generated electricity could be used or sold if produced. The mill lacking a grid connection is expected to work to suit the power load which it is connected to firmly. Any indications of trouble to manage load fluctuations or surplus/ shortage of power as a consequence of it was not reviewed. The single risk assessment conducted was differences of various input values in the sensitivity analysis. As long as it is feasible to retail electricity at any given moment, the calculated LCOE matches the electricity sale cost where the project attains economic break-even. This implies that the LCOE can be compared to current and future electricity tariffs.

Due to PLN's existing monopoly on state grid distribution network, the estimated electricity price is reliant on the electricity being traded straight to the user or to the state power grid. The electricity price was fixed for operation during the day to the industrial purchase rate for the grid voltage intensity that majority of rice mills are coupled with [7].

Relying on the raises explained above and present electricity prices in Indonesia, this charge was assessed to 25 ¢USD/kWh. Rice mill was intended to trade surplus of electricity to the state grid and therefore depends also on the Indonesian feed-in tariff. Basing on a Policy Brief [8] this value was assessed as 10,71¢USD/kWh. All prices excluded taxes.

- **Technical-economic evaluation**

Capital expenses (CAPEX): The capital costs describe the cumulative expense invested in the rice husk gasification system. The entire CAPEX comprises the own - acquired capital and loans. Moreover, the lifespan of the technology was presumed to be 20 years which signifies the typical lifetime for rice husk gasifier. Land expenses were not reflected in this investigation as it was concluded that investment is carried out on existing premises of a rice mill. The expenses for the technology contain the gasifier (fluidized-bed reactor), IC-engine, SI gas engine, cyclones and scrubbers, conveyor belt, and electrostatic precipitator. Those expenses were associated only with rice mill; the distribution for outside connections was not included.

Table 3 Information applied to calculate revenue

Element	Value	Unit
Industry electricity	25	¢USD/kWh
Feed-in tariff	10,71	¢USD/kWh
Annual net	1,494	GWh

The values adopted in this part were adapted from various research references. The total CAPEX combines all expenses of rice husk gasification unit for the standard plant value of gross 1,4 MWe capacity and amounts to 1,6-1,8 kUSD/kWe. Cash flow estimations included the technology depreciation by distributing the CAPEX to identical values over its lifespan.

Operational expenses (OPEX): Operational cost involves total expense required for the handling of the bio-waste, containing expenses for the labour and workforce (administrative and operational). The expenses for energy utilised during the operation were not included as it was estimated total energy demand was satisfied internally. The OPEX was calculated and assessed to be 4,5% of the CAPEX and confirmed based on values from previous EIFER projects. Operational cost covers the expenses for repairs, servicing, and comprehensive maintenance of the devices.

The cost of insurance of the biomass plant was estimated in this study at a commonly accepted value of 0,5% of CAPEX. The labour costs were acknowledged in regard to the minimum wage in Indonesia 257 USD per month for manual workers and 290 USD for administration. The transport expenses were not determined in this study, and all internal feedstock movement was included in the auxiliary consumption.

Revenue: The revenue of the biomass plant was earned from the feed-in tariff. The assumption was that the volume of rice husk to be gasified was accessible continuously and that power generation was consistent through the complete lifespan of the project. The estimation of the electricity revenue was relying on the surplus electricity open to be contracted and the feed-in tariff. The electricity available was 1 494 000 kWh per year (based on estimated available volume of rice husk) and the feed-in tariff, introduced by the Indonesian Ministry of Energy and Mineral Resources [8], was assessed as 10,71 ¢USD/kWh. Aggregation of the data applied to estimate revenue can be viewed in Table 3.

- **Economic analysis**

CAPEX and OPEX: The capital expenditure for both Model A and Model B were addressed to be identical, whereas the operational expenditure was higher for Model B due to additional 6-hour shift, and consequently, higher salary. Additionally, the cost of the feedstock was assumed to be zero because it is a residue from rice milling process. The overall costs comparison can be viewed in Table 4.

Revenues and savings: As previously mentioned, the revenues originate from the feed-in tariff. The outcomes of calculations for both Models are presented in Table 5. Savings from internal electricity generation were also included.

Return of investment: Based on data presented in previous parts, calculation of the Economic Performance Metrics was performed. Outcomes of each calculation for both Models are presented in Table 6. What can be observed is that the NPV values are alike positive, which designates that the Models are economically feasible. Model B was more attractive, as the NPV and IRR were higher than for Model A. In both cases, values were positive; therefore, rice mill can recover the cost of investment and receive benefits from implementing rice husk gasification. Moreover, the IRR scores from both Models were more significant than the supposed discount factor of 8% backing up the outcomes of the NPV approach. In terms of the break-even and payback time, Methods presented the same results for prior - 2 years and diverged in case of latter. About seven years are required for 100% return of CAPEX in Method A, whereas the implementation of additional 6-hours shift decreases this time almost in half.

Levelized cost of electricity: The LCOE induced 9,34 ¢USD/kWh for Model B. Reflecting on this method solely, Model B is the preferred option due to the lower value of LCOE. However, this approach assesses the expenses of generating electricity exclusively. Therefore, LCOE can be applied to compare energy expenses from diverse technologies and not to compromise decision-making like it is with the NPV and IRR approaches which assess the total project cost and revenue also covering the energy price. Analysing the outcomes of the LCOE for Method A and Method B with the energy cost in Indonesia, it was observed that the variation between these prices is characteristic.

Table 4 Comparison of cost models

Expenditures	**Model A**	**Model B**
CAPEX	Cost [k USD]	
Gasifier and gas engines	1 048	1 048
Construction	104,7	104,7
Engineering	105	105
Other costs	45	45
	1 458	1 458
OPEX		
Spare Parts and labour	51,03	58,32
Insurance	7,29	7,29
Other maintenance	7,29	7,29
	65,61	72,9

The LCOE estimations calculated were lower than the present electricity price, 25 ¢USD/kWh, in both cases (Table 7). This variation was principal to the fact that electricity generated onsite does not contain any transmission fees, which makes it more competitive in comparison to electricity from the grid.

Table 5 Comparison of revenues and savings

	Model A	**Model B**
Rice mill self-consumption [GWh]	1,026	2,052
Electricity savings [k USD]	256,5	513
Net power generation [GWh]	1,494	2,988
Revenues [k USD]	160	320

- **Social benefits**

Source of renewable energy: Climate change consistently confirms its presence and shows the consequences of its attendance. Hurricanes, flooding, storms, and ecological catastrophes are showing seasonally throughout these decades. Indonesia, positioned at 39th place of the Climate Change Performance Index [9], continues to perform low when it comes to emissions reduction. The implementation of bio-waste valorisation technologies can support and promote diverse regions of Indonesia to become contributors to climate change mitigation. Indonesia is a country with an abundance of coal, which causes it to be greatly dependent on it. This fossil fuel is profoundly pollutant, and consequently, different energy sources and supplies need to be examined. WtE technologies could match these requirements and pose feasible alternatives to overcome coal dependency and reduce emissions in Indonesia.

Reduction of waste: The application of the rice husk gasification could decrease the volume of waste being dumped or illegally incinerated. Yearly, up to seven thousand tons of bio-waste from one, average-size mill could be utilized. This perspective can also be combined with the mitigation of GHG emissions, considering that avoiding open-air incineration reduces them.

Additionally, biochar produced from the gasification of rice husk is also a good fertilizer.

Employment creation: The introduction of this project can create employment opportunities for local inhabitants. It was determined that a possibility of eight new job openings could be created for the gasification plant: six positions for the system operators and two managerial positions. Furthermore, this project's realisation in one of the Indonesian rice mills can be the driving force for introducing bio-waste valorisation technologies in other mills in the region or country. Consequently, this could lead to the generation of more substantial job possibilities for Indonesians in rural areas. Bio-waste technologies require operators, managers, and administrators to operate the systems and qualified technicians to construct and install it, which could contribute to short-term benefits and long-term returns for the citizens.

Table 6 Comparison of Economic Performance Metrics

Economic Performance Metric	Model A	Model B
NPV [k USD]	2 034	6133
IRR [%]	21,23	41,31
Break-even time [years	7	4
Payback time [years]	2	2

3. Conclusions

- French Guiana

Size and biogas yield are the benchmarks for regulating the form of a prefabricated digester. To begin with, investing in a prefabricated digester can tackle the waste management challenge of rural communities and decrease family's monthly LPG expenses. Furthermore, it was remarked that a digester fed with animal manure outputs the most significant biogas yield, and meets more than four times the monthly cooking gas demand for a family of five; nevertheless, with an overall digester volume higher than 2,1 m^3, diameters are too large for application of prefabricated digesters available in the market, when HRT is taken into account. This would imply a digester lager three to four times, based on digesters available on the market. Moreover, organic fertilizer could be obtained from the slurry produced during the anaerobic digestion process. Both human and food waste digesters satisfy the prefabricated size specification with digester measurements for 0,5 m^3 and 0,09 m^3, respectively. Alike, they have reduced biogas efficiency, which meets 67% and 45%, respectively, a demand for cooking. Subsequently, the best digester dimensions were related to a feedstock of food-human waste mixture. This digester fulfilled the prefabricated size specifications, with a volume of 0,55 m^3, and satisfied 120% of demand for cooking for a five-person family.

Various and diverse topographical areas, the influence of climate, and varied family members number could demand few alterations in the design; nevertheless, it could also produce the needed amount of biogas to match the requirement of a rural household elsewhere in the world.

Table 7 Comparison of electricity prices

Reference	LCOE / electricity price [¢USD/kWh]
Model A	18,68
Model B	9,34
Indonesia	25

Basing on market data and literature review, it was concluded, considering the overall lifetime of biodigester is around 20 years, that the investment cost for the prefabricated digester opposed with the fixed dome digester, is more economical. Besides, the initial capital expenditure of the former was approximately 30% that of the latter. The analysis of the LCA revealed that plastic prefabricated digester prompted the most significant environmental impact as a consequence of the comparatively short-term lifetime of plastic elements. The most significant environmental impact of the fixed-dome digester was related to concrete and bricks. Ultimately, the primary convenience of the prefabricated digester was its easiness of application and handling, as well as much lower initial investment cost as opposed to the fixed-dome model, which seemed to occur more environmentally sustainable. [10]

According to available research analysis [11], it was determined that biogas generation, compression, and storage are a financially viable undertaking for the rural families where significant volumes of food-human waste are obtainable. It was established that biogas could be compressed and put in the LPG cylinder, for storage or transport. To adapt biogas for the cooking application, the gas should be compressed to around four bars after refinement. Nevertheless, in general, it is not necessary, and utilisation of uncompressed biogas is safer. The best way is to use it directly or with a small bag storage for one or two days. Moreover, the viability study for families is defined by cost-saving, timesaving, and revenue from bio-fertiliser. A significant part of biogas household users reports abovementioned savings as a notable compensation of the technology. Advantages of bio-fertiliser can frequently be more relevant in economic terms by creating revenue or decreasing the expense of farm means of production [12]. Transformation of bio-waste into bio-fertiliser could minimise its impact on the environment, advance nutrition ranks of the soil, moderate demands for artificial chemical fertiliser and become a straightforward bonus on food production.

- Indonesia

There is an abundance of rice husk in Indonesia from which only a fraction is utilised. If total rice husks formed through rice mills operation in the country was used for electricity generation, it could satisfy nearly 2,04% of the existing electricity demand. This research estimated that every year roughly 5,04 GWh of electrical power could be generated and save 830 000 USD by utilising 7,2 thousand tons of rice husks toward more affordable electricity.

The owner of the rice mill could employ their bio-waste production to provide electricity to the grid, supported by the feed-in tariff system. Out of various rice residues, solely bio-waste in the form of rice husk is considered economically viable as a biomass solution for electricity generation from the agricultural rice sector [6]. Since 2015, the feed-in tariff for small and medium biomass projects (up to 10 MW) contracting their electrical power to PLN is 10,71 ¢USD/kWh. The highest technical and financial potential emerges on Java and Bali, where the majority of rice plants are located.

Alongside revenue from electrical power generation, trading rice husk ash could become a source of further income. Ash is a relevant asset which can be sold as a filler for the ready-mix concrete manufacturers, as non-conductor in the steel production, or as filter material in various industries. The sell-outs of the ash might actively enhance project profitability. Rice husk ash reaches a market value of about 86 UDS/ton. [13]

Additional and interesting savings / income source for bio-waste project like this, could be the application of carbon contracts. The tradable carbon credits model is used to calculate avoided CO2 emissions through the generation of electricity using biomass alternatively to fossil fuels. Contracts can be manifested in the formation of the potential revenue that might be made by applying renewable technology. Currently, Indonesia does not practice this mechanism, but first concepts and drafts for the regulation have been started at the end of 2019 [14].

The milling capacity of the rice industry in Indonesia is widely different. It varies between 4 and 100 tons of paddy per day in smaller, family-owned mills, and up to over 1 000 tons in industrial mills [13].

The economies of scale are another significant determinant for the saving possibilities. In general, smaller rice mills run just several hours per day, hence humbler savings. Introduction of additional shift resulted in overall higher profitability of the project, which was confirmed by greater values of Economic Performance Metrics, i.e. NVP, IRR, and payback time. A feasibility investigation could be initiated for a larger scale project, e.g., 5-10 MW. The electric power could be traded directly from the rice mill to the nearby area and surplus of electricity could be sold to the national grid through feed-in contract. The compliance to pay a premium for a reliable and stable supply of power could likely bring a source of investment or PPA, particularly from commercial and industrial users.

The large-scale power generation can turn out to be economically feasible and further reduce the environmental impact of singular rice mill. Additionally, a larger scale could potentially lessen the burden of the rice mill to manage and administer such a system. To be up to date with a fast-changing milling industry, it was recommended to develop a combined technical support program which could provide information and knowledge on possible investments and profitability of the investment. Furthermore, to provide commercial support, rice mills likewise require high-skilled workers and operators to run advanced machinery and be proficient with appliances driven by electricity. Schooling and training organisations could give such training to current workers or combine needed experience in their program.

Gasifiers are not simple in operation in small industries like village rice mills. Experience from other countries, like India, indicates that small steam engines could be used for similar power demands.

The steam engines have a comparatively affordable price, and no supplementary diesel is needed to manage them. In comparison to gasifiers, steam engines can utilise any biomass type and bear higher moisture content. Additionally, they do not produce tar or wastewater contamination.

The viability and efficiency of this technology need to be assessed and examined in a pilot project.

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