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Opportunities and Challenges in Developing Livestock Waste as Transportation Fuel

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ABSTRACT

In 2023, Indonesia became a top 10 carbon emitter, which is contradictory to its net zero emissions agenda. One of the causes is the use of fossil energy, and it is necessary to transition energy sustainably, especially for the transportation sector, which is the largest contributor to emissions. New renewable energy sources from livestock manure waste can be used as fuels in the transportation sector. Many livestock produce waste that needs to be utilized. Livestock manure waste is widely used as biogas for household-scale applications but is rarely utilized as a biofuel in the transportation sector. This study aimed to analyze the potential and challenges of developing biofuels from livestock waste in Brebes Regency (Indonesia). Biofuel development must be conducted at the regional level to support the acceleration of greenhouse gas emission reduction targets. This research uses data sources in the form of literature studies and interviews, the Analytical Hierarchy Process was used to formulate sustainable energy transition policies. The results of this study describe the opportunities and challenges of developing livestock manure waste as transportation fuel. The Brebes Regency Government can encourage this through policies to accelerate the energy transition.

Keywords: biogas, energy transition, livestock waste, transportation fuel

INTRODUCTION

The energy transition to support net-zero emissions must be pursued immediately to address the increase in greenhouse gas (GHG) emissions and mitigate climate change. Almost one-third of total GHG emissions are contributed by the transportation sector, and 90% of emissions come from land transportation. The energy transition in this sector is carried out by replacing fossil fuels with new and renewable energy (NRE). Biofuels are considered more environmentally friendly transportation fuels and are sourced from plants, animals, agricultural and livestock waste, and waste.

Livestock accounts for 18% of global biogenic GHG emissions from methane gas production; therefore, its mitigation is needed. The methane gas produced is sourced from the digestion of ruminant animals, livestock manure, and waste treatment. Breaking the GHG cycle produced from livestock does not necessarily mean eliminating the livestock sector because, in terms of food security, livestock contributes to the fulfillment of animal protein (Widianingrum and Septio 2023) but by managing livestock manure waste as part of climate solutions. Biogenic emissions from the livestock sector are climate pollutants with a short life cycle, where after 12 years, the emissions are processed naturally in the atmosphere (Clear Center 2020). Although biogas production can generate emissions, biogenic emissions do not increase GHG levels in the atmosphere; thus, it can be said to have a net zero emission contribution (European Biogas Association 2020). Processing livestock waste into biofuel can be a solution to overcome GHG emissions from the transportation and livestock sectors.

From the perspective of physics and thermodynamics, agricultural and livestock waste can be converted into liquid or gaseous fuels through thermochemical and biological processes, wherein the chemical energy of the waste is converted into thermal energy and then into useful energy. An anaerobic process commonly used to produce biogas involves the fermentation of organic waste under oxygen-free conditions, which utilizes the principles of thermodynamics to optimize the production of methane (CH_4) and carbon dioxide (CO_2) gases. Countries with tropical and subtropical climates have significant opportunities to produce bioethanol, biobutanol, biomethane, and biogas from agricultural and livestock waste, which can reduce dependence on fossil fuels. Based on the European Biogas Association (2020), biomethane is a sustainable alternative fuel that allows decarbonization in the transportation sector and can be

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solidified into Bio-CNG or liquefied into Bio-LNG. In fact, 94% of vehicle fuel consumption in Sweden is contributed by biofuel in the form of biomethane.

In Indonesia, the use of livestock manure waste is limited to processing it into fertilizer, biogas as fuel to replace household-scale stoves, and biogas power plants. Until 2015, 16,000 biogas plants using livestock manure were spread across rural areas in 10 provinces, namely Bali, Banten, and Central Java. Yogyakarta, East Java, East Nusa Tenggara, Lampung, South Sulawesi, West Java, and West Nusa Tenggara. The use of livestock manure waste is very promising considering that one cow can produce 8–10 kg of manure per day (Huda and Wikanta 2017; Rianawati *et al*. 2021), up to 20–30 kg of manure per day (Central Java Provincial Regulation No.12/2018 concerning RUED Central Java Province; Semin *et al*. 2020) so that it can be used for new and renewable energy sources (Putra *et al*. 2020).

Brebes Regency has great potential for livestock development, with the leading commodities in the livestock sector being poultry, cows, sheep, and goats. According to BPS Brebes Regency (2024), the livestock population in this regency in 2023 was 18,574 beef cattle, 5,029 buffaloes, 59,783 goats, and 128,979 sheep. For poultry, there were 625,133 local non-breed chickens, 1,324,412 laying hens, 6,971,563 broilers, and 190,926 ducks. The Regency has processed livestock manure waste into biogas for household-scale stoves in Buara, Paguyangan, and several other villages. Departing from this, Brebes Regency could process livestock manure waste into motor vehicle fuel. With the use of 847 tons of livestock manure waste per day, it has the potential to reduce GHG emissions by 2.6 tons of CO_2eq per year (Ministry of Energy and Mineral Resources 2016) and improve the economy because of the added value in the livestock sector (Sampat *et al*. 2018). The Brebes Regency Government's optimistic scenario is also contained in Brebes Regency Regional Regulation No. 10 of 2024 concerning the Regional Long-Term Development Plan for 2025–2045, which targets a reduction in carbon emissions by 141,825.56 tons of CO_2eq by the end of 2045. Therefore, the Regency Government needs to aggressively pursue energy transition in various sectors, namely, overcoming biogenic emissions produced by the livestock sector and emissions from fossil fuels in the transportation sector.

This study aims to analyze the potential and challenges of developing transportation fuel from livestock waste in Brebes Regency, as well as the strategies that can be pursued to accelerate the energy transition. Energy transition research in the transportation sector in Indonesia has mostly focused on the substitution of fossil fuels with biofuels from plant waste. With this research, it is hoped that it will be able to provide an overview that efforts to reduce GHG emissions can be carried out by utilizing livestock manure waste.

METHODS

This descriptive research aims to provide an overview of the research object. The data were collected by digging up information in literature such as books, journal articles, proceedings, and articles on online media to describe the opportunities and challenges as well as strategies in the implementation of the energy transition. Data were also collected using a questionnaire with 7 respondents consisting of Regional Apparatus in Brebes Regency and academics to choose the right strategy to accelerate the energy transition, which was then analyzed using the Analytical Hierarchy Process (AHP). The selection of 7 respondents refered to Darko *et al.* (2018), which stated that of the 77 articles that used AHP, the average respondents used were 2–9 respondents.

RESULTS AND DISCUSSION

The large population of livestock in Brebes causes the production of animal manure, which results in difficulties in disposing of large amounts of manure, which can pose a danger of environmental pollution. In addition, slaughterhouses produce waste in the form of blood and rumen content from ruminant animals. However, from the perspective of NRE, livestock waste can be used as biogas and biofuel. In Brebes Regency, livestock manure waste has been applied to several villages, such as Pandansari, Buara, Malahayu, Kutamendala villages. However, the obstacle to its development is that because the processing is only on a household scale, the cost required is relatively large, where the initial investment to build a biogas installation costs up to IDR 20 million with a daily labor of 100 thousand waste processors per day. This reduces the demand for livestock waste in the community.

Potential Development of Livestock Waste for Biogas and Biofuels

A large amount of livestock waste can be processed into biogas and transportation fuel (biofuel), where the process can be illustrated in Figure 1. Afotey and Sarpong (2023) in their research stated that livestock waste can be used entirely for NRE. Farm animals were categorized into large ruminants (buffalo and cows), small ruminants (sheep and goats), and poultry (chickens and ducks). The waste in question is livestock manure, blood produced during the slaughter process, and the rest of the stomach contents (rumen) of livestock. To reduce the impact of livestock waste pollution on the environment, it is necessary to utilize livestock waste as a low-cost renewable energy source, especially in the context of sustainable energy production (Table 1).

In general, daily fecal output can vary based on the type, weight, and age of the animal. The following are

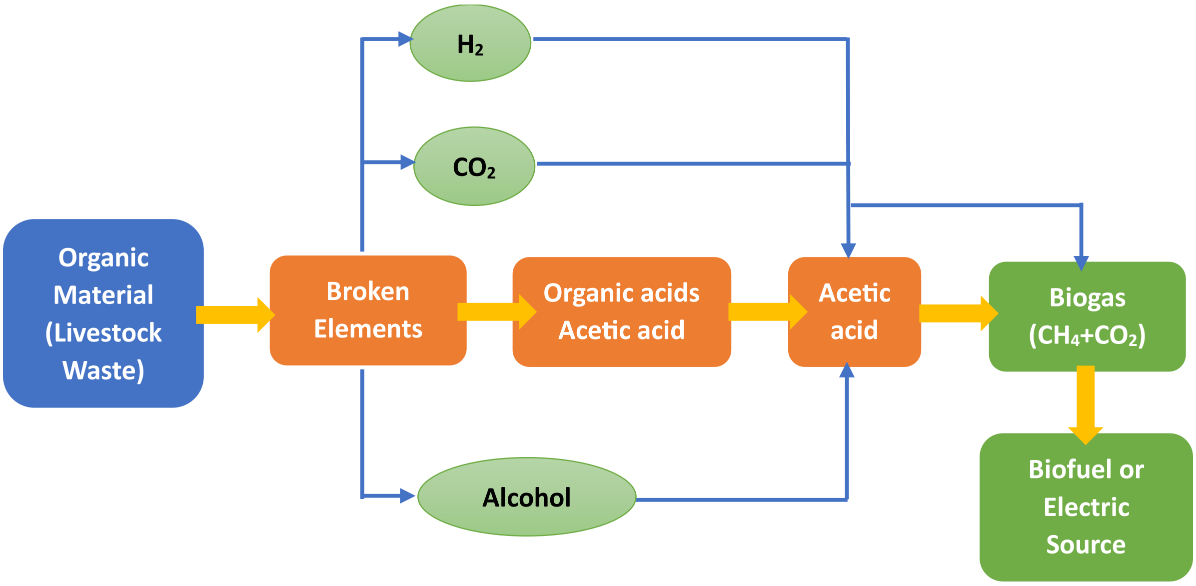

Figure 1 Schematic diagram showing the stages of biogas production through the anaerobic digestion process to become biofuel.

Table 1 Potential of treatable livestock waste (kg per day)

Livestock	Body weight (kg)	Manure (kg/day)	Blood (kg/day)	Rumen (kg/day)
Large ruminant				
Beef cattle	200–300	20–25	2–3	2–3
Buffalo	200–300	20–25	2–3	2–3
Small ruminant				
Kecil				
Goat	30–50	1–2	0.2–0.4	0.2–0.4
Sheep	30–50	1–2	0.2–0.4	0.2–0.4
Poultry				
Local chicken	1–2	0.04–0.05	-	-
Laying hens	1–2	0.04–0.05	-	-
Broiler	1–2	0.04–0.05	-	-
Duck	1–2	0.04–0.05	-	-

Source: Afazeli *et al.* (2014); Kefalew and Lami (2021); Afotey and Sarpong (2023).

the potential for livestock waste generated based on Afazeli *et al*. (2014), Kefalew and Lami (2021), and Afotey and Sarpong (2023). Based on the above-mentioned considerations, the average amount of manure was 22.5 kg/day for large ruminants, 1.6 kg/day for small ruminants, and 0.045 kg/day for poultry. Meanwhile, the number of animals slaughtered averaged as much as 10% of the total animal population, so the average amount of blood and rumen weight was 2.5 kg for large ruminants and 0.3 kg for small ruminants. Based on this assumption, the average amount of livestock waste in Brebes from 2022 to 2023 was calculated (Table 2). From the calculations, the potential for livestock waste is 446,215,161 kg or as much as 446,215.16 tons of livestock waste per year in the Brebes Regency. Based on the estimate of GHG emission reduction, if all livestock waste is processed, it would be as much as 3.8 tons of CO_2eq per year.

Calculation of Biogas Production Potential from Livestock Waste

The cumulative biogas produced from livestock waste is influenced by various factors, such as diet, animal type, weight, total proportion of solids, and waste availability. The total solids in livestock waste are an important factor in biogas production. Table 3 shows the range of total solid ratios in different livestock wastes. However, manure collection is not always efficient for biogas production, and the availability of manure varies. Therefore, in the calculation of biogas production from animal manure, the availability coefficient should be considered when calculating the cumulative biogas volume. The theoretical potential for biogas production from manure was calculated using the following formula:

$$BTP = M \times TS \times AC \times EB_{TS}$$

where

BTP = Biogas theoretical potency (m^3 $year^{-1}$)

Table 2 Average amount of estimated animal waste in Brebes in 2023

Livestock (head)		Potential waste per head			Potential waste per population		
		Manure (kg/day)	Blood (kg/day)	Rumen (kg/day)	Manure (kg/day)	Blood (kg/day)	Rumen (kg/day)
Beef cattle	18,574	22.5	2.5	2.5	417,915	4,644	4,644
Buffalo	5,209	22.5	2.5	2.5	117,203	1,302	1,302
Goat	58,783	1.6	0.3	0.3	94,053	1,763	1,763
Sheep	128,979	1.6	0.3	0.3	206,366	3,869	3,869
Local chicken	625,133	0.045	0	0	28,131	-	-
Laying hens	1,187,612	0.045	0	0	53,443	-	-
Broiler	6,971,563	0.045	0	0	313,720	-	-
Duck	190,926	0.045	0	0	8,592	-	-
Daily average	9,186,779	48	6	6	1,239,422	11,579	11,579
Yearly average		17.417	8	8	446,192,003	11,579	11,579

Remarks: Average daily manure (kg/animal) reflects an average estimate of the amount of manure produced per day based on the type of animal. Annual manure (kg) is the total estimated manure waste per year, assuming that one slaughter of livestock in a year is 10% of the total population.

Table 3 The range of total solids in animal waste and biogas produced based on the total amount of solids

Animal type	Range of total solid (TS) (%)
Large ruminants	20–30
Small ruminants	20–30
Poultry	25–35

M = The total amount of manure produced for each region (kg $year^{-1}$)
TS = Total ratio of solid manure
AC = Availability coefficient
EB_{TS} = The amount of biogas estimated to be produced per kg of total solids (m^3 kg^{-1} TS)

In this study, the *TS* values were assumed to be 25% for large ruminants, 25% for small ruminants, and 29% for poultry, with a value of EB_{TS}. 0.6, 0.4, and 0.8 m^3 kg^{-1} TS, respectively. The coefficient of availability was 50% for large ruminants, 13% for small ruminants, and 99% for poultry. For the calculation of biogas from blood and rumen content, it was assumed that all waste obtained from the slaughterhouse was transferred to the biogas plant without loss of moisture. The amount of biogas production from blood and rumen content was calculated as 0.3 m^3 per kg of fresh waste collected. The amount of potential biogas that can be processed from animal manure in Brebes Regency is presented (Table 4). The potential for biogas production from livestock waste in Brebes Regency is 49,249,329 m^3 per year.

Calculation of Methane (CH_4) Levels in Biogas and Energy Potential for Biofuels of Transportation Vehicles or Electrical Energy Sources

Anaerobic digestion (AD) of livestock manure shows that the percentage of methane in the biogas produced varies depending on the source of the manure. Biogas from the AD process of large ruminant feces contains 50–70% methane, while in biogas from small ruminant feces ranges from 40 to 50%. Meanwhile, biogas produced from poultry manure can contain methane in the range of 50 to 70%. In this study, methane levels for large ruminants, small ruminants, and poultry were set at 60%, 45%, and 60%, respectively. The percentage of methane in biogas obtained from slaughterhouses (rumen and blood content) was assumed to be 60%. For the calculations in this study, the methane value was assumed to be 30%. Overall, the amount of E_{biogas}. was calculated using the following formula:

$$E_{biogas} = \text{Energy content}_{\text{biogas}} \times M$$

where
Energi content$_{\text{biogas}}$ = Biogas calorific value (kWh/m^3)
M = Amount of biogas produced per year (m^3 $year^{-1}$)

Energy content$_{\text{biogas}}$. was assumed to be 6 kWh/m^3, considering the calorific value of biogas of 21.5 MJ per m^3 of biogas (1 kWh = 3.6 MJ). Based on this formula, biofuel or electrical energy sources that can be produced from the treatment of livestock waste in Brebes Regency are listed in Table 5. The potential energy produced was 295,495,972 kWh (295,496 GWh) with a calorific value equivalent to 1,063,785,498 GJ. If it is assumed that the energy used per kg of fuel is 45.8 MJ (ACEA 2016), then the potential for biofuel produced is 23,226,758 kg or 23,266.7 t per year.

Energy Transition Regulation

Indonesia already has regulations that can accelerate the energy transition. Starting from the mandate in the 1945 Constitution, Article 33, which reads: (1) The economy is arranged as a joint effort based on the principle of family; (2) The branches of production that are important to the state and that control the lives of the people are controlled by the state; (3) The earth and

Table 4 Volume of biogas potential from animal waste in Brebes Regency

Livestock	Total manure (kg/day)	Total manure (M) (kg year⁻¹)	Ratio of total solid (TS) (%)	Availability coefficient (AC) (%)	EB_{TS} m³ kg⁻¹ TS	BTP (m³ year⁻¹)
Beef cattle	417,915	150,449,400	25	50	0.6	11,283,705
Buffalo	117,203	42,192,900	25	50	0.6	3,164,468
Goat	94,053	33,859,008	25	13	0.4	440,167
Sheep	206,366	74,291,904	25	13	0.4	965,795
Local chicken	28,131	10,127,155	29	99	0.8	2,326,005
Laying hens	53,443	19,239,314	29	99	0.8	4,418,886
Broiler	313,720	112,939,321	29	99	0.8	25,939,903
Duck	8,592	3,093,001	29	99	0.8	710,401
Average in a year						49,249,329

Table 5 The potential of biofuel as a motor vehicle fuel

Livestock	M (m³/year)	Energy content$_{biogas}$ (kWh/m³)	E_{biogas} (kWh)
Beef cattle	11,283,705	6	67,702,230
Buffalo	3,164,468	6	18,986,805
Goat	440,167	6	2,641,003
Sheep	965,795	6	5,794,769
Local chicken	2,326,005	6	13,956,029
Laying hens	4,418,886	6	26,513,314
Broiler	25,939,903	6	155,639,419
Duck	710,401	6	4,262,403
Average amount per year	48,538,928,11		295,495,972

water and the natural resources contained therein are controlled by the state and used for the greatest prosperity of the people; (4). The national economy is organized based on economic democracy with the principles of togetherness, efficiency, justice, sustainability, environmental insight, independence, and maintaining a balance of progress and national economic unity. In terms of energy security, this study accommodates the guarantee of access to energy security. Following the energy regulations in Law No. 30 of 2007 concerning Energy, Government Regulation No. 79 of 2014 concerning National Energy Policy states that new energy sources are those that can be produced by new technologies, and NRE sources are the best alternative for reducing dependence on fossil energy. The National Energy Policy targets a new renewable energy mix of 23% by 2025 and 31% by 2050. At the central level, Presidential Regulation No. 22 of 2017 concerns the Regional Energy General Plan, and at the level of the Central Java Provincial Government, Regional Regulation No. 12 of 2018 concerns the Regional Energy General Plan of Central Java Province. In 2023, there is Presidential Regulation No. 73 of 2023 concerning Procedures for the Preparation of the National Energy General Plan and Regional Energy General Plan was issued.

In addition to these regulations, there are also regulations that encourage the reduction of GHG emissions, namely Law No. 32 of 2009 concerning Environmental Protection and Management, which emphasizes the role of the Government in controlling and reducing environmental pollution, Government Regulation No. 46 of 2018 concerning GHG Management as an emission mitigation strategy through the economic sector and encouraging the use of clean technology, and Presidential Regulation No. 98 of 2021 concerning Carbon Economic Value (CEV), which is the conversion of the value of one ton of CO_2eq into IDR.

In the transportation sector, Presidential Regulation No. 40 of 2023 concerning the Acceleration of National Sugar Self-Sufficiency and the Supply of Bioethanol as Biofuel, Presidential Regulation No. 55 of 2019 concerning the Acceleration of the Battery Electric Vehicle Program for Road Transportation, which was amended by Presidential Regulation No. 79 of 2023. Although the Government policy encourages the use of transportation with electrical energy as a substitute for transportation with fossil fuels, as well as the use of oil palm plantation waste as biofuel, it is possible that there will be policy support for the use of livestock waste for biofuels.

Challenges of Utilizing Livestock Waste

According to data from the Ministry of Energy and Mineral Resources (2023), the energy potential from bioenergy in Indonesia reaches 57 GW, consisting of 52.1 GW of biomass, 1.3 GW of POME (palm oil mill effluent), 1.4 GW of waste, and 2.3 GW of biogas. The largest biomass potential is in Riau Province, with 10.4 GW, which is supported by oil palm plantations. The largest potential for waste and biogas is in West Java Province at 0.25 GW and 0.46 GW, respectively. However, until 2023, the utilization of bioenergy will only reach 5.07%. The lack of utilization of livestock waste as NRE is because investment in NRE tends to be expensive, the unavailability of NRE supporting infrastructure, research and development for NRE technology are still minimal, and the application of fiscal incentives in NRE processing is not optimal (BRIN 2023; CELIOS 2024; Rebecca and Erviantono 2024; IESR 2024).

Based on the Energy Statistics issued by IRENA (2023), an investment of approximately USD 16 billion per year until 2030 is required to develop and strengthen the electricity grid in Indonesia to accommodate the increase in the renewable energy mix. In line with the IEEFA (2024), Indonesia needs an investment of around USD 20–25 billion per year to achieve the 2025 renewable energy target. This financing challenge requires a realistic mechanism to continue implementing the NRE mix without requiring expensive investments. Lestari (2021) stated that the need to encourage private investment in accelerating the use of NRE is due to the lack of funding from the government. In addition, the government needs to have both fiscal and non-fiscal incentive schemes for developers to increase NRE investment. In addition, the lack of research and development, especially in technology in the field of NRE, further hampers the NRE mix. Therefore, an increase in the budget is required for efficient research and technology development in the field of NRE. Another challenge is the minimal availability of NRE infrastructure because the existing energy infrastructure is dominated by fossil fuels, such as coal and petroleum. The transition to renewable energy requires significant investments in new technologies and distribution networks.

Energy Transition Strategy

In implementing the energy transition, we refer to research by Al Huda (2013), BRIN (2023), CELIOS (2024), Rebecca and Erviantono (2024), and IESR (2024). Strategies that need to be implemented include: (1) Implementation of Carbon Economic Value (CEV); (2) Development of NRE infrastructure; (3) Increased investment in research on NRE technology; (4) Fiscal incentives for NRE investment; and (5) International cooperation in supporting the energy transition, including cooperation in innovative financing mechanisms.

From the results of the respondents' responses to the questionnaire and analyzed with AHP, a ranking was obtained for the implementation of strategies to accelerate the transition to renewable energy:

Strategy 1 Building integrated research and development
Strategy 2 International cooperation for NRE research and financing
Strategy 3 NRE infrastructure development
Strategy 4 Fiscal incentives for business actors who invest in NRE
Strategy 5 Implementation of CEV.

With the research and development of NRE technology, it is hoped that it can be used of NRE resources and does not require large investments. Then, collaborate worldwide in terms of research and development as well as NRE financing, build NRE infrastructure, implement fiscal incentives, and implement CEV in an integrated manner both at the Central Government level and encourage Regional Governments to implement CEV.

CONCLUSION

Livestock waste, consisting of livestock manure, blood, and rumen content from slaughterhouses, has the potential to be used as NRE. The total annual potential of biogas in Brebes Regency is 49,249,329 m^3 per year, and the potential for biofuel is 295,496 GWh, equivalent to a calorific value of 1,063,785,498 GJ. Of the total livestock waste per year of 446,215.16 tons, it can contribute to reducing GHG emissions by 3.8 tons CO_2eq per year. This potential can certainly drive NRE development, considering that there are already regulations from the Central Government regarding the NRE mix. However, challenges remain, such as the high cost of NRE investment, lack of NRE supporting infrastructure, minimal research and development for NRE technology, and suboptimal application of fiscal incentives in NRE processing. Therefore, a comprehensive strategy is required to accelerate energy transition. Building integrated research and development in the field of NRE utilization technology is expected to trigger more efficient NRE utilization.

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