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INVESTIGATING THE ENVIRONMENTAL IMPACTS OF DIFFERENT APPROACHES OF AGRICULTURAL WASTE MANAGEMENT USING AHP TECHNIQUE

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Environmental problems and the ever-increasing growth of population dictate the need for new methods to turn the problem into an opportunity. The recycling of agricultural waste is very important to achieve sustainable development of agriculture. Present paper focuses on how the proper disposal and recycling of agricultural waste can significantly reduce greenhouse gas emissions, conserve resources, and improve soil fertility. Hereupon, the specified criteria were determined by relevant organisations. Five final products including composting, biochar, biogas, reuse/recycling, and incineration resulting from the technologies used were investigated using the AHP technique. In addition to the effective management of agricultural waste, these technologies help in the production of electricity, fertiliser, and carbon absorption, which results in the reduction of climate change and the reduction of economy. Among the proposed products, biochar was preferred, and the incineration method was ranked the last. Biochar offers potential environmental benefits in terms of reducing greenhouse gas emissions, increasing the quality and quantity of agricultural products, and preventing soil erosion and degradation as well as water pollution. High rank was assigned to environmental criteria, and the actual waste production sub-criterion was preferred over other criteria with a weight of 0.170. The lowest weight was obtained for the shipping distance (weigh = 0.013).

Keywords: analytical hierarchy process; criteria; sustainable agriculture; compost; biochar; biogas

The aggravation of environmental problems and the increase in population has become the main challenge in pursuing sustainable practices. The application of traditional methods in the agricultural industry has adverse effects on the environment, and humans are required to replace new methods to create a balance between agricultural efficiency and environmental impacts (Eyhorn et al., 2019). Agricultural waste management significantly affects climate change, resource depletion, and ecosystem health. The abandon of agricultural residues may lead to the release of methane and carbon dioxide and exacerbate global warming (Sharma et al., 2023a,b; Al-Qudaimi and Kumar, 2016). Compared to carbon dioxide, methane gas is 21–23 times more effective in global warming (Chen et al., 2021; Jabraeili et al., 2021). Improper waste management threatens water contamination and ecosystem destruction (Budihardjo et al., 2023a; McAuliffe et al., 2020).

The balance between human requirements and preserving the environment is one of the main foundations of agricultural waste management, which needs to increase the socio-economic welfare of the farmer and reduce negative environmental impacts (Nigussie et al., 2021; Kurbatova and Abu-Qdais, 2020; Zeug et al., 2023). In other words, the strategy of sustainable development is the combination of economy and ecology (Hemidat et al., 2022). The level of sustainability varies from country to

country based on the economic situation. Different scenarios such as financial incentives for recycling/reusing waste or setting punishments for improper disposal of waste can be effective on waste management decisions (Ma et al., 2023). In developing countries, several factors such as urbanisation, inequality, economic factors, socio-cultural aspects, politics, institutional issues, and international influences have an impact on waste management performance (Marshall and Farahbakhsh, 2013).

The best approach for agricultural waste management includes tasks related to waste classification, resource recovery, sustainability, public awareness, and regulatory considerations (Tseng et al., 2022). It is necessary to evaluate the type and volume of agricultural residues and waste (Budihardjo et al., 2023b). The opinion of „reducing and preventing waste production“ is of particular importance because income is maximised and waste production is reduced by applying precise agricultural operations, e.g. effective irrigation, pest control, mechanised harvesting, etc. (Starek-Wójcicka et al., 2023). The amount of waste will decrease, but it will never reach zero. The next option to reduce waste is to produce compost and biochar from agricultural waste (agricultural residue and animal manure) to supply soil nutrients. The burning of agricultural waste releases dangerous pollutants into the atmosphere.

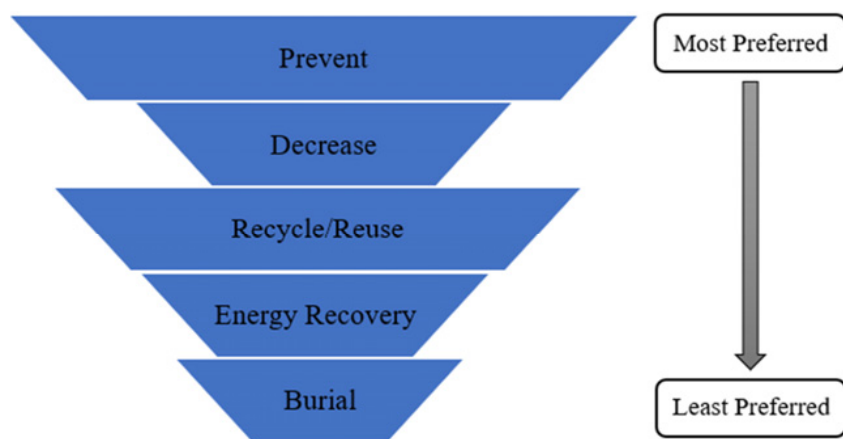


Fig. 1 Different approaches to waste management in the order of priority
Source: Abdull and Abedin, 2024

The transformation of agricultural waste and waste into valuable goods such as composite materials is called recycling (Mujtaba al., 2023), which is a two-way process of profit because the problems caused by these wastes are solved and a valuable product is produced to prevent the destruction of the ecosystem. There is no single technology that is suitable for all waste management. In any case, the environmentally friendly waste management approaches listed in Fig. 1 in the order of importance should be followed.

Organic waste and residues (plant residues, wood chips, etc.) are converted into nutrient-rich humus in the biological process (Pajura, 2024). If agricultural waste and residues are decomposed by microorganisms in the presence of oxygen under controlled conditions, high-quality compost is produced that has the ability to improve soil quality, conserve water, and increase nutrient content (Adejumo and Adebisi, 2021).

The by-product obtained from biological organic materials (different types of biomass) by the pyrolysis process (thermal conversion) in oxygen-free conditions at a temperature of 300–1000 °C is called biochar. Biochar is a porous and carbon-rich material that exhibits favourable physical and chemical properties for safe and long-term carbon storage in the environment. Raw materials for biochar preparation include agricultural and forestry waste (straw, rice husk, peanut shell, etc.), urban solid organic waste (sludge, household waste, etc.), and other waste

(algae, etc.) (Shackley et al., 2012). Biochar as a soil softener can directly and indirectly reduce the emission of carbon and other greenhouse gases from the soil. It increases the storage capacity of nutrients, reduces the need for fertilisers, and reduces the environmental impact on agricultural land.

Incineration is one of the waste disposal solutions that has the ability to reduce a large percentage of the volume and solid mass of waste. But initial costs are very low and will result in air and water pollution. There are different types of agricultural wastes, such as grass and tree leaves, branches and pruning waste, roots, etc. Therefore, it can be said that all agricultural wastes contain moisture, which significantly increases the emission of greenhouse gases due to incomplete combustion.

As a product of anaerobic digestion, biogas is compatible with the environment for waste disposal because it reduces the volume of waste and the emission of greenhouse gases (Budihardjo et al., 2023b). One of the major environmental concerns of waste decomposition is the release of gases that contribute to climate change and, in addition, leachate from hazardous waste to water systems. The need for a large land to build a digester, its management and maintenance problems are among the forms of anaerobic digestion (Qazi al., 2018).

From an economic point of view, it is expected to reduce costs due to the effective management of agricultural waste, use less primary

raw materials, earn money from manufactured products, and reduce disposal costs.

The successful integration of agricultural waste and residues into the circular economy depends on access to new and robust technologies that maximise financial benefits and minimise environmental impacts. Scientists and researchers play a crucial role in providing innovative solutions to convert waste into valuable products. It is important to incentivise farmers to utilise digestible materials as soil conditioners and animal feed through the provision of privileges, educational programmes, and explanatory sessions detailing the benefits of product use and the drawbacks of waste disposal (Haque et al., 2023).

The present study gives the concepts of agricultural waste recycling, analyses its environmental impacts, and suggests the best waste management option by choosing the optimal waste-to-energy (WTE) technology. In general, the aim of this study is to promote and implement new methods of disposal/recycling of agricultural waste for a peaceful coexistence between the human-animal environment and the agricultural industry.

Material and methods

Data collection

The presence of many criteria in the model can increase accuracy and precision, but the best model is the one that provides the best results with the least criteria. The criteria were selected based on the standards defined by relevant organisations. After careful analysis, 13 key criteria were selected that were highly relevant:

1. Initial capital: the amount of initial cost required to start the technology.
2. Job creation: human resource is needed to create the project as well as its operation and maintenance.
3. Environmental effects: avoiding soil and water pollution as well as minimising greenhouse gas emissions play a role in choosing the best waste management methods.

4. Production of hazardous waste: every operation has an output, and some materials will be left behind.
5. Professional and public health: creation and continuation of activity in any technology is done in relation to human and animal environment.
6. Resource recovery potential: the type of technology that effectively transforms waste into valuable products such as compost and biochar.
7. Economic viability: waste management strategies must be economical for long-term sustainability.
8. Social factors: social acceptance is effective in the successful implementation of agricultural waste management.
9. Energy consumption: it is an accepted technology that needs the least amount of energy for operation and maintenance.
10. Energy production: an operation that can extract the maximum amount of energy will be popular.
11. Ability to implement technology: the implementation of any operation depends on environmental, geographical, etc. conditions.
12. Market demand and supply: the circular economy is successful when it considers the dynamics of supply and demand of products produced from agricultural waste.

13. Shipping distance: as much as possible, the distance between waste production sites and management facilities should be reduced to minimise carbon emissions and transportation costs.

The weight of the criteria was considered based on the opinions of 10 experts in the fields of agriculture, environment, renewable energy, etc.

Development of model based on analytical hierarchy process (AHP) approach

In order to choose the optimal waste to energy (WTE), it is needed to have a methodology that allows decision makers to identify the best strategy with respect to economic, environmental, social, and technical issues. Several multi-criteria decision analysis techniques such as AHP, fuzzy AHP, weighted product model, and additive weight model have been proposed. Among them, AHP is the most popular method (Ahmed et al., 2012; Ahmed and Azeem 2013). Expert choice software is used for decision-making in AHP which was first proposed by Saaty in 1980 and is based on pairwise comparisons. This process is called hierarchical because the decision-making process starts from the goals and strategies of the organisation, and it will identify and evaluate different decisions by expanding them. The proposed hierarchical model is presented in Fig. 2.

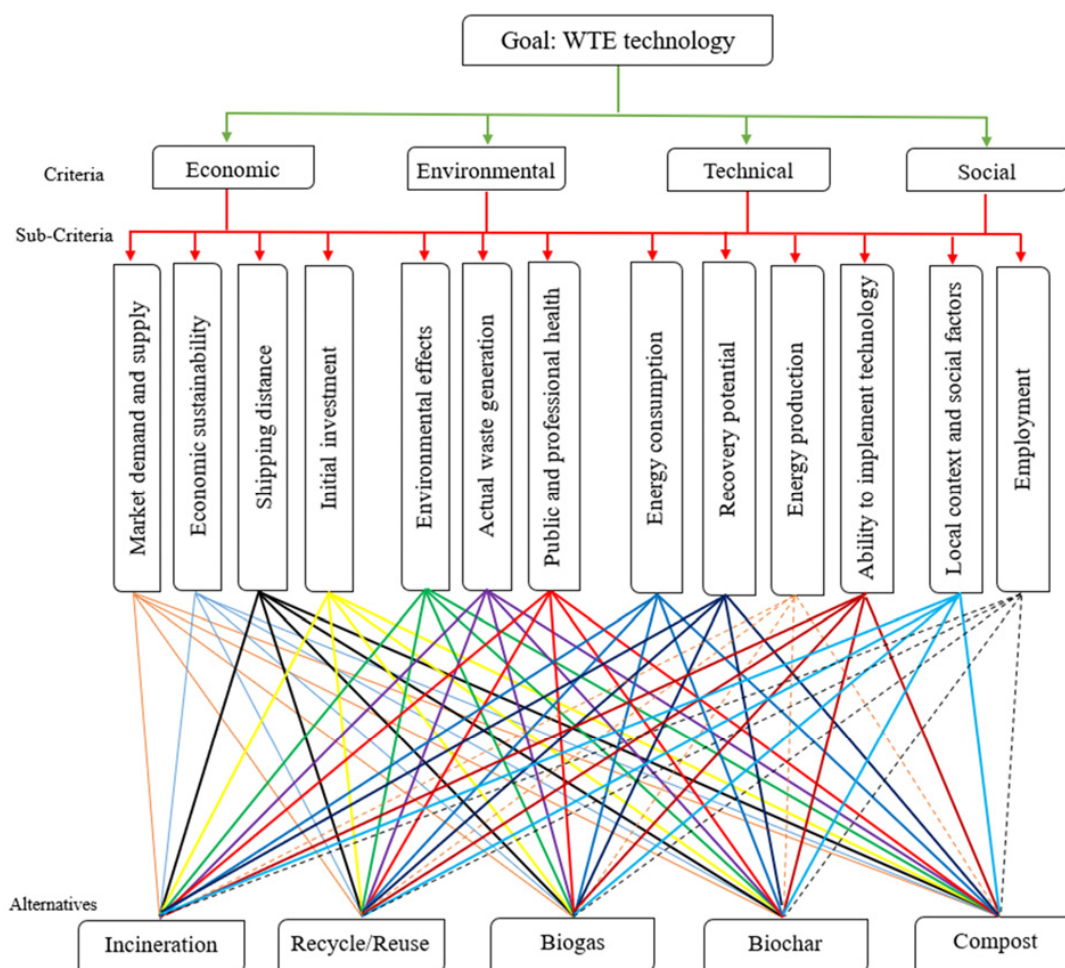


Fig. 2 Proposed AHP based model

Table 1 Random index value for different matrix size

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.40	1.49

N – dimension of matrix

Table 2 Relative comparison of indicators

Equal importance	Weak importance	Great importance	Very important	Absolute importance
1	3	5	7	9

The criteria of each project are defined according to the subject and needs. In the present study, economic parameter is essential when evaluating biomass potential and having an economic impact on biomass production. The environmental (ecological) parameter is necessary as an index of sustainable development. The social factors make it possible for the project to fail, that's why it is mandatory and necessary to be considered. This factor evaluates whether the productive biomass threatens or exposes the food source to competition or not.

Calculation of weights for criteria

The following steps are followed to determine the priority weight of the main criteria and sub-criteria:

1. Building a pairwise comparison matrix for all criteria and sub-criteria.
2. Comparison matrix addition.
3. Determining the relative weight of each criterion and sub-criterion using a normalised matrix, and then the compatibility of pairwise comparisons is evaluated.

The weight of the main and sub-criteria is estimated using Eq. (1).

$$A_w = \lambda_{\max} \times w \quad (1)$$

where: A_w – comparison matrix; w – priority vector; $\lambda_{\max}$ – the maximum eigenvector

The consistency of the matrix is checked using consistency ratio (CR) and consistency index. First, consistency index (CI) is calculated using Eq. (2), where n is the rank of the matrix.

$$CI = \frac{(\lambda_{\max} - n)}{n - 1} \quad (2)$$

Due to randomness in judgment, compatibility ratio is calculated using Eq. (3), where RI is the randomness index that indicates the expected value of CI related to the order of the matrices. If the consistency index is less than 0.10, experts' judgment is consistent and acceptable. The standard RI values are shown in Table 1.

$$CR = \frac{CI}{RI} \quad (3)$$

The experts expressed their theory regarding the superiority of the indicators in the form of numbers,

which were divided and compared in Table 2 in terms of importance.

Results and discussion

The answers of all experts regarding the main criteria and sub-criteria were collected using geometrical methods. The weighing of comparative matrices was presented in Table 3. It should be noted that the quantity and quality of agricultural waste are the main factors involved in the criteria and this feature has a direct effect on the weight of the criteria and indicators, which was not considered separately in this regard. The results are acceptable because the consistency ratio was less than 0.1. Notably, numbers smaller than zero (negative numbers), which have a lower likelihood of being compared, are highlighted in red.

Based on the following criteria related to the environmental factor, actual waste production (weight = 0.170) is of particular importance. Wastes have the ability to be converted into valuable materials, and after this process, some materials that have no use and are worthless will remain. These materials are called real waste, and the only way is to dispose of them. These harmful substances threaten human and animal ecosystems as well as surface and underground waters due to the presence of a series of harmful substances. The environmental effects (weight = 0.134) obtained the second place of importance, which is shown in Fig. 3.

In Fig. 4, two products, biochar and compost, which are the first and second priorities, were examined in terms of criteria. Biochar was shown in red and compost in blue. For example, both products were evaluated in terms of economic sustainability, and biochar was superior to compost. The length of the red colour indicates the size of superiority over the compost.

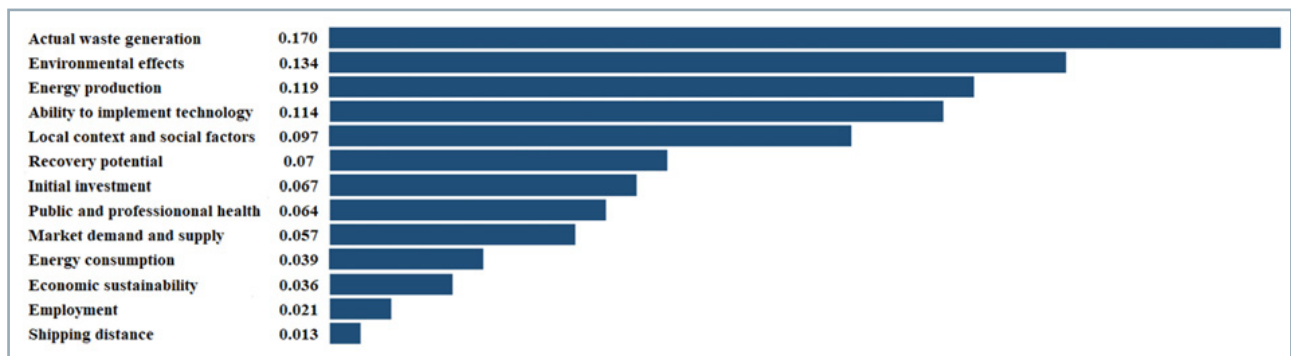
In the subsets related to the technical factor, energy production (weight = 0.119) got the first rank, and technology implementation capability with the weight of 0.114 got the second place. Among the criteria related to the economic factor, initial capital (weight = 0.067) was the most preferred sub-criterion, and shipping distance (weight = 0.013) was ranked the last. Among the environmental criteria, the greatest effect was related to the actual waste production sub-criterion (weight = 0.170).

Among the proposed alternatives, biochar, compost, biogas, and burial were ranked from the first to the fourth, with a weight of 0.324, 0.263, 0.172, and 0.106, respectively. Biochar will prevent the spread of waste and carbon into

Table 3 Comparative criteria and indicators

	Economic sustainability	Market demand and supply	Shipping distance	Initial investment	Environmental effects	Actual waste generation	Public and professional health	Recovery potential	Energy consumption	Energy production	Ability to implement technology	Local context and social factors	Employment
Economic sustainability		1.0	7.0	1.0	3.0	7.0	3.0	3.0	1.0	5.0	5.0	3.0	1.0
Market demand and supply			7.0	1.0	3.0	5.0	1.0	1.0	1.0	5.0	1.0	1.0	3.0
Shipping distance				7.0	9.0	9.0	5.0	5.0	5.0	7.0	5.0	5.0	1.0
Initial investment					1.0	5.0	1.0	1.0	1.0	1.0	3.0	1.0	5.0
Environmental effects						1.0	3.0	5.0	3.0	1.0	1.0	1.0	7.0
Actual waste generation							3.0	3.0	5.0	1.0	1.0	1.0	9.0
Public and professional health								1.0	3.0	1.0	3.0	3.0	3.0
Recovery potential									1.0	1.0	1.0	1.0	5.0
Energy consumption										5.0	3.0	3.0	1.0
Energy production											1.0	1.0	5.0
Ability to implement technology												1.0	5.0
Local context and social factors													3.0
Employment													

red colour is a negative sign

**Fig. 3** Priorities with respect to the goal of WTE technology selection

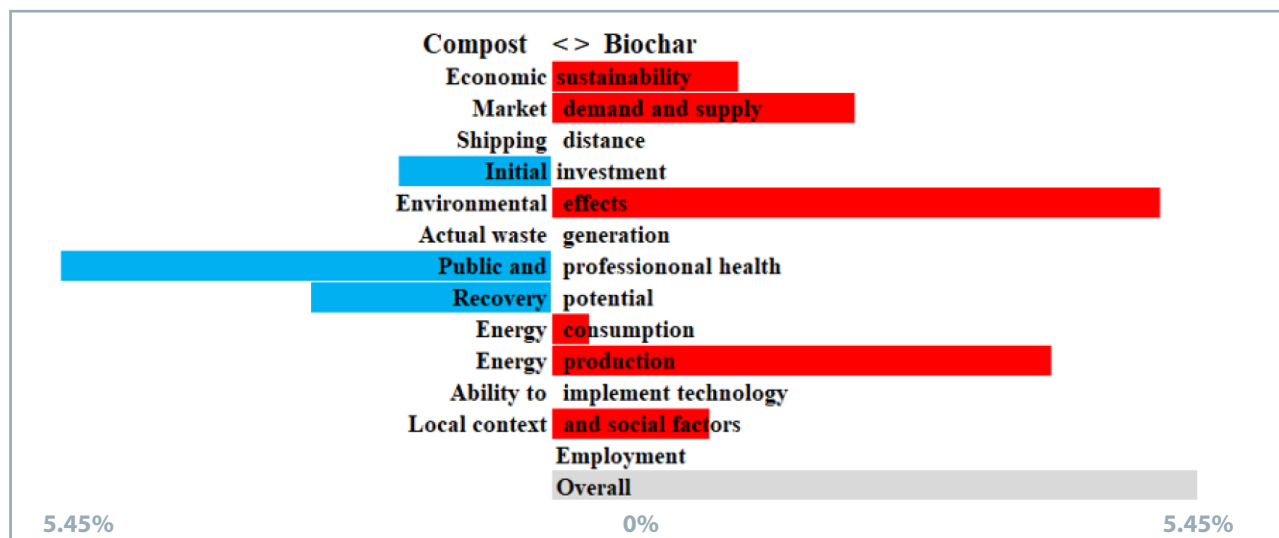


Fig. 4 Comparative analysis of compost and biochar using weighted criteria

the environment, and it will increase crops and preserve the land. On the other hand, due to the moisture content of agricultural products, their burning speed is extremely low, and they need petroleum derivatives to burning that lead to the emission of greenhouse gases. Thus, the final product contains heavy metals, which are very harmful to the ecosystem. If they are buried in the landfill, they will cause groundwater pollution. Figure 5 gives the priority of options.

In the subsets related to demand and supply, biochar and burial got the highest and lowest rank, respectively. In terms of the criteria of transportation distance, compost and biochar were on the same level with a big difference with other alternatives. In terms of environmental effects, biochar was preferable and had a big difference with other alternatives. The sub-criterion of real waste production is a basic parameter in choosing alternatives and must be taken into consideration. The burial option obtained the highest rank in producing of real and hazardous waste. Also, it ranked the first in terms of recovery potential and

energy consumption criteria because it does not require any special capital. Compost was more preferable than others in terms of public and professional health sub-criterion. In terms of local and social factors, biogas was ranked the first, followed by compost and burial because it does not require special infrastructure and conditions. Biogas had the highest amount of job creation. Figure 6 gives the comparison of alternatives based on criteria.

All the products were collectively reviewed based on selection criteria. Each product can be readily compared with other mobile products based on specific criteria, with each criterion listed in its own column. Each of the five products is represented by a different colour indicating its weight. In the last column (OVERALL), the overall outcome of all the criteria is collectively weighed and arranged in the order of importance. Waste transformation into products was given the lowest priority initially.

The comparison of literature with the present study is given in Table 4.

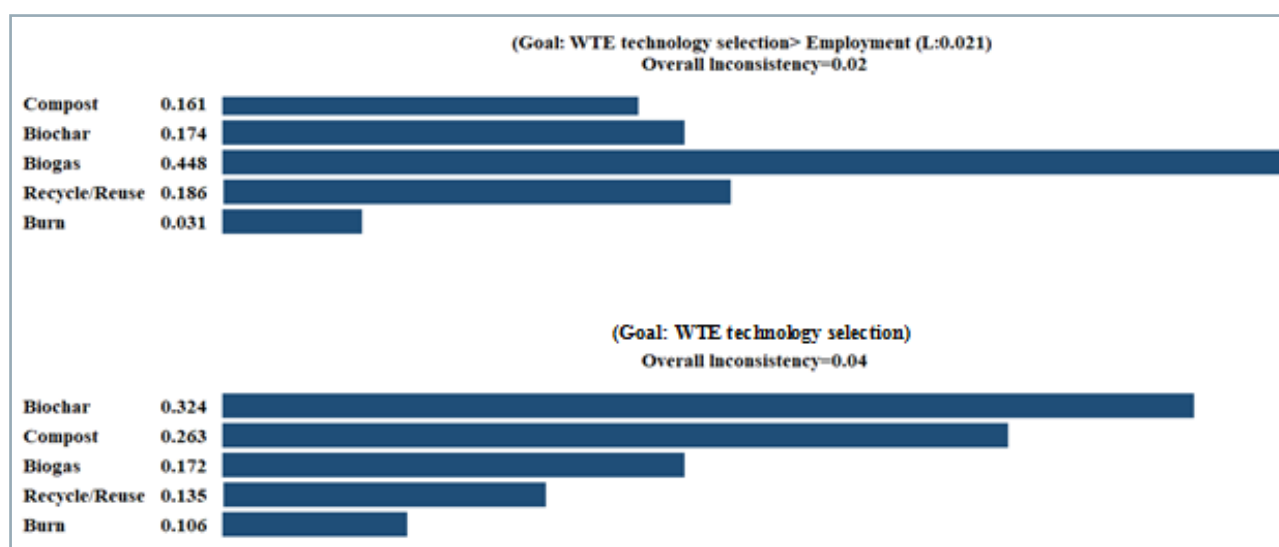


Fig. 5 Priority of criteria based on weighing

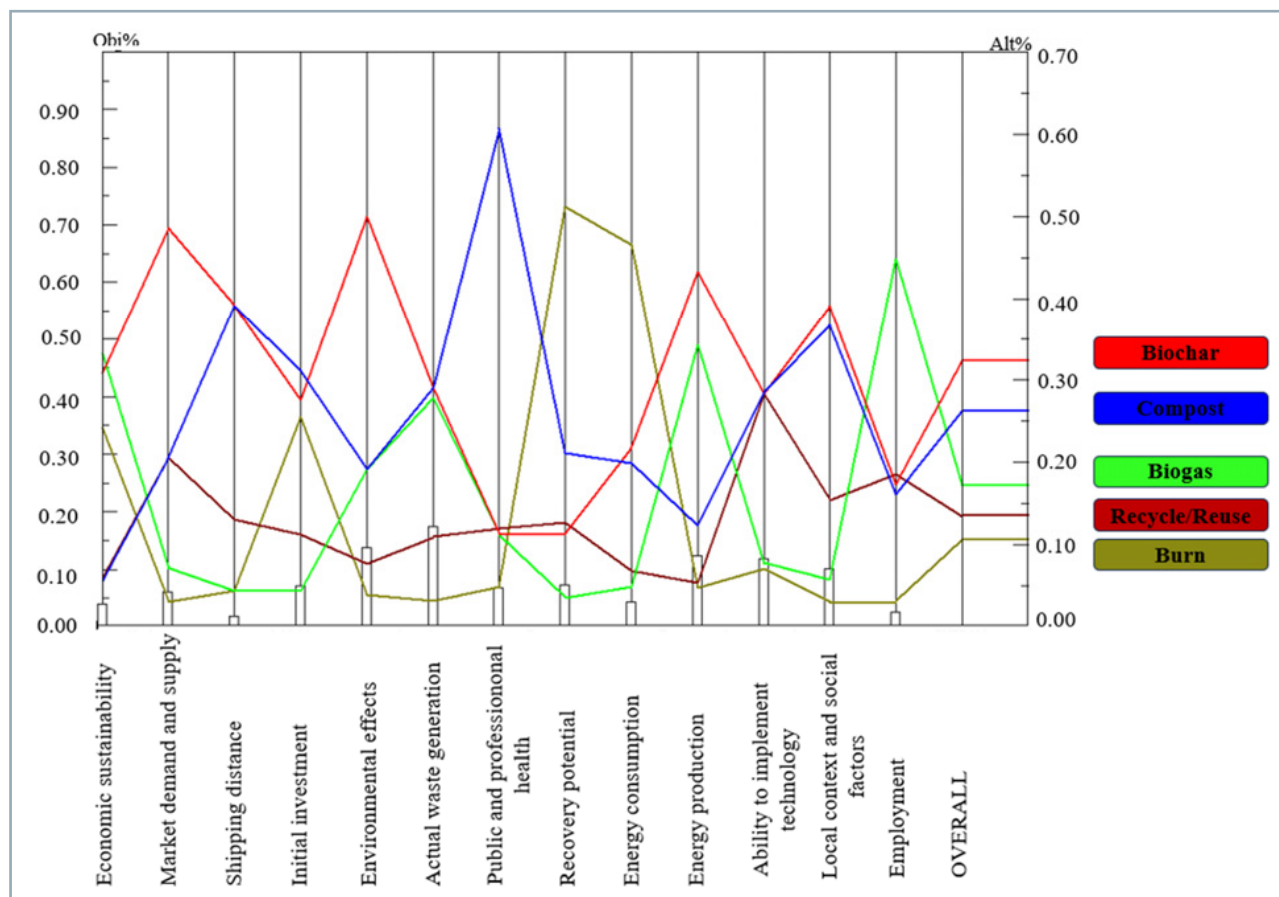


Fig. 6 Comparison of alternatives based on each of the sub-criteria

Table 4 Comparison of similar studies with the present paper

Authors	Method	Result
Amo-Asamoah et al. (2020)	the most suitable technology for urban solid waste with AHP	burning was the best method
Rahman et al. (2017)	appropriate technology for waste to energy conversion in with AHP in Dhaka	plasma gasification was identified as the best alternative
Jusakulvijit et al. (2021)	the evaluation of criteria and indicators for bioethanol production with Delphi-AHP hybrid method in Thailand	economic criteria were the most important factor

Conclusion

This study shows the importance of special techniques in agricultural waste recycling. The adaptation of waste management solutions and resource availability is essential as farming practices vary. Identifying and prioritising criteria when choosing agricultural waste management are essential to ensure efficient methods. Identifying and prioritising sensitive criteria when choosing agricultural waste management is essential to ensure efficient and long-term waste treatment methods.

Applying new methods in the management of agricultural waste will preserve forest resources. Forest per capita will remain constant, or by using products produced from these materials in the forests, the per capita amount can be strengthened. Forest per capita has a direct relationship with the health of the ecosystem and the reduction of climate and weather changes. The manufactured products

will reduce the consumption of wood in industry, which results in reducing the finished price of the manufactured product and preserving the ecosystem. By using the adverse effects on the environment, humans are required to replace new methods to create a balance between agricultural productivity and environmental effects.

In order to select the best product produced from agricultural waste, five products of compost, biochar, biogas, reuse/recycling, and incineration were examined in terms of four main criteria (economic, environmental, social, and technical issues) using the AHP method.

Among the selected criteria, the environmental criterion (weight = 0.170) was particularly important, and shipping distance (weight = 0.013) had the least impact.

By considering all aspects, the manufactured products were prioritised. Biochar was given the first priority, but in emergency situations or in a certain period of time, other

methods can also be used to dispose of waste. But it should be noted that other priorities have special problems, that's why biochar should be used preferentially.

According to the criteria and sub-criteria selected and weighed by experts, biochar was chosen as the best product produced from waste, and incineration was the last choice for disposal.

Eco-friendly waste management systems can be implemented more quickly if the government provides subsidies, tax breaks, and favourable laws. Regional cooperation can accelerate sustainable solutions.

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