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A DEMATEL Approach to Analyzing Barriers to Implementing Integrated Biorefineries in the Philippines

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An integrated biorefinery (IBR) is a multi-process facility that uses agricultural waste to produce valuable bioenergy products. Several studies already have shown the potential economic, environmental, and social benefits of setting up IBRs. However, planning is crucial in the development of IBRs since several stakeholders are involved in its operation and the entire biomass-bioenergy supply chain. As an initial step, it is essential to identify the potential barriers to implementing IBRs at the local level prior to its nationwide scale-up. In this preliminary work, a Decision-Making Trial and Evaluation Laboratory (DEMATEL) framework was used in analyzing barriers to implementing IBRs on a municipality level. DEMATEL-based methods determine the relation between cause-effect factors in a given problem. Based on the results, the primary causal barrier is the "Lack of potential feedstocks due to climate change and other factors (B6)" and the “Lack of technology and infrastructure readiness (B1)” is the highly-correlated barrier. The results from this preliminary study can be used to develop a more robust assessment of establishing IBRs. Farmers, investors, local government units, and policymakers can then use such analysis to create mechanisms to address the barriers and formulate policies in developing IBRs.

1. Introduction

The Philippines, an agricultural country, has a land area of about 30 Mha, and 41 % is used for agriculture purposes (Zafar, 2020). According to available data, approximately 4.6 Mha are specifically used for rice crops, and 19 Mt of rice has been produced in recent years (PSA, 2019). Rice harvesting and processing generate a large amount of rice straw, husk, and bran. The Food and Agriculture Organization of the United Nations estimated that the country produced 3.7 Mt of rice husk and 8.8 Mt of rice straw (FAOSTAT, 2014). However, rice waste is still perceived to have little value due to a lack of opportunity to use it as a source of income, leading the farmers to open-field burning (Migo-Sumagang et al., 2020). Though this activity may be classified as a carbon-neutral activity, it is a quick way to lose soil nutrients, contribute to greenhouse gas emissions, and release toxic gases into the atmosphere (Magcale-Macandog et al., 2016). Rice residues can be better utilized as a biomass feedstock in an integrated biorefinery (IBR) to increase the production of alternative renewable energy and fuel sources.

An IBR is an industrial plant comprising varied conversion platforms and technologies to utilize biomass as feedstock. It uses various biomass feedstocks to produce biorefinery products such as biofuels, energy (i.e., electricity and heat), and biochemicals (Kasivisvanathan et al., 2012). The bioenergy products are usually utilized within the IBR for its operation, and the remaining are sold to customers. Sangalang et al. (2021) designed a rice waste-based IBR with the aid of the P-graph (process graph) method. This work shows the potential of producing various bioenergy products (e.g., bioethanol, biodiesel) using rice straw, husk, and bran. Since IBRs are considered state-of-the-art, designing a sustainable IBR is necessary. According to Sacramento-Rivero et al. (2015), suitable design tools must consider an IBR’s sustainability in terms of its potential to displace

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fossil fuels, renewability, economic feasibility, and social impact. It is necessary to analyze the barriers to implementing sustainable IBRs before their design via the aid of decision-making tools.

DEMATEL (Decision Making Trial and Evaluation Laboratory) method can analyze the relationship among the identified barriers in implementing an IBR. DEMATEL is a mathematical tool that can solve and explain complex problems by determining the cause-and-effect correlation and converting it into a structural model that can be understood (Falatoonitoosi et al., 2013). This tool helps visualize the causal relationships with matrices and digraphs. Recent works on the use of the DEMATEL-based approach include developing systematic eco-innovations within an industrial symbiosis (IS) environment (Jayakrishna et al., 2020), comparing municipalities in terms of environmental sustainability (Kilic and Yalcin, 2020), analyzing the sustainable manufacturing indicators in terms of cause and effect (Bhanot et al., 2020), determining the local government's role in mitigating barriers to IS (Palm and Södergren, 2021), and identifying and analyzing the barriers for implementing circular supply chain in emerging economies (Lahane and Kant, 2021). DEMATEL is not yet implemented to investigate barriers to implementing IBRs in the Philippines.

A DEMATEL-based method to initially analyze the barriers to implementing an agricultural waste-based IBR in a municipality in the Philippines was developed in this study. Through this work, several stakeholders such as farmers, investors, local government units, and policymakers can use the preliminary results of this study to assess whether the implementation of IBRs is practical and beneficial. The study can also be a basis for determining the appropriate solutions to address the barriers and can lead to formulating policies in developing IBRs. The study will be expanded later to incorporate a larger number of respondents from various municipalities in the country.

2. General Framework

Rice waste utilization is seen as promising in producing various bioenergy products, and several barriers must be considered before implementing a rice waste-based IBR to ensure successful operations. A municipality-level case study was selected, and the framework for analyzing the barriers to implementing an agricultural waste-based IBR is described in Figure 1. The initial stage of the research is the literature review, which is essential in determining the common barriers that will affect the implementation of the IBR in a municipality.

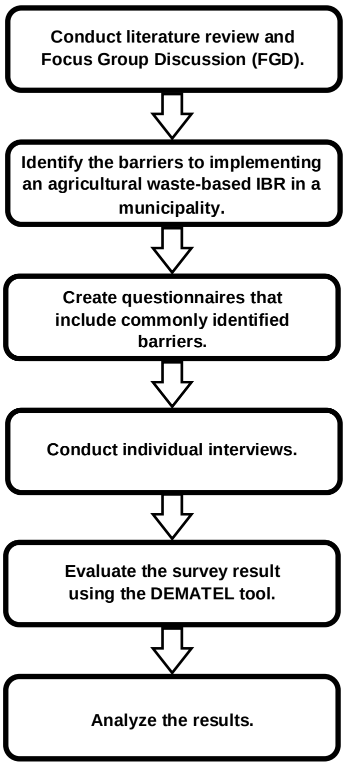

Figure 1: General framework for analyzing barriers to implementing integrated biorefineries

Through focus group discussions (FGDs), the identified barriers were then incorporated into questionnaires and disseminated to stakeholders from different sectors (i.e., farmers, business owners, municipal officials, and academic experts). The interviews will reveal the stakeholders' point of view and understanding of the relationships between the identified barriers. Once the interviews were accomplished, the results were evaluated, analyzed, and interpreted using the DEMATEL mathematical tool. The results can then be used to inform the decision-makers prior to implementing the IBR.

3. DEMATEL Methodology

This section shows the implementation of the DEMATEL method for this work. It is a mathematical tool to visualize the complicated structure of causal relationships through matrices and digraphs. This technique analyzes the cause-and-effect correlations of the barriers, such as an IS network (Bacudio et al., 2016). The outlines the steps in implementing DEMATEL:
Step 1: Determine A_k, the direct relation matrix for each interviewee, k, as shown in Eq(1).

$$A_k = \begin{bmatrix} 0 & a_{12k} & a_{13k} & \cdots & a_{1(n-1)k} & a_{1nk} \\ a_{21k} & 0 & a_{23k} & \cdots & a_{2(n-1)k} & a_{2nk} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{(n-1)1k} & a_{(n-2)2k} & a_{(n-1)3k} & \cdots & 0 & a_{(n-1)nk} \\ a_{n1k} & a_{n2k} & a_{n3k} & \cdots & a_{n(n-1)k} & 0 \end{bmatrix} \tag{1}$$

Each interviewee will subjectively evaluate the relationships between any two factors (i.e., barriers) using the measurement scale of 0, 1, 2, 3, and 4 to form the matrix, A_k. Where a_{ijk} illustrates the degree of criterion in which factor i influence factor j, and n signifies the maximum number of barriers considered in this study. The scale corresponds to "no influence (0)", "very low influence (1)", "low influence (2)", "high influence (3)", and "very high influence (4)". A high score denotes that a significant improvement in factor i is needed to improve factor j. The average rating was calculated and used as input for Eq(2).
Step 2: With the results obtained from the respondents, the overall direct relation matrix, A, was constructed using Eq(2):

$$A = \begin{bmatrix} 0 & a_{12} = \frac{\sum_{k=1}^{r} a_{12k}}{r} & a_{13} = \frac{\sum_{k=1}^{r} a_{13k}}{r} & \cdots & a_{1(n-1)} = \frac{\sum_{k=1}^{r} a_{1(n-1)k}}{r} & a_{1n} = \frac{\sum_{k=1}^{r} a_{1nk}}{r} \\ a_{21} = \frac{\sum_{k=1}^{r} a_{21k}}{r} & 0 & a_{23} = \frac{\sum_{k=1}^{r} a_{23k}}{r} & \cdots & a_{2(n-1)} = \frac{\sum_{k=1}^{r} a_{2(n-1)k}}{r} & a_{2n} = \frac{\sum_{k=1}^{r} a_{2nk}}{r} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{(n-1)1} = \frac{\sum_{k=1}^{r} a_{(n-1)1k}}{r} & a_{(n-2)2} = \frac{\sum_{k=1}^{r} a_{(n-2)2k}}{r} & a_{(n-1)3} = \frac{\sum_{k=1}^{r} a_{(n-1)3k}}{r} & \cdots & 0 & a_{(n-1)n} = \frac{\sum_{k=1}^{r} a_{(n-1)nk}}{r} \\ a_{n1} = \frac{\sum_{k=1}^{r} a_{n1k}}{r} & a_{n2} = \frac{\sum_{k=1}^{r} a_{n2k}}{r} & a_{n3} = \frac{\sum_{k=1}^{r} a_{n3k}}{r} & \cdots & a_{n(n-1)} = \frac{\sum_{k=1}^{r} a_{n(n-1)k}}{r} & 0 \end{bmatrix} \tag{2}$$

where A is the overall direct relation matrix, a_{ij} is the average of a_{ijk} of all respondents, and r is the sum of the number of respondents.
Step 3: Normalize the direct relation matrix, B, using Eq(3). The overall direct relation matrix factors were divided into whichever is larger among the maximum column sum or the maximum row sum. Each element, b_{ij}, of matrix B, ranges from 0 to 1.

$$B = [b_{ij}]_{nxn} = \frac{A}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}, where\ 0 \le b_{ij} \le 1 \tag{3}$$

Step 4: Calculate the total relation matrix, C, using Eq(4). The total relation matrix was solved using the normalized direct relationship matrix by getting the sum of the direct and indirect effects; I in the equation is the identity matrix.

$$C = [c_{ij}]_{nxn} = B(I - B)^{-1} \tag{4}$$

Step 5: Calculate the values of prominence $(D + E)$ and net cause/effect $(D - E)$ using Eq(5) and Eq(6).

$$D = [d_{ij}]_{nx1} = \left[\sum_{j=1}^{n} c_{ij}\right]_{nx1} \tag{5}$$

$$E = [e_{ij}]_{1xn} = \left[\sum_{j=1}^{n} c_{ij}\right]_{1xn} \tag{6}$$

Using the total relation matrix, calculate the sum of the rows (D) and the sum of the columns (E). D evaluates direct and indirect effects given by factor, i, to the other factors. The term E depicts the direct and indirect effects received by factor, i, coming from other factors. Eq(5) and Eq(6) was used to calculate the prominence and net cause/effect. The sum $(D + E)$ represents the total effects given and received by factor, i, which indicates the degree of prominence of the factor in the system. $(D - E)$ denotes the net effect of factor, i, in the system. If the net effect value is positive, it is included in the cause group. If the net effect value is negative, it belongs to the effect group.

4. Results and Discussion

Through literature review and focus group discussion (FGD), ten barriers were identified in developing an agricultural waste-based IBR that can serve as the basis for future implementation. The barriers considered are summarized in Table 1. The respondents from different sectors considered for this study are seven employees from the agriculture office, three farmers, one researcher, and one businessman. Individual interviews were done to identify how each stakeholder perceived the connection and the influence of the ten barriers with each other. The data collected from the respondents were treated and analyzed using the DEMATEL method.

Table 1: Barriers to implementing agricultural waste-based integrated biorefinery (IBR)

Code	Description of barriers	Source
B1	Lack of technology and infrastructure readiness	Södergren and Palm (2021)
B2	Lack of technical knowledge gaps in terms of sustainable agriculture	Kwant et al. (2018)
B3	Lack of openness to modern advancements in agricultural business	Laurett et al. (2021)
B4	Lack of awareness of the IBR and sustainability concepts	Södergren and Palm (2021)
B5	Lack of qualified staff to facilitate the IBR	Kwant et al. (2018)
B6	Lack of potential feedstocks due to climate change and other factors	FGD
B7	Lack of trust, willingness, and engagement between stakeholders	Södergren and Palm(2021)
B8	Lack of financial confidence in the return of large investments	Kwant et al. (2018)
B9	Lack of long-term, entrepreneurial vision	Laurett et al. (2021)
B10	Lack of understandable legislation and specific regulations to support the local agricultural industry	FGD

Using the interview results and Eq(1) to Eq(6), Figures 2 and 3 were developed. In Figure 2, each barrier's prominence (D + E) is presented decreasingly. From the figure, "Lack of technology and infrastructure readiness (B1)" has the highest correlation with the other barriers. This result shows that the Philippines is still adapting to new technologies and infrastructure that will be sufficient to cater to the needs and requirements of an IBR. It is known that IBR is a state-of-the-art that will require novel technology to convert agricultural waste to bioenergy products. Modern technologies and updated infrastructure should be considered to increase production efficiency and economic profitability of an IBR.

The other barriers that are in the top five of the prominence graph, Figure 2, are "Lack of financial confidence in the return of large investments (B8)", "Lack of trust, willingness, and engagement between stakeholders (B7)", "Lack of awareness of the IBR and sustainability concepts (B4)" and "Lack of understandable legislation and specific regulations to support the local agricultural industry (B10)". The lack of trust, willingness, and engagement between stakeholders (B7) should also be given importance since this is a significant factor in the implementation because IBR would be sustainable if there is confidence between stakeholders. The implementation requires strong support from the higher authorities and stakeholders to have lasting economic improvement. This relates to the lack of awareness of the IBR and sustainability concepts (B4) because a deeper understanding of the IBR and its sustainability would increase the stakeholder's trust.

In addition, implementing an IBR will require financial investments because of its technological and infrastructure requirement. The lack of economic confidence in the return of significant investments (B8) is one of the top five barriers that affect the implementation of IBR. This shows that clarity on the potential return of substantial investment is needed to assure investors that IBR would provide benefits (and revenues) in every aspect. The introduction of government subsidies and incentives can help encourage investments in this area. IBR would be successful if there is a two-way understanding between the stakeholders. A deeper awareness of the IBR and sustainability concepts (B4) will give the stakeholder higher confidence. Discussion with farmers, investors, and other stakeholders should be conducted to widen the knowledge and understanding of how IBR would benefit them and the environment. It will give a strong foundation and support in the implementation of IBR. This connects to the fifth highly-correlated barrier, the lack of understandable legislation and specific regulations to support the local agricultural industry (B10). Policies and regulations regarding the agricultural sector that will help this shift from burning waste to an agricultural waste-based IBR should be established. The creation of legislation and specific regulations would indicate that the implementation of IBR in the area is prioritized and planned.

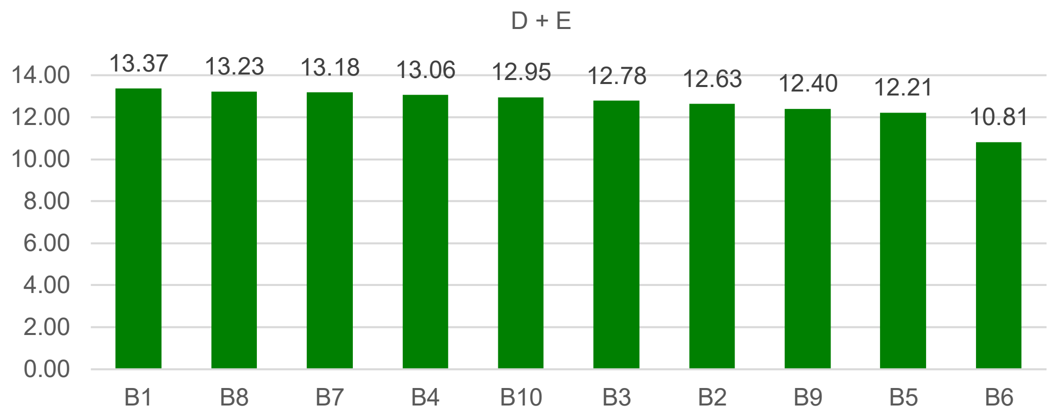

Figure 2: Prominence graph in decreasing order of values

Figure 3 shows the net cause/effect value for each identified barrier. If the (D – E) value is positive, it is considered a cause. A negative value of (D – E) suggests that it is an effect barrier. According to Figure 3, “Lack of potential feedstocks due to climate change and other factors (B6)”, “Lack of awareness of the IBR and sustainability concepts (B4)”, “Lack of qualified staff to facilitate the IBR (B5)”, and “Lack of technical knowledge gaps in terms of sustainable agriculture (B2)” are considered the causal factors. It can be seen in Figure 3 that “Lack of potential feedstocks due to climate change and other factors (B6)" has the highest (D – E) value and shows that it is the primary causal factor. This result implies that actions towards addressing climate change should be implemented since it mainly affects the productivity of agricultural activities; if not addressed, this leads to a decrease in the production of agricultural waste used as feedstock in the IBR. Also, "Lack of awareness of the IBR and sustainability concepts (B4)" should be focused on since it would be difficult to establish an IBR facility that converts agricultural waste into products like biofuels, biochemicals, and bioenergy if the people who will operate it do not know about the conversion process and its purpose.

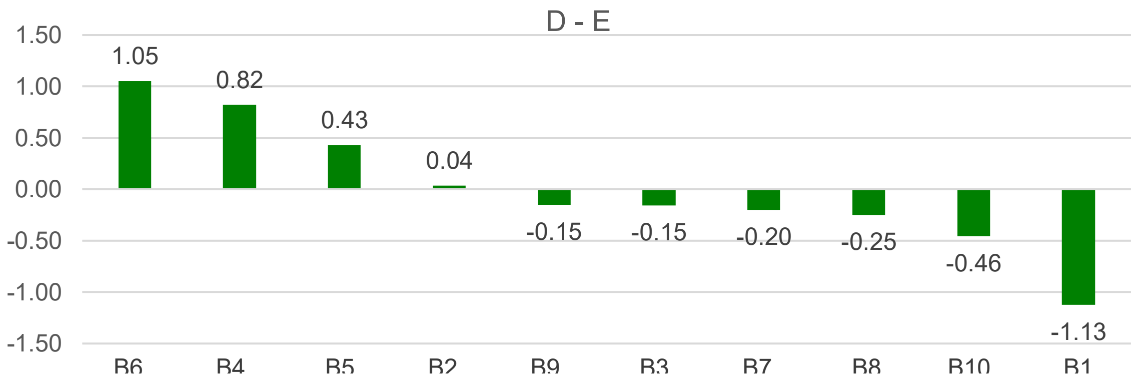

Figure 3: Net cause/effect graph

The six other barriers: "Lack of long-term, entrepreneurial vision (B9)", "Lack of openness for modern advancements in agricultural business (B3)", "Lack of trust, willingness, and engagement between stakeholders (B7)", "Lack of financial confidence in the return of large investments (B8)", "Lack of understandable legislation and specific regulations to support the local agricultural industry (B10), and "Lack of technology and infrastructure readiness (B1)" are considered as the effect factors. The effect barriers are affected by the causal barriers – hindering the development of agricultural waste-based IBRs in the municipalities. Looking at the effect barriers, "Lack of long-term, entrepreneurial vision (B9)" is located nearest the centre of the graph – meaning the identified causal factors least influence it. Meanwhile, "Lack of technology and infrastructure readiness (B1)" has the smallest (D – E) value, which suggests that it is the least influencing barrier. In eliminating the barriers to implementing an agricultural waste-based IBR, B1 can be considered the barrier that can be given the least priority.

5. Conclusions

A DEMATEL-based framework was developed in this work to analyze the barriers to implementing an IBR utilizing agricultural waste. Addressing the barriers will be helpful in developing IBRs at a local or national level. Results show that the "Lack of technology and infrastructure readiness (B1)" has the highest correlation with the other barriers or factors; such can be addressed by slowly introducing innovations in the agricultural sector. "Lack of potential feedstocks due to climate change and other factors (B6)" is the primary causal barrier and suggests that climate risk is seen as greatly affecting the IBR implementation. For future work, the researchers will aim to expand the number of respondents and municipalities to be studied. The fuzzy DEMATEL method can be used to analyze the impact of uncertainties such as subjectivity in the answer of the stakeholders in implementing IBRs.

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