TOWARDS A GREENER FUTURE: USING DEMATEL-ANP FOR SUSTAINABLE INDONESIAN FIBER CEMENT BOARD MANUFACTURING COMPANY

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Abstract

The Indonesian fiber cement board industry faces increasing pressure to enhance sustainability due to growing environmental global concerns and regulatory demands. The companies in this sector must address multiple sustainability criteria such as waste management, resource utilization, and compliance with environmental regulations to remain competitive and sustainable. However, identifying which criteria are the most influential in driving overall sustainability outcomes presents a challenge. Previous studies have often examined these criteria in isolation, without considering their interdependencies. To address this gap, this study integrates the Delphi method with DEMATEL and ANP to analyze and prioritize key sustainability criteria for a fiber cement board company. By developing a comprehensive framework, this research aims to provide actionable insights that will help companies enhance their sustainability performance. In this research, PT. XYZ, a well-known fiber cement board manufacturer in Central Java, Indonesia, was used as a case study. The result shows that the DEMATEL-ANP method reveals that waste management, compliance with environmental regulations, and resource and material management are the most critical criteria, with high prominence and influence scores. These findings suggest that focusing on these critical areas first, followed by processing other criteria accordingly, can significantly enhance the company's sustainability performance.

Keywords: Sustainability, Fiber Cement Board, Environmental Impact, Waste Management, Energy Efficiency.

JEL Classification: Q01, Q56, L61, C63, M11

Article History: Submitted: 2024-08-31; Revision: 2024-10-08; Accepted: 2024-10-23; Published: 2025-01-18

How to Cite: Sulandjari, S. (2025). Towards a Greener Future: Using DEMATEL-ANP for Sustainable Indonesian Fiber Cement Board Manufacturing Company. *Media Ekonomi dan Manajemen, 40*(1), 82-99.

INTRODUCTION

The cement board manufacturing sector occupies a crucial and indispensable position within contemporary construction practices, attributable to its remarkable durability, extensive versatility in application, and impressive cost-effectiveness that appeals to a wide array of stakeholders. Nonetheless, it is crucial to recognize that this specific sector simultaneously serves as a significant contributor to ecological harm, as demonstrated by its considerable input to elevated carbon emissions, significant energy usage during the manufacturing procedures, and the extensive dependence on non-renewable resources (Mishra et al., 2023). As global awareness of environmental sustainability becomes significant (as shown by the emergence of new UN policies about environmental safety), there is mounting pressure on this industry to adopt greener practices. The fiber cement board sector, in particular, faces scrutiny for its environmental and health impacts due to the use of asbestos and other hazardous materials (Sadrolodabaee et al., 2022). PT. XYZ, a fiber cement board company located in Jawa Tengah, Indonesia, has identified these challenges and is committed to developing sustainable manufacturing processes to reduce environmental impacts and align with global sustainability goals.

Despite numerous advancements in sustainable materials and production technologies, the cement board industry continues to confront several pressing issues such as: the efficient utilization of raw materials, reducing energy consumption during production, and effectively managing waste and emissions (César et al., 2022). Furthermore, it is critical to balance environmental sustainability with economic feasibility to ensure that sustainable practices do not compromise product quality or increase production costs (Jena et al., 2023). PT. XYZ faces the specific challenge of optimizing production processes to reduce waste, enhance energy efficiency, and incorporate sustainable materials without sacrificing the quality and durability of its fiber cement boards.

Numerous studies have explored sustainability in the cement board industry, each contributing valuable insights but often lacking comprehensive solutions in production process. Sadrolodabaee et al. (2022) investigated recycled textile-reinforced cement facade cladding to enhance sustainability through waste reduction and energy savings, yet the study primarily focuses on material reuse rather than broader production efficiency. Another work examined plant-based cementitious composites, advocating for renewable fibers and bio-aggregates in order to replace traditional materials (César et al., 2022). Influenced by global green policy, it analysed the potential of other material such as Oil Palm Empty Fruit Bunch Fiber (OPEFB) in fiber cement boards. This research was emphasizing the reduction of wood usage. Unfortunately, it does not consider the entire lifecycle of environmental impacts (Akasah, Z. A. et al., 2021). Meanwhile, Jena et al. (2023) focused on the optimal use of industrial by-products like fly ash and GGBS to reduce raw material use, highlighting potential cost savings but not fully resolving issues related to product quality and consumer acceptance. However, the specific challenge of optimizing production processes lies in finding the right balance between reducing waste, enhancing energy efficiency, and incorporating sustainable materials, all while maintaining the quality and durability of fiber cement boards. This challenge stems from the difficulty of implementing environmentally friendly practices that do not compromise the product's performance or significantly increase production costs. As companies aim to meet sustainability goals, they must navigate these competing priorities, which forms the core of the problem phenomena in the industry.

In addition to environmental challenges, cement companies face social sustainability issues, such as worker health risks and community impact from hazardous materials like asbestos (Sadrolodabaee et al. 2022). Economically, balancing sustainable practices with rising production costs is difficult, as implementing green technologies requires significant investment (Makul, 2020). Moreover, transitioning to sustainable methods can lead to workforce disruptions, requiring reskilling or job losses (Jena et al., 2023). These challenges make achieving comprehensive sustainability difficult without affecting financial stability or social responsibility.

While various studies have advanced the sustainability of cement boards in terms of material engineering, an important unresolved issue remains: most studies fail to provide comprehensive solutions that address environmental, economic, and social aspects simultaneously. For example, Seneviratne et al. (2022) examined the use of nano-materials, but their high cost and complex manufacturing processes limit scalability, creating inefficiencies in the market. Similarly, Babu et al. (2021) explored bio-based additives to improve mechanical properties, but these solutions are regionally restricted, limiting their broader environmental benefits, especially in countries like Indonesia. Kumar et al. (2022) focused on energy-efficient kiln technologies but did not account for the waste generated during production. Furthermore, Raj et al. (2021) conducted lifecycle assessments of manufacturing processes but lacked actionable strategies for immediate implementation. A significant gap exists in the literature regarding the exploration of antecedent variables such as operational efficiency, waste management, and regulatory compliance that directly influence sustainability performance. Our research aims to address this gap by analyzing how these interrelated factors impact the overall sustainability of the fiber cement board industry.

This research aims to address the existing gap by employing a more integrated approach to sustainability in the fiber cement board industry, specifically at PT. XYZ in Jawa Tengah, Indonesia. Unlike previous studies that often focus on single aspects of sustainability, this research adopts a comprehensive view that integrates environmental, economic, and social factors. These include sustainable raw material sourcing, energy-efficient production processes, advanced waste management strategies, and the promotion of safe working conditions and community well-being, aligning with global sustainability standards (Wu et al., 2022). By doing so, this study will develop a holistic framework that if it is being implemented within the industry, it will enhance the sustainability. In this research we employ the DEMATEL (Decision-Making Trial and Evaluation Laboratory) method. By implementing it, we can gain the crucial factors of sustainability, which allows for identifying and analysing complex causal relationships among various sustainability factors (Wu et al., 2022). Therefore, when see the research finding, it will enable a deeper understanding of how different sustainability practices interact, facilitating more informed decision-making and strategic planning (Yazdani et al., 2021).

LITERATURE REVIEW

The concept of sustainability in cement board industry

The cement industry faces significant sustainability challenges, primarily due to its high carbon emissions and substantial resource use. Recent studies have focused on alternative materials and innovative processes to mitigate these environmental impacts utilizing recycled and plant-based materials to replace traditional, non-renewable aggregates (Sadrolodabaee et al., 2022) (César et al., 2022). By incorporating recycled textiles and plant fibers such as lechuguilla, flax, wood, and hemp shavings into cement-based products, these studies demonstrate a reduction in waste and an improvement in resource efficiency. By implementing this approach, the method proven to conserve the natural resources and reduce the carbon footprint of cement production. Similarly, Akasah, Z. A. et al. (2019) advocate for the use of agricultural waste products, like Oil Palm Empty Fruit Bunch Fiber (OPEFB), to produce fiber cement boards, emphasizing the potential to replace wood and other traditional materials with more sustainable alternatives.

In the profound landscape of the cement industry, alongside the burgeoning advancements in material science and innovation, there is an increasingly pronounced emphasis on refining and optimizing the processes involved in manufacturing to foster an enhanced sense of sustainability throughout the sector. This is noticed by research that conducted from Jena (2023) that delves into the fascinating exploration of incorporating industrial by-products, such as the finely

p-ISSN: 0854-1442 (Print) e-ISSN: 2503-4464 (Online)

powdered fly ash and Ground Granulated Blast Furnace Slag (GGBS). In order to diminish the overdependence on conventional cement and the often contentious asbestos fibers that are utilized in the production of fiber cement sheets this innovative approach not only successfully addresses the pressing challenges associated with the disposal of waste materials but also simultaneously contributes to a significant augmentation of both the environmental and economic sustainability inherent to the entire production process. Moreover, researchers Ojo et al. (2019) and Alanbari et al. (2015) embarked investigation the potential of utilizing sustainable waste materials, which include waste paper, the invasive water hyacinth, and the agricultural residues from date palms. These studies underscore the critical urgency of harmonizing production engineering practices with the distinct sustainability considerations unique to each company, thereby fostering a more conscientious approach to manufacturing will benefit the holistic aspect of sustainability (Wang et al., 2024).

In addition to environmental and economic considerations, social sustainability that play a crucial role in the cement industry's move toward a more complete and holistic approach. The social sustainnability encompasses the well-being of workers, communities, and other stakeholders that impacted by the production process. Previous research of Wang et. al. (2024) said that when enhancing workplace safety process happened, it will also impacted on how to ensure the fair labor practices, and maintain positive relationships with local communities. They are essential components of a sustainable operation that ensuring the loop of everlasting production process. Cement production often involves hazardous materials, which necessitates stringent health and safety measures to protect workers. As highlighted by Misran et al. (2021), addressing worker safety and community health risks is vital for fostering long-term social sustainability. Furthermore, fostering community engagement by mitigating pollution and contributing to local development helps cement companies maintain social licenses to operate (Drexhage & Murphy, 2010). Incorporating these social dimensions alongside environmental and economic factors ensures that sustainability efforts are truly comprehensive and beneficial across all fronts.

Sustainability Management in Cement Board Industry

Resource and material management is an important foundation in the sustainability of the fiber cement board industry. The use of environmentally friendly raw materials, such as natural fibers and recycled materials can significantly reduce environmental impacts, however as mentioned before the process will lead to cost inefficient. One research according to Asif et al. (2021), replacing conventional raw materials with more sustainable materials not only reduces carbon emissions but also helps in reducing dependence on limited natural resources. In addition, water management and the use of recycled water in the production process are also important to reduce freshwater use and prevent water pollution. Singh and Joseph (2019) emphasized that water recycling technology can improve sustainability by reducing water waste and reducing the burden on water resources. By optimizing the use of materials and water, the industry can contribute to more environmentally friendly production practices.

Process efficiency and environmental impact reduction are other important aspects of sustainability as the efficient energy is used and its reduction of production waste can imply the overall carbon footprint of the industry. According to the International Energy Agency (2020), we found that the application of energy efficiency technology in the production process will degrade or reduce energy consumption by up to 30%. In addition that complement of this finding another proof was given by Tseng et al. (2018). In this research, he underlined the importance of a waste reduction system as a strategy or policy to improve operational efficiency and reduce production costs. The finding remarkably found that by implementing environmentally friendly technologies, like energy-efficient production equipment and improved waste management systems, the companies can reduce their negative impact on the environment and improve sustainability.

Compliance with environmental regulations and the development of innovative, environmentally friendly products are also essential to support sustainability in the fiber cement board industry. Several companies that comply with environmental regulations not only avoid sanctions when they are dealing with global standard that reduce profit portion but also enhance their reputation as socially responsible businesses. Fikru (2018) showed that companies committed to environmental compliance tend to adopt practices that go beyond minimum standards to achieve competitive advantage. Another evidence that gives positive and compelling factor, shows that environmentally friendly product innovation allows companies to remain relevant in an evolving market and meet the demands of consumers who are increasingly aware of the importance of sustainability (Kesidou & Demirel, 2012). Thus, we it is stated that the compliance and innovation are key pillars in a company's sustainability strategy.

Another factors that need to be assess when dealing with sustainability is the employee. This actor need to be improved on engagement and education sectors regarding with the sustainability practices which are used for ensuring the successful implementation of an environmentally friendly strategy in a company. As reported from Daily et al. (2007) this impotance and crucial factors is defined as a process that emphasized the employee training on sustainability which it can improve their understanding of the company's environmental goals, as well as increase their involvement in achieving those goals. Therefore, when involving employees in sustainability initiatives not only improves operational efficiency but also builds a corporate culture that is more responsive to environmental issues. In consequences of this improve it will create a more proactive work environment in adopting sustainable practices, which ultimately improves overall company performance.

In the market section, consumer interaction and marketing strategies should not only emphasize sustainable products but also integrate social sustainability, which is equally crucial for comprehensive sustainability efforts. In the social sustainability aspect, it involves parameter such as corporate social responsibility (CSR), employee engagement, and community impact program. It is understandable that when company that effectively incorporate CSR initiatives, such as fair labor practices, community development, and contributions to social causes, can strengthen their brand reputation and appeal to socially conscious consumers. Moreover, many modern consumers are already aware for improving brand awareness that not only happens in the environmental impacts but also in the social responsibility practices of companies (Ottman et al., 2006). Effective marketing strategies, therefore, must communicate both the environmental and social sustainability values of the product in an engaging manner. By highlighting efforts such as worker welfare programs, safe working conditions, and contributions to local communities, fiber cement board companies can differentiate themselves in the marketplace which not only attracts environmentally and socially conscious consumers but also strengthens customer loyalty, improves employee satisfaction, and expands the company’s market share. Therefore, this research stated that through employee engagement and CSR, the

p-ISSN: 0854-1442 (Print) e-ISSN: 2503-4464 (Online)

company can build a positive corporate culture that aligns with both environmental and social sustainability and this will achieve a more holistic sustainability framework.

Based on the theory above, the Table 1 will scrutinize the theory to create criteria of latent variable that together measure the sustainability of PT. XYZ. These criteria will be used in further analysis for identifying the relation between factor that influence sustainability. Relevant and proper criteria analysis for extracting the criteria is depicted by using Delphi method. In the next chapter of research methodology will show in detail the step-by-step process of DEMATEL-ANP algorithm and comply with Delphi for creating objective research of measuring sustainability of PT. XYZ.

RESEARCH METHODS

This research is a quantitative study that employs a hybrid approach between DEMATEL (Decision-Making Trial and Evaluation Laboratory) and ANP (Analytic Network Process) to identify and measure the relationship between sustainability criteria in the XYZ company. This process began with the determination of fundamental criteria using Delphi method. After this, it will follow by analysis using DEMATEL-ANP for choosing the key factor in the company sustainability.

Delphi Method Setup

Based on Hsu & Standford (2021), Delphi method is a forecasting and group decision technique which used for achieve consensus among the group of experts. In this research we use it for targeting the proper criteria that relevant in the XYZ company of fiber cement board when achieving sustainability. In our process, we use several experts that involving several rounds of giving their arguments about 'what factors in achieving sustainability' based on their expertise. They will act as anonymous to one and another, in order to keep the fairness play. Since each round is followed by previous process summary, thus enabling current process participants to review and revise their opinions to find consensus. Table 1 will show the selection of these experts. This ensures that a variety of perspectives are considered in determining the criteria that are important to corporate sustainability.

From the discussion above we bring 10 topics that match the literature review. Table 2 shows in detail of given topic. Those topic are becoming group descripttion of given expertise. From environment consultant and regulation that practice in sustainability will concern on resource and material management and water management. From production manager will concern on energy efficiency and waste management that lead to cost efficiency. R&D will focus on the product innovation with environmental comply standard. While Senior Field Engineer will focus on employee engagement and education. Finally, the Head of quality and compliance will focus on consumer interaction and marketing strategies, operational efficiency, and corporate social responsibility.

Table 1. Expert Types for Delphi

No	Expert type	Description
1	Environment Consultant	Expert with in-depth knowledge of environmental regulations and best practices in sustainability.
2	Production Manager	Responsible for production efficiency and waste management, which are important in the context of sustainability.
3	R&D team	Involved in the innovation of environmentally friendly products and technologies.
4	Senior Field Engineer	Has direct understanding of day-to-day operations and implementation of sustainability practices in the field.
5	Head of Quality and Compliance	Oversees compliance with quality standards and regulations related to materials and production processes.

Table 2. Criteria of Sustainability

Code	Criteria	Description	Reference	Subcriteria
C1	Resource and Material Management	Using environmentally friendly materials to ensure sustainability, including water management and recycled raw materials	Asif et al. (2021)	Use of recycled water, Raw material optimization, Pollution reduction
C2	Water Management	Efficient water management through water recycling and reducing water consumption in production	Singh & Joseph (2019)	Water recycling, Reduction of water usage, Protection of water resources
C3	Energy Efficiency	Implementing energy-efficient technologies to lower energy consumption and enhance overall sustainability	International Energy Agency (2020)	Energy consumption reduction, Use of renewable energy, Energy process optimization
C4	Waste Management	Managing waste effectively by adopting recycling practices to minimize environmental impact	Tseng et al. (2018)	Waste reduction, Recycling of production materials, Hazardous waste handling
C5	Compliance with Environmental Regulation	Compliance with environmental regulations provides competitive advantages while avoiding sanctions	Fikru (2018)	Compliance with local and international regulations, Environmental impact management
C6	Innovation and Environmentally Friendly Product	Developing environmentally friendly products that remain competitive in the market while promoting sustainability	Kesidou & Demirel (2012)	Innovation in eco-friendly raw materials, Sustainable product design
C7	Employee Engagement and Education	Engaging and educating employees in sustainability practices to improve operational efficiency	Daily et al. (2007)	Sustainability training programs, Employee involvement in green practices
C8	Consumer Interaction and Marketing Strategies	Promoting sustainable products to consumers who are increasingly aware of social and environmental impacts	Ottman et al. (2006)	Sustainability-focused marketing strategies, Consumer education
C9	Operational Efficiency	Enhancing process efficiency to reduce energy consumption and emissions, positively impacting production costs	Jena et al. (2023)	Process optimization, Emission reduction, Resource management
C10	Corporate Reputation and Social Responsibility	Building a company's reputation as a socially responsible business that prioritizes environmental sustainability	Fikru (2018)	Corporate social responsibility (CSR) programs, Environmental reputation

Creating DEMATEL Approach using ANP

This research algorithm is derived from Xu et. al (2024) methodology. Because this study wants to produce quantitative values of the influence on sustainability factors that not only monotonously define themselves separately in one group, but can also provide an explanation of the strength or weakness of the relationship between one factor and another, therefore we use the DEMATEL-ANP Algorithm (Figure 1). This is because this system has a combined approach that integrates the DEMATEL and ANP to analyze complex relationships between various criteria in a system. As we understand that DEMATEL is used to build and visualize a network model of relationships between criteria, while ANP method is used to determine the relative weight of each criterion based on the influence matrix that generated by DEMATEL.

 p-ISSN: 0854-1442 (Print) e-ISSN: 2503-4464 (Online)

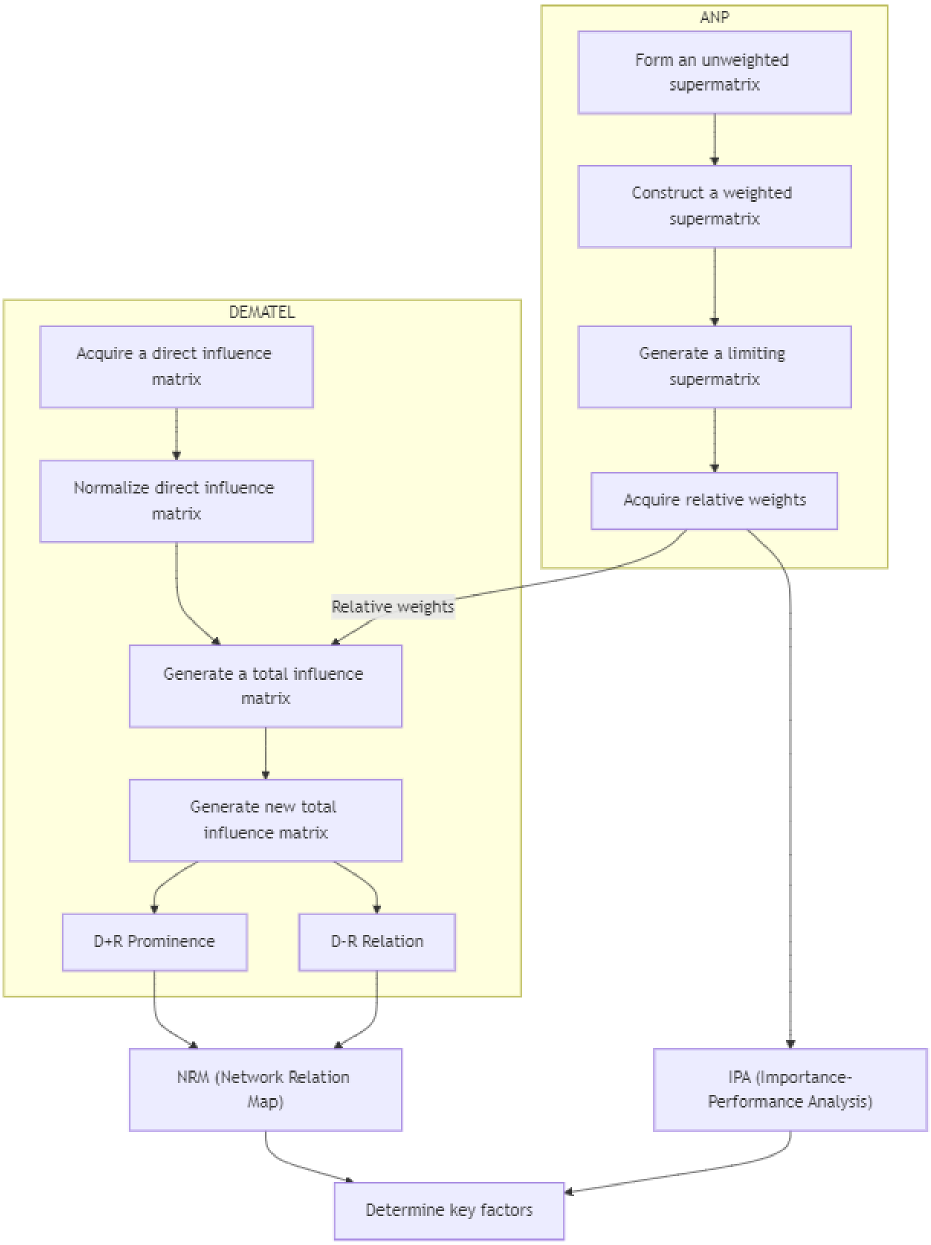

Figure 1. Algorithm of DEMATEL-ANP

The aim of DEMATEL is to create direct relationship matrix (Direct Influence Matrix, A). Where the process describes the strength of influence of one criterion on another criterion. Suppose we have n criteria in the system. Each expert rates the level of influence between criteria using a numeric scale (*i.e.* 0 = no influence, 1 = low influence, 2 = medium influence, 3 = high influence). Direct influence matrix A is $n \times n$ dimension and has a_{ij} element where:

a_{ij} is average value from assessment of direct influence i to criterion j. (1)

In this research a_{ij} diagonal will be set 0 since there is no criteria that influence itself.

The second step is to normalize the direct influence matrix in order to ensure that the values in the matrix are in a uniform range and we the matrix will be used for capturing the significance of component's feature. This normalization is done to change the scale of the matrix A

into a normalized matrix X. The scale factor S is calculated using the formula:

$$S = min\left(\frac{1}{\max_i \sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_j \sum_{i=1}^{n}|a_{ij}|}\right) \quad (2)$$

The direct normalized influence matrix X is computed by $X = S \times A$. This normalization will ensure that the total given or accepted from each criterion is not more than one.

The third step is to form a total influence matrix T, which describes the direct and indirect influences between criteria. The total influence matrix is calculated by adding the direct influence matrix and all the rank matrices of the indirect influence until convergent, which can be formulated as:

$$T = X + X^2 + X^3 + \cdots = N(I - X)^{-1} \quad (3)$$

In here, I is the identity matrix of $n \times n$ dimension. T shows the total influences on one criterion towards other criteria this is including direct or indirect influences.

After the total influence matrix T is calculated, the next step is to set a threshold α to determine the significant elements in this matrix. This threshold is usually calculated as the average value of the elements in the matrix T^*. The new total influence matrix is formed by the rule:

$$T_{ij}^* = \begin{cases} T_{ij} & if\ T_{ij} > \alpha \\ 0 & if\ T_{ij} < \alpha \end{cases} \quad (3)$$

This matrix T^* is used for visualized the significant causal relation between criteria.

The last step in our algorithm is to calculate two important indices, namely the total influence given and received by each criterion. The total index of influence given by criterion i is D_i (the amount of influence given), and the total index of influence received by criterion i is R_i (the amount of influence received):

$$D_i = \sum_{j=1}^{n} T_{ij}^*, R_i = \sum_{j=1}^{n} T_{ji}^* \quad (4)$$

Then, the following two values are calculated to determine the role of each criterion in the system:

- Importance describes how important the criterion is in the network of influence, both as a cause and an effect.

$$D_i + R_i \quad (5)$$

- Net Cause/Effect describes whether the criterion is more of a cause (positive value) or more of an effect (negative value).

$$D_i - R_i \quad (6)$$

Formula (5) and (6) are to identify which criteria are most important and whether they function primarily as causes or effects in the system. This algorithm allows us to understand the structure of the network of influences among the criteria and make better decisions based on their interactions. For the application of ANP, in order constructing the super matrix W of ANP, we use prominent value of D_i and R_j from equation (4). The block corresponding to the C_i and C_j that filled normalized $D + R$ value using the equation of mean $w_{ij} = \frac{w_{ij}}{\sum_i w_{ij}}$. Based on that we then replace the old T matrix with normalized supermatrix W and we denoted as matrix T new or T^*.

In the application, we design the questionnaire. The main purpose of this is to investigate the level of interaction between various sustainability criteria and then identify the key factors that influence sustainability practices in fiber cement board companies. The context was structured into 10 sections of criteria as in Table 2, each corresponding to one of the sustainability criteria: Resource and Material Management, Water Management, Energy Efficiency, Waste Management, Compliance with Environmental Regulations, Innovation in Environmentally Friendly Products, Employee Engagement and Education, Consumer Interaction and Marketing Strategies, Operational Efficiency, and Corporate Reputation and Social Responsibility. There are a total of 40 questions, with each section containing 4 questions designed to assess the direct influence of each criterion on the others and to evaluate their relative importance within PT. XYZ. The aim of these questions is to gather insights on how these criteria interact and affect one another, providing a comprehensive understanding necessary for conducting the DEMATEL-ANP analysis to identify and prioritize key sustainability factors.

Data collection

In the collecting the data process, we divided into two categories such as one is for the Delphi method the other is for DEMATEL method. In the Delphi's data collection, we aimed to gain an in-depth understanding of the views and experiences of stakeholders in the company on various aspects of sustainability, such as raw material quality, energy efficiency, waste reduction, and water management in fiber cement board companies. Another one is for DEMATEL method we conduct it in August 2024. There, we distributed 215 questionnaires to various stakeholders in the company, including production managers, R&D teams, environmental consultants, senior field employees, and heads of quality and compliance. Of these, we received 150 valid questionnaires for analysis (the result of selection and pre-processing). The proportion of male and female participants in this questionnaire was almost balanced, with a ratio close to 5:5. The descriptive of data is for the total of 40% of the respondents were between 25 and 34 years old, 30% were between 35 and 44 years old, 20% were between 45 and 54 years old, and 10% were over 55 years old. This age distribution reflects a wide variation in experience and perspectives, allowing us to gain more nuanced insights into sustainability in fiber cement board companies.

RESULTS

In the simulated Delphi rounds for PT. XYZ's sustainability assessment, experts evaluated 10 criteria related to sustainability across three rounds as shows in Table 3. The results show convergence in expert opinions, as indicated by the Coefficient of Deviation Index (CDI), which remained below 0.1 for all criteria. This low CDI reflects a high level of agreement among experts, suggesting that they reached a strong consensus on the importance and interrelationships of the criteria. This is resulted by small standard deviation σ of given mean μ in all across the rounds R. A CDI below 0.1 is generally considered a threshold for strong consensus in Delphi studies, as it indicates minimal variability in expert responses across rounds (Hsu & Sandford, 2021). Therefore, all experts are having consensus that all given criteria are acceptable. The stability of the results across the rounds confirms that the criteria selected for sustainability evaluation at PT. XYZ are well-founded and supported by expert opinion, thus providing a robust basis for further analysis using the DEMATEL-ANP method.

Table 3. Delphi Results

Dimension	Indicator	R1	R2	R3	μ	σ	CDI	Accept
Environment Consultant	Resource and Material Management	6	5	4	5.0	0.0816	0.0163	Yes
Environment Consultant	Water Management	7	8	8	7.667	0.0471	0.0061	Yes
Environment Consultant	Compliance with Environmental Regulation	6	6	5	5.667	0.0471	0.0083	Yes
Production Manager	Energy Efficiency	7	8	7	7.333	0.0471	0.0064	Yes
Production Manager	Waste Management	7	8	8	7.667	0.0471	0.0061	Yes
R&D team	Innovation and Environmentally Friendly Product	8	7	8	7.667	0.0471	0.0061	Yes
Senior Field Engineer	Employee Engagement and Education	6	6	5	5.667	0.0471	0.0083	Yes
Head of Quality and Compliance	Consumer Interaction and Marketing Strategies	8	8	9	8.333	0.0471	0.0057	Yes
Head of Quality and Compliance	Operational Efficiency	6	6	5	5.667	0.0471	0.0083	Yes
Head of Quality and Compliance	Corporate Reputation and Social Responsibility	6	7	6	6.33	0.001	0.0043	Yes

The Total Influence Matrix T^* in Table 4 reveals significant insights into the relationships among the sustainability criteria. The matrix entries represent the cumulative effect each criterion has on the others, accounting for both direct and indirect influences. For example, $T_{13} = 0.541$ indicates the total impact that C1 has on C3, suggesting that effective resource and material management can significantly enhance energy efficiency. This strong influence highlights C1 as a critical driver of sustainability, impacting various aspects of the system. Other criteria, such as C2 (water management), also show considerable influence over others, with values like $T_{14} = 0.457$ indicating its effect on waste management (C4). This implies that improving water management practices can lead to better waste management outcomes, demonstrating a clear interdependency. Conversely, C10 (corporate reputation and social responsibility) is more influenced by other criteria, with lower influence values of its own. For instance, $T_{71} = 0.376$ and $T_{91} = 0.34$ show that C10 is significantly shaped by employee engagement (C7) and operational efficiency (C9). This dependency suggests that enhancing reputation and social responsibility efforts requires improvements in other sustainability areas first. Moreover, the matrix identifies balanced relationships where certain criteria, like C7 (employee engagement and education), moderately influence and are influenced by other criteria, as seen with $T_{74} = 0.483T$ and $T_{78} = 0.358$. This balance indicates that while C7 contributes to shaping sustainability outcomes, it also heavily relies on improvements in other areas, such as compliance with regulations (C5) and consumer interactions (C8). We found that the matrix demonstrates that criteria such as Resource and Material Management (C1), Water Management (C2), and Waste Management (C4) are key influencers within the sustainability framework in the company of XYZ, exerting strong control over other criteria. Meanwhile, criteria like Corporate Reputation and Social Responsibility. (C10) are more dependent on improvements elsewhere. These insights can help PT. XYZ prioritize actions by focusing on the most influential criteria to achieve a comprehensive enhancement in sustainability.

The results in Table 5 of the significance Total Influence Matrix provide information of dynamics and interdependencies among the sustainability criteria. The analysis reveals that criteria such as Resource and Material Management, Waste Management, Compliance with Environmental Regulation, Innovation and Environmentally Friendly Product, and Employee Engagement and Education have high total influence values (around 4.1). This indicates that these criteria exert significant influence over others and are key drivers in the system. Enhancing these areas could have a widespread positive impact across other sustainability practices.

In terms of prominence, Waste Management has the highest D+R value at 4.861, closely followed by Resource and Material Management at 4.676 and Compliance with Environmental Regulation at 4.679. These criteria are highly prominent, meaning they are both influential and are influenced by many other criteria. Focusing on these criteria could provide the most substantial overall impact on sustainability outcomes for PT. XYZ.

The cause-or-effect analysis shows that Resource and Material Management and Waste Management have the highest D-R values, at 3.504 and 3.437, respectively. This suggests they act more as causes rather than effects, driving changes in other criteria and serving as foundational elements in the sustainability strategy. On the other hand, Energy Efficiency and Corporate Reputation and Social Responsibility, with lower D-R values of 2.412 and 2.401, respectively, are more influenced by other criteria. This indicates that these areas are more of an effect within the system, meaning that changes in other sustainability practices are likely to impact them significantly. The matrix results suggest that PT. XYZ should prioritize Resource and Material Management and Waste Management, as these are crucial for driving sustainability improvements throughout the organization. By understanding these interdependencies, the company can effectively target its efforts to maximize sustainability outcomes, focusing on key drivers while supporting areas that require further development.

Table 4. Total Influence Matrix T^*

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.306	0.488	0.541	0.457	0.492	0.492	0.483	0.409	0.427	0.495
C2	0.314	0.337	0.538	0.433	0.458	0.415	0.372	0.343	0.333	0.43
C3	0.26	0.324	0.318	0.375	0.32	0.357	0.3	0.288	0.247	0.384
C4	0.327	0.475	0.509	0.342	0.475	0.372	0.408	0.367	0.407	0.467
C5	0.332	0.469	0.536	0.44	0.355	0.424	0.38	0.361	0.339	0.426
C6	0.359	0.422	0.523	0.418	0.455	0.335	0.417	0.338	0.353	0.45
C7	0.376	0.434	0.508	0.483	0.455	0.418	0.325	0.358	0.353	0.46
C8	0.295	0.383	0.457	0.33	0.406	0.403	0.359	0.253	0.334	0.423
C9	0.34	0.342	0.46	0.325	0.398	0.399	0.356	0.302	0.251	0.393
C10	0.231	0.332	0.386	0.302	0.331	0.294	0.288	0.29	0.329	0.27

Table 5. Significance of Influence Matrix T

Criteria	**D**	**D+R**	**D-R**
C1	4.090	4.676	3.504
C2	4.063	4.615	3.511
C3	3.173	3.934	2.412
C4	4.149	4.861	3.437
C5	4.162	4.679	3.646
C6	4.134	4.729	3.539
C7	4.167	4.604	3.729
C8	3.643	4.257	3.028
C9	3.919	4.421	3.416
C10	3.094	3.787	2.401

Table 6. Ranking of the Criteria based on $D + R$

Rank	Criteria	D+R
1	C4 (Waste Management)	4.861
2	C5 (Compliance with Environmental Regulation)	4.679
3	C1 (Resource and Material Management)	4.676
4	C6 (Innovation and Environmentally Friendly Product)	4.729
5	C2 (Water Management)	4.615
6	C7 (Employee Engagement and Education)	4.604
7	C9 (Operational Efficiency)	4.421
8	C8 (Consumer Interaction and Marketing Strategies)	4.257
9	C3 (Energy Efficiency)	3.934
10	C10 (Corporate Reputation and Social Responsibility)	3.787

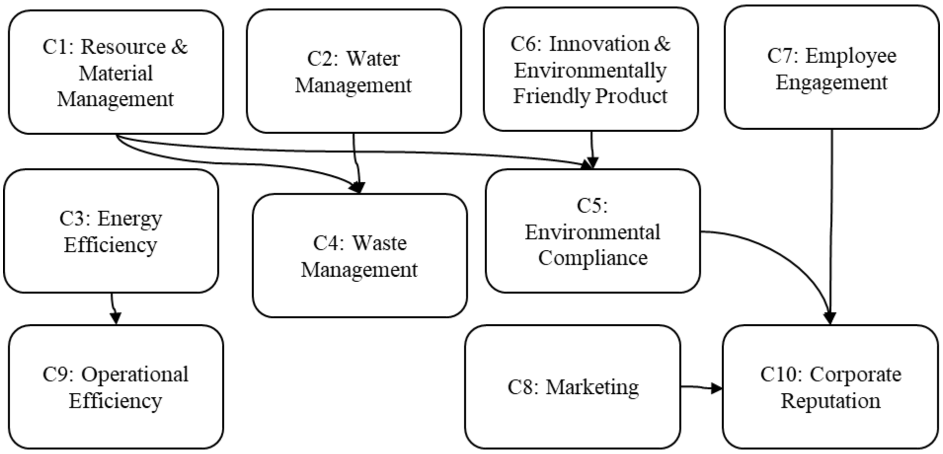

Figure 2. Causal effect relation diagram

Table 6 shows the rank of the sustainability criteria based on their prominence, represented by the D+R values from the Total Influence Matrix. This value reflects the total influence a criterion has within the system, considering both its impact on and the influence it receives from other criteria. By sorting the criteria according to their D+R values, we identified the most critical factors driving sustainability outcomes at PT. XYZ. The ranking allows us to prioritize criteria such as Waste Management, Compliance with Environmental Regulation, and Resource and Material Management, which have the highest D+R values, indicating that they play pivotal roles in influencing and being influenced by other sustainability aspects. This structured approach provides a clear basis for developing targeted interventions to enhance the company's overall sustainability performance. Figure 2 shows the causal realtion of each given criteria based on Table 6.

The ranking of sustainability criteria based on their $D + R$ values provides PT. XYZ with crucial insights into which areas to prioritize for enhancing overall sustainability performance. Waste Management ranks highest with a $D + R$ value of 4.861, indicating its significant interdependence with other criteria such as energy efficiency and compliance with regulations (Tseng et al., 2018). This suggests that focusing on waste management can lead to broad improvements in sustainability. Compliance with Environmental Regulation, with a $D + R$ of 4.679, is also critical as it ensures adherence to laws and boosts corporate reputation and stakeholder trust. Resource and Material Management, with a $D + R$ of 4.676, emphasizes the efficient use of resources, aligning with sustainable practices that reduce costs and environmental impacts. Innovation in Environmentally Friendly Product ($D + R = 4.729$) highlights the need for continuous innovation to meet market demands for sustainability. Water Management and Employee Engagement, with D + R values of 4.615 and 4.604 respectively, underscore the importance of conserving resources and fostering a sustainability-oriented culture among employees. Operational Efficiency ($D + R = 4.421$) points to optimizing processes to reduce energy use and emissions. Consumer Interaction and Marketing Strategies ($D + R = 4.257$) emphasize communicating sustainability efforts effectively to build a loyal customer base. Finally, Energy Efficiency and Corporate Reputation, with lower $D + R$ values of 3.934 and 3.787, are still important but are more influenced by improvements in other areas. This ranking helps PT. XYZ identify key drivers and dependent areas in their sustainability strategy, aligning with theories on integrated sustainability practices (Ghisellini et al., 2020; Kesidou & Demirel, 2022). The findings support the theoretical framework of circular economy and sustainable innovation, where waste management, resource efficiency, and regulatory compliance are not just isolated actions but interconnected elements of a comprehensive sustainability strategy. Moreover, the circular economy theory emphasizes minimizing waste and resource use through systemic integration, which is reflected in PT. XYZ’s focus on waste management as the top criterion (Ghisellini et al., 2020). Additionally, the role of innovation in sustainability, demonstrating that companies adopting innovative waste management practices are more likely to improve environmental performance and maintain competitiveness (Kesidou and Demirel, 2022). Therefore, the findings reinforce these theories by showing that prioritizing waste management and integrating it with energy efficiency and compliance can drive broader sustainability outcomes.

Discussion

The findings of this study that this paper presented were that waste management, compliance with environmental regulations, and resource and material management are the most critical factors that influence sustainability in the fiber cement board industry. This aligns with the work of Makul (2020), who highlighted the importance of reducing waste and improving regulatory compliance to enhance sustainability in cement-based industries. However, while Makul focused primarily on the environmental benefits of material reuse, our study extends the analysis by showing the interconnectedness between waste management and other sustainability criteria, such as energy efficiency and operational performance. This integrated approach addresses a key gap in previous research, which often examined sustainability factors in isolation (César et al., 2022). By using DEMATEL-ANP, this study provides a more holistic understanding of the relationships among various sustainability criteria, offering practical insights for companies aiming to optimize multiple areas of sustainability simultaneously.

Moreover, this research takes Jena et al.'s (2023) findings further, where they only explored the role of industrial by-products like fly ash and GGBS in cutting down raw material usage. Their findings suggested that this approach could also help mitigate production costs in the manufacturing of cement boards. While the previous research emphasized the potential for cost savings, this study delivered parameter using DEMATEL approaches that goes beyond economic factors that highlighting the importance of regulatory compliance and resource management in achieving long-term sustainability. Additionally, the results are consistent with the research of Sadrolodabaee et al. (2022), who advocated for the reduction of hazardous materials in cement board production, yet our study shows that focusing on waste management and regulatory adherence can have a broader, more significant impact on sustainability performance. By comparing the influence of these factors, this study contributes to the theoretical understanding of how interrelated sustainability criteria can drive improved performance in the fiber cement board industry.

CONCLUSION AND RECOMMENDATION

This study provides a comprehensive analysis of the interrelationships within the various sustainability criteria in PT. XYZ, an Indonesian fiber cement board company. By examining the Total Influence Matrix, the study highlights the most influential criteria, such as waste management, compliance with environmental regulations, and resource and material management, which are critical drivers of sustainability. As the findings, we suggest that prioritizing of these areas could lead to significant improvements in the company's sustainability performance such as in the criteria like innovation. In this factor of innovation in environmentally friendly products and water management are becoming key elements that, while not as influential, are essential for supporting the company's long-term sustainability goals. Secondly, we also found that this study also underscores the importance of fostering employee engagement and operational efficiency, which can enhance the implementation of sustainable practices across the organization. Despite the all above mentioned result, this research also has limitations in the study's scope that confined to the sustainability criteria which may not fully capture all potential sustainability factors applicable to other organizations or industries. Therefore, this limited focus could affect the generalizability of the findings and we suggest that there is a need for special caution or focus in interpreting the results while applying them to broader contexts of holistic business process.

Based on this fact finding, this research recommends that PT. XYZ should prioritize improvements in waste management, regulatory compliance, and resource optimization as part of their sustainability strategy. For future research implementation of the same conjecture, we could expand on this study by exploring additional sustainability criteria such as using a more diverse range of data sources to enhance the robustness of the findings. Therefore as consequence, additionally, if we add with more longitudinal studies, it could provide insights into the long-term impacts of sustainability practices and helping them to refine and optimize strategies over time.

ACKNOWLEDGEMENT

We would like to extend our sincere gratitude to PT. XYZ in Central Java, Indonesia, for their cooperation in this research. Due to internal policy, the specific name of the company is withheld, but their support and collaboration were invaluable to the success of this study. We also wish to thank Atyanta from the Electronic and Computer Engineering Faculty of Universitas Kristen Satya Wacana (UKSW) for their significant contributions to data gathering and the development of the source code. Their expertise and assistance have been crucial in advancing this research.

APPENDIX

Figure A1. Left is PT. XYZ Fiber Cement Board manufacture condition and right is the product results.

 p-ISSN: 0854-1442 (Print) e-ISSN: 2503-4464 (Online)

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