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Assessing the Barriers to Nuclear Power Development in the Philippines using the DEMATEL Approach

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ABSTRACT

Nuclear power is increasingly recognized as a viable low-emission energy source, with the potential to enhance energy security and sustainability. In the context of the Philippines, integrating nuclear power into the energy mix presents a complex challenge due to numerous barriers spanning technical, political, economic, and social dimensions. This study aims to evaluate the interdependencies among these barriers using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. A total of eight (8) barriers were identified through expert consultations and literature reviews, and their causal relationships were analyzed to determine key drivers and effects. Results revealed that “Political and Policy Barriers,” “Economic and Financial Barriers,” and “Technological and Technical Barriers” are critical to enabling nuclear power adoption. Political and policy factors emerged as the most prominent, emphasizing the need for a robust regulatory framework and political stability. Economic and financial considerations were identified as core barriers, with cost-effectiveness and innovative financing mechanisms being pivotal to public acceptance and regulatory support. Technological and technical barriers, while less prominent, were key drivers influencing the overall system, highlighting the importance of reliable technologies, supply chains, and waste management. The findings highlight the need for integrated policy recommendations focused on regulatory clarity, financial viability, and technical preparedness to overcome the challenges of nuclear power adoption in the Philippines.

Keywords: Nuclear Energy Adoption, Barrier Analysis, Philippine Energy Policy, DEMATEL, Multi-Criteria Decision Making (MCDM)

Abbreviations: BNPP, Bataan Nuclear Power Plant; CES, Clean Energy Scenarios; DEMATEL, Decision-Making Trial and Evaluation Laboratory; DOE, Department of Energy; FGD, Focus Group Discussion; GHG, Greenhouse Gases; GW, Gigawatts; IRM, Influence Relations Map; KII, Key Informant Interview; NDC, Nationally Determined Contributions; NEP, Nuclear Energy Program; PEP, Philippine Energy Plan; PV, Photoviltaic; RE, Renewable Energy; UNECE, United Nations Economic Commission for Europe

I. INTRODUCTION

Climate change, largely driven by global warming, is a pressing global challenge, with the power sector accounting for over 40% of energy-related emissions worldwide (International Atomic Energy Agency 2022). In the Philippines, the energy sector is predominantly reliant on fossil fuels, with coal (62.5%), natural gas (14.1%), and oil-based sources (1.1%) comprising the majority of the electricity generation mix. Renewable energy (RE), despite its growing role, contributed only 22.3% as of 2023 (Department of Energy 2024a). This dependence on fossil fuels persists alongside an annual 5.5% increase in electricity demand. By 2022, the country's total greenhouse gas (GHG) emissions reached 135.7 million tons of CO_2-equivalent ($MtCO_2e$), reflecting a 4% increase from the previous year, with over 56% of these emissions attributed to power generation.

The Philippine Department of Energy (DOE), through its Philippine Energy Plan (PEP) 2023–2050, has outlined a roadmap to transitioning toward cleaner energy sources. This strategy is anchored on the pillars of energy security, economic growth, and the country's Nationally Determined Contributions (NDC) commitment to a 75% reduction in cumulative GHG emissions based on the PEP 2018–2022 baseline (Department of Energy 2024b). A critical component of this transition involves increasing the share of renewable energy to over 50% of the electricity generation mix by 2050. Key initiatives include harnessing onshore and offshore wind resources, scaling up solar photovoltaic (PV) installations, and raising RE contributions to 65–70.7% under clean energy scenarios (CES). Notably, the plan introduces nuclear energy as a phased approach, targeting 1.2 gigawatts (GW) by 2032, 2.4 GW by 2035, and 4.8 GW by 2050. The 2022 issuance of Executive Order No. 164 solidified the country's commitment to a National Position on a Nuclear Energy Program (NEP), addressing economic, political, social, and environmental objectives.

The development of nuclear power in the Philippines dates back to the 1970s, when the government initiated the construction of the Bataan Nuclear Power Plant (BNPP) in response to the global oil crisis and rising energy demands. Completed in 1984 during the Marcos administration, the 623-MW plant was never commissioned due to mounting concerns (Navarro 2022). Several barriers have hindered the country's nuclear development. Politically, the absence of a consistent national position has created uncertainty and stalled long-term planning, a situation exacerbated by frequent leadership transitions and public opposition (Andal et al. 2022). On the policy and institutional front, gaps persist in regulatory frameworks and investment facilitation, while outdated laws complicate compliance with international nuclear safety standards (Navarro 2022). Technical and environmental concerns also remain unresolved, particularly regarding site safety and waste management at the BNPP site (Navarro 2022). Geological assessments indicate that the plant likely sits on an active fault line within the potentially active Natib Volcano, with volcanic hazards including pyroclastic deposits and radon emissions posing significant risks (Lagmay et al. 2012). Socially, the lack of public awareness, negative perceptions, and the influence of religious and civil society groups have further contributed to resistance to nuclear initiatives (Andal et al. 2022). Despite recurring discussions about reviving the plant, it has remained in preservation mode for decades, incurring annual maintenance costs with no power output.

Globally, nuclear power has attracted increasing interest among developing nations. As the second-largest low-emission energy source after hydropower, it offers advantages such as high availability, operational flexibility for baseload power, and potential contributions to a secure, diverse, and sustainable energy mix (International Atomic Energy Agency 2022; International Energy Agency 2022). While technically non-renewable, nuclear power is significantly more energy-dense compared to other sources (Nøland et al. 2022). Its low-carbon profile is comparable to, or even surpasses, renewable energy in CO_2 reduction capabilities (Liu et al. 2023). According to the United Nations Economic Commission for Europe (UNECE) (2021), the lifecycle GHG emissions of nuclear power range from 5.1 to 6.4 g CO_2-eq/kWh, significantly lower than coal (751–1095 g CO_2-eq/kWh), hydropower (6–147 g CO_2-eq/kWh), solar PV (8–83 g CO_2-eq/kWh), and wind energy (7.8–23 g CO_2-eq/kWh). Currently, more than 400 nuclear reactors in 31 countries generate approximately 10% of global electricity (International Atomic Energy Agency 2023). The adoption of nuclear energy is increasingly explored for its dual benefits of environmental sustainability and energy reliability.

Despite its advantages, the transition to low-carbon technologies in developing countries faces numerous challenges, including inadequate grid infrastructure, limited investment capacity coupled with high country-risk factors, and low electrification rates (International Atomic Energy Agency 2023). Establishing nuclear power presents an additional layer of complexity, with barriers spanning technological, regulatory, social, economic, environmental, and energy security dimensions. These barriers often interact in intricate ways, making their resolution a "wicked problem" requiring a problematique approach to uncover the systemic interdependencies.

In light of these challenges, this study aims to:

1. identify the key drivers among the barriers to nuclear power development;
2. evaluate the interdependencies among these barriers; and
3. provide policy recommendations based on the analysis.

Given the multifaceted challenges of establishing nuclear power in the country, where numerous factors appear equally urgent and critical, this study plays a pivotal role in highlighting the intricate interdependencies among these factors. The study provides a structured framework for identifying which elements of nuclear power development are most critical to the system as a whole by systematically evaluating how these factors influence one another. This prioritization is essential for ensuring that policy and strategic efforts are directed toward addressing the most impactful components, thereby facilitating a more effective and sustainable approach to advancing nuclear energy in the Philippines.

While the Philippines possesses an existing but dormant nuclear facility, this study focuses exclusively on evaluating the barriers to new nuclear power development. It aims to identify and analyze the interrelated factors that continue to impede progress, recognizing that future deployment must overcome legacy challenges while aligning with modern energy, safety, and governance standards.

II. METHODS

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was developed in 1971 by the Battelle Memorial Institute's Geneva Research Center (Gabus and Fontela 1972). This methodology evaluates the cause-and-effect interrelationships among factors or criteria, thereby identifying the key drivers of the problem (Si et al. 2018). There are six main steps to the DEMATEL methodology.

Step 1: Define the problem and identify the criteria

The classical DEMATEL methodology begins with identifying the main problem around which the structure will be designed. Si et al. (2018) identified three main types of DEMATEL research based on purpose:

1. to clarify the interrelationships between key factors or criteria (Hsieh and Yeh 2015);
2. to identify key factors based on causal relationships and the degrees of interrelationship between them (Bacudio et al. 2016); and
3. to determine criteria weights by analyzing the interrelationships and impact levels of criteria (Cebi 2013).

Once the main problem and objectives of the study are established, relevant factors influencing the problem are identified. The factors are then validated through literature reviews and/or expert consultations, such as Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), or the Delphi technique, among others (Si et al. 2018). Step 1 concludes with identifying n factors that influence the problem.

Step 2: Generate the direct influence matrix (Z)

The DEMATEL technique relies on critical decision-making and judgement of experts who have access to a large amount of reliable information, and who can exert influence on actions related to the issues (Fontela and Gabus 1974). For n factors $F = \{F_1, F_2, F_3, \dots F_n\}$, l experts are asked $n(n-1)$ pairwise questions to quantify the direct influence of factor F_i on factor F_j using a linguistic scale (Si et al. 2018), such as the following: 0 – no influence; 1 – low influence; 2 – medium influence; 3 – high influence; and 4 – very high influence. An individual direct influence matrix Z_k is formed from the responses of the kth expert such that each z_{ij}^k represents the judgement of expert k pertaining to how much F_i affects F_j. The principal diagonal elements are set to zero to represent no initial influence of a factor on itself. The group Direct Influence Matrix $Z = [z_{ij}]_{n\times n}$ is obtained by aggregating the responses of l experts by obtaining the arithmetic mean of each matrix element as shown in Eq. 1 (Si et al. 2018).

$$z_{ij} = \frac{1}{l}\sum_{k=1} {z_{ij}}^k, i, j = 1, 2, \dots, n \qquad \text{Eq. 1}$$

Step 3: Normalize to establish the initial influence matrix (D)

The normalization factor ***s*** is obtained by solving for the larger value of the maximum row and column sums of the Direct Influence Matrix Z as shown in Eq. 2 (Si et al. 2018).

$$s = \max\left(\max_{1\le i\le n}\sum\nolimits_{j=1}^{n} z_{ij}, \max_{1\le j\le n}\sum\nolimits_{i=1}^{n} z_{ij}\right) \qquad \text{Eq. 2}$$

Matrix Z is then divided by the value of s to establish the Initial Influence Matrix D (Si et al. 2018). All row and column sums of Matrix D, as the matrix elements, are less than 1 upon normalization, except for the maximum row or column sum that corresponds to the normalization factor *s*, which should be equal to 1.

$$D = \frac{Z}{s} \qquad \text{Eq. 3}$$

Step 4: Solve for the total influence matrix (T)

Through the concept of Power Series Convergence, the Total Influence Matrix $T = [t_{ij}]_{n\times n}$ is computed by adding all the direct and indirect factor influences using the Initial Influence Matrix D, or using the derived inverse matrix formula, where I is an identity matrix as in Eq. 4 (Si et al. 2018). Element t_{ij} represents both the direct and indirect influence of factor F_i on factor F_j.

$$T = D + D^2 + D^3 + \cdots + D^\infty \approx D\big(I - D\big)^{-1} \qquad \text{Eq. 4}$$

Step 5: Determine the cause/effect relationship and derive the inner dependence matrix (T')

The row and column sums of the Total Influence\ Matrix T are computed to obtain vectors R_i and C_j , respectively, where R_i represents the total direct and indirect influences of F_i on all other factors in the system, and C_j represents the total direct and indirect influences F_i received from all other factors (Si et al. 2018). Taking the sum of R_i and C_j solves for the Prominence of a factor $(R+C)_n$, which illustrates the overall strength of influence of a factor, representing its degree of central role within a system. On the other hand, the difference of R_i and C_j solves for the Relation of a factor $(R-C)_n$, which shows the net effect, or directional impact, a factor contributes to the system. If $(R-C)_n$ is positive, then F_n is a causal factor that has a net influence on other factors. If $(R-C)_n$ is negative, then F_n is an effect factor that is being influenced by other factors (Si et al. 2018).

Subsequently, the Threshold Value θ is calculated by averaging all elements in the Total Influence Matrix T. To create the Inner Dependence Matrix T', all values in Matrix T that meet or exceed θ are kept while the remaining values are set to zero (Si et al. 2018).

Transactions NAST PHL Vol. 47 (2025)
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Step 6: Plot the influence relation map (IRM) and complete the diagraph

The Influence Relation Map (IRM) is constructed into four quadrants divided by the x-axis and the mean of the $(R + C)$ values, as shown in Figure 1 (Si et al. 2018). Each quadrant holds factors with four combinations of high and low prominence and relation values. Factors are plotted onto the IRM using prominence as the x-coordinate and relation as the y-coordinate. Then, the digraph is illustrated using the Inner Dependence Matrix T' values and arrows, such that the direction of influence is represented by an arrowhead. If a T' value for the influence of F_i on F_j is beyond the θ, then the arrow must originate from F_i then terminate with an arrowhead at F_j, illustrating a uni-directional relationship. Moreover, if the T' value for the influence of F_j on F_i is also beyond the θ, then a bi-directional relationship exists and is illustrated by arrowheads at both ends of the line.

III. RESULTS AND DISCUSSION

The goal or objective considered in the study is to "adopt nuclear power in the Philippine energy mix." The DEMATEL methodology was employed to determine key barriers to nuclear power development. This was accomplished by analyzing the cause-effect relationships and the extent of interconnectedness among these barriers. Barriers were identified primarily via expert consultation through FGDs and KIIs, as well as a comprehensive literature review. The barriers are summarized in Table 1.

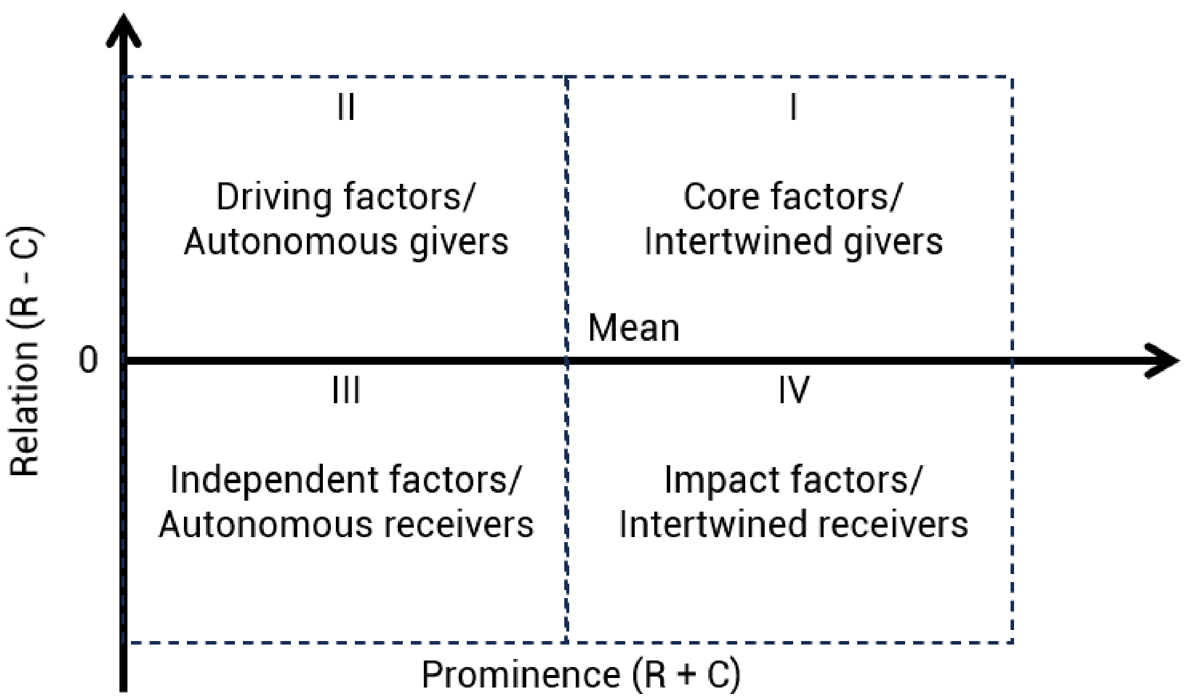

Figure 1. Influence Relation Map structure (adapted from Si et al. (2018))

Table 1. Barriers to nuclear power adoption in the Philippine energy mix

Barriers		Definition	Key References
B1	Social and Socio-ecological Barriers	This dimension focuses on societal attitudes, perceptions, and ecological impacts related to technology or policy. Factors include public education, community engagement, and environmental considerations.	(Andal et al. 2022) (Islam et al. 2021) (Karim et al. 2018) (Kosai and Yamasue 2019) (Poumadère et al. 2011)
B2	Political and Policy Barriers	This dimension encompasses the political landscape and policy framework surrounding the technology or policy. Factors include policy development, political stability, regulatory environments, and international relations.	(Andal et al. 2022) (Poumadère et al. 2011) (Testoni et al. 2021)
B3	Economic and Financial Barriers	This dimension addresses the financial feasibility and economic viability of the technology or policy. Factors include financing mechanisms, cost-effectiveness, revenue streams, and budgetary considerations.	(Andal et al. 2022) (Karim et al. 2018) (Testoni et al. 2021)
B4	Legal and Administrative Barriers	This dimension deals with legal regulations and administrative processes governing the technology or policy. Factors include legal frameworks, regulatory procedures, and administrative efficiency.	(Andal et al. 2022) (Islam et al. 2021) (Karim et al. 2018) (Kosai and Yamasue 2019) (Testoni et al. 2021)
B5	Logistics and Location (Geographic) Barriers	This dimension considers the physical and logistical aspects of implementing the technology or policy. Factors include infrastructure requirements, supply chain, site selection, emergency preparedness, and geographical risks.	(Andal et al. 2022) (Islam et al. 2021) (Karim et al. 2018)
B6	Organizational/ Institutional Barriers	This dimension focuses on organizational structures and institutional capacities related to technology or policy. Factors include agency oversight, research and development capabilities, workforce development, and stakeholder coordination.	(Andal et al. 2022) (Islam et al. 2021) (Karim et al. 2018)

Transactions NAST PHL Vol. 47 (2025)
doi.org/10.57043/transnastphl.2025.5583

Barriers		Definition	Key References
B7	Uncertainty and Risk Barriers	This dimension addresses uncertainties and risks inherent in technology or policy. Factors include safety concerns, environmental risks, technological uncertainties, financial risks, and geopolitical risks.	(Islam et al. 2021) (Karim et al. 2018) (Testoni et al. 2021)
B8	Technological and Technical Barriers	This dimension encompasses the technical aspects of the technology or policy. Factors include technological capabilities, supply chain reliability, waste management, and decommissioning processes.	(Andal et al. 2022) (Islam et al. 2021) (Karim et al. 2018) (Poumadère et al. 2011)

A survey material was prepared to gather pairwise influence scores from 13 experts. The characteristics of the respondents are summarized in Table 2.

Table 2. Respondent Characteristics

Respondent ID	Sex	Age	Years of relevant experience in the energy sector	Years of relevant experience in the nuclear sector	Sector
Respondent 1	Male	50	27	1	Power/Energy
Respondent 2	Male	38	14	0	Power/Energy
Respondent 3	Male	37	12	0	Government
Respondent 4	Male	42	7	3	Government
Respondent 5	Female	36	1	1	Government
Respondent 6	Male	71	30	10	Power/Energy
Respondent 7	Male	72	44	8	Power/Energy
Respondent 8	Female	35	1	0	Government
Respondent 9	Male	73	44	7	Power/Energy
Respondent 10	Male	75	24	16	Power/Energy
Respondent 11	Male	45	0	0	Academe
Respondent 12	Male	39	5	0	Academe
Respondent 13	Male	74	24	20	Medical Physics

Transactions NAST PHL Vol. 47 (2025)
doi.org/10.57043/transnastphl.2025.5583

The individual direct influence matrices were aggregated into the Direct Influence Matrix Z shown in Table 3.

Table 3. Direct Influence Matrix Z

Z	B1	B2	B3	B4	B5	B6	B7	B8	Row sum
B1	0.000	4.308	3.615	4.000	3.231	3.615	3.231	2.769	24.769
B2	4.154	0.000	4.000	4.462	3.308	3.462	3.769	2.769	25.923
B3	3.769	4.000	0.000	3.692	3.846	3.154	3.692	4.231	26.385
B4	4.000	4.538	3.923	0.000	3.308	3.538	3.615	2.923	25.846
B5	4.538	3.846	3.692	3.385	0.000	3.000	3.462	4.077	26.000
B6	3.692	4.077	3.462	4.077	3.154	0.000	3.308	3.231	25.000
B7	4.154	4.000	3.615	3.615	3.538	3.308	0.000	3.385	25.615
B8	3.231	3.385	3.846	3.077	4.000	3.077	3.538	0.000	24.154
Col sum	27.538	**28.154**	26.154	26.308	24.385	23.154	24.615	23.385	**28.154**

From Table 3, the normalization factor s was identified as the column sum of B2 (s=28.154), which is the larger value between the maximum row and column sum of Matrix Z. Dividing the matrix elements of Matrix Z by s resulted in the Initial Influence Matrix D as shown in Table 4.

Table 4. Direct Influence Matrix D

D	B1	B2	B3	B4	B5	B6	B7	B8	
B1	0.000	0.153	0.128	0.142	0.115	0.128	0.115	0.098	0.880
B2	0.148	0.000	0.142	0.158	0.117	0.123	0.134	0.098	0.921
B3	0.134	0.142	0.000	0.131	0.137	0.112	0.131	0.150	0.937
B4	0.142	0.161	0.139	0.000	0.117	0.126	0.128	0.104	0.918
B5	0.161	0.137	0.131	0.120	0.000	0.107	0.123	0.145	0.923
B6	0.131	0.145	0.123	0.145	0.112	0.000	0.117	0.115	0.888
B7	0.148	0.142	0.128	0.128	0.126	0.117	0.000	0.120	0.910
B8	0.115	0.120	0.137	0.109	0.142	0.109	0.126	0.000	0.858
SUM	0.978	**1.000**	0.929	0.934	0.866	0.822	0.874	0.831	

Transactions NAST PHL Vol. 47 (2025)
doi.org/10.57043/transnastphl.2025.5583

Using Eq. 4 with the Direct Influence Matrix D and identity matrix I, the Total Influence Matrix T was established as shown in Table 5. Taking the average of all the elements in Matrix T further yielded the Threshold Value $\theta = 1.190$.

Table 5. Direct Influence Matrix T

T	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	Ri
B1	1.142	1.299	1.205	1.225	1.125	1.094	1.137	1.072	9.299
B2	1.318	1.214	1.260	1.283	1.169	1.130	1.194	1.113	9.681
B3	1.324	1.354	1.152	1.276	1.200	1.135	1.207	1.168	9.816
B4	1.311	1.350	1.255	1.143	1.166	1.130	1.187	1.114	9.654
B5	1.328	1.333	1.252	1.252	1.065	1.117	1.186	1.150	9.683
B6	1.266	1.301	1.208	1.235	1.130	0.987	1.146	1.092	9.366
B7	1.304	1.324	1.236	1.245	1.163	1.114	1.063	1.118	9.567
B8	1.219	1.246	1.186	1.173	1.124	1.056	1.122	0.961	9.087
Cj	10.213	**10.420**	9.754	9.831	9.142	8.764	9.241	8.787	

Table 6. Summary of barrier prominence and relation

Table 6. Summary of barrier prominence and relation

	Row sum Ri	**Col sum Cj**	**Prominence R+C**	**Relation R-C**	**Net influence**
B1	9.299	10.213	19.512	-0.914	Effect
B2	9.681	10.420	20.101	-0.740	Effect
B3	9.816	9.754	19.570	0.061	Cause
B4	9.654	9.831	19.485	-0.177	Effect
B5	9.683	9.142	18.825	0.541	Cause
B6	9.366	8.764	18.129	0.602	Cause
B7	9.567	9.241	18.808	0.326	Cause
B8	9.087	8.787	17.874	0.300	Cause
	Mean (R+C) =		19.038		

Subsequently, retaining the elements of Matrix T that are greater than or equal to the Threshold Value and setting the rest to zero yields the Inner Dependence Matrix as illustrated in Table 7.

Table 7. Inner Dependence Matrix T'

T'	B1	B2	B3	B4	B5	B6	B7	B8
B1	0	1.299	1.205	1.225	0	0	0	0
B2	1.318	1.214	1.260	1.283	0	0	1.194	0
B3	1.324	1.354	0	1.276	1.200	0	1.207	0
B4	1.311	1.350	1.255	0	0	0	0	0
B5	1.328	1.333	1.252	1.252	0	0	0	0
B6	1.266	1.301	1.208	1.235	0	0	0	0
B7	1.304	1.324	1.236	1.245	0	0	0	0
B8	1.219	1.246	0	0	0	0	0	0

Taking the mean value of the prominence scores, the IRM was constructed as illustrated in Figure 2.

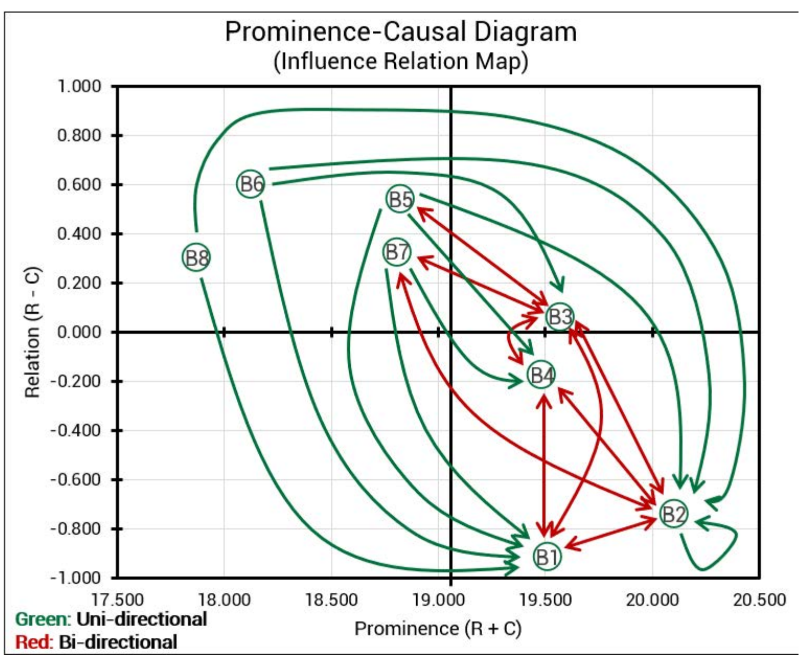

Figure 2. Influence relation map of the barriers to adopting nuclear power in the Philippine energy mix

The barriers were plotted using their respective prominence and relation values presented in Table 6. To illustrate the digraph, the values in the Inner Dependence Matrix T' (Table 7) were used, such that the value of t_{ij}' warrants an arrow originating from B_i and terminating with an arrowhead pointing at B_j. A uni-directional influence relationship occurs when only one value among t_{ij}' and t_{ji}' exists beyond the threshold value. When both matrix values are non-zero, then a bi-directional relationship exists, warranting arrowheads at both ends of the line.

Based on the prominence values in Table 6 and the relative position of the barriers from right to left in Figure 2, the order of barriers from the most to least prominent is as follows:

B2>B3>B1>B4>B5>B7>B6>B8.

"Political and Policy Barriers (B2)" emerges as the most prominent, indicating a high degree of interconnection with other barriers. On the other hand, "Technological and Technical Barriers (B8)" is the least correlated in the system.

Prominence does not indicate causal influence. When considering relation, the causal and effect barriers can be distinguished. From the IRM in Figure 2, it can be observed that the causal barriers are found above the horizontal axis, while the effect barriers are found below. Looking further at the relation values and net influence classification in Table 6, causal barriers in order of magnitude are arranged as follows:

B6>B5>B7>B8>B3.

In this case, "Organizational/Institutional Barriers (B6)" is the primary causal factor. This implies that a well-coordinated structure among government agencies and stakeholders, R&D capabilities to develop the technology, and human capital development are critical to enable nuclear power deployment in the Philippines. Another key causal barrier is "Logistics and Location (Geographic) Barriers (B5)", which indicates that the geographical siting of the technology, infrastructure and logistics requirements, supply chain streamlining, and emergency preparedness are some of the primary considerations that hinder nuclear power deployment in the Philippines.

Effect barriers ranked in order of decreasing value are as follows: B4>B2>B1. Among the effect barriers, "Social and Socio-ecological Barriers (B1)" is the most affected barrier, indicating that any developments or detriments to other barriers will result in positive or negative effects on the aspects of B1.

Looking at the quadrants of the IRM, "Economic and Financial Barriers (B3)" is found in quadrant I, signifying that it is a core barrier and an intertwined giver, a cause barrier with high prominence. The driving barriers and autonomous givers found in quadrant II are barriers B5, B6, B7, and B8. While they are causal barriers, they demonstrate low interconnectedness in the system. Barriers B1, B2, and B4 are found in quadrant IV, indicating that they are impact barriers and intertwined receivers, characterized by high connectivity in the system while receiving shocks from other barriers.

Analyzing further the implications of these relationships, the study investigates three key barriers of interest: "Political and Policy Barriers (B2)", "Economic and Financial Barriers (B3)", and "Technological and Technical Barriers (B8)".

As established in the analysis, "Political and Policy Barriers (B2)" is the most prominent barrier to nuclear power development. Literature confirms that government commitment, stable policies, and independent regulatory agencies are crucial in determining the success and timeline of nuclear projects (Andal et al. 2022). In politically unstable areas or where policies frequently change, nuclear efforts often face significant delays and uncertainty. However, "Political and Policy Barriers (B2)", despite being the most prominent, is an effect barrier and intertwined receiver. In fact, it is affected by any changes in all other barriers, as seen in column 2. Thus, while B2 is central to the system's dynamics, it does not initiate change; rather, it reflects the downstream impact of more fundamental drivers.

Literature points to improvements in organizational capacity (B6), infrastructure logistics (B5), financing mechanisms (B3), and technological readiness (B8) are more likely to indirectly enhance B2 (Dinçer and Uluer 2021). Meanwhile, its strong influence is illustrated in row 2 of Table 7, which shows that any developments (or detriments) to "Political and Regulatory Barriers (B2)" may generate ripple effects of influence on "Social and Socio-ecological Barriers (B1)", "Economic and Financial Barriers (B3)", "Legal and Administrative Barriers (B4)", “Uncertainty and Risk Barriers (B7)”, and even on itself. The self-influence, as illustrated by the self-loop in the IRM (Figure 2), indicates that having an established regulatory framework and stable political landscape can further facilitate the development of the other aspects influenced by B2. Say, for example, it increases public acceptance and involvement; facilitates the economic viability of its investment and development; promotes administrative efficiency; and addresses risks related to policy. Since B2 is highly prominent, the positive ripple effects it exudes to other barrier aspects may further contribute to enhancing the regulatory framework and/or to strengthening the political stability of the country towards nuclear power development. However, the opposite may be true when a poor regulatory framework is laid out.

Looking at “Economic and Financial Barriers (B3)”, it is the only core barrier that demonstrates high prominence and is net-influencing on the system. As shown in row 3 of Table 7, B3 strongly affects “Social and Socio-ecological Barriers (B1)” and “Political and Regulatory Barriers (B2)”, among others. The effect on “Social and Socio-ecological Barriers (B1)” may likely be attributed to the financial viability of the technology option relating to public perception, which may be driven by the cost-friendliness of electricity when nuclear power is utilized. This may lead to improved social acceptance and public involvement in nuclear power development. Most notably, the highest influence value in Table 6 is the effect of B3 on “Political and Regulatory Barriers (B2)”, which likely means that the financial viability of nuclear power development may significantly facilitate the establishment of a sound regulatory environment as well as improve political position towards nuclear power. Literature confirms that financial feasibility and access to capital vis foreign investments can influence public acceptance and the formation of supportive policies (Dinçer and Uluer 2021).

“Technological and Technical Barriers (B8)” is a driving barrier, demonstrating low prominence yet is net-influencing on the system. Table 7 shows that it only influences “Social and Socio-ecological Barriers (B1)” and “Political and Regulatory Barriers (B2)” (row 8), while it is not influenced by any of the other barriers in the system (column 8). Pursuing proven technologies and having clearly defined provisions for supply chain reliability, waste management, and decommissioning processes, B8 strongly influences public acceptance as well as the development of a tailor-fit regulatory framework, aligning with the study of Zio et al. (2025). Moreover, it can be observed that B8 only influences highly prominent barriers (which are B1 and B2), while no other barriers affect it beyond the threshold value. This supports the common idea from experts that nuclear power development is technology-specific.

IV. CONCLUSION

Using the classical DEMATEL technique, the proponent was able to analyze the cause-and-effect relationships among the barriers; confirm the interdependence among barriers (including a self-loop); and visualize the structure of the barriers in an IRM. Based on the analysis, it is evident that adopting nuclear power in the Philippine energy mix requires a large-scale and complex infrastructure change in terms of the eight identified barriers. While they all seem equally urgent, significant, and crucial on the surface, the DEMATEL technique was used to identify three key aspects that must be prioritized to facilitate the adoption of nuclear power in the Philippine energy mix, namely Political and Policy landscape, Economic and Financial viability, and Technological and Technical considerations.

1. **Political and Policy Barriers (B2)**: This barrier emerged as the most prominent and highly interconnected. However, it is classified as an effect barrier, meaning it is more influenced by other barriers than it influences them. While Political and Policy Barriers are critical to nuclear power deployment, they are not the root cause of systemic challenges. Therefore, establishing a clear and stable regulatory framework remains essential, but such progress is more likely to occur as a result of improvements in upstream barriers such as institutional capacity, financing mechanisms, and technical readiness. Addressing these causal barriers will help support the political stability, administrative efficiency, and international cooperation necessary to support long-term nuclear energy development in the Philippines.

2. **Economic and Financial Barriers (B3)**: Financial feasibility plays a pivotal role in enabling nuclear power adoption. Beyond ensuring cost-effectiveness, a strong economic case for nuclear power can

enhance public acceptance and drive the creation of favorable policies. The financial feasibility of nuclear power must be demonstrated through cost-effective solutions, innovative financing mechanisms, and robust economic models. Ensuring affordability can enhance public acceptance while providing the foundation for political and regulatory support.

3. **Technological and Technical Barriers (B8)**: While less prominent, this barrier is a driving factor that influences the development of regulatory frameworks and public perceptions. Investing in proven technologies, reliable supply chains, and effective waste management is crucial to addressing this barrier. Advancing proven technologies and ensuring the reliability of supply chains, waste management processes, and decommissioning plans are vital. These efforts will not only address technical challenges but also improve stakeholder confidence and public trust in nuclear power.

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Contribution of authors:

AB Culaba conceptualized the study, defined its overall direction and objectives, and guided its methodological framework; contributed to data analysis and interpretation; and played a key role in developing the study's conclusions. DJR Diamante administered the DEMATEL survey; conducted the data gathering, processing, and analysis; prepared the data tables and illustrations; contributed to the development and implementation of the DEMATEL model; and led the manuscript writing. MAB Promentilla guided the study conceptualization and methodological framework; structured the DEMATEL model; designed the survey; contributed to data analysis and interpretation; and played a significant role in formulating the study's conclusions.

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None.

References Cited

Andal A, PraveenKumar S, Andal E, Qasim M, and Velkin V. 2022. Perspectives on the Barriers to Nuclear Power Generation in the Philippines: Prospects for Directions in Energy Research in the Global South. Inventions, 7(3), 53. https://doi.org/10.3390/inventions7030053

Bacudio L, Benjamin M, Eusebio R, Holaysan S., Promentilla M, Yu K, and Aviso K. 2016. Analyzing barriers to implementing industrial symbiosis networks using dematel. Sustainable Production and Consumption, 7, 57-65. https://doi.org/10.1016/j.spc.2016.03.001

Cebi S. 2013. Determining importance degrees of website design parameters based on interactions and types of websites. Decision Support Systems, 54(2), 1030-1043. https://doi.org/10.1016/j.dss.2012.10.036

Department of Energy. 2024a. 2023 Power Statistics. https://doe.gov.ph/sites/default/files/pdf/energy_statistics/01_Summar_2023.pdf; accessed December 15, 2024.

Department of Energy. 2024b. Philippine Energy Plan 2023-2050. https://doe.gov.ph/sites/default/files/pdf/pep/PEP%202023-2050%20%28Volume%20I%29.pdf; accessed December 15, 2024.

Dincer H and Uluer G. 2021. Significant issues of nuclear energy investment decisions for energy importer countries. Economics Literature, 3(1), 1-12. 10.22440/elit.3.1.1. https://doi.org/10.22440/elit.3.1.1

Fontela E, and Gabus A. 1974. DEMATEL: Progress Achieved. Futures, 361-363.

Gabus A, and Fontela E. 1972. World problems, an invitation to further thought within the framework of DEMATEL. Battelle Geneva Research Center, 1(8), 12-14.

Hsieh P, and Yeh T. 2015. Developing a cause and effect model of factors influencing fast food restaurants' service quality using DEMATEL. International Journal of Services and Operations Management, 20(1), 21-42. https://doi.org/10.1504/IJSOM.2015.065970

International Atomic Energy Agency. 2022. Climate Change and Nuclear Power 2022. https://www.iaea.org/sites/default/files/iaea-ccnp2022-body-web.pdf; accessed December 15, 2024.

International Atomic Energy Agency. 2023. Annual Report. https://www.iaea.org/publications/reports/annual-report/2023; accessed December 15, 2024.

International Energy Agency. 2022. Nuclear Power and Secure Energy Transitions. https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions; accessed December 15, 2024.

Islam M, Faisal S, and Khan S. 2021. Development and strengthening of the nuclear and radiation safety infrastructure for nuclear power program of Bangladesh. Nuclear Engineering and Technology, 53(5), 1705-1716. https://doi.org/10.1016/j.net.2020.11.020

Karim R, Karim M, Muhammad-Sukki F, Abu-Bakar S, Bani N, Munir A, Kamir A, Ardila-Rey J, and Mas'ud A. 2018. Nuclear energy development in Bangladesh: A study of opportunities and challenges. Energies, 11(7), 1672. https://doi.org/10.3390/en11071672

Kosai S, and Yamasue E. 2019. Recommendation to ASEAN nuclear development based on lessons learnt from the Fukushima nuclear accident. Energy Policy, 129, 628-635. https://doi.org/10.1016/j.enpol.2019.02.058

Lagmay AMF, Rodolfo R, Cabria H, Soria J, Zamora P, Abon C, Lit C, Lapus MRT, Paguican E, Bato MG, Tiu G, Obille E, Pellejera NE, Francisco PC, Eco RN, Aviso J. 2012. Geological hazards of SW Nativ Volcano, site of the Bataan Nuclear Power Plant, the Philippines. Geological Society, London, Special publications, 361, 151-169. doi:10.1144/SP361.13.

Liu L, Guo H, Dai L, Liu M, Xiao Y, Cong T, and Gu H. 2023. The role of nuclear energy in the carbon neutrality goal. Progress in Nuclear Energy, 162, 104772. doi:10.1016/j.pnucene.2023.104772

Navarro A. 2022. The Implications of Developing a Philippine Nuclear Energy Program. Discussion Paper Series No. 2022-61, Philippine Institute for Developmental Studies.

Nøland J, Auxepaules J, Rousset A, Perney B, and Falletti G. 2022. Spatial energy density of large-scale electricity generation from power sources worldwide. Scientific Reports, 12, 21280. https://doi.org/10.1038/s41598-022-25341-9

Poumadère M, Bertoldo R, Samadi J. 2011. Public perceptions and governance of controversial technologies to tackle climate change: Nuclear power, carbon capture and storage, wind, and geoengineering. Wiley Interdisciplinary Reviews: Climate Change 2(5): 712–727. https://doi.org/10.1002/wcc.134

Si S, You X, Liu H, Zhang P. 2018. DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. Mathematical Problems in Engineering 2018: 3696457. https://doi.org/10.1155/2018/3696457

Testoni R, Bersano A, Segantin S. 2021. Review of nuclear microreactors: Status, potentialities and challenges. Progress in Nuclear Energy 138: 103822. https://doi.org/10.1016/j.pnucene.2021.103822

United Nations Economic Commission for Europe. 2021. Life cycle assessment of electricity generation options. https://unece.org/sites/default/files/2021-11/LCA_final.pdf; accessed December 15, 2024.

Zio E, Shirvan K, Duffey R, D'Auria F. 2025. Nuclear power technology: An analysis and informed opinions. Frontiers in Nuclear Engineering 4: 1501247. https://doi.org/10.3389/fnuen.2025.1501247