Modelling the Critical Success Factors of Net-zero Energy Buildings in India

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Abstract. Amidst the widespread consciousness and several awareness programs to combat the adverse impact of greenhouse gas emissions on the climate, Net-zero energy buildings (NZEB) have emerged as one of the potential solutions. Various factors, including the need for heavy initial capital investment, weather conditions, government regulations, policies, training and development, technology, and so forth, were figured out by carrying out a literature review and interviewing the area experts. Further, investigating the inter-contextual relationships helps to have key success factors of NZEBs in India that are multidimensional in nature. To achieve this goal, the Interpretive Structural Modelling (ISM) approach was employed to compute the mutual influence of the ten key success factors in the Indian context. The results report that favorable weather conditions, government policies, and regulations are the most crucial factors for the NZEB sectoral development in Indian contexts.

1 Introduction

Knowing the key success factors of NZEB in India is essential, given India's emphasis on meeting sustainable goals and manifesting the same in various means, specifically, the food served to the visiting delegates in the recent G20 Summit, 2023, held in New Delhi. United Nations' Sustainable Development Goals (UNSDGs) aim to achieve certain goals by 2050, out of which providing renewable sources of energy as a widespread solution (Goal 7) ensures lesser greenhouse gas emissions (GHG). Another goal aims toward climate action for a sustainable environment (Goal 13). NZEBs are likely to be a potential contributor toward achieving these two goals as they not only generate solar energy but store the surplus for further usage during outages, given continuous technology innovation [1], [2]. For economic and environmental improvement, sources of green energy offer promising prospects due to their being unlimited and natural, unlike the constraints packaged with traditional energy sources [3]. While NZEBS need to have a sensible energy consumption along with the generation, the focus is to generate a sufficient amount of energy for annual consumption [4]. Providing energy solutions that too from green, clean, and unlimited sources is concurrently conducive to environmental resilience toward achieving the sustainable development goals mentioned above [5]. Diverse factors, such as building construction materials and employed technology, adequate training to the workers, consumer acceptance in response to changing needs of the ecosystem, the impact of certifications and

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ratings on all the stakeholders, including consumers, Government, policymakers, concerned industries, impact the adoption and potential success of NZEBs in India [1]. An efficient NZEB can become an effective system for collecting, converting, storing, and utilizing solar energy efficiently. Therefore, the present study aims to investigate the key success factors of the viability of NZEBs in India by employing ISM based approach, which helps in analyzing multi-dimensional factors that are inter-related [6]. ISM highlights all the critical factors.

The rest of the paper is arranged as follows- The literature review is Section 2, which contains detailed information about the identified success factors. The further section contains the Methodology and its steps, which are followed by the Results and analyses. Implications and conclusion are discussed in Sections 5 and 6, respectively followed by future research and limitation section.

2 Literature Background

The rising demand for green and renewable energy solutions for a sustainable climate and, thereby, sustainable human existence on earth has been an intriguing topic of research recently. The potential of NZEBs in solar energy storage and consistent making it available for consumption even during outages depend on NZEB technology [7], [8]. Cost is also an important consideration, as every decision starts with financial viability [1]. Given the dynamic technological environment, NZEBs should be able to accommodate any changes needed based on the needs of the hour [9]. As the NZEBs demand heavy initial capital expenditure, shorter payback periods seem rewarding and are likely to encourage consumer acceptance [10]. Long-term monitoring of NZEBs performance also revealed its potential for a positive future as it produces more energy than its requirements [9]. Overall, from reviewing the literature, it is understood that the extant research on NZEBs focuses on its appropriate technology selection, geographical assessment of its viability for Eastern Europe [11] and strategies for minimized consumption. Analyzing critical success factors of NZEBs in India, given the urgency of the implementation in its rural and urban areas, becomes important. Hence, in the present study, an ISM-based approach has been applied to get critical success factors for NZEBs in India.

2.1 Success Factors for Net-Zero Energy Buildings

Achieving net-zero energy buildings is a challenging but crucial goal for reducing carbon emissions and combating climate change. Several success factors are essential for the successful implementation of net-zero energy buildings in India. The factors are identified from the review of literature and interviewing domain experts.

2.1.1 Energy Efficient Technologies (EET)

Energy-efficient technology plays a pivotal role in the development and success of Net-Zero Energy Buildings (NZEBs) in India. Use of energy-efficient building materials and technologies, including high-performance windows, LED lighting, and energy-efficient HVAC systems play a crucial role for the development and implementation.

2.1.2 Integrating Renewable Energy (INT)

Integrating renewable energy sources into building design and operation not only reduces carbon emissions but also helps achieve energy self-sufficiency. It involves installation of on-site renewable energy sources such as solar photovoltaic panels and wind turbines to generate clean energy.

2.1.3 Energy Storage & Management (ESM)

Energy storage and management is another factor that plays a pivotal rôle in the NZEB development. Implementation of energy storage solutions like batteries to store excess energy for use during periods of low generation can offer numerous advantages in Indian contexts for regions having longer periods of daylight. Further, efficient energy management smart meters and energy management software for effective control and optimization are significant for sectoral development.

2.1.4 Government Policies (GPOL)

Governmental policies can provide the necessary framework, incentives, and guidance to encourage the construction and adoption of NZEBs. Implementing policies like net metering and feed-in tariffs can facilitate the integration of on-site renewable energy generation into NZEBs, making it financially viable for building owners to invest in renewable technologies.

2.1.5 Heavy Financial Investments (FIN)

There should be adequate focus on funding mechanisms to make net-zero energy buildings financially viable, including options for low-interest loans and grants. Further, there should be an apt highlight of long-term cost savings associated with reduced energy bills and maintenance costs.

2.1.6 Public Awareness (AWAR)

The people of India should be made aware of the benefits of net-zero energy buildings and encourage them to adopt NZEB as a significant amount of constructions are privately owned and managed. Engagement with communities and stakeholders to build support for sustainable building practices should be promoted.

2.1.7 Public-Private Partnerships (PART)

Collaborations and partnerships among various stakeholders are necessary for the NZEB infrastructural development in India. There is a need for active collaboration between government agencies, private sector stakeholders, NGOs, and research institutions to share knowledge and resources. Further, partnerships with utilities for grid integration and demand response programs should be encouraged.

2.1.8 Favorable Weather Conditions (WTHR)

India's weather conditions and climate are favorable for NZEB deployment. A large number of areas that expériences high intensity and long-duration of sunlight make it highly conducive.

2.1.9 Regulatory Support (REG)

Governmental Regulations that favor the adoption of NZEBs through tax or financial incentives are one of the success factors to promote NZEBs.

2.1.10 Training & Development (TRN)

Proper training and development programs provide technical skills to the key stakeholders involved in the construction and implementation of NZEBs. It also creates adequate awareness of the potential benefits of the system.

3 Methodology

The Interpretive Structural Modeling (ISM) technique is a systematic method used to analyze complex relationships among various elements or factors in a problem or system. It was proposed by Warfield [12]. It helps in understanding the hierarchical structure and influence among these elements. It facilitates the analysis of the elements of a complex system [13]. Due to its varied applicability, it has found numerous applications in the extant literature including studies by [6], [14]–[16]. The steps involved in ISM are given below:

Step 1: Judgments of domain experts are used and a structural self-interaction matrix (SSIM) was developed to represent the pairwise relation of elements.

Step 2: Reachability Matrix is constructed using ‘1’ for influential relation, and ‘0’ otherwise.

Step 3: In this step, level partitioning is carried out using the following rules. For every factor, reachability and antecedent sets are generated based on the data from the reachability matrix. The two sets are subsequently used to construct an intersection set, which denotes the elements shared between both sets. If, in a particular instance, the intersection set matches the reachability set for a given factor, that factor assumes the role of a top-level variable within the hierarchy of relationships. Subsequently, the factor is isolated from the others, and the process of level partitioning is reiterated. This iterative procedure persists until all factors have achieved their respective levels within the hierarchy.

A questionnaire was administered to fifteen experts, both from the industry and from the academia who possess research and practice experience of at least ten years in the domain of energy policy. The responses were captured using step 1 to create the SSIM. The reachability matrix is further developed and given in Table 1.

Table 1. Reachability Matrix

	EET (1)	INT (2)	ESM (3)	GPOL (4)	FIN (5)	AWA (6)	PART (7)	WTHR (8)	REG (9)	TRN (10)
EET (1)	1	1	1	0	1	0	0	0	0	1
INT (2)	1	1	1	0	1	0	1	0	0	1
ESM (3)	1	0	1	0	1	0	0	0	0	1
GPOL (4)	1	1	1	1	1	1	1	0	1	1

FIN (5)	1	1	1	0	1	1	1	0	1	1
AWA (6)	0	0	0	0	1	1	0	0	1	1
PART (7)	0	1	1	1	1	0	1	0	1	1
WTHR (8)	1	1	1	1	0	0	0	1	1	0
REG (9)	0	1	1	1	1	1	1	0	1	0
TRN (10)	0	0	1	0	1	1	0	0	0	1

The level partitioning was carried out based on the reachability matrix as explained in Step 3. Table 2, 3, and 4 represent the four levels created which were later used to create the interpretive model shown in Figure 1.

Table 2. Level Partitioning- Stage I

	Reachability Set	**Antecedent Set**	**Intersection Set**	**Level**
EET (1)	1,2,3,5,10	1,2,3,4,5,8	1,2,3,5	
INT (2)	1,2,3,5,7,10	1,2,4,5,7,8,9	1,2,5,7	
ESM (3)	1,3,5,10	1,2,3,4,5,7,8,9,10	1,3,5,10	I
GPOL (4)	1,2,3,4,5,6,7,9,10	4,7,8,9	4,7,9	
FIN (5)	1,2,3,5,6,7,9,10	1,2,3,4,5,6,7,9,10	1,2,3,5,6,7,9,10	I
AWA (6)	5,6,9,10	4,5,6,9,10	5,6,9,10	I
PART (7)	2,3,4,5,7,9,10	2,4,5,7,9	2,4,5,7,9	
WTHR (8)	1,2,3,4,8,9	8	8	
REG (9)	2,3,4,5,6,7,9	4,5,6,7,8,9	4,5,6,7,9	
TRN (10)	3,5,6,10	1,2,3,4,5,6,7,8,10	3,5,6,10	I

Table 3. Level Partitioning- Stage II

	Reachability Set	**Antecedent Set**	**Intersection Set**	**Level**
EET (1)	1,2	1,2,4,8	1,2	II
INT (2)	1,2,7	1,2,7,8,9	1,2,7	II
GPOL (4)	1,2,4,7,9	4,7,8,9	4,7,9	
PART (7)	2,4,7,9	2,4,7,9	2,4,7,9	II
WTHR (8)	1,2,4,8,9	8	8	
REG (9)	2,4,7,9	4,7,8,9	4,7,9	

Table 4. Level Partitioning- Stages III & IV

	Reachability Set	**Antecedent Set**	**Intersection Set**	**Level**
GPOL (4)	4,9	4,8,9	4,9	III
WTHR (8)	4,8,9	8	8	IV
REG (9)	4,9	4,8,9	4,9	III

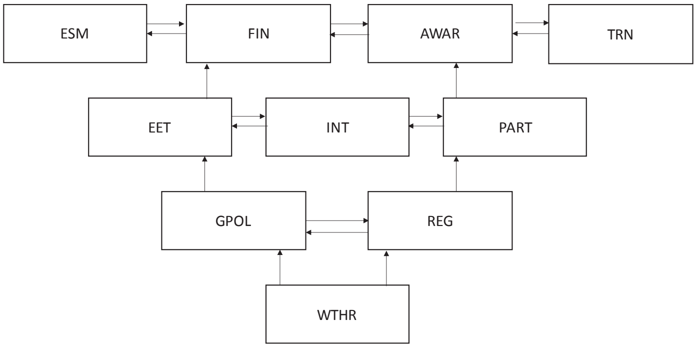

Fig.1. Interpretive Structural Model

The authors conducted MICMAC analysis to examine the driving forces and dependencies among the elements. This analysis is based on the multiplication property, which suggests that if factor C affects factor D, and factor D drives factor F, then factor C may also affect factor F. The factors are categorized into four quadrants. The four quadrants of factors influencing a system are denoted as autonomous factors with low driving power and low dependency; dependent enablers with low driving power and high dependency; linkage factors, which represent high driving power and high dependency; and independent factors with low dependency and high driving power. The results of the MICMAC analysis are shown in Figure 2.

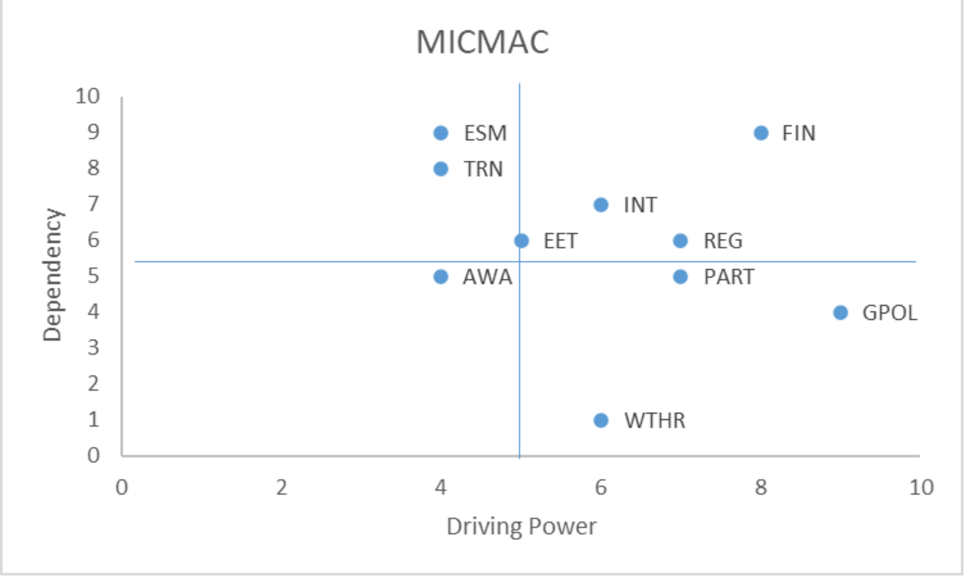

Fig. 2. MICMAC Output

The analysis of the interpretive structural model reveals that the favorable weather conditions in India are one of the most influential success factors for the development of the NZEB. It further influences the governmental policies and regulatory support factors that are the second lowest in the hierarchy, representing their relevance among others. The integration of renewable energy, efficient technologies, and partnerships find the third place in terms of their influential effects on other dimensions. The MICMAC analysis also reveals certain significant observations. Weather conditions (WTHR), policies (GPOL), and partnerships (PART) are the most influential factors that pose a significant effect on all other factors in the system. They are, thus the independent factors. Further, the linkage factors are INT, FIN, EET, and REG, as given in the MICMAC analysis

4 Concluding Remarks

This research paper focuses on the critical success factors for Net-Zero Energy Buildings (NZEBs) in India, using an Interpretive Structural Modeling (ISM) approach. The study aimed to identify and understand the hierarchical relationships among these factors to facilitate the development and adoption of NZEBs in India. Through a comprehensive analysis, ten success factors were identified, such as energy-efficient technology, renewable energy integration, government policies, training and development, favorable weather conditions, energy storage and management, awareness, partnerships, regulatory support, and financial investments.

The study underscores the significance of favorable weather conditions and governmental policies and regulations in promoting NZEBs. They provide the necessary framework, incentives, and guidance for creating environmentally responsible and energy-efficient buildings. If the deployment of NZEBs is expanded, it may lead to significant reduction in energy consumption and carbon emissions. The present research opens avenues for several future works in the domain. Future studies may develop experimental designs to test the effectiveness of the system. Further, real case studies in Indian contexts may be used to identify potential challenges faced in the deployment.

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