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Identification and prioritization of factors affecting the transition to renewables in developing economies

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Abstract

There is a rapid increase in energy demand across several developing economies all over the world. This can be attributed to population growth, industrialization, urbanization, globalization, and occasional unforeseen events such as the COVID-19 pandemic, in which operations, functions, and activities are mostly executed virtually. With a major transition to renewables by developed economies to meet their energy obligations and mitigate greenhouse gas (GHG) emissions, developing economies are left with no choice but to join the transition in a bid to uphold the United Nations' Sustainable Development Goal 13 (SDG13-Climate Action). This study has identified and prioritized barriers to renewable energy transition in developing economies. The Hybrid Structural Interaction Matrix (HSIM) was utilized to employ the weight based prioritization model with hierarchical structural layout of the interacting renewable energy transition barriers. This study will be of great benefit to policymakers and academics in making informed decisions on measures to fast-track the transition to renewables in developing economies by considering weighted prioritized driving forces for optimum resource allocation.

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Keywords: Renewables; Energy transition; Energy sustainability; HSIM; Developing economies; HTSD

1. Introduction

In recent times, the developed economies are frantically embarking on a significant shift towards renewable energy sources for power generation. This is as a result of its reduced negative impact on the environment, capacity to regenerate, ability to provide jobs, price stability, reliability, resilience, and energy security. Developing nations continue to rely on fossil fuels for their lighting, air conditioning, and heating needs, amongst others. Consequently, it is necessary to determine the factors impeding the transition to renewables in developing countries and then rank them in order of importance. The process of transitioning to an energy mix made up of renewable energy sources will be sped up as a result, and developing economies will be able to take advantage of all of the benefits outlined above [26].

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The use of energy in developing countries is increasing at an unparalleled rate. There are about 620 million people who do not have access to electricity in Africa and several Asian nations; this number is expected to continue to rise over the next 25 years [14,26]. It is well acknowledged that these developing countries have significant challenges in terms of achieving economic growth [24,25]. As the population, economic growth, and a host of other factors continue to increase in these developing nations, the existing energy gap will only worsen. Sources of energy such as natural gas, biomass, coal, uranium, sunlight, wind, and tidal energy, among others, are utilized for various applications ranging from electricity generation, transportation, agriculture, etc. Electricity demand constitutes about 18% of the world's total energy consumption in 2013, making it an extremely important factor in both the social and economic well-being of countries [24].

According to research carried out by the EIA of the United States, the demand for energy in non-OECD countries would be 89% higher than that of OECD nations in the year 2040 [19]. Because of these alarming energy demand projections, it is of utmost importance for developing economies to transition towards renewable energy sources. This will enable developing countries to reduce their carbon footprint, and ensure that people have access to energy, improved health, and increased employment opportunities, among other benefits. Despite sensitizations and enlightenments, the contribution of renewable energy sources to the energy mix is just 23% in Nigeria [11], 10% in South Africa [3], 12% in Egypt [16], 4.5% in Malaysia [27], 36% in Pakistan [20], and 7% in Iran [15].

This study identified and prioritized the factors that affect the transition to renewables in developing countries. This will ensure that resources are distributed in a hierarchical or priority manner. This study will be of substantial benefit to policymakers, academics, and students to establish an effective management strategy based on the most essential factors impacting the transition to renewables.

2. Methodology for the research

The Hybrid Structural Interaction Matrix (HSIM) approach was used for the prioritization of factors impeding the transition to renewable energy in developing economies. Even though the analytical hierarchy process (AHP) was utilized for prioritization in sectors including maintenance, health, safety, and energy. With the incorporation of a weighting model into the prioritizing model, the HSIM has a major advantage over AHP's inherent shortcomings due to its ability to formulate dynamic models in resource allocation and the adoption of a root-cause approach. Resource decision-making in such context benefits water resource planning [13] and data mining approaches [17]. The multi-objective optimization technique is another analogous strategy for resource allocation [30]. [22] and [12] effectively used the HSIM technique to prioritize and plan for safety engineering maintenance resources.

To prioritize barriers responsible for the slow transition to renewables in developing economies, the concept of subordination inherent in the HSIM approach was used to effect the ranking order. Hence, to allocate resources to the identified barriers, the fundamental model of resource allocation was used with the normalized weight of variables.

2.1. Identified barriers to renewable energy transition

The barriers to renewable energy transition in developing countries as identified from various literature are briefly discussed in this section. The following are the barriers which are listed from one to eighteen:

1. ***Competing against fossil fuels:*** Fossil fuels are still a cheaper alternative to renewables, making them very competitive in developing countries.
2. ***Subsidies and government grants***: More subsidies for fossilized energy sources put renewable energy sources at a significant disadvantage, impeding the transition to renewables in developing economies.
3. ***Non or few renewables financing institutions***: There is a restricted number of organizations and financial methods available to provide finance for renewable energy projects [2,21].
4. ***High capital cost***: Investors are forced to take a defensive stance owing to the comparatively high initial capital costs associated with renewable technologies [2].
5. ***Intangible expenses***: At present, the total cost of fuel in practically all countries includes the cost of discovery, production, distribution, and usage, but it does not include the cost of the damage that it does to the environment and society [4].

6. ***Inadequate infrastructure and facilities***: A hurdle to the penetration of renewable energy sources is the limited availability of advanced technology that is required for renewable energy [7].
7. ***Poor attitude towards operation and maintenance***: Because the technology behind renewable energy sources is still in its initial stages and has not been developed to its full potential, there is a paucity of knowledge surrounding its management and maintenance [28].
8. ***Inadequate R&D capabilities***: Renewables in developing countries are still in their initial stages, making governments and investors cautious about investing [6].
9. ***Technology complexity***: Renewable energy technologies lack standards, protocols, and recommendations for durability, dependability, performance, and other issues. This prevents the large-scale commercialization of renewable energy [18].
10. ***Barriers to public awareness and information***: Understanding of renewable energy technologies, the environmental and economic benefits, and the financial viability constitute the major barriers to public awareness [18].
11. ***'Not in my backyard" (NIMB) syndrome***: Various people and organizations are in favor of renewable energy, but not in their backyards [10].
12. ***Loss of other/impact on other***: Renewable energy sources need far more land than fossil fuels to provide the same quantity of energy [5].
13. ***Experienced professionals are scarce***: Reducing dependence on fossil fuels requires a skilled work-force which is inadequate in developing countries [2].
14. ***Ineffective government policies***: Energy policy instability, lack of belief in renewable energy technology, and under-equipped government institutions [31].
15. ***Inadequate financial incentives***: Feed-in tariffs are government-sponsored subsidies designed to make renewables competitive but are absent in nearly all developing nations [29].
16. ***Administrative and bureaucratic complexities***: Lobbying also results in higher expenses which in turn delay renewable energy projects [1].
17. ***Government commitments are impractical***: There is a disconnect between the policy objectives governments choose to pursue and the actual outcomes accomplished via implementation [9].
18. ***Standards and certifications are lacking***: Uncertainty arises as a result of the unavailability of standards, which forces energy suppliers to contend with additional impediments [8].

2.2. prioritization of factors affecting renewable energy transition

2.2.1. Concept of the HSIM

As mentioned in this study, the concept of HSIM highlights the interaction between barriers responsible for the renewable energy transition in developing countries. Unlike utilizing the structural interaction matrix (SIM) concept alone, a weighting factor for arithmetical investigation of the factors in the hierarchy is contained in the HSIM, and it illustrates the hierarchical organization using the subordination principle and the hierarchical tree structure diagram (HTSD). According to the HSIM, a given element pair may interact in several ways. In contrast, an interaction based on a specific contextual relationship is relevant.

The HSIM operational model is inextricably linked to the concepts of orientation and direction. As a result, if $e_{ij} = 1$, $e_{ji} = 0$, implying transitivity in a single direction hence, if element *j maps into i*, element *i cannot map into j*.

This is mathematically stated as Eq. (1):

$$e_{ij} = \begin{cases} 1 & if\ i\ depends\ on\ activity\ j, \\ 0 & if\ i\ doesn't\ depend\ on\ activity\ j, \end{cases} \tag{1}$$

where e_{ij} represents elements that are in row *i* and column *j*. The procedure for determining the HSIM is represented in Fig. 1 in a step-by-step way. The essential procedure to develop the HTSD is illustrated in Fig. 2 which represents the priority order of a set of barriers, factors, or elements in a hierarchical order.

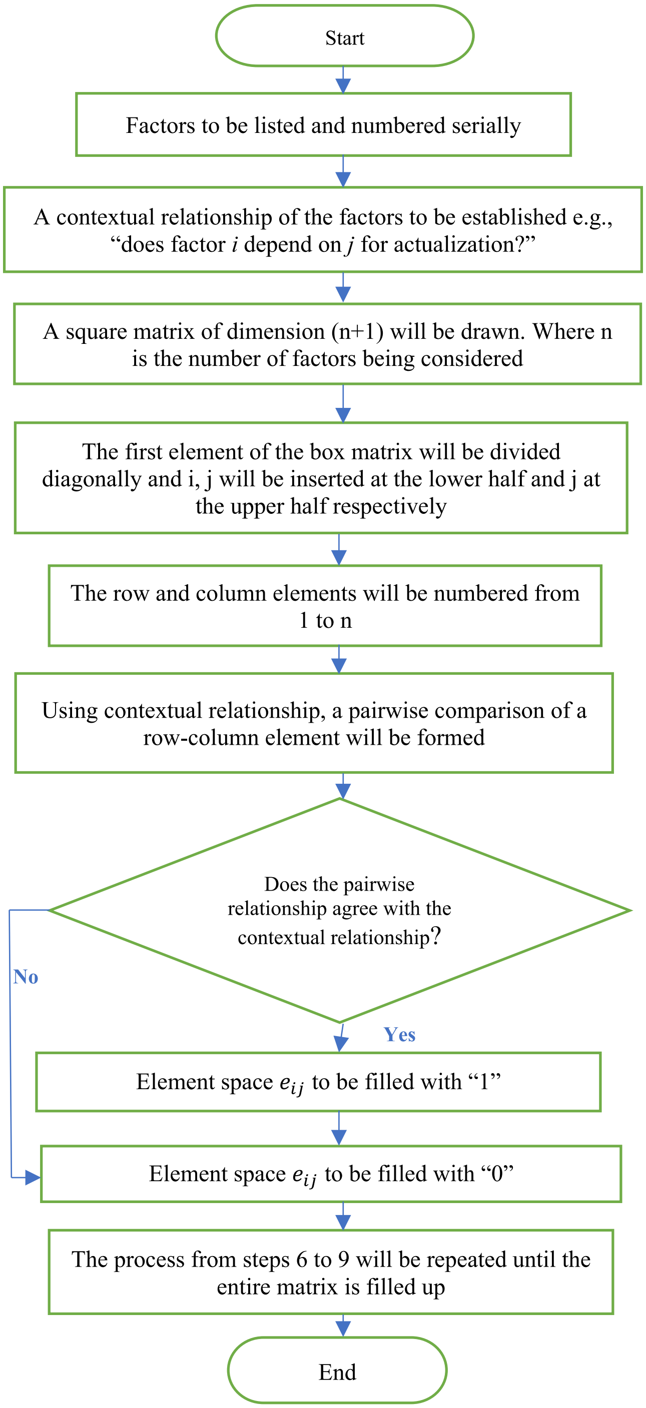

Fig. 1. HSIM development process [23].

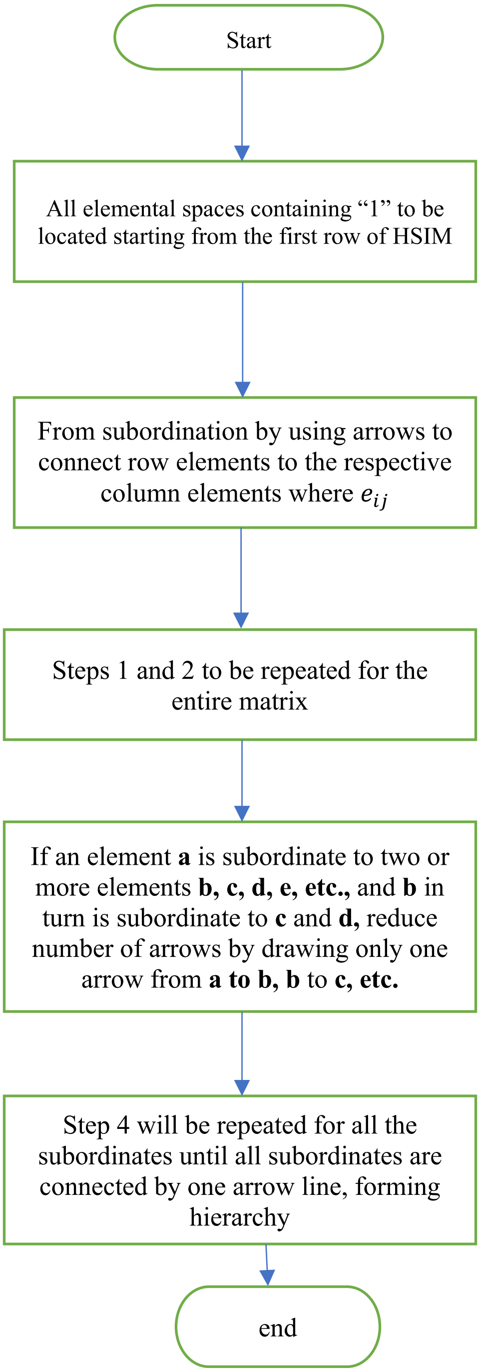

Fig. 2. The HTSD framework's flow diagram [23].

2.2.2. *Weights of factors impeding renewable energy transition*

The weight calculation model: the following methodology was used to calculate the priority criterion's weight/intensity of significance in Eq. (2):

$$I_{IRFi} = \left\{ \frac{N_{SFi}}{T_{NF}} x M_{SR} \right\} + \left\{ \frac{b}{T_{NF}} \left(M_{SR} - C \right) \right\} \tag{2}$$

$$C = \frac{M_{PSF}}{T_{NF}} x M_{SR} \tag{3}$$

$$b = N_{SFi} + 1 \tag{4}$$

N_{SFi} no of subordinate factors to factor *I*, M_{PSF} maximum possible subordinate factors, I_{IRFi} is a factor's intensity of importance rating, T_{NF} total number of variables considered, M_{SR} maximum scale rating, *C* is a constant, *b*= variant that increases with the no of subordinate factors *a*nd M_{SR} maximum scale rating.

2.2.3. Normalization of weights

The normalization was carried out using the following steps:

1. Grouping of ratings to form a matrix for each of the eighteen factors, as shown in Table 1.
2. The *n*th root of each rating was determined, with n being the total number of variables investigated.
3. The results of step 2 was added to arrive at a total.
4. The *n*th root of each element was used to divide the total in step 2.

In Eq. (5), these steps are merged to give the following model:

$$N_{wi} = \frac{x_i^{\frac{1}{n}}}{\sum_{i=1}^{n} x_i^{\frac{1}{n}}} \tag{5}$$

where N_{wi} is the factor's normalized weight *i*, n is number of variables, and x_i is the original intensity of importance rate of factor *i* before normalization.

2.2.4. Resource allocation model

It is vital to have a model that is capable of effectively distributing resources based on the priority order of the entire factors considered as a measure towards reducing the negative impacts that impedes the transition to renewables. This indicates that factors with a high priority have a high probability of being the primary cause or initiating factor, and thus, they call for a greater investment of resources. In this paradigm, rather than concentrating on the symptoms of a problem, the emphasis is placed on finding and addressing its underlying causes. The generalized model for determining the optimal approach for resource distribution is represented in Eq. (6).

$$C_i = \frac{N_{wi}}{\sum_{i=1}^{n} N_{wi}} x C_T \tag{6}$$

$$C_T = \sum_{i=1}^{n} C_i N_{wi} = C_i N_{wi} + C_{i+1} N_{wi+1} + C_{i+2} N_{wi+2} + \cdots + C_{i+n-1s} N_{wi+n-1} + C_{i+n} N_{wi+n} \tag{7}$$

While C_T represents the total available resources, N_{wi} represents the normalized weights of factor *i* and C_i resources available for each factor.

2.2.5. Resource allocation model for factors affecting the transition to renewable energy

The identified factors' normalized weights are then entered into the resource allocation model. As previously stated, values for each factor. To be equivalent in criticality, factors with the same priority level are allocated the resource Eq. (8).

$$\begin{aligned} C_T = \sum_{i=1}^{18} C_i N_{wi} &= C_1 N_{w1} + C_2 N_{w2} + C_3 N_{w3} + C_4 N_{w4} + C_5 N_{w5} \\ &+ C_6 N_{w6} + C_7 N_{w7} + C_8 N_{w8} + C_9 N_{w9} + C_{10} N_{w10} \\ &+ C_{11} N_{w11} + C_{12} N_{w12} + C_{13} N_{w13} + C_{14} N_{w14} \\ &+ C_{15} N_{w15} + C_{16} N_{w16} + C_{17} N_{w17} + C_{18} N_{w18}, \end{aligned} \tag{8}$$

Table 1. HSIM pair-wise connection between factors affecting the transition to renewables in developing nations.

i	*j*																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
6	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0
7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8	0	1	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0
9	0	1	1	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

3. Results

The HSIM of the factors that were identified as barriers to renewable energy transition are highlighted in Table 1 with the HTSD being represented in Fig. 3.

In the HTSD framework, the variables and the significant rating weights of the factors are shown in Table 2 and **3**, respectively.

Table 2. The HTSD subordination table.

Number of elements	Number of subordinate factors	Element number	Number of subordinate factors
1	0	10	5
2	4	11	1
3	4	12	0
4	1	13	4
5	1	14	5
6	3	15	4
7	0	16	2
8	2	17	1
9	4	18	0

As shown in Table 3, factors **1** (competing against fossil fuels), **7** (Poor attitude towards operation and maintenance), **12** (Loss of other/impact on other), and **18** (standards and certifications are lacking) are the least important when it comes to barriers for the transition to renewable energy in developing nations. The most important factors are **10** (barriers to public awareness and information) and **14** (ineffective government policies), followed by **2** (subsidies and government grants), **3** (non or few renewables financing institutions), **9** (technology complexity), **13** (experienced professionals are scarce), and **15** (inadequate financial incentives). The least important factors are **1** (competing against fossil fuels) and **7** (poor attitude towards operation and maintenance). Table 4 presents the normalized factor weights for the barriers of renewable energy transition.

The decision-maker is given some insight into the interconnection that exists among the many aspects that were taken into consideration by the hierarchical order that has been exhibited so far. In addition, it displays the sequence in which actions are carried out according to the subordination order.

Table 3. Significance rating of factors.

Element number	Rating	Element number	Rating
1	0.028	10	2.667
2	2.139	11	0.556
3	2.139	12	0.028
4	0.556	13	2.139
5	0.556	14	2.667
6	1.611	15	2.139
7	0.028	16	1.083
8	1.083	17	0.556
9	2.139	18	0.028

Table 4. Normalized weights for renewable energy transition barriers.

Number of elements	C	IRFi	$\frac{1}{n}/x_i$	Nwi
1	8.5	0.028	0.843	0.048
2	8.5	2.139	1.037	0.059
3	8.5	2.139	1.037	0.059
4	8.5	0.556	0.972	0.055
5	8.5	0.556	0.972	0.055
6	8.5	1.611	1.023	0.058
7	8.5	0.028	0.843	0.048
8	8.5	1.083	1.004	0.057
9	8.5	2.139	1.037	0.059
10	8.5	2.667	1.048	0.060
11	8.5	0.556	0.972	0.055
12	8.5	0.028	0.843	0.048
13	8.5	2.139	1.037	0.059
14	8.5	2.667	1.048	0.060
15	8.5	2.139	1.037	0.059
16	8.5	1.083	1.004	0.057
17	8.5	0.556	0.972	0.055
18	8.5	0.028	0.843	0.048
		Total	**17.573**	**1.000**

A factor's "weight" or "intensity of relevance" is directly proportional to the number of factors that it subordinates to. The intensity rating will be increased according to the amount of subordinating factors present. Because of this, the importance of a factor increases in proportion to the number of other factors that it subordinates. It is possible that the priority rating or hierarchical position of a factor is not the ideal metric to use when attempting to determine the degree to which a factor is important. This inference is based on the observation that a component that has a sizeable number of subordinating factors may, in turn, be subordinated to a factor that has a smaller number of subordinates. As a result, the aspect that is the most significant could not necessarily express itself in the position that is highest up in the hierarchy. On the other hand, the hierarchical structure in this study has adhered to the weight magnitude of the components, which indicates the relevance of the factors. The HTSD is generally used to represent the sequence in which a group of factors, components, objectives, actions, etc. that are all part of the same system and are working towards the same goal are put into effect. With Eq. (9), the normalized weights of the identified factors were determined:

$$\begin{aligned} C_T = \sum_{i=1}^{18} C_i N_{wi} &= 0.05C_1 + 0.05C_2 + 0.05C_3 + 0.05C_4 + 0.05C_5 \\ &+ 0.05C_6 + 0.05C_7 + 0.05C_8 + 0.05C_9 \\ &+ 0.05C_{10} + 0.04C_{11} + 0.05C_{12} + 0.05C_{13} + 0.04C_{14} \\ &+ 0.05C_{15} + 0.05C_{16} + 0.05C_{17} + 0.05C_{18}, \end{aligned} \tag{9}$$

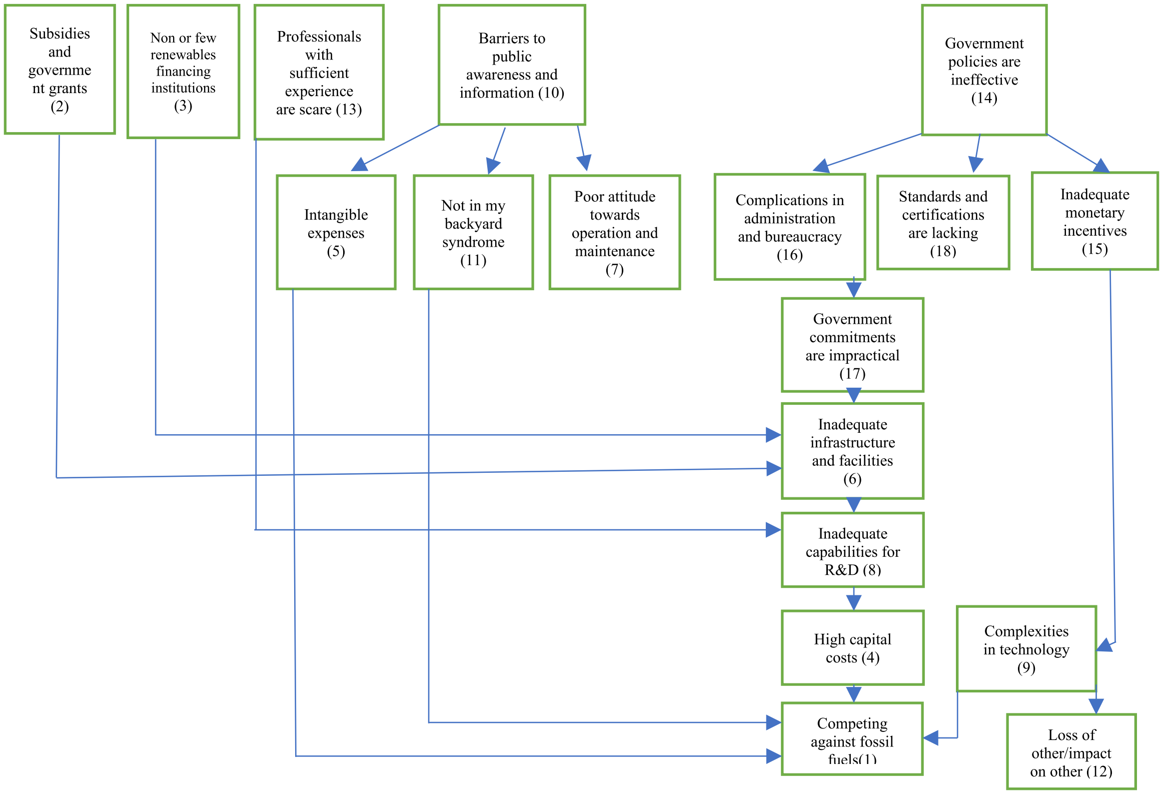

Fig. 3. HTSD for factors affecting the transition to renewables in developing nations.

Despite computing the factors' normalization weights with a constant value of C, dissimilar n_{th} roots of x_i and normalized weights for the factors were obtained. Factors **10** (barriers to public awareness and information) and **14** (ineffective government policies) have the highest intensity of importance ratings I_{IRFi} and normalized weight N_{wi} for the identified factors.

4. Discussion

This study has presented barriers to renewable energy transition in developing countries. Factors **2** (subsidies and government grants), **3** (non or few renewables financing institutions), **13** (experienced professionals are scarce), **10** (barriers to public awareness and information), and **14** (ineffective government policies) were assigned higher priority order on the hierarchy, as indicated in Fig. 3. These are the barriers for renewable energy transition in developing countries. Factors **5** (intangible expenses), **11** (not in my backyard syndrome), **7** (poor attitude towards operation and maintenance), **16** (administrative and bureaucratic complexities), **18** (standards and certifications are lacking), and **15** (inadequate financial incentives) make up the second degree of significance. The top-level factors have a direct effect on the second-level factors while the second-level factors also have a direct relationship with the third, fourth, and fifth hierarchy-level factors, etc., as presented in Fig. 3.

Table 3 displayed the relative relevance of each factor and other variables analyzed, as well as the intensity of the multiple barriers impacting the transition to renewables in developing countries. Subordinate factors weighting is determined by the number of subordinate factors available to a factor. This will make the numerical analysis of prioritized factors simplified. The amount of subordinate factors that are accessible to a factor is a primary consideration in the application of the weighting principle, which determines how intensely important a component is. The rationale behind this is to facilitate further numerical examination of issues that have been prioritized.

In addition to this, the factors' weights after being normalized were calculated. In most cases, the total of the normalized weights assigned to the various factors under consideration will amount to one. Because of this, expressing the ratio of proportionality between the various components was made much simpler.

As can be seen in the model for resource allocation, the normalized weight serves as the foundation for the distribution of resources among the various criteria. This method demonstrates that a component i may have an identical weight value as another factor j, but be lower than it in the hierarchical position. This is because of the fact that this methodology takes into account weight values. The evidence for this may be found in factors **10** (barriers to public awareness and information) and **14** (ineffective government policies). Factors **10** and **14** have a larger weight value, and both are put in the same hierarchy because they have been identified as a possible root cause of the slow transition to renewable energy in developing countries. The number of subordinates tied to a factor reflects the extent to which it is important or its weight value, while the ordering of factors in the hierarchy shows the order of preference for the execution of solutions to handle renewable energy transition issues. One of the most fundamental benefits of activity prioritization is that it acts as a guide to the transition of renewables in developing countries. This is accomplished by assisting the decision-maker in determining which set of systemic factors are to be given preference and to what extent at various points in time. It is obvious that knowing the order in which the components are ranked is one thing but knowing the relative weight of significance of each aspect in order to assist in making decisions is another.

5. Conclusion

A strategy for optimal planning and sustainable policy formulation towards accelerating the integration of renewable energy sources in developing countries has been explored and presented in this paper. The study identified the barriers responsible for the slow transition to a renewable energy-dependent economy in developing economies. The HSIM approach was used to analyze and rank the identified barriers ensuring that resources are dispersed in a prioritized order in a bid to address these barriers. A long-term strategy to meet rising energy demand while reducing GHG emissions would be particularly beneficial to developing nations. Owing to reasons such as financial investments, power purchase agreements, regulatory and legislative frameworks, politics, policy and strategies, technology and innovation, environmental programs, public awareness, etc., the transition to renewable energy has remained an exceedingly sluggish act that requires a holistic intervention to ensure sustainable renewable power supply in the affected low-income nations. The study found out that the factors that are immensely responsible for the slow transition to renewable energy in developing countries are absence of subsidies and government grants, non or few renewables financing institutions, experienced professionals are scarce, barriers to public awareness and information, and ineffective government policies. A significant benefit of the weighted factors prioritization approach as presented herein is that it is capable of aiding stakeholders such as the government, legislators, members of the academia, research students, etc., to identify system drivers requiring the most significant to the least attention in all ramifications. Understanding the components' relative importance for improved management decision-making is a critical activity that is premised on the hierarchical order.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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