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A Decision-Making Framework for the Development of Molten-Salt Reactors: Prioritizing Environmental and Technological Factors

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ABSTRACT

The development of molten-salt reactors is of key importance for the development of countries. Although these reactors have many advantages, some issues pose a barrier to the development of these projects. In this context, it is necessary to identify the most important factors affecting the development of molten-salt reactors. This situation allows action to be taken without incurring very high costs. However, there are limited studies in the literature on determining the factors that most affect the performance of these reactors. Accordingly, the purpose of this study is to determine the most significant indicators of molten-salt reactors. In this framework, the main research question is to identify which strategies should be mainly implemented for the improvements of these projects. In the first stage, important variables are determined according to literature review results. Secondly, the weights of these indicators are calculated. In this process, the DEMATEL methodology is taken into consideration. Based on the analysis results, appropriate investment strategies are identified for the improvements of these investments. It is concluded that environmental factors play the most significant issue in the improvements of the molten-salt reactors. In addition to this issue, technological factors are also important for this situation. Nevertheless, social and political factors have the lowest weights in this regard. For the development of molten-salt reactors, improvements in environmental factors must be made first. People's biggest concern about nuclear reactors is the negative effects on the environment. In this context, the radioactive wastes generated may have a negative impact on the environment. This situation negatively affects the image of the projects. In this context, it is appropriate to use thorium instead of uranium in molten-salt reactors. This significantly reduces the amount of radioactive waste generated as a result of the energy production process.

1. Introduction

This section includes the general information, literature review results, the missing parts in the literature and the purpose of the study.

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1.1 General Information about Molten-Salt Reactors

Molten-salt reactors are types of nuclear reactors that use molten salts as both fuel and coolant. The biggest difference between these reactors is that they use liquid fuel. By using molten salts, the reactor can be generated quickly [1]. In this way, these reactors have the capacity to operate at high temperatures. This reactor has some important advantages [2]. By operating at high temperatures, it is possible to obtain more electricity from these reactors. Thus, it may be easier to increase the energy efficiency of these projects. Similarly, the lower risk of explosion is an important advantage of molten-salt reactors compared to other types. In these reactors, the risk of steam explosion is less due to the high boiling point of molten salts [3]. Moreover, the use of both uranium and thorium is an important advantage for molten-salt reactors as it will provide fuel diversity. This situation is very critical to ensure long-term nuclear fuel supply security. In addition, producing less radioactive waste is one of the important advantages of this reactor in this context [4].

There are also some issues that negatively affect the development of molten-salt reactors. Technological challenges are very important in this process. These reactors must have a system that can operate at very high temperatures. Therefore, the technological infrastructure must be sufficient for these complex structures to operate effectively. Similarly, if the technical infrastructure is sufficient, it is possible to minimize the disruptions that may occur in this process [5]. The complexity of bureaucratic processes is also a significant obstacle to the development of these projects. Since molten-salt reactors are a new technology compared to others, the investment initiation process may be more detailed. The length and complexity of these processes may prevent investors from focusing on these projects. In addition to them, the initial investment amount of these projects is quite high. This situation creates a need for high amounts of financing resources. As a result, there are some financial obstacles to the development of these investments [6]. As a result of not solving these problems, the development of molten-salt reactors slows down significantly.

1.2 Literature Review on Molten-Salt Reactors

Some actions need to be taken to improve the efficiency of molten-salt reactors. There are many factors that affect the performance of this process. Technological development is a necessary issue for these reactors to operate more effectively [7]. With the use of advanced technologies, it is possible to obtain more energy from molten-salt reactors. This significantly increases the efficiency of the process. Thus, the financial profitability of these investments can also increase [8]. Profitable investments are also preferred by more investors. The safety of reactors can also be increased by ensuring technological development. With current practices, these reactors can operate safely at very high temperatures. This increases the confidence of both investors and users in this reactor [9]. Thus, it is possible to ensure social acceptance of the projects. Economic factors are also important to ensure the effectiveness of these reactors. Initial investment costs are quite high in these reactors [10]. This situation also increases the need for financial resources. Therefore, the development of innovative financial products is important for financing these reactors. In this way, financial diversity will be achieved, and businesses can access financing resources at lower costs [11].

Another variable affecting the development of molten-salt reactors is political factors. The fact that legal regulations are sufficient and simple attracts investors' attention to this issue [12]. Otherwise, the excessive bureaucratic issues increase the reluctance towards this project [13]. In this context, the legal permit processes required to realize these investments should not be too complicated [14]. Future energy policies of countries are another important factor in this context. In this context, the importance of molten-salt reactors is increasing at a point where countries aim for energy independence [15,16]. Thanks to these energy projects, countries can produce the energy they need on their own [17]. Environmental factors are also very critical for the development of these reactors. One of the most criticized issues about nuclear power plants is radioactive waste [18]. It is possible to minimize this problem by using thorium in molten-salt reactors. This also enables social acceptance of the projects to be increased [19,20].

1.3 The Need for a New Study

The development of molten-salt reactors is of key importance for the development of countries. Although these reactors have many advantages, some issues pose a barrier to the development of these projects. Therefore, the right strategies for the development of these reactors need to be implemented. In this context, it is necessary to identify the most important factors affecting the development of molten-salt reactors. This allows action to be taken without incurring very high costs. Otherwise, businesses will not be able to use their resources effectively. However, there are limited studies in the literature on determining the factors that most affect the performance of these reactors. This situation causes an increase in the need for this study in the literature.

1.4 The Details of This Study

This study aims to find the most significant indicators of molten-salt reactors. In this context, the main research question is to identify which strategies should be mainly implemented for the improvements of these projects. Firstly, some indicators are determined according to literature review results. Secondly, the weights of these indicators are computed. In this process, DEMATEL methodology is taken into consideration. Based on the analysis results, appropriate investment strategies are identified for the improvements of these investments.

2. Methodology

In this study, it is aimed to find the most important strategies for the development of the molten-salt reactors. To achieve this objective, the most effective criteria of these investments are determined. In this scope, DEMATEL methodology is taken into consideration [21]. The details of the methodology are explained in the following steps.

Step 1: The problem of the study is defined.

Step 2: Some indicators are determined according to literature review results.

Step 3: The evaluations of five different experts are obtained. In this process, five different scales are taken into consideration that are 0-no, 1-bad, 2-adequate, 3-effective and 4-excellent [22].

Step 4: After the collection of the assessments, direct relationship matrix is generated. For this purpose, the average values of all evaluations are calculated [23].

Step 5: The following process is related to the normalization. Within this framework, firstly, the highest value of all row sums identified. All values in the direct relationship matrix are divided into this value.

Step 6: Total relation matrix is created. In this context, following formula is taken into consideration [24].

"Total Relationship Matrix = Normalized Matrix*(Identity Matrix - Normalized Matrix)$^{-1}$"

Step 7: Weights of the criteria are calculated. In this process, firstly, the sums of rows and columns are computed. Next, the total of these sums is considered to weight the factors. On the other side, the difference between these sums is used to create impact relation map.

3. Results

Critical indicators are determined according to literature review results. Table 1 gives information about selected five different criteria.

Table 1
Selected Criteria

Criteria	Codes
Technological factors	TECHNO
Social Factors	SOCIAL
Environmental Factors	ENVIRO
Economic Factors	ECONOMY
Political Factors	POLITIC

The evaluations of the experts are indicated in Table 2.

Table 2
Assessments of the Experts

Expert 1					
	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	0	4	4	4	4
SOCIAL	1	0	2	1	1
ENVIRO	2	3	3	4	4
ECONOMY	1	2	1	0	1
POLITIC	1	1	1	1	0
Expert 2					
	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	0	3	4	3	3
SOCIAL	1	0	1	2	1
ENVIRO	1	4	3	3	3
ECONOMY	1	2	1	0	1
POLITIC	1	1	1	1	0
Expert 3					
	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	0	3	4	4	3
SOCIAL	1	0	1	1	2
ENVIRO	3	3	3	3	3
ECONOMY	1	1	1	0	1
POLITIC	1	1	1	2	0
Expert 4					
	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	0	3	4	4	3
SOCIAL	2	0	1	1	1
ENVIRO	1	1	3	4	2
ECONOMY	1	1	1	0	1
POLITIC	1	2	1	1	0
Expert 5					
	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	0	3	3	4	4
SOCIAL	1	0	1	2	1
ENVIRO	2	3	2	3	2
ECONOMY	1	2	1	0	1
POLITIC	1	1	1	2	0

In the next process, direct relationship matrix is constructed. The details of this matrix are denoted in Table 3.

Table 3
Direct Relationship Matrix

	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	-	3.20	3.80	3.80	3.40
SOCIAL	1.20	-	1.20	1.40	1.20
ENVIRO	1.80	2.80	2.80	3.40	2.80
ECONOMY	1.00	1.60	1.00	-	1.00
POLITIC	1.00	1.20	1.00	1.40	-

After that, these values are normalized. Table 4 highlights the details of the normalized relation matrix.

Table 4
Normalized Relationship Matrix

	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	-	0.23	0.27	0.27	0.24
SOCIAL	0.08	-	0.08	0.10	0.08
ENVIRO	0.13	0.20	0.20	0.24	0.20
ECONOMY	0.07	0.11	0.07	-	0.07
POLITIC	0.07	0.08	0.07	0.10	-

The next step includes the generation of the total relation matrix. The details of this matrix are shown in Table 5.

Table 5
Total Relation Matrix

	TECHNO	SOCIAL	ENVIRO	ECONOMY	POLITIC
TECHNO	0.18	0.47	0.53	0.53	0.46
SOCIAL	0.15	0.11	0.20	0.22	0.18
ENVIRO	0.29	0.45	0.47	0.52	0.44
ECONOMY	0.13	0.20	0.18	0.11	0.16
POLITIC	0.13	0.18	0.18	0.20	0.09

By considering the values in Table 5, the weights of the criteria can be identified. The weights of the criteria are demonstrated in Table 6.

Table 6
Weights of Criteria

Criteria	Weights
TECHNO	0.225058204
SOCIAL	0.168251216
ENVIRO	0.275479885
ECONOMY	0.174680966
POLITIC	0.15652973

Table 6 denotes that environmental factors play the most significant issue for the improvements of the molten-salt reactors. In addition to this issue, technological factors are also important for this situation. Nevertheless, social and political factors have the lowest weights in this regard.

4. Conclusions

In this study, it is aimed to define the most significant indicators of molten-salt reactors. Within this framework, the main research question is to identify which strategies should be mainly implemented for the improvements of these projects. In the first stage, important variables are determined according to literature review results. Secondly, the weights of these indicators are calculated. In this process, DEMATEL methodology is taken into consideration. Based on the analysis results, appropriate investment strategies are identified for the improvements of these investments. It is concluded that environmental factors play the most significant issue for the improvements of the molten-salt reactors. In addition to this issue, technological factors are also important for this situation. Nevertheless, social and political factors have the lowest weights in this regard. For the development of molten-salt reactors, improvements in environmental factors must be made first. People's biggest concern about nuclear reactors is the negative effects on the environment [25]. In this context, the radioactive wastes generated may have a negative impact on the environment. This situation negatively affects the image of the projects [26]. In this context, it is appropriate to use thorium instead of uranium in molten-salt reactors. This significantly reduces the amount of radioactive waste generated as a result of the energy production process [27].

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Conflicts of Interest
The authors declare no conflicts of interest.

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