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GOVERNING APPROPRIATE STRATEGIES FOR EFFECTIVE COST MANAGEMENT IN NUCLEAR ENERGY INVESTMENTS

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Abstract

Effective cost management is an important factor for the performance of nuclear energy investments. This management is a method used to reduce costs, increase efficiency, and increase profitability in nuclear energy investments. Effective cost management reduces the costs of the investment by reducing the construction, operation, and maintenance costs of nuclear energy investments. In this study, it is aimed to find the most critical costs for nuclear energy investments. For this purpose, an evaluation is performed by using both AHP and DEMATEL methodology. In this case, firstly, the different cost types in nuclear energy investments are defined. In the analysis process, AHP and DEMATEL methods are taken into consideration. It is concluded that the analysis results of both AHP and DEMATEL are the same. This situation gives information about the reliability of the findings. Based on these analysis results, it is identified that decommissioning cost plays the most critical role in nuclear energy investments. Additionally, uranium cost is also another key cost type for these investments. Hence, it is strongly recommended that nuclear energy investors should mainly focus on these issues to provide effective cost management.

Keywords: AHP, Cost Management, Dematel, Energy Investment, Energy Finance, Nuclear Energy

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1. Introduction

Energy is one of the most vital needs of all people. Because people consume energy directly or indirectly. It can be said that industrialization, which ended the increasing human population and agricultural economy, has increased the energy need day by day. In addition, it is known that increasing energy demand is associated with economic growth and the increase in people's living standards. In addition, the increase in the rate of urbanization after the industrial revolution has also led to an increase in energy demand. Thus, it is obvious that the concept of energy will be among the most critical issues in the next century. Hence, governing effective cost management decreases the risks of energy investments. When, the energy resources are examined depending on the concept of energy, 3 distinctive features of energy resources emerge.

First, energy resources are limited. Secondly, energy resources are unevenly distributed in nature. One country may have abundant energy resources, while other countries may be poor in energy resources. Finally, obtaining, processing, and using some energy sources as fuel may have negative environmental consequences (Boretti, 2023). In addition, energy sources are divided into 2. Non-renewable energy sources and renewable energy sources are the 2 main categories for energy sources. Non-renewable energy sources, on the other hand, are divided into two separate groups: fossil-based and core-sourced. To elaborate, coal, oil and natural gas are examples of fossil origins. Uranium and thorium are sources of nuclear origin. Solar, wind, wave, biomass, hydraulic, geothermal and hydrogen are examples of renewable energy sources.

In this study, it is aimed to find the most critical costs for nuclear energy investments. For this purpose, an evaluation is performed by using both AHP and DEMATEL methodology. In this case, firstly, the different cost types in nuclear energy investments are defined. In the analysis process, AHP and DEMATEL methods are taken into consideration. These techniques are mainly considered to weight the criteria. The main reason for using these two different techniques at the same time is to make a comparative evaluation. This situation helps to measure the consistency and reliability of the findings. In the analysis process, three decision-makers made evaluations about these criteria. After that, the steps of AHP and DEMATEL are implemented to these evaluations.

2. Theoretical Background of Energy Types

Recently, the need for energy has been increasing day by day. Although various technologies and energy sources are used to meet the increasing energy demand, fossil fuels occupy a key place in energy production. The formation of fossil fuels is directly linked to the fossilization of plants and animals. Fossil fuel is a compound formed by the fossilization of plants and animals under the ground for millions of years under high pressure. Since fossil fuels are the remains of living organisms, it can be said that all fuels are of hydrocarbon origin. Because two elements, carbon, and hydrogen, are essential elements of fossil fuels. Fossil fuels, which have a high carbon content due to their origin, are non-renewable energy sources and require millions of years to form (Sadiq et al., 2023).

In this sense, fossil fuels have limited supplies and are in danger of running out of reserves eventually. Although these fuels, which are used by burning to meet the energy needs, are classified as

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non-renewable resources due to the long process required for their formation, these fuels constitute most of the energy production. Due to the emissions, they cause in the production and usage stages, their negative environmental impacts are much higher compared to renewable energy sources. In addition to carbon emissions, another important problem caused by fossil fuels is that products made using fossil fuels cause serious damage to nature.

For example, we frequently encounter petroleum-based plastic products today. These products cause an increase in environmental pollution and damage to the living spaces of living things. The formation of fossil fuels from fossils is determined by the type of fossil, the amount of heat and the amount of pressure. Accordingly, when classifying fossil energy sources, three main sources are generally emphasized (Meng et al., 2021). Coal, oil and natural gas are the 3 main sources that make up fossil resources. Hence, these are non-renewable energy sources.

Coal is a sedimentary rock consisting of organic and inorganic components formed because of the compression and solidification of plant residues and inorganic minerals under high pressure and temperature. Coal, on the other hand, can be divided into types. For example, peat can be converted to coal under suitable conditions or coal can be found in the form of lignite. Therefore, there are 4 types of coal: anthracite, hard coal, lignite, and peat. Petrol, on the other hand, consists of components exposed to the same temperature and pressure and can be used like gasoline, propane, kerosene, and jet fuel after extraction.

It can also be turned into products such as plastic and paint. Natural gas is another fossil energy source. Among the components of natural gas; methane (CH4), ethane (C2H6), propane (C3H8), butane (C4H10) gases are included. Natural gas, which is generally transported by pipelines, can also be liquefied and transported in pressurized tanks. Although it has gone through similar processes as other fossil energy sources, natural gas is considered a cleaner burning fossil fuel compared to other fossil energy sources.

Many damages occur in the process of obtaining fossil fuels and the process of obtaining electrical energy from these sources. For example, fossil fuels pollute the air during their production and use. At the same time, they cause the release of harmful gases into the atmosphere and cause many diseases such as cancer. These fuels, which cause air pollution even at the production stage, directly threaten the health of those working in the relevant fields and those who have close contact due to their profession. Among the emissions resulting from the combustion of fossil fuels, there are other emissions harmful to health apart from carbon emissions.

Especially during transportation activities, gases such as carbon dioxide and nitrogen oxide arising from the use of fossil fuels are harmful to human health. Emissions caused by fossil fuels trigger the greenhouse effect in addition to air pollution and consequently increase global warming. Climate change, which occurs as a result of global warming, causes changes in the natural order of our planet that are very difficult to return. Therefore, reducing the use of fossil fuels is one of the most important steps in the fight against global warming. Pollution of water resources, including groundwater, is among the damages of fossil fuels.

During the extraction of these fuels, wastewater containing heavy metals and radioactive substances is produced. If waste management is unsuccessful, it can cause great harm to the environment,

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especially to the local people. These damages include damaging the habitat of many living things and causing diseases such as cancer. For this reason, it is necessary to take all precautions to prevent the related wastewater from mixing with clean water sources. Considering all these, human health is faced with a very big risk (Ali et al., 2022). To reduce these risks, it is necessary to reduce the use of fossil fuels and to provide transition to alternative sources.

Increasing industrialization, technological progress, developing health systems and increasing world population due to these factors reveal an intense energy need. Although fossil fuels meet this need to date at the expense of polluting the environment, it is not sustainable. Therefore, there is a need for cleaner and more sustainable energy sources. In this context, renewable energy is one of the most popular and promising topics in the field of energy today. The various properties of renewable energies make them a good alternative to fossil fuels.

As a concept, renewable energy refers to energy resources that are used during the natural cycle but become reusable the next day. The fact that fossil fuel reserves are currently decreasing significantly is a great danger considering the increasing energy demand. Based on this idea, renewable energy investments are increasing day by day. Because it offers various advantages such as using renewable energy sources to meet energy needs and reducing carbon emissions.

When renewable energy sources are mentioned, energy sources such as solar, wind, hydrogen, geothermal, wave and hydraulic are generally mentioned. No carbon emissions occur in the consumption of these resources and the energy produced fully complies with the definition of renewable energy. Therefore, during the use of these energy resources, there is no decrease in the reserves of the resources. In line with this feature, the sustainability of these resources is higher than fossil fuels and other resources.

When talking about the advantages obtained after the use of renewable energies, the first thing that comes to mind is that renewable resources minimize carbon emissions. The energy generated during the use of these resources does not include carbon-based gases and other harmful gases. Therefore, it can be said that renewable energy sources have the status of green energy that does not harm the environment. Because it does not cause environmental problems such as air or water pollution due to carbon emissions during energy production and conversion. In this sense, it is a very reliable type of energy.

One of the advantages of renewable resources is that they are an effective tool in the fight against global warming. Because one of the most important reasons accelerating climate change is the gases that emerge during the burning of fossil fuels. Simply put, these gases envelop the atmosphere, making it difficult for excess heat to escape from the earth and causing the earth to overheat. Thus, due to global warming, the average temperature of the world rises slowly, the glaciers melt and cause huge forest fires (Dinçer et al., 2023). Renewable energy sources have an important contribution in this sense. Another positive feature of renewable resources emerges in terms of cost. Since no flammable fuel is used during the energy production with these sources, maintenance costs are lower than other energy sources.

Another important feature is the high public acceptance of these energy sources. Since energy investments undoubtedly affect the health and welfare of societies, public acceptance of investments will be beneficial both politically and economically. Renewable energy sources are used extensively today, especially in rural areas, for hot water or electricity production. Therefore, it can be said that no one, from

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the lowest strata of the people to the highest strata, is unfamiliar with these energy sources. Thus, renewable energy investments will generally not be met with a reaction from the public, and with this feature, it is a very advantageous investment.

Like every energy source, renewable energy sources also have advantages and disadvantages. One of these disadvantages is that the electricity generation capacity of renewable resources is not yet as large as fossil fuels and core fuels. Therefore, it does not seem possible yet to produce a large amount of energy using renewable resources compared to other resources. In this sense, renewable energy technologies need to be further developed and improved. Another most important disadvantage is that the energy provided by renewable energy sources will not be "uninterrupted for 24 hours" with the current technology. Because renewable energy sources are completely dependent on the weather to produce energy.

In case of adverse weather conditions, the ability of renewable energy sources to generate electricity will also be adversely affected. Therefore, continuity is a major disadvantage for renewable resources. Another important disadvantage is the high installation costs. Although the maintenance costs of renewable resources are relatively low compared to other resources, their installation costs are high. For example, the construction of solar panels, hydroelectric power plants and wind turbines are very expensive investments. In addition, to transfer the produced energy to the cities, it is necessary to make infrastructure investments such as power lines. All these disadvantages necessitated the use of different energy sources than fossil and renewable energy sources. In this context, nuclear energy is one of the alternative sources.

3. General Information about Nuclear Energy Investment

In connection with the energy need and the human population, the interest in nuclear energy is increasing in direct proportion. Because nuclear energy is one of the most important energy sources in the context of sustainability. Thus, research on nuclear energy is increasing day by day. Nuclear energy is a core-based energy source. Therefore, a powerful fuel is needed to produce nuclear energy from the atomic nucleus. In this context, uranium appears as the most suitable fuel for nuclear power plants (NPP). Because uranium is the element with the highest number of protons and neutrons (Kwag et al., 2022). However, uranium is not used in its pure form in NPPs. Uranium is enriched for use in NPPs. In this way, enriched uranium is broken down by fission reactions, releasing a large amount of energy.

Fission reactions basically start when neutrons collide with the uranium nucleus at great speed. After the first fission, the neutrons that start to spread hit other uranium nuclei and continue this process until they fission in each atomic nucleus. The powerful energy released during the fission reaction reaches extremely high temperatures, so keeping the fission reactions under control is one of the most vital issues. Failure to control the resulting energy will have extremely deadly consequences (Yüksel et al., 2022). Control rods are used to control the resulting strong energy. Control rods are usually made of materials such as boron or silver. These control rods are also called neutron traps.

Neutron scavengers placed in the reactor trap neutrons moving at great speed, thus slowing the reaction. Again, neutron scavengers can be used for the opposite process. Neutron scavengers can be withdrawn to accelerate or increase the fission reaction that occurs. Thus, nuclear reactions are kept under

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control. This whole process is done to obtain a high temperature from the reactor. Because the motion energy required to obtain electrical energy is obtained by the evaporation of the water from the heat coming out of the reactor. The high temperature generated by the fission reaction evaporates the water and turns the turbines connected to the generators, thus supplying the motion energy required for electrical energy (Wilson et al., 2022). Electricity is sent to the desired areas via generator and transmission lines.

Although there are concerns about the process of obtaining energy in NPPs, considering the advantages of the energy produced, it is understood that nuclear energy technologies can be quite effective for the future. Environmental factors in terms of the benefits of nuclear energy, environmental factors come first. Combating global warming and carbon emission is one of the most talked about topics today. In this context, nuclear energy is especially important in combating global warming and reducing carbon emissions (Yuan et al., 2021). Because the energy produced in NPPs provides a great environmental advantage with its zero-carbon feature.

The feature of being zero carbon is effective not only in the fight against global warming, but also in reducing environmental pollution. Air pollution caused by fossil fuels negatively affects human health and well-being. In the long run, the increasing number of patients due to air pollution can create vulnerabilities in the economy. Therefore, nuclear energy is one of the most effective solutions to prevent air pollution as it does not cause any carbon emissions. It should be said that nuclear energy is advocated for economic reasons as well as environmental benefits. Considering the decrease in fossil fuel reserves and the danger of energy supply, using nuclear energy supplies is an advantage (Sadiq et al., 2022). Because fuels such as uranium and even thorium used in NPPs are relatively high in terms of reserves for now.

Considering that these fuels are reusable, it can be said that the efficiency of the fuels used is quite high. The main reason for the current account deficit, which is a major problem of the country's economies, comes from energy expenditures. Countries that have limited energy resources and have to import energy can make a significant gain in terms of current account deficit by investing in nuclear energy. One of the biggest advantages of nuclear energy, which distinguishes it from renewable energy sources, is that it can produce a large amount of energy 24 hours a day without interruption (Hassan et al., 2022).

Since NPPs are not affected by weather conditions like renewable energy sources, the energy they produce is uninterrupted and the desired amount is maintained. Since nuclear energy investments are large investments, they also provide employment. In addition, it can be said that nuclear energy provides political advantages. Energy supply security is a major problem in energy-dependent countries. Countries that reduce their energy imports with nuclear energy investments can gain a significant political advantage.

In addition to the advantages of nuclear energy, there are also disadvantages. Generally, security is cited as the most important disadvantage. The energy produced in the energy production process from NPPs must be kept under control, otherwise serious dangers are faced. Therefore, any adverse effect that would complicate the control procedures in question also endangers nuclear safety. Natural disasters are one of these negative effects. Natural disasters such as earthquakes and tsunamis can cause leaks in the

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reactor and even cause the reactor to explode. In fact, the main cause of the accident at the Fukushima 1 NPP was based on natural disasters.

The Fukushima 1 NPP accident, the second largest NPP accident the world has faced after Chernobyl, occurred because of a strong tsunami that occurred just after a 9.0 magnitude earthquake. Leaks and explosions occurred at the NPP damaged by the tsunami, so most people in the area were evacuated and workers at the plant were exposed to excessive radiation. Another important security issue is the danger of misuse and terrorism. Explosions may occur due to improper use in NPPs or NPPs may be damaged due to terrorist activities (Mathew, 2022).

In the light of this information, the issue of safety in nuclear energy is one of the most important issues. It can be said that another risk factor related to NPPs is waste management. Although nuclear wastes can be reused, they must be disposed of after a certain period, therefore, NPP wastes should be disposed of in a controlled manner. Because nuclear wastes can cause serious damage to the environment and human health in the long run, especially by polluting water and soil (Wang et al., 2023).

Another important disadvantage in nuclear energy investments is the high level of knowledge and qualified personnel needed in this field. Because the operation of NPPs with qualified personnel is directly related to the safety of NPPs. The people responsible for the NPP must have strong knowledge and experience in maintenance and repair, crisis management, waste management and accident prevention. In this way, minor errors that may occur in the NPP will be prevented from causing major accidents.

Another important factor to be considered in nuclear energy investments is the difficulty of public acceptance of these investments. The public may be worried about nuclear energy investments in matters such as security and cost. Therefore, public awareness and acceptance of the risks of nuclear energy investments will increase the political and economic efficiency of the investment. At the same time, achieving a national consensus on nuclear energy investment will motivate investors to invest in this area.

Additionally, cost is one of the critical issues that comes after security in nuclear energy investments. Because nuclear energy investments are quite large and costly investments. The initial installation costs and waste disposal costs of power plants are especially high. Therefore, nuclear energy investors will have great difficulties in constructing a NPP without implementing effective cost management. For example, the physical structure of the region where the power plant will be established can have cost-increasing and reducing effects (Alwaeli & Mannheim, 2022).

If there is no uranium reserve in the country where the power plant is established, the raw material cost will be an important factor. Another important cost factor is the cost of maintenance and repair. In addition to all these, the cost of equipment, the cost of qualified personnel, and the cost of dismantling constitute other cost items. Accordingly, the emergence of quite a variety of cost items in nuclear energy investments is one of the biggest obstacles to investment. Therefore, effective cost management and financial strategy implementation is essential for nuclear energy investments.

4. An Evaluation about the Cost Management of Nuclear Energy Investment

In this study, it is aimed to find the most critical costs for nuclear energy investments. For this purpose, an evaluation is performed by using both AHP and DEMATEL methodology. In this case,

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firstly, the different cost types in nuclear energy investments are defined. The details of these costs are given in Table 1.

Table 1. Different Cost Types in Nuclear Energy Investments

Cost Types	Supported Literature
Maintenance and repair cost	Majeed et al. (2022)
Initial setup cost	Dinçer et al. (2022)
Equipment cost	Nadaleti et al. (2022)
Skilled personnel cost	Yüksel et al. (2023)
Decommissioning cost	Obekpa and Alola (2023)
Uranium Cost	Pata and Samour (2022)
Waste Disposal Cost	Yüksel et al. (2022)

Nuclear energy investments are very high-cost investments and there are various types of costs. Nuclear power plants take a long time to build and are very costly. Construction costs include many factors such as the basic structure, safety systems, fuel storage areas and environmental protection measures. Nuclear power plants are strictly regulated by the regulatory authorities throughout the licensing process, which may incur additional costs.

In addition, measures taken to reduce the environmental impact of nuclear power plants may cause additional costs. The operating costs of nuclear power plants are quite high. These include many factors such as personnel costs, safety costs, maintenance costs, fuel replacement costs and the costs incurred to meet stringent regulatory requirements. Nuclear power plants use nuclear fuel, and the cost of this fuel is quite high.

Moreover, the storage and processing of spent nuclear fuel may incur additional costs. Nuclear power plants require special facilities for the storage and processing of spent nuclear fuel. The construction and operation of these facilities may also incur additional costs.

In the analysis process, AHP and DEMATEL methods are taken into consideration. These techniques are mainly considered to weight the criteria. The main reason for using these two different techniques at the same time is to make a comparative evaluation. This situation helps to measure the consistency and reliability of the findings. In the analysis process, three decision-makers made evaluations about these criteria. After that, the steps of AHP and DEMATEL are implemented to these evaluations. The analysis results of these two different methods are demonstrated in Table 2.

Table 2. Weighting Results

Cost Types	Weighting Results (AHP)	Weighting Results (DEMATEL)
Maintenance and repair cost	0,106	0,112
Initial setup cost	0,026	0,021
Equipment cost	0,065	0,061
Skilled personnel cost	0,040	0,049
Decommissioning cost	0,393	0,401
Uranium Cost	0,230	0,226
Waste Disposal Cost	0,140	0,130

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Similarly, for better understanding the findings, the results are also illustrated in Figure 1.

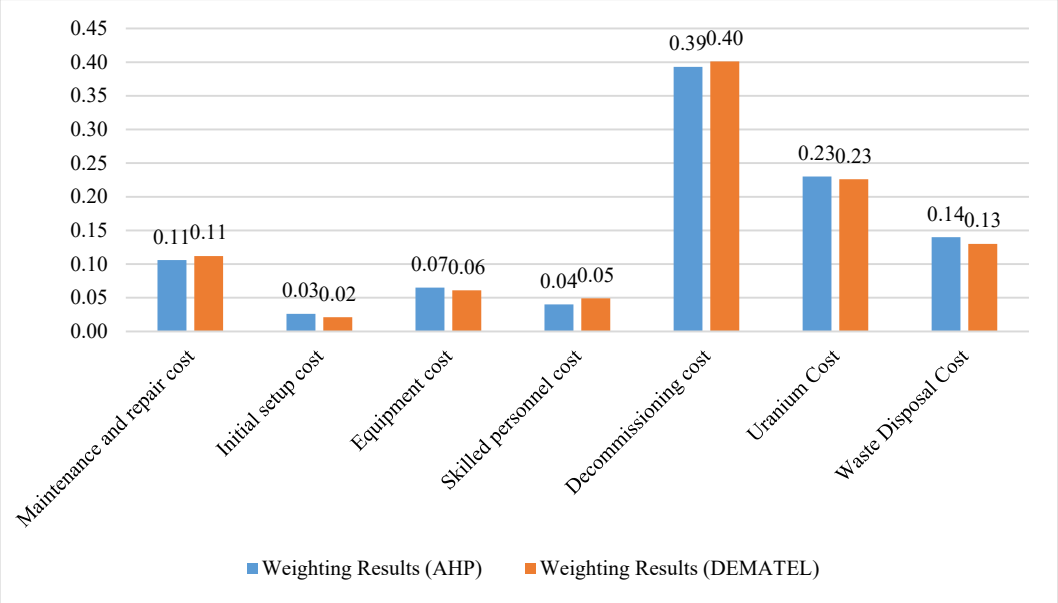

Figure 1. Comparative Weighting Results

Both Table 2 and Figure 1 indicate that the analysis results of both AHP and DEMATEL are the same. This situation gives information about the reliability of the findings. Based on these analysis results, it is identified that decommissioning cost plays the most critical role in nuclear energy investments. Additionally, uranium cost is also another key cost type for these investments. Hence, it is strongly recommended that nuclear energy investors should mainly focus on these issues to provide effective cost management.

5. Conclusion

Effective cost management is an important factor for the performance of nuclear energy investments. This management is a method used to reduce costs, increase efficiency, and increase profitability in nuclear energy investments. Effective cost management reduces the costs of the investment by reducing the construction, operation, and maintenance costs of nuclear energy investments. This increases the profitability of the investment. Effective cost management increases the efficiency of nuclear energy investments. A more efficient nuclear energy investment produces lower-cost energy, thus increasing the profitability of the investment. On the other hand, effective cost management reduces the risks of nuclear energy investments. Good cost management ensures that the investment stays within the budget and operating costs are kept under control. Finally, effective cost management increases the competitiveness of nuclear energy investments. A lower cost nuclear power investment may offer a more competitive price than other energy sources.

In this study, it is aimed to find the most critical costs for nuclear energy investments. For this purpose, an evaluation is performed by using both AHP and DEMATEL methodology. In this case, firstly, the different cost types in nuclear energy investments are defined. In the analysis process, AHP

and DEMATEL methods are taken into consideration. It is concluded that the analysis results of both AHP and DEMATEL are the same. This situation gives information about the reliability of the findings. Based on these analysis results, it is identified that decommissioning cost plays the most critical role in nuclear energy investments. Additionally, uranium cost is also another key cost type for these investments. Hence, it is strongly recommended that nuclear energy investors should mainly focus on these issues to provide effective cost management.

The decommissioning cost of nuclear energy investments is a cost that arises in the last stage of the investment's life cycle. The cost of decommissioning covers the costs required for the complete decommissioning of the nuclear power plant and the safe disposal of waste materials. Effective management of this cost is important for the performance of nuclear energy investments. Effectively managing the cost of decommissioning reduces the financial risks of nuclear power investment. The cost of decommissioning occurs towards the end of the nuclear plant's life and ensures that investors have ample time to estimate and finance the cost.

Effectively managing the cost of decommissioning reduces the safety risks of nuclear power investment. The decommissioning process requires the safe disposal of radioactive materials and is critical to the safety of nuclear energy investment. Effective management of the cost of decommissioning ensures regulatory compliance of nuclear power investment. Nuclear energy investments are subject to local and international regulations and these regulations must be fully complied with during the decommissioning process. Effective management of the decommissioning cost reduces costs. A good dismantling plan helps complete the decommissioning process more quickly and efficiently, thus reducing costs. Effective management of the cost of decommissioning provides a competitive advantage to nuclear energy investment. Lower decommissioning costs can help nuclear power investment become more competitive against other energy sources.

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