

# **A Systemic Framework Analysis for Designing Financial Model in Nuclear Cogeneration Investment for Low-Carbon Emission Hydrogen Production**

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## **Abstract**

Decarbonization is one of the policies, strategies, and efforts the Indonesian government can take to achieve the net zero emissions target by 2060 or sooner. The efforts include producing low-carbon emission hydrogen, which could play an essential role in decarbonization in the industrial and transportation sectors. Nuclear cogeneration can be an alternative technology and investment strategy for low-carbon emission hydrogen production. In investment planning, it is necessary to design a financial model that is a stakeholder decision-making tool. This study aims to identify important factors, actors, stakeholders, goals, and their relationships using a systematic framework based on a soft system methodology. This identification is essential to ensure a better understanding of the problem's systems, leading to a better model and decision-making, especially with relatively new technology and topics of its kind in Indonesia.

## **Keywords**

Systemic framework, Soft System Methodology (SSM), nuclear cogeneration, low-carbon emission hydrogen, financial modeling, decision-making.

## **1. Introduction**

The Indonesian government has committed to accelerating the transition to sustainable clean energy to achieve its net zero emissions (NZE) target by 2060 or sooner. This transition to the NZE requires sustainable and comprehensive policies, strategies, and efforts across all sectors, including the deployment of various applications of clean energy technologies. In general, there are four pillars of the transition path in the road map to NZE in Indonesia: energy intensity improvements, decarbonizing electricity generation, switching to low-emissions fuels in end-uses, and carbon capture utilization and storage (CCUS). (International Energy Agency (IEA) 2022).

In harder-to-abate sectors, where industrial and transportation sectors are the largest categories of greenhouse gas (GHG) emissions (Ministry of Energy and Mineral Resources of Indonesia (MEMR) 2020), the use of renewable energy is not the only way to achieve decarbonization. Hydrogen development will play a strategic role and become the next pillar of decarbonization in both sectors. Therefore, the Indonesian government requires technological applications that can significantly contribute to the energy transition to produce hydrogen.

Based on IEA data (2022), hydrogen demand in Indonesia was around 1.75 million tonnes in 2021, most of which is produced for the needs of the chemical industry and refineries using natural gas as fuel. Hydrogen production through the steam methane reforming process is the most widely used process today, with high thermal efficiency (~85%). However, the steam methane reforming process is highly endothermic (consumes heat), which implies the need for continuous large and high amounts of heat energy in the range of 750-900 °C. Renewable energy resources can offer opportunities to produce hydrogen with low carbon emissions through water electrolysis. However, electrolysis usually operates on a small scale with relatively low electrical conversion efficiency (<35%) and a thermal efficiency of around 25-30% (Salimy 2004). Producing hydrogen on a large scale requires continuous electricity, which is less economical unless electricity is available at a meager price.

With nuclear being one of the lowest-emission fuels, switching to nuclear cogeneration offers a promising decarbonization opportunity for the hydrogen production process. Nuclear cogeneration is a reactor used in addition

to electricity production and utilizes the heat produced by the reactor for industrial processes (non-electric applications) (Setiadipura 2022). A High-Temperature Gas-cooled Reactor (HTGR) is a type of reactor that will be used to produce heat energy as a substitute for fossil fuels to produce hydrogen using an electrolysis process with a thermal efficiency of around 50% (Salimy 2004). In addition, HTGR also generates electrical energy that can be utilized for internal consumption in the production process by channeling some of the heat generated to drive turbines (Setiadipura 2022).

Regarding switching the use of cogeneration nuclear as one of the technological alternatives for low-carbon emissions hydrogen production, a financial model is needed to analyze the feasibility of the investment. A financial model is an essential tool in decision-making by stakeholders, namely the government as a policy maker, and industry players are shareholders and lenders who will become investors. This study uses a systematic framework based on a soft system methodology to identify stakeholders and their relationships in making decisions using financial models. So with the financial model, stakeholders can obtain indicators of the feasibility of the nuclear cogeneration investment plan by considering the impact of risks from uncertainties in the future.

## 2. Literature Review

### 2.1 Low-Carbon Emission Hydrogen as a Decarbonization Strategy for Hard-to-Abate Sectors

Based on data from the MEMR (2020), the energy sector in 2019 recorded 638,452 Gg CO<sub>2</sub>e GHG emissions. Industry and transportation are the hard-to-abate sectors, which are the most significant GHG emission contributors. Figure 1 shows the contribution of GHG emissions from the energy-producing industry at 43.83%, the manufacturing and construction industry at 21.46%, and the transportation sector at 24.64%.

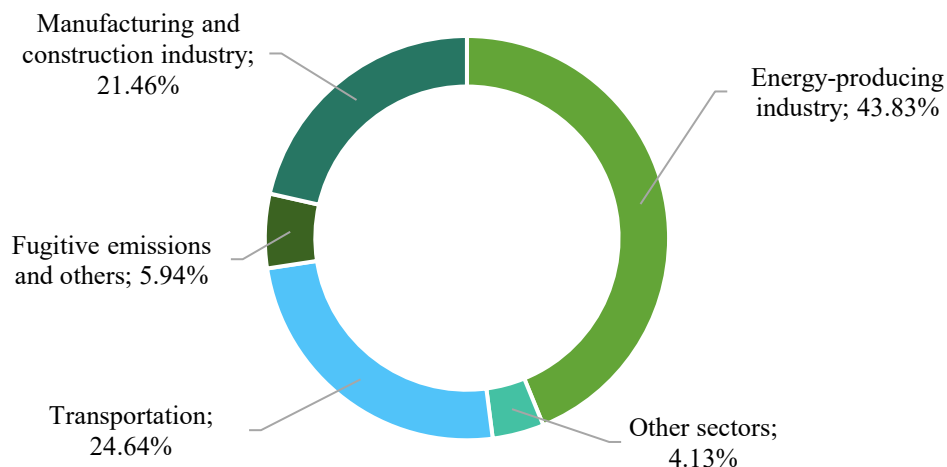


Figure 1. Indonesian Energy Sector GHG Gas Emissions in 2019 (MEMR 2020)

In the future, low-carbon emission hydrogen will have a strategic role and become the key pillar in the decarbonization strategy for the energy system in the harder-to-abate sectors because it will help penetrate the use of clean energy. However, using low-carbon emission hydrogen as an energy source initially took a long time at the end of the NZE transition due to the need for the development of several technologies with low-emission fuels (IEA 2022). Until 2060, production and demand for low-carbon emission hydrogen are estimated to increase in Indonesia's industrial and transportation sectors to replace fossil energy sources, as can be seen in Figure 2 (IEA 2022).

Hydrogen is an energy carrier for various industrial processes. For example, in oil refineries, hydrogen is required as a hydrodesulfurization agent to improve the quality of petroleum fuels. In the fertilizer industry, hydrogen is required as a raw material for ammonia (NH<sub>3</sub>) for the manufacture of urea fertilizer (Institute for Essential Services Reform (IESR) 2022). In other chemical industries, hydrogen is required to manufacture methanol (CH<sub>3</sub>OH).

Methanol is a chemical compound widely used as a solvent in organic and inorganic compounds to act as a reagent for forming formaldehyde or methyl ester, which is widely used as an anti-freezing agent in the automotive and aircraft industries (Salimy 2015). In the future, hydrogen is required as a substitute for coking coal in the steel industry is expected to reduce carbon emissions (IESR 2022). Meanwhile, in the future transportation sector, hydrogen is required as a fuel cell in electric vehicles (IEA 2022).

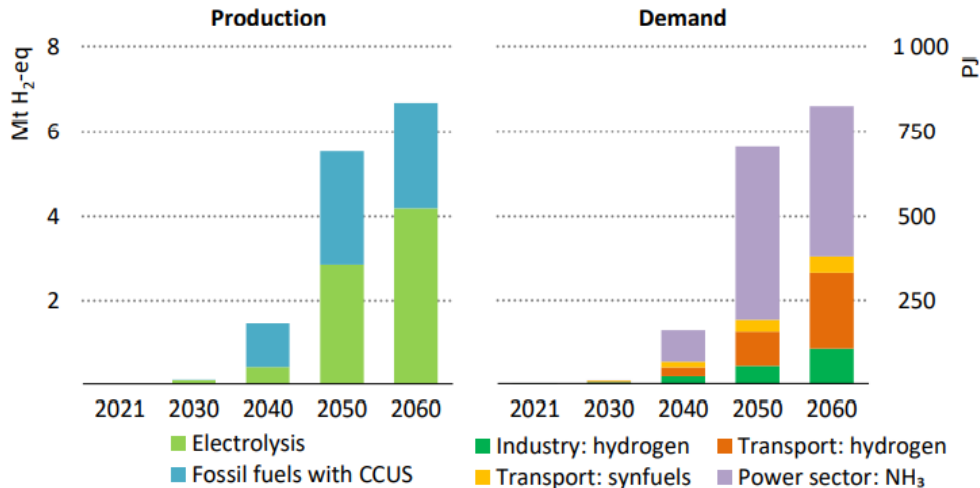


Figure 2. Scenario for Estimating Hydrogen Production and Demand in Indonesia (IEA 2022)

## 2.2 Nuclear Cogeneration for Low-Carbon Emission Hydrogen Production

Since operating in the mid-20th century, nuclear energy has contributed to decarbonization efforts and will continue to do so. Based on data from the United Nations Economic Commission for Europe (UNECE) (2022), the average life cycle GHG emissions from nuclear generated in 2020 is only around 4.9 - 6.3 g CO<sub>2</sub>e per Kwh, lower than renewable energy sources such as which can be seen in Figure 3. In February 2022, the European Union Commission declared nuclear as green energy (Brussels 2022).

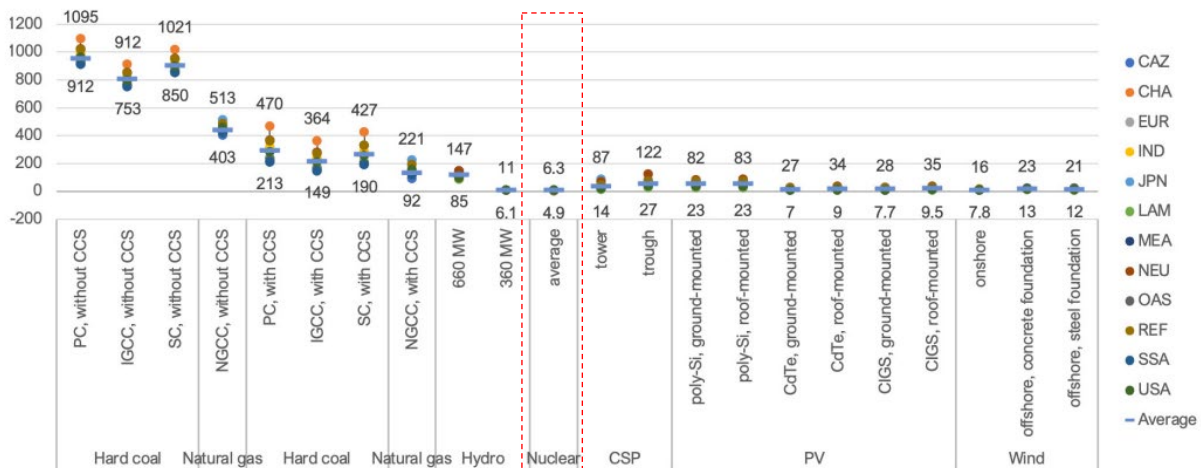


Figure 3. Average Life Cycle of GHG Emissions in 2020 (UNECE 2022)

In addition to being a source of electricity, nuclear technology has also been used as a source of heat for industrial purposes e.g seawater desalination, paper and cardboard manufacturing, heavy water production, hydrogen production, and salt purification. The application of electricity and non-electricity is a function of nuclear cogeneration, which provides many benefits to the economy, environment, and efficiency. Cogeneration is a series

of generations of two or more different forms of energy from one type of generator (Dewita 2019). The energy flow system in nuclear cogeneration is shown in Figure 4 below.

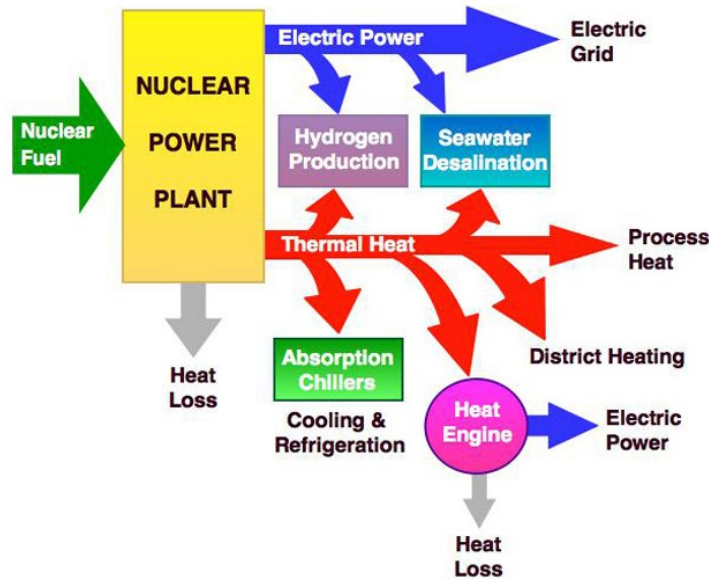


Figure 4. Energy Flow System in Nuclear Cogeneration (Source: IAEA 2022)

Nuclear cogeneration with the HTGR type offers an alternative technology for low-carbon emissions hydrogen production on a large scale. The HTGR is one of the fourth-generation nuclear technologies that can generate heat at high temperatures (750-950°C). HTGR technology has been technically proven based on the development and operational experience of several experimental and commercial-scale demonstration reactors (Nuclear Energy Agency 2022). Figure 5 below shows the HTGR design plan for low-carbon emission hydrogen production.

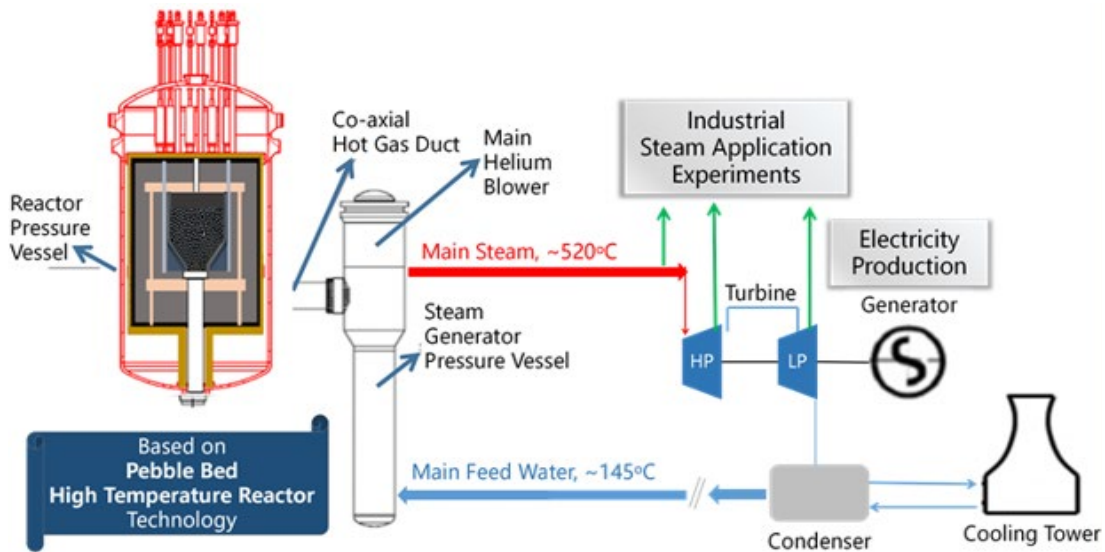


Figure 5. High-Temperature Gas-cooled Reactor (Priambodo et al. 2022)

Hydrogen is produced through electrolysis using heat energy from nuclear cogeneration, which separates water into hydrogen and oxygen. In addition, some of the heat generated by nuclear cogeneration will be used to drive turbines that produce the electricity needed for the internal needs of the nuclear reactor.

### **2.3 Designing a Financial Model to Support Investment Decision-Making**

Financial modeling is a representation in numbers of a company's operations in the past, present, and the forecasted future that are intended to be used as decision-making tools (Kopp 2022). Financial modeling is about decision-making and forecasting (Samonas 2015). In making decisions based on the feasibility study of a business project, forecasting future cash flows is very important because an investment can be made with cash. In addition, with cash, financial obligations can be paid (Husnan et al. 2014). Therefore, the expected future investment net cash flow can be estimated using the Discounted Cash Flow (DCF) method (Fernando 2022).

Several indicators are usually considered for use in feasibility studies using the DCF method i.e Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). NPV is the difference between the present value of the investment and the present value of all net cash receipts (from operations and terminal cash flows) in the future. Meanwhile, IRR calculates the cost of capital, which equates the present value of the investment with the present value of all net cash receipts in the future. Finally, to calculate the return on investment capital, we can use PP (Husnan, et al. 2014).

A financial model requires to be designed to support investment decision-making for stakeholders, the government as a regulator, and shareholders and lenders as investors. The financial model that has been designed is also required to be developed. The financial model of nuclear cogeneration will be developed to estimate the Levelized Cost of Hydrogen (LCOH). LCOH is a method used to calculate the overall capital costs and operating costs of hydrogen production and allows comparisons to be made on the same basis from different production processes (Perkins 2019). The financial model of nuclear cogeneration will also be developed to examine the impact of risks from various sources of uncertainty using the Value at Risk (VaR) method. VaR is a statistical measurement technique that can explain the risk of reduction (Jorion 2003).

### **2.4 A Systems Framework Analysis Based on Soft Systems Methodology**

This study uses a system-based approach with a soft system methodology. The soft system methodology is a set of methods, and each method is represented by a set of ideas (concepts) structured in such a way that their use is appropriate to the situation being analyzed (Wilson 2001). The primary benefit of SSM is in analyzing complex cases where there are divergent views about the definition of the problem (Reynolds 2010).

The SSM consists of seven stages of the process: define the problematic situation, express the situation, select concepts that may be relevant iterations, assemble concepts into an intellectual structure, use the structure to explore the situation, define changes to the situation, and implement change processes. In this study, we are only implementing process stages first to fourth of the SSM approach. The next stages (fifth to seventh) will be implemented in further research.

## **3. Research Method**

There are four stages of the SSM process implemented in this study. The first and second stages are an understanding of the problem situation explored from all perspectives. In the exploration process, it is necessary to find out about real-world problems related to the application of nuclear cogeneration technology and investment for low-carbon emission hydrogen production as a decarbonization solution in Indonesia's industrial and transportation sectors. The decision-making for nuclear cogeneration investment plans will use financial models that have been described by applying a visual tool, namely a rich picture.

The third stage is developing a root definition of a relevant purposeful activity system using Customer, Actors, Transformation, Weltanschauung or Worldview, Owner, and Environment (CATWOE) analysis. Finally, the fourth stage is developing a conceptual model of the system named in the root definition. The root definition and conceptual model are ideally developed based on real-world conditions, which will be compared with the existing conditions in the real world.

## 4. Result and Discussion

### 4.1. Problem Situation and Descriptions

Nuclear cogeneration is an alternative clean energy technology that can be applied to produce low-carbon emissions hydrogen. Using low-carbon emission hydrogen has a strategic role in achieving the target of NZE 2060 or sooner. It is also the key pillar of decarbonization in Indonesia's industrial and transportation sectors.

Building nuclear cogeneration for low-carbon emissions hydrogen production requires an investment plan from the government and both shareholders and lenders as investors. Through the Ministry of State Enterprises, the government will encourage State-Owned Enterprises to invest as the majority shareholder by establishing a Special Company Purpose to build a nuclear cogeneration project. The government can also invite private companies to participate as investors or minority shareholders in the Special Company Purpose. On the other hand, for lenders interested in developing a nuclear cogeneration project, the government has to conduct policies related to loan guarantees.

The stakeholders involved in the nuclear cogeneration investment plan, including the government and shareholders and lenders as investors, will need a financial model as a tool for decision-making. The problem situation of the decision-making of cogeneration nuclear technology investment plans can be seen in Figure 6.

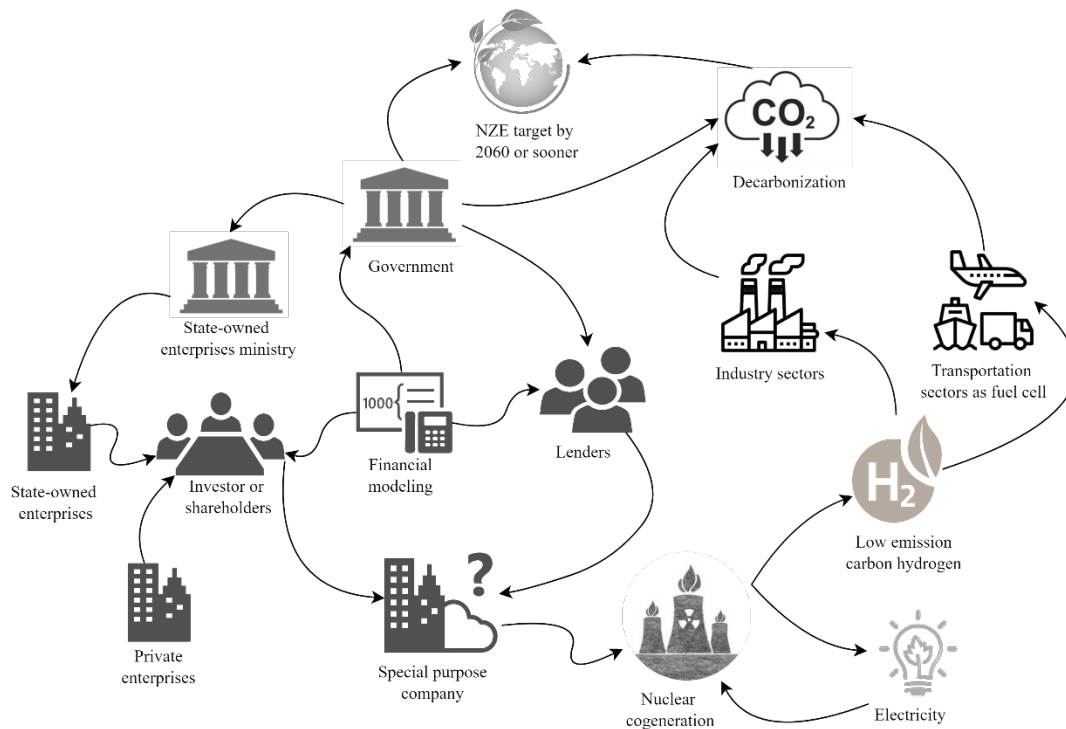


Figure 6. Rich Picture of Nuclear Cogeneration Investment Plan Decision-Making

### 4.2. Defining Systems' Problem

The main problem in this system is that stakeholders need a financial model to decide on plans to apply and invest in nuclear cogeneration technology for low-carbon emission hydrogen production. The CATWOE analysis developed from the root definition of the system can be seen in Table 1.

Table 1. The CATWOE Analysis

Root Definition	CATWOE	Elements
The decision-makers need a financial model in making decisions on the application and investment of nuclear cogeneration for low-carbon emission hydrogen production	Customer	Low-carbon emission hydrogen customers in the industrial and transportation sectors
	Actors	1. Government 2. State-Owned Enterprises and private companies as shareholders of a Special Company Purpose as owners of nuclear cogeneration investment plans 3. Lender(s)
	Transformation	Application and investment of nuclear cogeneration technology for low-carbon emissions hydrogen production
	Worldview	Decarbonization of the industrial and transport sectors to achieve the NZE target of 2060 or sooner
	Owner	Government
	Environment	Investment decision-making tool and policy maker

Analysis of the roles of the actors in the transformation process is presented in Table 2. The analysis of decision-making actors shows the perspective of a problem perception, objective(s), interest(s), causes of the problem(s), resource(s), and position of each actor.

Table 2. The Analysis of Decision-Making Actors

	Actor(s)		
	Government	Shareholder(s)	Lender(s)
<b>Problem Perception</b>	Employment of clean energy technologies in the industrial and transportation sectors	Willingness to invest in nuclear cogeneration for low-carbon emission hydrogen production	Willingness to invest in nuclear cogeneration for low-carbon emission hydrogen production
<b>Objective(s)</b>	NZE 2060 or sooner	Optimal equity rate of return	Optimal debt rate of return
<b>Interest(s)</b>	Decarbonization in the industrial and transportation sectors	Dividends from a Special Company Purpose (as the owners of the cogeneration nuclear project) and support the government's decarbonization policy	Operating income from payment of loan principal and interest expense from a Special Company Purpose (as the owner of nuclear cogeneration project)
<b>Causes of Problem(s)</b>	The need for designing a financial model for financial feasibility analysis as an initial step before conducting a Cost Benefit Analysis in policy and decision making	The need for designing a financial model for financial feasibility analysis in decision-making	The need for designing a financial model for financial feasibility analysis in decision-making
<b>Resource(s)</b>	Authority as a regulator in planning the application and investment of clean energy technology	Financing resource	Financing resource
<b>Position</b>	The Policy-makers and decision-makers	The decision-makers	The decision-makers

### 4.3. Conceptual Model of System's Problem

From the CATWOE framework, the conceptual model of an ideal system is described in the system diagram in Figure 7.

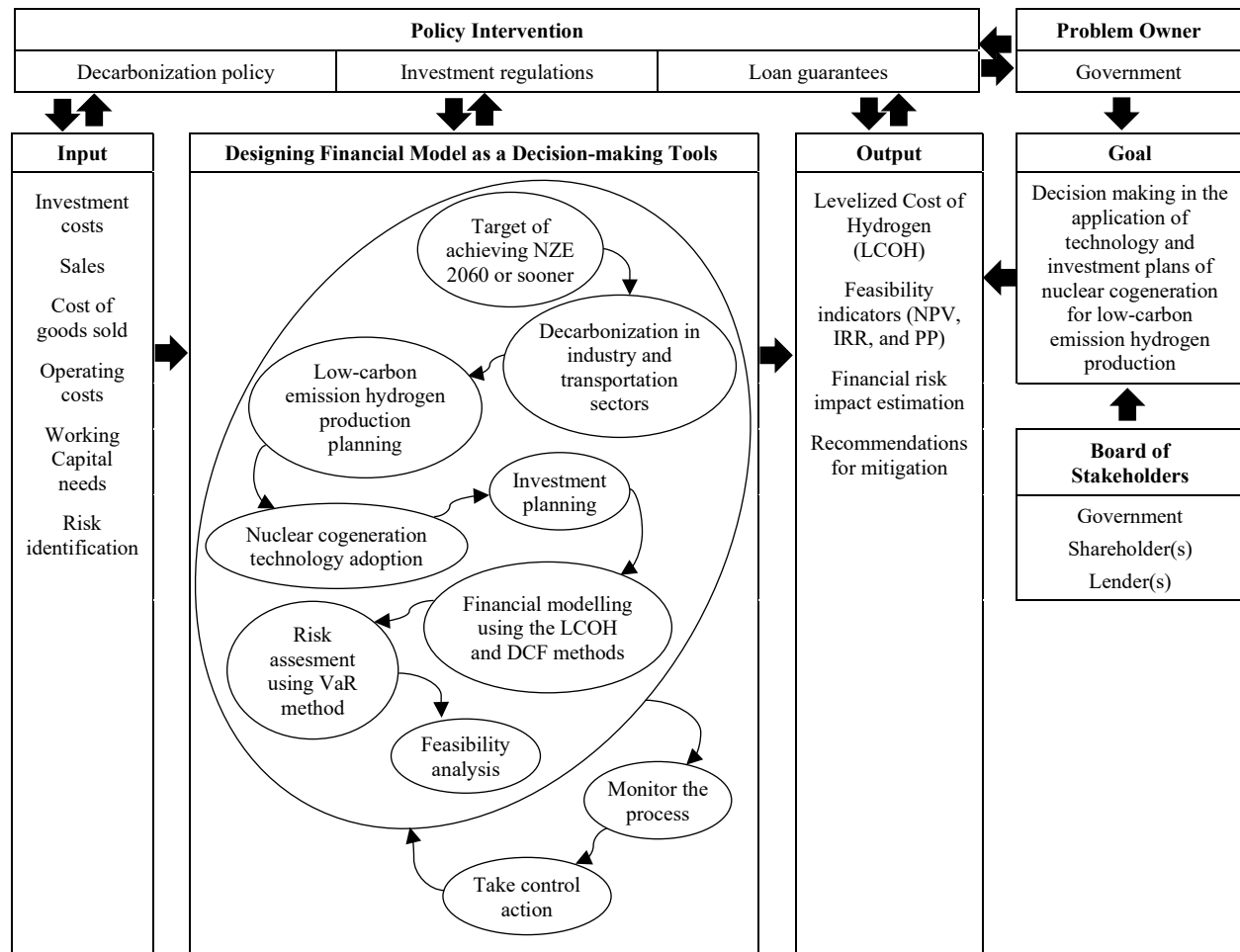


Figure 7. System diagram in the Designing Financial Modeling for Nuclear Cogeneration Investment Planning

The government (as the owner of the problem and also the board of stakeholders) can conduct the following three policy interventions: the establishment of decarbonization policies, investment regulations, and loan guarantees. The shareholder(s), as one of the board of stakeholders, planned to invest in nuclear cogeneration technology. Furthermore, the shareholder(s) also expect a rate of return or dividends from developing new business segments through establishing a Special Company Purpose. The Special Company Purpose is to be a business entity that will become the nuclear cogeneration project plan owner. Other stakeholders, i.e., interested lenders, can also invest in the project plan and expect a rate of return.

The objective of the system's transformation is making decisions regarding the application of technology and investment plans for nuclear cogeneration for low-carbon emission hydrogen production. Inputs to the system are investment costs, sales, cost of goods sold, operating costs, working capital needs, and risk identification. The outputs generated by the system are the Levelized Cost of Hydrogen (LCOH), feasibility indicators (NPV, IRR, and PP), financial risk impact estimation, and recommendations for mitigation.

### 5. Conclusion

The designing financial model for the feasibility analysis on investment planning of nuclear cogeneration for low-carbon emissions hydrogen production needs to be conducted as a decision-making tool for stakeholders, namely the



government, investors or shareholders, and lenders. The nuclear cogeneration investment decision is an alternative solution to decarbonization in the industrial and transportation sectors.

The results of this study have identified stakeholders and their relationships as actors who need financial models as a decision-making tool. The systemic framework analysis using the SSM has provided benefits in this study. The use of SSM in the study could clarify the essential aspects that must be considered in designing a financial model in nuclear cogeneration investment planning following the multi-actor mapping and other variables. In future research, it is necessary to design a financial model to obtain analysis and indicators of the feasibility of the investment plan by considering risk factors for future uncertainty.

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