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THE MULTIPLIER EFFECT AND DYNAMIC SYSTEM MODELING FOR SUSTAINABLE DRINKING WATER RESOURCE MANAGEMENT (CASE STUDY OF PERUMDA TIRTA PAKUAN, BOGOR CITY)

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Abstract

Background: Clean water is an essential basic need for the community, so its management must be carried out sustainably.
Purpose: This study aimed to quantify the multiplier effect on economic, social, and environmental aspects of the existence of Perumda Tirta Pakuan Kota Bogor for the period 2025-2029 and project the availability of managed drinking water.
Design/methodology/approach: The data used in this study are secondary data from both internal sources at Perumda Tirta Pakuan (annual reports and the company website) and macroeconomic data for the city of Bogor obtained from various sources relevant to the purpose of the study. Data analysis in this study used a systems approach, namely a hard system methodology, namely dynamic systems. The dynamic systems approach was used through the stages of input-output diagrams, causal loop diagrams (CLD), and stock flow diagrams (SFD) using Vensim PLE Version 10.3.2 software. Then the model's prediction results were verified and validated through face validity in two FGDs involving experts and practitioners from drinking water management, resulting in a model that is scientifically accountable and well-tested.
Finding/Result: The results of the study show that clean water production capacity remains stable at 2.59 m³ per second, whereas usage increases from 1.86 m³ per second in 2025 to 2.26 m³ per second in 2029. Thus, there is a surplus of 0.33 m³ per second or around 10.4 million m³ per year in 2029, which opens up opportunities to expand customer service coverage. This surplus not only guarantees the availability of clean water for the community, but also strengthens the multiplier effect that drives economic productivity and increases the purchasing power of the people of Bogor City.
Conclusion: These findings confirm that dynamic system-based planning is important not only to maintain the continuity of clean water supply, but also to maximize its contribution to comprehensive regional development.
Originality/value (State of the art): This study provides an up-to-date review by integrating sustainability analysis (triple bottom line) into a dynamic system model for water utilities. Its originality lies in its ability to measure the indirect impacts (multiplier effects) of clean water services on economic productivity and public purchasing power, which are often overlooked in company performance assessments. The findings regarding surpluses that create opportunities for service expansion are practical contributions that policymakers can directly act upon, specifically in Bogor City and more generally in Indonesia.

Keywords: drinking water, dynamic system, perumda tirta pakuan, vensim, water resources

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NTRODUCTION

Clean water is a basic human need and a strategic factor in supporting economic, social, and environmental development. Adequate water availability not only affects the quality of life of the community, but also creates a significant multiplier effect on household, industrial, trade, and tourism economic activities. The city of Bogor, with a population of more than 1.1 million and an average growth rate of 1.23% per year (BPS, 2024), faces serious challenges in ensuring the sustainability of clean water supply amid rapid urbanization and the expansion of new residential areas. In this context, the Regional Public Company (Perumda) Tirta Pakuan serves as the main provider of clean water with a service coverage of 66.04% or equivalent to 180,597 customers (Public Accountant Audit Results, 2024). Perumda's role is not only limited to meeting the basic needs of the community, but also as a driving force for regional economic growth through its contribution to social welfare and Regional Original Income (PAD).

Perumda Tirta Pakuan is a Regional Owned Enterprise (BUMD) that contributes the most to the Local Revenue (PAD) of Bogor City. In 2021, Perumda Tirta Pakuan contributed the most to the total of approximately Rp 32.4 billion in BUMD profit deposits, with Rp 22.6 billion (including taxes and dividends), surpassing the contributions of BJB and Perumda Pasar Pakuan Jaya (Anonim, 2021). The Acting Mayor of Bogor officially expressed his appreciation for Perumda Tirta Pakuan's contribution to PAD, through dividends and taxes. The government considers this BUMD to be at the forefront of driving the regional economy, including through added value to the GRDP and employment, as well as its nationally recognized service achievements (Anonim, 2024).

Over the past decade, Perumda Tirta Pakuan has shown asset and revenue growth of up to 100%, with an annual profit increase of 5.63%. The number of customers also increased significantly by 60,000, reaching a total of 178,000 customers. In addition, the company added three new Water Treatment Plants (WTP): Unitex, Cipinang Gading, and Palasari, and successfully reduced non-revenue water (NRW) to 7.8% since 2014 (Anonim, 2023). Perumda Tirta Pakuan also actively implements corporate social responsibility (CSR) programs. For example, in 2020, they allocated Rp 175 million from the company's profits for the renovation of uninhabitable houses (RTLH), demonstrating their commitment to social development and the quality of life of the people of Bogor City (Anonim, 2020).

Research by Putri and Samsuddin (2025) confirms that access to clean drinking water has a real impact on reducing poverty rates. A panel study of 18 districts in West Java during the 2020–2024 period shows that a 1% increase in access to clean drinking water can reduce poverty rates by 0.05784% (p-value = 0.0484). These findings provide empirical evidence that clean water is not only a basic need but also an important instrument for reducing household expenditure, increasing productivity, and expanding economic opportunities. Therefore, the sustainability of Perumda Tirta Pakuan's performance needs to be assessed not only from a financial perspective, but also from the socio-economic contributions it generates.

At the global level, Amorocho-Daza et al. (2023) found that access to basic water services has a positive reciprocal relationship with the Human Development Index (HDI). A 1% increase in HDI correlates with a 1.3–3.2% increase in water and sanitation coverage, reinforcing the argument that clean water is an instrument of sustainable development transformation. Furthermore, Ortiz-Correa et al. (2016) added an important perspective on the social impacts of clean water. Their research in Brazil showed that children from households with tap water connections spent an average of 0.7 years longer in formal education than those without access. This fact confirms that investment in clean water infrastructure directly supports the improvement of human resources through education and health.

However, the challenges faced by the city of Bogor are quite complex, one of which is the high rate of water loss or NRW, which reaches 24.96%. Based on a World Bank study by Kingdom et al. (2006), the amount of NRW due to network leaks and a weak billing system causes significant losses to water utilities. They suggest implementing performance-based service contracting as an effective strategy to reduce water loss rates. This situation emphasizes that improving governance and infrastructure efficiency are key requirements for clean water services to be more inclusive and reach communities with limited access. On the other hand, the availability of drinking water resources managed by Perumda Tirta Pakuan in Bogor City is still quite abundant, while the market potential remains large and many residents still use drinking water sourced from wells or other sources, rather than from the Bogor City Water Utility (PDAM). The question is whether the community has not yet realized the importance of the water resource management provided by Perumda Tirta Pakuan Bogor, which is why many still use well water? What is the multiplier effect of the existence of Perumda Tirta Pakuan in terms of economic, social, and environmental aspects? What is the projected balance of supply and demand for clean water in Bogor City for the years 2025-2029?

An empirical study in Cirebon Regency shows that PDAM services only cover around 31.66% of the population, while the rest still rely on independent water sources. The projected demand for clean water is estimated to increase by 15.72% per year over the next five years, or 3.93% per year over the next 20 years, indicating a potential crisis if not balanced with an increase in production and distribution capacity (Fasa et al. 2020). This study emphasizes the urgency of long-term planning to achieve the government's target of 100% service coverage.

In addition, Banyuurip revealed that although water availability in 2020 (234.81 l/sec) was still higher than the projected demand in 2025 (186.73 l/sec), water distribution faced serious technical challenges. Only 25.5% of the pipe network nodes met the pressure standards and 14% met the flow velocity standards. Through the development of the pipe network, the standard achievement can be increased to 95.9% of the nodes, which confirms that improving the distribution system is as important as increasing production capacity (Setiawan et al. 2024).

Dynamic system models have been applied by various researchers in the context of water resources. For example, Komariah and Matsumoto (2021) used a dynamic system to assess the impact of river restoration plans in the Upper-Middle Ciliwung River Basin. The results show that interventions such as irrigation efficiency and the use of reclaimed water can significantly reduce water pressure. Meanwhile, Rubio-Martín et al. (2020) built a dynamic system model for the Júcar River in Spain to support drought management. Their research showed that simulation-based strategies can help reduce the economic impact of dry seasons through adaptive reservoir operations. Thus, dynamic systems are relevant in this study to analyze the multiplier effect and project the availability of clean water managed by Perumda Tirta Pakuan Bogor City. This is quite reasonable because the causal loop diagram (CLD) can map cause-and-effect relationships between variables, both reinforcing loops and balancing loops, and the existence of the stock flow diagram (SFD) plays an important role in depicting changes in stocks (accumulations) and flows, so that system dynamics can be consistently tracked over time. Finally, time-based simulations allow the analysis of various future scenarios based on certain assumptions, especially regarding the availability and demand for drinking water. Thus, this study hypothesizes that the dynamic system model will show significant positive multiplier effects on the Bogor economy and identify a sustainable water surplus until 2029.

This research focuses on the existence valuation of Perumda Tirta Pakuan, including economic, social, and environmental valuation for the city of Bogor, and predicts the adequacy of drinking water needs that can be supplied by Perumda Tirta Pakuan according to the population growth rate and development rate in the city of Bogor. The study aims to analyze the multiplier effect of the regional drinking water company's presence in Bogor and to analyze projections of managed drinking water availability. The results of the study are expected to produce a model that can project a stable water surplus, quantify opportunities for service expansion, and provide a basis for formulating a more equitable, effective, and sustainable water management policy strategy for the people of Bogor.

METHODS

This research was conducted from May to August 2025 at Perumda Tirta Pakuan in Bogor City. The data and information collected were qualitative and quantitative. The data used in this study were secondary data from both internal sources at Perumda Tirta Pakuan (annual reports and the company's website) and macroeconomic data on Bogor City obtained from various sources relevant to the purpose of the study.

This research was conducted at Perumda Tirta Pakuan Bogor from May to August 2025. Perumda Tirta Pakuan Bogor is a regional company that provides drinking water to the people of Bogor City and its surroundings. This study used primary and secondary data. Primary data were obtained from the results of focus group discussions (FGD) involving experts/ key persons, drinking water management business operators, and other stakeholders to ensure the drinking water/water resource management business processes, confirm the variables used, and verify and validate the resulting model (face validity). As stated by Sargent (1998), model verification is often defined to ensure that the computer program of the analysis model and its implementation are correct. The validation and verification of models are related to the process of developing models for a specific purpose or application. A model is considered valid under certain conditions of a study, requiring an acceptable level of accuracy. In this study, verification and validation use face validity as stated by Sargent (1998), who argued that validation can be conducted by using or seeking the opinions of experts who are truly knowledgeable about the issue, especially in the development of predictive models for dynamic systems used in projecting drinking water resources for Perumda Tirta Pakuan Bogor. In addition, this study uses secondary data derived from the operational data of Perumda Tirta Pakuan Bogor (BPS, 2024) and the macroeconomic data of Bogor City for the period from 2021 to 2024.

The data processing and analysis method in this study uses a systems approach, namely the hard system methodology, specifically system dynamics. To provide a more comprehensive understanding, this study also applies dynamic system analysis. This approach is used to comprehensively illustrate the multiplier effect generated by the presence of Perumda Tirta Pakuan. The analysis takes into account various important variables, such as the customer growth rate, water usage rate, raw water discharge capacity, water tariff rate, and operational costs, in order to provide a more accurate projection of the long-term sustainability of water resource management using secondary data from Perumda Tirta Pakuan Bogor's Annual Reports from 2021-2024.

The dynamic system model is an effective simulation approach for understanding the behavior of complex systems through feedback, stock, and flow structures. Based on Richardson's (2011) research, this method focuses on interrelated cause-and-effect relationships, enabling it to explain how the dynamics of a system develop in the long term. This approach is widely used in the economic, social, and environmental fields due to its ability to analyze the impact of policy interventions in a sustainable manner.

The main principles of dynamic systems include three components. First, CLD is used to map the cause-and-effect relationships between variables in the form of feedback loops, both reinforcing loops and balancing loops. Second, SFD, which according to Martinez-Moyano (2013) plays an important role in describing changes in stock (accumulation) and flow, so that system dynamics can be tracked consistently over time. Third, time-based simulations allow for the analysis of various future scenarios based on specific assumptions. This provides policymakers with the opportunity to test various alternative strategies before implementing them in real-world contexts.

In addition to these three principles, input-output diagrams (IOD) are used in dynamic system modeling. These diagrams serve to illustrate how input variables, such as government policy, population growth, or rainfall affect process variables, which ultimately produce outputs, such as clean water availability, service quality, or socio-economic impacts. According to Elsawah et al. (2017), the use of IOD is very helpful in the early stages of modeling because it can simplify the complexity of the system and facilitate communication between researchers and stakeholders. By integrating CLD, Stock & Flow, time-based simulation, and IOD, dynamic system modeling is able to provide a more holistic picture of the interactions between variables and projections of their impact on system sustainability.

The framework of the dynamic system for the Existence Valuation Model of Perumda Tirta Pakuan, Bogor City, is illustrated in Figure 1. The framework of the dynamic system for the Existence Valuation Model of Perumda, using the system water management meta-model in the scope of coupled human and natural systems approach (R = reinforcing loop, B = balancing loop, + = positive causal effects, – = negative causal effects), was adapted from Liu et al. (2024). Then the model's prediction results were verified and validated through face validity in two FGDs involving experts and practitioners from drinking water management, resulting in a model that is scientifically accountable and well-tested.

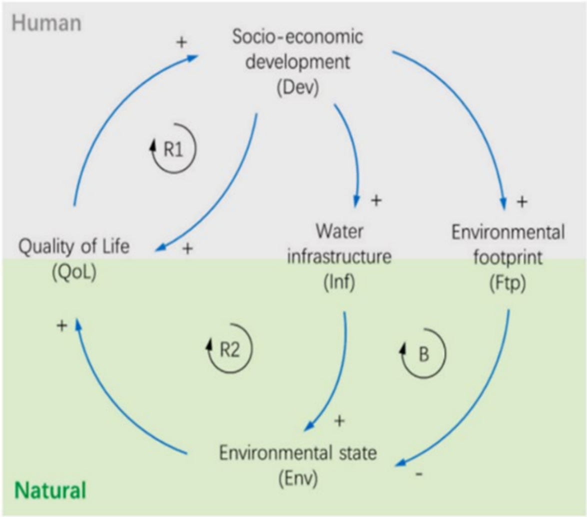

Figure 1. Conceptual framework of the dynamic system for the existence valuation model (Liu et al. 2024)

RESULTS

Stakeholder Analysis

In developing a dynamic system to assess the existence of Perumda Tirta Pakuan and understand its multiplier effect on economic, social, and environmental aspects, the involvement of various parties or stakeholders is crucial. Stakeholder participation in dynamic system modeling has been proven to increase the collective understanding of system complexity and strengthen the legitimacy of the model results. Rouwette et al. (2002) emphasize that stakeholder involvement in the joint modeling process results in shared learning that contributes to the quality of policy decisions. Rahmanea & Rarasati (2024) examined the dynamics of stakeholder involvement in drinking water infrastructure using the interpretative structural modeling (ISM) method. The main findings highlight that the Ministry of Planning (Bappenas), PUPR, and local governments are included in the "Manage Closely" quadrant, meaning they have high influence and significant interest in the provision of proper drinking water. This confirms the important role of local governments (such as the Bogor City Government) in tariff regulation, policy formulation, and subsidy allocation.

Dynamic systems are not only technical representations of water or financial flows but also reflections of the complexity of interactions between actors with interrelated interests, influences, and responsibilities. Stave (2003) shows that community involvement in dynamic water modeling in Las Vegas can increase public understanding of water management policy options. This confirms that each stakeholder has a unique and complementary role: the government as a policy regulator, water companies as service providers, the community as beneficiaries, and health and environmental agencies as guardians of quality of life and resource sustainability.

Darmastuti et al. (2023) conducted a stakeholder analysis in sustainable domestic waste management in the city of Bogor. The MACTOR analysis results show that PDAM (Perumda), DINKES, the Environmental Agency (DLH), Bappeda, DPUPR, Disrumkim (housing), and DPRD are the most influential stakeholders. This reflects the importance of collaboration among government agencies, Perumda, and the community in water system management.

Through a dynamic systems approach, the impact of one party's decisions on other variables can be traced, both in the short and long term. Videira et al. (2010) emphasize that stakeholder integration in dynamic systems is crucial for designing more effective and equitable policies, especially in complex environmental issues. Therefore, understanding the roles of each stakeholder holistically is not only important for building accurate models and designing sustainable and inclusive policy interventions.

The following describes the key roles of the main stakeholders in this context and how their contributions are integrated into a dynamic system that reflects the reality of clean water management in the Bogor City area (Table 1). The key roles of these stakeholders are based on a synthesis of various references and reinforced by interviews and discussions with stakeholders, experts, and practitioners.

Input-Output Diagram

In understanding the existence and impact of clean water companies, an important first step is to identify all elements that enter and exit the system. Input-output diagrams are an initial visualization tool that can comprehensively illustrate the flow of resources, energy, information, and outputs in a system. This approach is in line with research showing that multi-objective input-output models can integrate economic planning, water supply, and environmental aspects in a resource-based urban context, thereby representing the complexity of inter-sectoral relationships (Ke et al. 2016).

Table1. Stakeholder roles

Stakeholder	Role
Bogor City Local Government	Formulator of clean water tariffs and regulations.
	Provider of subsidies for the poor.
	Supervisor of the social and environmental impacts.
Clean Water Company (Perumda Tirta Pakuan)	Operational manager of clean water systems (production, distribution, and maintenance).
	Water efficiency technology innovator.
	Data recorder for services and finances that serve as inputs for the model.
Community/Customers	Primary beneficiaries (access to water and health).
	Providing feedback on service satisfaction.
	Actors in changing water consumption behavior.
Health Department	Providing data on the impact of clean water on public health.
	Monitoring sanitation and water-related diseases (WASH).
Environmental Agency	Assessing the environmental impact of water extraction and disposal.
	Overseeing the sustainability of water sources (groundwater, rivers, and springs).
Public Works/Infrastructure Agency	Building and maintaining water pipeline and treatment infrastructure, as well as drainage systems.
	Providing the necessary infrastructure data in stock-flow diagrams.
Local Business/Industry	Large consumers of clean water, providing a significant economic impact.
	Part of the multiplier effect in the production sector.
NGOs/Civil Society Organizations	Advocating for the right to water and social justice.
	Educating the public and encouraging community participation.
Academics and Researchers	Designing dynamic system models and analyzing policy scenarios.
	Generating data and recommendations based on scientific studies.
Financing Institutions/Donors (e.g., corporate CSR)	Funding Institutions/Donors (e.g., corporate CSR)
	Providing financial support for infrastructure development and valuation studies.
	Promoting the application of sustainability principles in water-business models.
National Regulators (Ministry of Public Works and Public Housing, National Development Planning Agency, Ministry of Finance, Ministry of Health)	Develop macro policies and minimum service standards.
	Providing valuation guidelines and multiplier-effect calculations.

Furthermore, Mohan et al. (2021) developed an input-output framework to evaluate direct and indirect water consumption at the provincial level in Indonesia, emphasizing the importance of a multisectoral perspective in understanding the link between clean water availability and economic development dynamics. This is reinforced by Cámara and Llop (2021), who added sustainability indicators, such as the water exploitation index (WEI), to the input-output model, thereby facilitating the analysis of water use pressures and their impact on socio-economic systems. Furthermore, Gelo and Knez (2021) through the application of a hybrid input-output model in analyzing water consumption in the Croatian industrial sector show how the distribution of benefits and risks can be mapped systematically. Thus, input-output diagrams are not merely conceptual tools but also an important foundation for building more complex dynamic system models, such as causal loop diagrams and stock flow diagrams. The input-output diagram model for the valuation of Perumda Tirta Pakuan is explained in detail in Figure 2.

The input-output model in the management of Perumda Tirta Pakuan in Bogor City illustrates the complex relationship between inputs, control management, and outputs. This framework provides a comprehensive overview of how internal and external resources are managed to produce clean water services. Thus, this model serves as an important strategic analysis tool for maintaining the sustainability of the company's services.

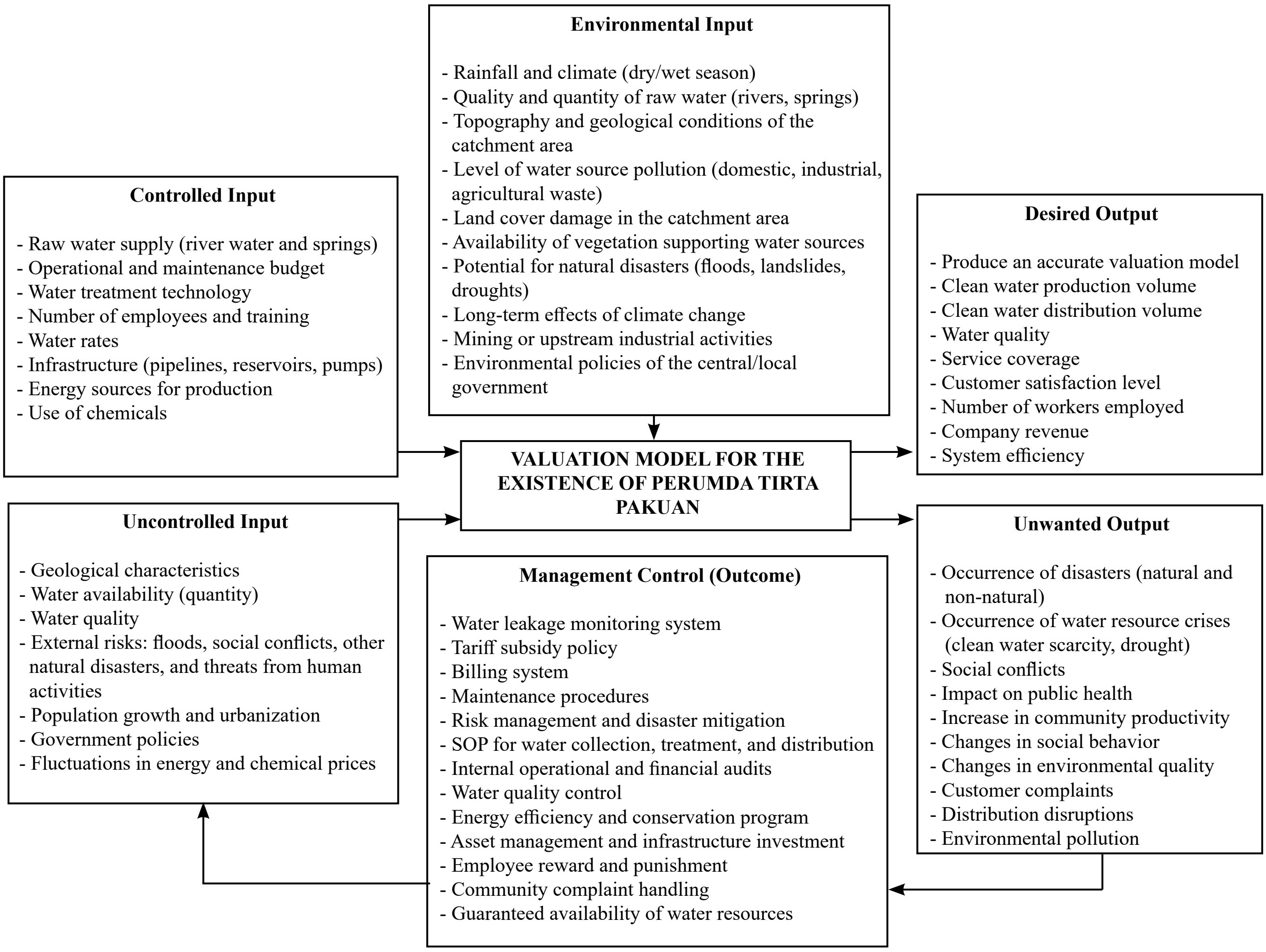

Figure 2. Input-output diagram of the valuation of Perumda Tirta Pakuan

First, controlled inputs include internal resources that can be directly managed by the company. These include the amount of raw water from rivers and springs, operational and maintenance budgets, the application of water treatment technology, the number of workers and their training, water tariff setting, the construction and maintenance of infrastructure such as pipelines, reservoirs, and pumps, and the fulfillment of energy and chemical needs for production. All of these factors are strategic instruments that can be directed to improve efficiency and service quality so that the company is able to maintain its operational sustainability.

Second, uncontrollable inputs reflect external factors that are difficult for companies to control but significantly affect service performance. Examples include geological conditions, the availability and quality of raw water, and external risks such as floods, social conflicts, and other natural disasters. In addition, population growth and urbanization drive an increase in water demand, whereas government policies and fluctuations in energy and chemical prices can create operational uncertainties that must be anticipated adaptively.

Third, environmental inputs describe the ecological variables that form the basis of the sustainability of the raw water supply. These factors include rainfall, climate, topography, and geology of the catchment area, pollution levels from domestic, industrial, and agricultural activities, as well as forest destruction and land cover changes. The availability of vegetation that protects water sources, the potential for disasters such as landslides and droughts, the long-term impacts of climate change, and mining or industrial activities upstream are also decisive factors. Furthermore, environmental policies from the central and regional governments are important references for preserving water resources from degradation.

All of these inputs are then processed through a control management system implemented by Perumda. This mechanism includes a water leakage monitoring system, tariff subsidy policies, a transparent billing system, and scheduled infrastructure maintenance procedures. In addition, risk management and disaster mitigation, SOPs for water collection, treatment, and distribution, internal audits, and water quality control are integral parts of the system. Energy conservation efforts, asset management, a reward-punishment system for employees, and a public complaint mechanism also help maintain service effectiveness. Most importantly, management strives to ensure the long-term sustainability of water resources so that services are not disrupted by external factors.

This process produces the desired outputs, including an appropriate valuation model to support planning, increased production and distribution of clean water, guaranteed water quality, and expanded service coverage. Other positive impacts include increased customer satisfaction, employment, increased company revenue, and overall system efficiency. Thus, the outputs produced strengthen the company's position as a reliable public service provider.

However, undesirable outputs are also a consequence of system dynamics. These can take the form of water resource crises due to scarcity or drought, natural and non-natural disasters, and social conflicts that affect the sustainability of water distribution. Other negative impacts include a decline in public health, changes in social behavior, environmental degradation, pollution, and customer complaints due to distribution disruptions. Therefore, the company needs to prepare mitigation strategies to minimize these negative impacts.

Thus, this input-output framework shows that the success of Perumda Tirta Pakuan's management is not only determined by internal factors but is also greatly influenced by the external environment and sustainability of the water source ecosystem. A good system can balance controlled inputs, environmental inputs, and control management produce optimal outputs. This is an important basis for companies to maintain performance, meet community needs, and support sustainable development in the city of Bogor.

Causal Loop Diagram (CLD) Valuation of Perumda Tirta Pakuan

After understanding the basic components of the system through the input-output diagram, the next step is to explore the cause-and-effect relationships between the elements that form the dynamics of the system using the CLD approach. CLD helps us see how variables in the system influence each other in a circular manner, either reinforcing or balancing each other. This diagram illustrates not only what changes, but also why and how these changes trigger each other in a series of repeated interactions.

In the context of clean water companies, CLD allows us to illustrate how increased access to clean water impacts public health, which in turn increases economic productivity, drives purchasing power, and ultimately increases demand for clean water. This pattern reflects a reinforcing loop that can drive sustainable system growth. Conversely, CLD also helps detect balancing loops, for example, when the pressure on water resources reaches a certain limit, demand growth slows down as a system stabilization mechanism.

A study on the application of CLD in upstream water management was conducted by Rajarethinam et al. (2021), who applied the system dynamics method to evaluate the vulnerability of water resources in Chennai, India. The cause-and-effect diagram they developed shows the complex feedback between water supply, demand, and environmental stress, which dynamically shapes the behavior of the system. In Indonesia, a dynamic system model that includes CLD was used in a study by PDAM Cilegon Mandiri to explain the relationship between clean water availability and management responses to operational disruptions (Saputro et al. 2024).

Through CLD, we can also identify leverage points, which are strategic intervention points in the system that, when controlled, can produce significant and sustainable changes. This is in line with the CLD framework in the WASH approach, as described by Purwanto et al. (2021), where CLD is used to engage stakeholders and visualize financial, social, and institutional interactions in water system models. Thus, CLD becomes an important bridge for understanding the complexity of the system and formulating better directions for change in clean water management. The following is a Causal Loop Diagram of the Valuation Analysis of the Existence of Perumda Tirta Pakuan and its Multiplier Effect on the Economy, Society, and Environment in Figure 3.

From the CLD, five causal loops that form a reinforcing interaction pattern and four causal loops that form a balancing interaction pattern were identified. The following is an explanation of each causal loop:

Reinforcing Loop (R)

R1. Clean Water Supply (+)→ Revenue (+)→ Company Profit (+)→ Infrastructure Investment (+)→ Water Treatment Capacity (+)→ Clean Water Supply.
The increasing availability of clean water drives an increase in revenue and profit from water sales. These profits can then be reinvested in infrastructure development, particularly in increasing the water treatment capacity. As this capacity increases, the availability of clean water can be achieved in a more sustainable manner.

R2. Clean Water Supply (+)→ Revenue (+)→ Company Profit (+)→ Dividends (+)→ Infrastructure Investment (+)→ Water Treatment Capacity (+)→ Clean Water Supply.

An increased clean water supply directly contributes to higher revenue and profits from water sales. These profits enable more optimal dividend allocation, while also increasing the scope for investment in infrastructure and improvements in water treatment capacity. With continuously improved capacity, the availability of clean water is better maintained and can meet the needs of the community sustainably.

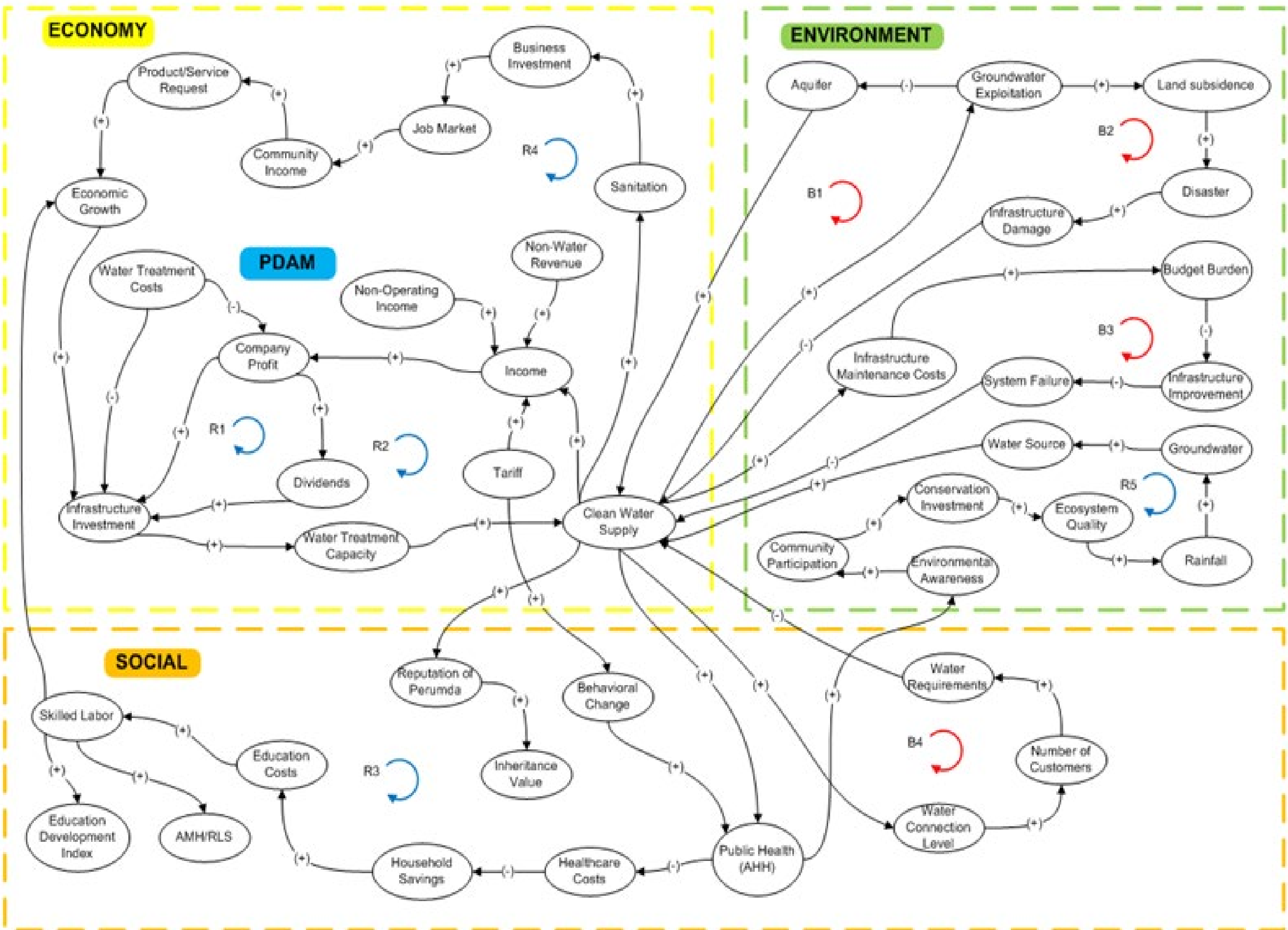

Figure 3. Causal Loop Diagram of the valuation of the existence of Perumda Tirta Pakuan

R3. Clean Water Supply (+)→ Public Health (-)→ Health Costs (-)→ Household Savings (+)→ Education Costs (+)→ Skilled Labor (+)→ Economic Growth (+)→ Infrastructure Investment (+)→ Water Treatment Capacity (+)→ Clean Water Supply.

The availability of adequate clean water has a positive impact on public health. When people are healthier, healthcare costs decrease, allowing them to allocate more funds for education. Greater investment in education encourages the creation of a more skilled workforce, which in turn strengthens economic growth. This growth supports increased budget allocations for infrastructure development, including water treatment capacity. With this increased capacity, the availability of clean water will be more sustainably guaranteed.

R4. Clean Water Supply (+)→ Sanitation (+)→ Business Investment (+)→ Employment (+)→ Community Income (+)→ Product/Service Demand (+)→ Economic Growth (+)→ Infrastructure Investment (+)→ Water Treatment Capacity (+)→ Clean Water Supply.

Increased clean water supply drives improvements in environmental sanitation. Good sanitation creates a healthier and more attractive climate for business investment, which ultimately opens up more job opportunities. Increased employment opportunities impact community income, which in turn drives economic growth through increased demand for products and services. This economic growth provides greater fiscal space for the government or relevant agencies to allocate budgets for infrastructure development, particularly to increase water treatment capacity. With this increased capacity, the availability of clean water is guaranteed on a sustainable basis.

R5. Clean Water Supply (+)→ Public Health (-)→ Environmental Awareness (+)→ Community Participation (+)→ Conservation Investment (+)→ Ecosystem Quality (+)→ Rainfall (+)→ Groundwater (+)→ Water Sources (+)→ Clean Water Supply.

The availability of adequate clean water has a positive impact on public health. As health improves, public awareness of the importance of protecting the environment also grows. This awareness encourages active participation in environmental conservation, which ultimately helps maintain the quality of the ecosystem. A healthy ecosystem contributes to microclimate stability and increased rainfall potential. Thus, the availability of groundwater and surface water sources can be maintained to continue meeting clean water needs sustainably.

Loop Balancing (B)

B1. Clean Water Supply (+)→ Groundwater Exploitation (-)→ Aquifer (+)→ Clean Water Supply.

The increasing demand for clean water has led to the intensive exploitation of groundwater. If not managed wisely, this can cause a decline in groundwater reserves or aquifer depletion. This condition ultimately becomes a serious obstacle meeting clean water needs sustainably.

B2. Clean Water Supply (+)→ Groundwater Exploitation (+)→ Land Subsidence (+)→ Disasters (+)→ Infrastructure Damage (-)→ Clean Water Supply.

The increased demand for clean water often leads to the excessive exploitation of groundwater. This exploitation can cause land subsidence, which poses a risk of disasters and infrastructure damage. These impacts not only endanger the safety and comfort of the community but also pose a serious obstacle to maintaining a sustainable supply of clean water.

B3. Clean Water Supply (+)→ Infrastructure Maintenance Costs (+)→ Budget Burden (-)→ Infrastructure Repairs (-)→ System Damage (-)→ Clean Water Supply.

The increase in demand for clean water requires greater infrastructure maintenance costs and adds to the budgetary burden. This condition can affect the allocation of funds for other infrastructure development, thereby disrupting the balance and synergy of the system as a whole. This imbalance risks weakening the system's performance, which ultimately negatively impacts the capacity and continuity of clean water production.

B4. Clean Water Supply (+)→ Water Connection Rate (+)→ Number of Customers (+)→ Water Demand (-)→ Clean Water Supply.

As the demand for clean water increases, so does the need to expand the distribution pipeline network to customers. This has a positive impact because more people can be served by access to clean water.

However, this increase in demand also puts pressure on water resources, which in the long term can reduce the availability of clean water if it is not accompanied by sustainable management.

Stock Flow Diagram (SFD)

After understanding the cause-and-effect relationship through CLD, the next step is to translate this relationship into a more quantitative and structured form through SFD. SFD describes how a variable changes over time by distinguishing between stock (accumulation) and flow components. With this approach, complex systems can be mapped to be more measurable, enabling data-based analysis for simulations and long-term dynamics prediction.

In the context of a clean water company, SFD can represent stock as the number of active customers, raw water reserves, or community health levels. Meanwhile, flow includes daily water distribution, new customer additions, or the amount of infrastructure investment flowing into the system. By distinguishing between these two components, researchers and policymakers can model scenarios more accurately, such as how increased water production capacity must be balanced with investments in the distribution network to maintain service sustainability.

SFD also plays an important role in evaluating the consequences of changes in system variables, both in the short and long term. For example, Martínez-Moyano and Richardson (2013) emphasized that SFD is the main foundation in system dynamics modeling because it provides a framework for understanding the accumulation and delays that shape the overall behavior of the system. In water management studies, Purwanto et al. (2021) also show that the use of SFD helps visualize the interactions between water availability, community participation, and institutional support, resulting in more adaptive and sustainable rural water management policies.

In other words, SFD helps us think systematically and dynamically, not only describing what is happening, but also how, how quickly, and with what consequences these changes are taking place. This makes the SFD an important instrument for designing drinking water company policies that are more responsive to customer needs while maintaining resource sustainability. Through this framework, water management can be directed towards economic efficiency, social justice, and environmental sustainability. The SFD Analysis of the Valuation of Perumda Tirta Pakuan's Existence and its multiplier effect on the economy, society, and environment through a dynamic systems approach. The variables used in the stock flow diagram modeling:

1) Economic Variables (Table 2)
2) Social Variables (Table 3)
3) Environmental Variables (Table 4)
4) Interconnected Variables (Multiplier Effect)
   - Increased productivity in the agricultural and industrial sectors due to access to clean water
   - Indirect employment (contractors, logistics, etc.)
   - Local economic added value from clean water investment
   - Improved quality of life → purchasing power → local economic growth
   - Household time efficiency (no need to fetch water from far away)

Simulation of Dynamic System Processing Results

In this simulation, five main scenarios are presented to illustrate various possible future conditions, namely: pessimistic scenario, moderate scenario, optimistic scenario, ideal scenario, and water usage scenario. The first four scenarios are compiled based on various assumptions related to the growth of water demand and availability, each reflecting different levels of certainty and risk. As for the water use scenario, the data used refer to the projection results from the ideal scenario, which is considered the most balanced condition between water demand and supply and takes into account factors of efficiency and sustainability in an optimal manner. The key variables in this scenario are explained in Table 5.

Pessimistic Scenario

In the pessimistic scenario, the values of the variables are: customer coverage rate of 2.11% per year, water usage rate of 0.54% per year, water tariff rate of 4.14% per year, and operational load rate of 14.6% per year. With these variable values, projections were generated. The detailed results of the dynamic system simulation are described in Table 6.

Table 2. Economic Variables in the stock flow diagram modeling

Variables	Name	Data Type	Unit	Description
Stock	Registered Customer	Numeric	Customers	Contains the number of Perumda Tirata Pakuan customers
	Water usage volume	Numeric	Cubic meters	Contains clean water usage volume
	Accumulated clean water supply	Numeric	Cubic meters	Contains the volume of clean water stored in the reservoir
	Water Price	Numerical	IDR	Contains information on clean water rates
	Operating expenses	Numeric	IDR	Contains information on operational expenses
	Total employees	Numeric	People	Contains information on the number of employees at Perumda Tirta Pakuan
Flow	New customer	Numeric	Customers	Contains the number of new customers of Perumda Tirata Pakuan
	Water production	Numeric	Cubic meters/ year	Contains the amount of clean water production that enters the reservoir
	Water consumption	Numerical	Cubic meters/ year	Contains the amount of clean water usage that exits the reservoir
	Water usage flow	Numerical	Cubic meters/ year	Contains the amount of clean water usage that reaches customers
	Water price flow	Numeric	IDR	Contains information on clean water rate increases
	Operational expenses flow	Numeric	IDR	Contains information on increases in operational costs
	New employees	Numeric	People	Contains information on the number of new employees at Perumda Tirta Pakuan
Auxiliary	Water rate	Numeric	Percent	Contains the percentage increase in water rates
	Reservoir capacity	Numeric	Cubic meters	Contains reservoir capacity
	Customer coverage rate	Numeric	Percent	Contains the percentage of customer coverage rate
	Water usage rate	Numeric	Percentage	Contains the percentage of water usage rate
	Operational expenses rate	Numeric	Percentage	Contains the percentage of operational load rate
	Employee rate	Numeric	Percentage	Contains the percentage of employee turnover
	Network leakage rate	Numeric	Percent	Contains the percentage of clean water leakage distributed to customers
External/ Parameter	Dividend	Numeric	IDR	Contains the dividend amount
	Business investment	Numeric	IDR	Contains the amount of business investment

Table 3. Social Variables in the stock flow diagram modeling

Variables	Name	Data Type	Unit	Description
External/ Parameters	Dug wella Replacement cost	Numeric	IDR	Contains the savings amount from the replacement cost of dug wells
	Water usage savings	Numeric	IDR	Contains the amount of water usage savings
	Inheritance	Numeric	IDR	Contains the amount of inheritance value
	Public Health	Numeric	IDR	Contains the amount of savings in public health costs
	Health costs due to unclean water	Numerical	IDR	Contains the amount of savings in health costs due to unclean water

Table 4. Environmental Variables in the stock flow diagram modeling

Variables	Name	Data Type	Unit	Description
Flow	Clean water production	Numeric	Cubic meters/ second	Contains information on clean water production
Auxiliary	Raw water discharge	Numeric	Cubic meters/ second	Contains information on raw water discharge
External/ Parameters	Environmental conservation costs	Numeric	IDR	Contains information on the amount of environmental conservation costs

Table 5. Key variable values for the dynamic system scenario

Scenario	Customer Coverage Rate	Water Usage Rate	Water Price Rate	Operating Expenses Rate
uom	percent/year	percent/year	percent/year	percent/year
Initial Data (2024)	2.11	0.54	4.14	6.28
Pessimistic	2.11	0.54	4.14	14.60
Moderate	3.15	1.37	6.74	10.44
Optimistic	4.22	2.19	9.34	6.28
Ideal	6.00	3.97	4.85	9.00

Table 6. Projected dynamic system simulation for the 2025-2029 period, pessimistic scenario

Scenario	Year	Registered Customer	Water Usage Volume	Water Price	Operational Expenses Projection	Total Revenue	Revenue Ratio
uom		Customer	m^3/year	IDR/m^3	billion rupiah/year	billion rupiah/year	
Initial Data (2024)		180,597	45,079,399	8,339	332.33	411.87	1.24
Pessimistic	2025	184,408	45,324,631	8,684	369.84	431.26	1.17
	2026	188,299	45,571,197	9,043	412.81	451.55	1.09
	2027	192,272	45,819,104	9,418	462.06	472.81	1.02
	2028	196,329	46,068,360	9,808	518.51	495.06	0.95
	2029	200,471	46,318,972	10,214	583.19	518.36	0.89

Table 6 illustrates the downward trend in the ratio of revenue to operating expenses from 2025 to 2029, from 1.17 to 0.89. This decline reflects that the company's revenue growth is unable to offset the annual increase in operating costs, despite an average revenue increase (2025-2029) of 15.0% compared to actual revenue in 2024. As a result, the company's financial efficiency continues to be under pressure, which could reduce its room for maneuver in supporting expansion and strengthening sustainable operational performance.

Moderate Scenario

In the moderate scenario, the values of the variables are a customer coverage rate of 3.15% per year, water usage rate of 1.37% per year, water tariff rate of 6.74% per year, and operational load rate of 10.44% per year. Table 7 shows a downward trend in the ratio of revenue to operating expenses from 1.24 in 2025 to 1.23 in 2029. This decline indicates that the company's revenue growth is not proportional to the increase in operating costs, despite an average revenue increase (2025-2029) of 27.5% compared to actual revenue in 2024. This imbalance causes the income ratio to be increasingly depressed from year to year, which in turn can reduce financial flexibility and hamper the company's ability to optimally develop its business.

Optimistic Scenario

In the optimistic scenario, the values of the variables are customer coverage rate of 4.22% per year, water usage rate of 2.19% per year, water tariff rate of 9.34% per year, and operational load rate of 6.28% per year. Table 8 illustrates a significant upward trend in the ratio of revenue to operating expenses, from 1.32 in 2025 to 1.69 in 2029, with an average revenue increase (2025-2029) of 41.2% compared to actual revenue in 2024. This increase reflects that the company's revenue growth rate is able to offset the increase in operating expenses that occurs from year to year. This condition demonstrates the company's financial efficiency, which has the potential to improve its operational performance sustainably.

Ideal Scenario

In the ideal scenario, the values of the variables are customer coverage rate of 6.0% per year, water usage rate of 3.97% per year, water tariff rate of 4.85% per year, and operational load rate of 9.0% per year. Table 9 shows an upward trend in the ratio of revenue to operating expenses from 1.24 in 2025 to 1.35 in 2029. This increase reflects that the company's revenue growth is able to offset, and even exceed, the rate of increase in operating costs with an average revenue increase (2025-2029) of 30.5% compared to actual revenue in 2024, although it is still smaller than the increase in the optimistic scenario. Thus, the company's financial efficiency is gradually improving, which in turn strengthens its operational performance and provides room for future service expansion.

The projected surplus contrasts with the potential crisis predicted by Fasa et al. (2020) in Cirebon, highlighting the successful infrastructure investments made by Perumda Tirta Pakuan. Our finding that water access drives economic growth is consistent with the global evidence presented by Amorocho-Daza et al. (2023), and we have quantified this relationship locally through reinforcing loops in our model (R3, R4). Therefore, these findings are expected to serve as a valuable reference and foundation for future investment planning aimed at expanding service coverage for Perumda Tirta Pakuan's management.

Table 7. Dynamic system simulation projections for the 2025-2029 period moderate scenario

Scenario	Year	Registered Customer	Water Usage Volume	Water Price	Operational Expenses Projection	Total Revenue	Revenue Ratio
uom		Customer	m^3/year	IDR/m^3	billion rupiah/year	billion rupiah/year	
Initial Data (2024)		180,597	45,079,399	8,339	332.33	411.87	1.24
Moderate	2025	186,286	45,696,987	8,901	359.15	445.65	1.24
	2026	192,154	46,323,035	9,500	388.77	482.21	1.24
	2027	198,207	46,957,661	10,141	421.47	521.76	1.24
	2028	204,450	47,600,981	10,824	457.60	564.56	1.23
	2029	210,890	48,253,114	11,554	497.49	610.86	1.23

Table 8. Dynamic system simulation projections for the 2025-2029 period optimistic scenario

Scenario	Year	Registered Customer	Water Usage Volume	Water Price	Operational Expenses Projection	Total Revenue	Revenue Ratio
uom		Customer	m^3/year	IDR/m^3	billion rupiah/year	billion rupiah/year	
Initial Data (2024)		180,597	45,079,399	8,339	332.33	411.87	1.24
Optimistic	2025	188,218	46,066,638	9,117	348.47	460.20	1.32
	2026	196,161	47,075,497	9,969	365.61	514.21	1.41
	2027	204,439	48,106,451	10,900	383.83	574.54	1.50
	2028	213,066	49,159,982	11,918	403.19	641.97	1.59
	2029	222,058	50,236,585	13,031	423.78	717.30	1.69

Table 9. Dynamic system simulation projections for the 2025-2029 period ideal scenario

Scenario	Year	Registered Customer	Water Usage Volume	Water Price	Operational Expenses Projection	Total Revenue	Revenue Ratio
uom		Customer	m^3/year	IDR/m^3	billion rupiah/year	billion rupiah/year	
Initial Data (2024)		180,597	45,079,399	8,339	332.33	411.87	1.24
Ideal	2025	191,433	46,869,051	8,743	355.45	448.99	1.26
	2026	202,919	48,729,752	9,167	380.65	489.46	1.29
	2027	215,094	50,664,324	9,612	408.12	533.57	1.31
	2028	228,000	52,675,697	10,078	438.05	581.66	1.33
	2029	241,680	54,766,922	10,567	470.69	634.08	1.35

Water Availability Scenario

In this water availability scenario, the volume of water usage was obtained from the ideal scenario projection. Table 10 shows that the clean water production capacity remains stable at 2.59 m^3 per second throughout the period from 2025 to 2029. Meanwhile, the total water usage increases from 1.86 m^3 per second in 2025 to 2.26 m^3 per second in 2029. Thus, there is still a water surplus of 0.33 m^3 per second, equivalent to 10,404,608 m^3 per year in 2029. The availability of this surplus indicates a significant opportunity to optimize the expansion of customer service coverage, particularly to meet the increasing demand for clean water in the Bogor City area.

Managerial Implications

The projection analysis results, it shows that the clean water production capacity of Perumda Tirta Pakuan in Bogor City will remain stable at 2.59 m^3 per second throughout the period from 2025 to 2029, with a surplus of 0.33 m^3 per second, equivalent to 10,404,608 m^3 per year. This indicates that there is still a potential opportunity to expand customer service coverage while maintaining the sustainability of the clean water supply. This surplus not only ensures that the future needs of the community are met, but also provides room for the company to improve distribution quality, expand service networks, and add new customers. Expanding service and distribution networks and adding customers will have implications for the investment needs of Perumda Tirta Pakuan Bogor, particularly investments to expand water distribution pipelines to customers, increase the capacity of clean water storage infrastructure, as well as process and maintain the distribution network. In addition, with the expansion of service coverage, it can also have implications for the need for professional and reliable human resources who must still be able to ensure excellent service quality.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Analysis of the multiplier effect shows that every IDR spent or invested by Perumda Tirta Pakuan creates a much greater economic impact.

a. Job Creation: Each employee recruited by Perumda triggers the creation of other jobs in related sectors (e.g., contractors, raw material suppliers, and support services).
b. Increased Community Income: Employee salaries and payments to suppliers increase purchasing power, which in turn drives local economic growth.
c. Contribution to Local Revenue: The company's profits contribute to the local revenue of Bogor City, which can then be used for development in other sectors.
d. Related Sectors: Reliable clean water supply supports other sectors, such as tourism, industry, and health, which ultimately increases productivity and overall economic growth in Bogor.
e. From an environmental perspective, it has a significant positive impact compared to uncontrolled groundwater exploitation. This is because using water from Perumda drinking water can prevent environmental damage, including reducing land subsidence, protecting groundwater quantity and quality, improving energy efficiency and reducing carbon emissions, and conserving water resources.

Table 8. Dynamic system simulation projections for the 2025-2029 period water usage scenario

Scenario	Year	Clean Water Production		Water Usage Volume		Water Leakage		Total Water Usage		Clean Water Surplus	
uom		m^3/sec	m^3/year	m^3/sec	m^3/year	m^3/sec	m^3/year	m^3/sec	m^3/year	m^3/sec	m3/year
Initial Data (2024)		2.59	81,601,608	1.43	45,079,399	0.43	13,523,820	1.86	58,603,219	0.73	22,998,389
Water Usage	2025	2.59	81,601,608	1.49	46,869,051	0.45	14,060,715	1.93	60,929,766	0.66	20,671,841
	2026	2.59	81,601,608	1.55	48,729,752	0.46	14,618,926	2.01	63,348,678	0.58	18,252,929
	2027	2.59	81,601,608	1.61	50,664,324	0.48	15,199,297	2.09	65,863,621	0.50	15,737,987
	2028	2.59	81,601,608	1.67	52,675,697	0.50	15,802,709	2.17	68,478,406	0.42	13,123,201
	2029	2.59	81,601,608	1.74	54,766,922	0.52	16,430,077	2.26	71,196,999	0.33	10,404,608

Thus, using PDAM water is not merely a matter of convenience but a collective responsibility to preserve the environment and ensure water availability for future generations.

By developing a validated dynamic system model, this study has demonstrated that the clean water production capacity of Perumda Tirta Pakuan in Bogor City remains stable, even as total water usage continues to increase, and conditions remain in surplus annually until 2029. This allows for significant opportunities to expand customer service coverage while maintaining the sustainability of clean water supply. This surplus not only ensures the fulfillment of community needs in the future but also provides room for the company to improve distribution quality, strengthen its role in driving regional economic growth, and contribute more broadly to the welfare of Bogor City residents. The findings also emphasize that sustainable water utility management, as modeled here, is not only a technical necessity, but also a fundamental driver of holistic regional development.

Recommendations

Based on the findings of this study, several strategic recommendations are proposed, including the need for Perumda Air Minum Tirta Pakuan to optimize the multiplier effect by strengthening the local supply chain and increasing long-term investments in infrastructure and technology modernization to enhance efficiency and stimulate regional economic growth. The Bogor City Government should support Perumda's sustainability through pro-investment regulations and ensure synergy between city development plans and the utility's service capacity. Meanwhile, communities and investors can take advantage of partnership opportunities with Perumda as a reliable water service provider, creating potential for mutually beneficial collaboration.

This study has several key limitations, including its reliance on secondary data, which makes the accuracy dependent on the quality of existing sources, and the simplification of complex real-world conditions, as not all social and environmental factors can be fully quantified. The outcomes also rely on specific assumptions such as projected growth rates and any changes to these assumptions could affect the results, especially given the absence of reported model validation. Additionally, the model assumes static production capacity with no major new water sources developed after 2024, an assumption that may not fully reflect future developments.

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