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Research Article

System Dynamics Modeling to Develop Industrial Wastewater Recycle Business in Indonesia

[1]Muhammad Ridho Fithri Wikarta, [2]Pri Hermawan
[1,2] School of Business and Management, Institut Teknologi Bandung, Indonesia.

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Abstract: *Water is an important resource for daily consumption, production, and industrial operations. Global freshwater demand has increased, and water scarcity has become a critical challenge in industry. Freshwater withdrawals and wastewater discharge hold significant potential for developing a wastewater recycling business in Indonesia. Factors such as the growth of industrial estates, rising freshwater costs, and industry-driven sustainability goals further amplify this opportunity. Establishing a wastewater recycling industry in Indonesia requires systemic solutions that address the complexities of diverse industrial sectors, varying water sources, and regional cost disparities. This study employs a quantitative approach, drawing on literature reviews, discussions with water treatment company stakeholders, and internal project data to identify key variables influencing the development of wastewater recycling. A system dynamics framework was used to analyze relationships between variables, employing Causal Loop Diagrams (CLD) and Stock and Flow Diagrams (SFD) for simulation. Scenario simulations were conducted on critical variables, including wastewater recycling demand, recycling ratios, and associated costs. Findings reveal that wastewater recycling offers significant benefits, including freshwater savings, reduced customer costs, and annuity revenue streams for water treatment companies. Using a case study of an industrial estate in West Java, the research demonstrates the high potential for wastewater recycling development in Indonesia. Vensim modeling shows that 2.38 million m3/year of fresh water might be saved overall, and that water treatment providers could earn 26 billion rupiah in 2027 from chemicals and equipment. The framework provided in this study serves as a valuable decision-making tool for considering investments in wastewater recycling processes.*

Keywords: *Causal Loop Diagram, Industrial Wastewater, System Dynamics, Stock and Flow Diagram.*

I. INTRODUCTION

Global freshwater demand has been rising steadily at an annual rate of approximately 1% over the past 40 years, with projections indicating a similar growth trend through 2050. This sustained increase, estimated to result in a 20–30% rise in water demand by mid-century, is primarily driven by global population growth and socioeconomic development. Emerging economies have experienced the most significant surges in water demand (WWDR, 2023). This growing demand and limited renewable water resources have intensified water stress and scarcity worldwide. Water scarcity has become a pervasive issue, exacerbated by local challenges such as physical water shortages and the pollution of freshwater sources, which are expanding and worsening in severity (FAO, 2022).

Addressing water scarcity is integral to achieving the Sustainable Development Goals (SDGs), particularly those related to sustainable water management. Recognizing water as a critical component of the circular economy (CE), the Circular Economy of Water (CEW) framework has emerged as a sustainable approach to managing water resources (Delgado et al., 2021). This framework emphasizes reducing water waste, optimizing water use, maintaining water quality, and ensuring environmental conservation (Morseletto et al., 2022). Within Southeast Asia, Indonesia ranks as the largest consumer of freshwater (Worldbank, 2023) and largest also for wastewater discharge (Ehalt MacEdo et al., 2022). Projections by Indonesia's National Development Planning Agency indicate that water scarcity in Java, Bali, and Nusa Tenggara will increase from 6.0% in 2000 to 9.6% by 2045 (National Development Planning Agency (Bappenas), 2020).

Applications for wastewater recycling and reuse have grown significantly in response to the world's water shortage. Customizing treatment procedures for particular water reuse applications has been made easier by technological developments in wastewater treatment (Kumar et al., 2021). Wastewater treatment and reuse initiatives are being actively developed across major Asian countries (Liao et al., 2021). Studies examining factors such as GDP, water resources, water withdrawal rates, and water stress have identified countries like Indonesia and the Philippines as experiencing severe water shortages. In Indonesia, corporate water disclosure remains limited. Nevertheless, research by Adhariani (2020) underscores the critical importance of water management and accountability in addressing these challenges. Similarly, a study on circular water management accountability by Meiryani et al., (2022) highlights an increase in water accountability reporting, with a focus on indicators such as reducing, reusing, and recycling water.

This study investigates the potential of wastewater recycling businesses in the industrial sector as a viable solution to Indonesia's water challenges. As depicted in Figure 1, Indonesia records the highest annual wastewater treatment plant discharge in Southeast Asia, illustrating the significant opportunities for recycling. Focusing on an industrial estate in West Java, this research demonstrates that wastewater recycling delivers substantial benefits, including freshwater conservation, cost savings for consumers, and recurring revenue opportunities for water treatment companies.

Fig.1 Waste Water Discharge, Source Data HydroWaste (Ehalt MacEdo et al., 2022)

II. LITERATURE REVIEW

A) Problem Exploration

Water treatment companies in the industrial sector become the main component in conducting technical reviews and implementation of wastewater recycling processes to answer customer needs in the industrial sector. Businesses that recycle wastewater have the potential to generate income from ongoing chemical and equipment replacements as well as one-time projects. Building knowledge, developing a value proposition, and crafting a business plan will assist water treatment suppliers in improving their market position and adding value for customers as the water sustainability sector grows.

A best-practice study of water recycling in Greater Jakarta identified the primary drivers for adoption in the business sector as cost savings on water bills, corporate commitments to global standards, and serving as a role model for sustainability (Priadi et al., 2017). Additionally, water reuse planning in Indonesia should consider three key aspects: environmental quality, economic value, and societal acceptance (Aru Yudhantoro et al., 2020).

Implementation challenges for wastewater recycling include issues related to tariff schemes for recycled water pricing. In factories, water costs often comprise both water usage and discharge fees. Tailored tariff structures, reflecting local socioeconomic conditions and the objectives of water authorities, are necessary for effective adoption (Fagundes & Marques, 2023). Through its NEWater program, which was started in 2003 as part of a long-term plan to broaden its water resources and lessen dependency on imported water from Johor, Malaysia, Singapore offers a successful example of wastewater recycling. By 2060, the initiative hopes to achieve self-sufficiency and resilience (Tortajada, 2020). Barriers to wastewater recycling have been further analyzed using a PESTEL framework, highlighting the critical role of technological applications in addressing challenges arising from political, legal, social, economic, and environmental factors (Morris et al., 2021).

Across Indonesia, a total of 113 industrial estates are registered, with 32 yet to commence operations (HKI, 2023). Industrial growth has increased demand for freshwater, raising sustainability concerns. Advancements in technology have accompanied this and heightened commitments to wastewater quality management. Implementing wastewater recycling offers a viable solution by recovering water to meet industrial and hygienic standards, thereby providing an alternative to freshwater resources and reducing overall water consumption. The growing demand for industrial wastewater recycling presents a significant business opportunity for water treatment companies.

B) System Dynamics

The goal of system dynamics, first presented by Jay Foresters at MIT in the 1950s, is to help us understand the dynamics and structure of the complex systems in which we live, create high-leverage policies for long-term betterment, and spark effective change and execution. Systems thinking is a crucial component of system dynamics, which is the capacity to view the world as a complex system and comprehend how everything is interconnected holistically. An object is referred to as a system if it contains not just elements but also interactions between those elements; the connections or relationships between each element are important. Sterman (2002) further explains that systems thinking is a lens for understanding the dynamic complexity of the world. In this context, complexity is characterized by the number of elements within a system and the links or interactions among them. The fundamental elements of dynamic complexity include feedback loops, time delays, and stocks and flows.

In water resource management, system dynamics is a powerful tool for capturing the collective non-linear interactions and dynamics among hydrologic, social, economic, and environmental subsystems. The Causal Loop Diagram (CLD) serves as a qualitative tool for understanding system interactions, while the Stock-and-Flow Diagram (SFD) quantitatively represents water resources (Naeem et al., 2023).

The schematic diagram below, for instance, developed a decision support system to improve stakeholder participation and help policymakers by applying a system dynamics approach to water resource management in Qatar. This method finds turning points in different water management plans and develops solutions that balance environmental and societal sustainability while taking rising socioeconomic growth rates into account (Naeem et al., 2024).

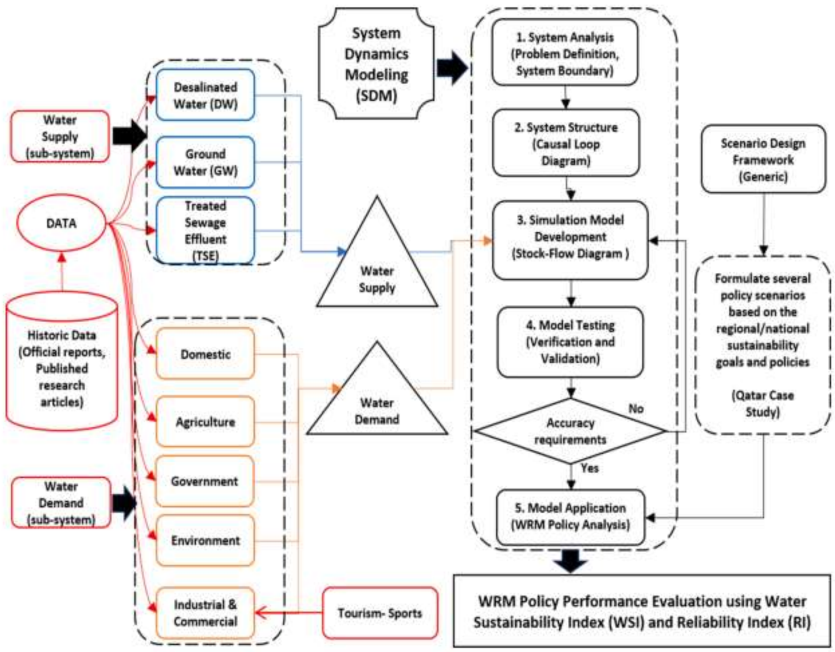

Fig 3. Schematic diagram framework developed by Naeem et al. (2024)

Water is not the only resource that can be recycled. A case study on implementing a circular economy approach was conducted for aseptic paper packaging. Kuo et al. (2021) developed a system dynamics model for recycling paper packaging waste in Indonesia. Producers can use the developed system dynamics model to simulate various scenarios of Extended Producer Responsibility (EPR) fund schemes, subsidies for recyclers, and subsidies for collection partners to determine the optimal impact on each stakeholder’s goals.

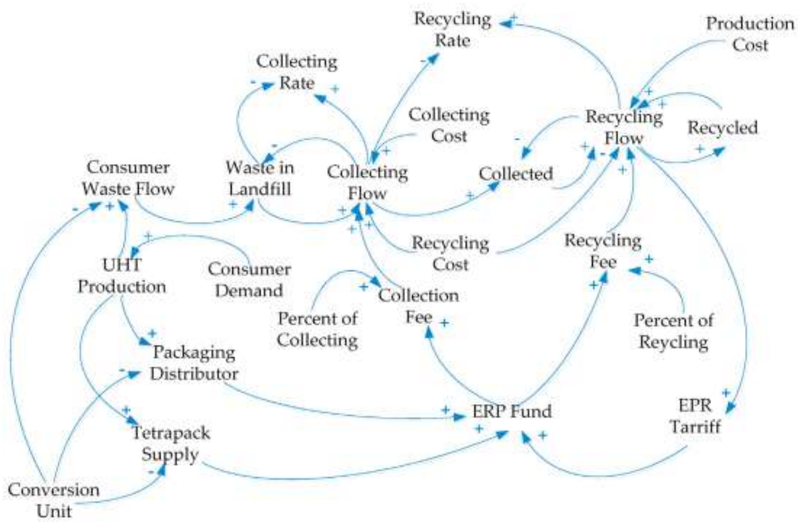

Fig. 4 CLD of Paper Recycling developed by Kuo et al. (2021)

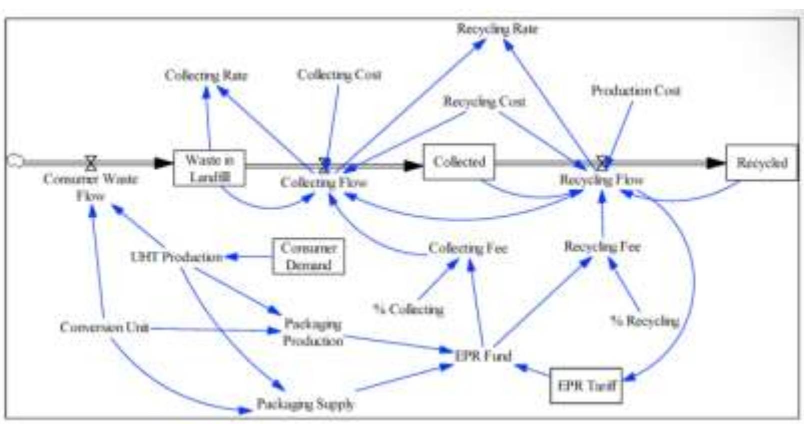

Fig. 5 SFD of Paper Recycling developed by Kuo et al. (2021)

C) *Conceptual Framework and Research Methodology*

The research's conceptual framework begins with the sustainability problem of water shortage and the business opportunities that arise from it. System dynamics result Modeling is the process of creating wastewater management plans. The output of a recycling firm is an estimate of possible revenue. The provider of water treatment services could potentially estimate the possibility of a reduction in freshwater use by using system dynamics analysis.

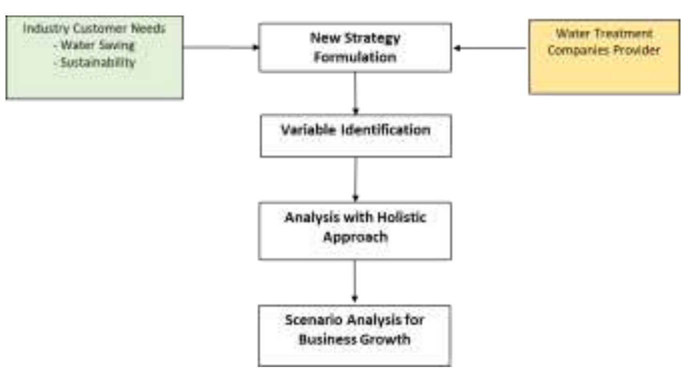

Fig 6. Conceptual Framework

The quantitative method of system dynamic modeling is used in the methodology of the study and data collection process to address the research issue. A literature review of published studies on wastewater recycling or water sustainability measures in the industry sector was another method used to gather data. Additionally, Focus Group Discussions (FGD) were held to validate the basic data and obtain the major internal data that was required.

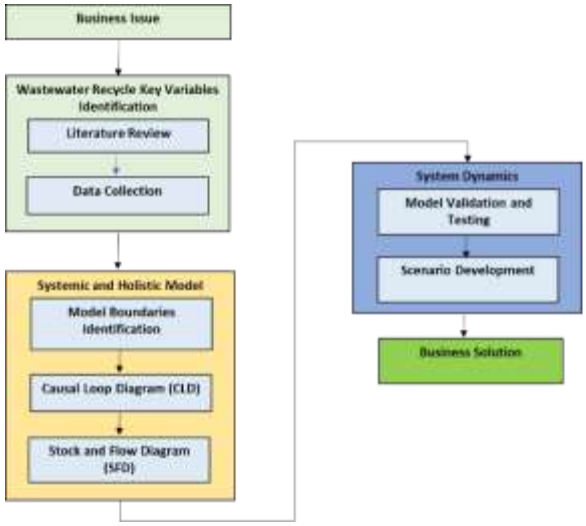

Fig 7. Research design flowchart

III. RESULTS AND DISCUSSION

A) Wastewater Recycle Process System Industrial Sector Key Factor

We must comprehend the customer's complete water use processes and limitations in order to discover important variables in wastewater recycling. For industrial wastewater applications, the customer's objective is to use less freshwater.

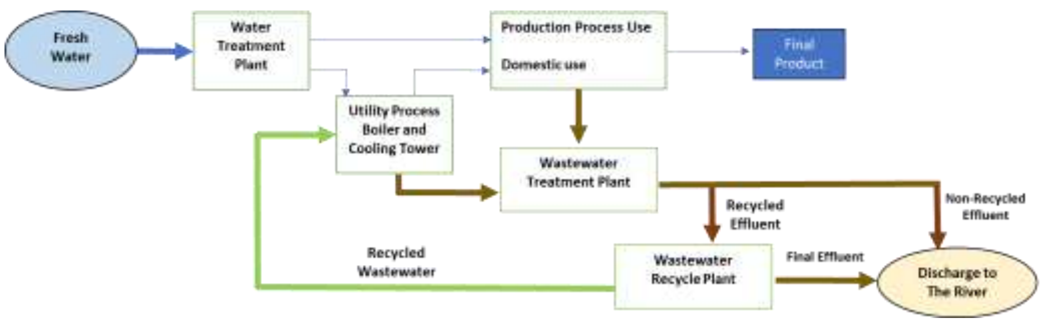

Fig 8. Wastewater recycling in the Industrial sector

The economic benefits of wastewater recycling will be impacted by a number of factors, including investment and operating costs. These factors will depend on the technology and machinery installed, and the technology installed will be determined by the effluent quality of wastewater treatment plants and the specifications for the use of recycled wastewater. Applications and technologies employed in the wastewater recycling process for industrial customers' utility needs will vary. The ultraviolet technology shown in Figure 6—employed at NEWater Singapore—and extra disinfection are required if recovered wastewater is used for residential purposes.

The design process for wastewater recycling is intricate and integrated; even with a simplified layout like Figure 8, the process must be viewed as integrated, particularly when using the outcomes of recycled water. One issue that the researcher discovered during the conversation is that corrosion occurs and is impacted by the high cost of repairing corrosion damage when recycling water products are utilized as the water source for cooling water systems without checking the cooling water unit's water specifications.

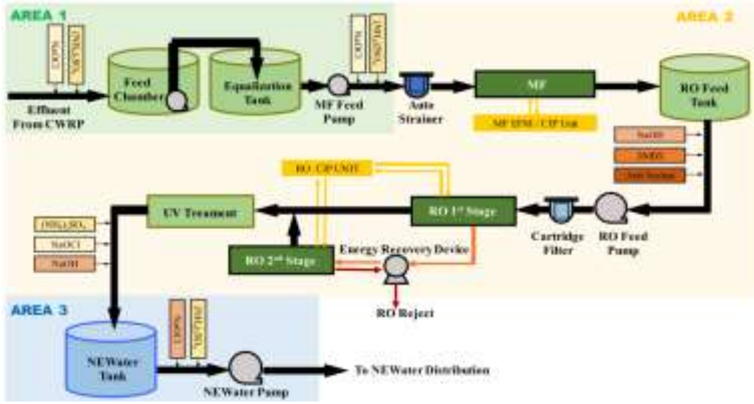

Fig 9. Changi airport wastewater recycling project (Bai et al., 2020)

B) Causal Loop Diagram

Given the complexity of wastewater recycling in this study, the Causal Loop Diagram will be used to investigate the relationships and linkages between the important variables of the customer and the variables of the water treatment company. Key variables' interrelationships will be constructed using system dynamics modeling and system thinking in the Causal Loop Diagram. Decision-makers in water treatment firms could assess the relationship between each variable and create successful plans for the wastewater recycling industry using the causal loop diagram. The causal loop diagram includes two loops, designated as the balancing loop and one loop, the strengthening loop. Five loops can be found in the causal loop diagram below.

a. Balancing Loop 1 (B1) and Balancing Loop 2 (B2)

The causal loop structure of how recycled wastewater is carried out in customer sites is depicted in balancing loop 1. As the industry grows at a faster rate, the need for fresh water will rise along with the industry's production requirement for water. A balancing loop is formed to recycle wastewater effluent to lower the consumer demand for freshwater. The recycling rate is the parameter that influences the amount of recycled wastewater produced. Other factors in other loops influence this recycling rate, and a higher recycling rate will result in less effluent being released into the environment. As demonstrated by balancing loop 2, the demand for freshwater will raise the demand for wastewater recycling and the capacity of wastewater recycling treatment facilities. The rate at which wastewater effluent is recycled will rise with an increase in wastewater recycling treatment capacity. Increasing the amount of recycled wastewater produced will create a balanced loop and lower the need for freshwater.

b. Balancing Loop 3 (B3) and Balancing Loop 4 (B4)

The determinant of wastewater effluent water pollutant grade forms Balancing Loop 3. If the environment is severely contaminated, the demand for wastewater recycling will decrease, the use of recycling equipment will go up, and the price of wastewater recycling will rise. The way that wastewater recycling treatment capacity and cost component variables influence industry investment decisions is known as the balancing loop 4. Potential cost savings may be increased by rising freshwater and wastewater discharge costs, while potential cost savings may be reduced by rising wastewater recycling costs. Company sustainability performance targets are another factor that may influence wastewater decisions because, in certain industries, wastewater recycling may not offer significant cost benefits because of the high investment and operating costs.

c. Reinforced Loop 1 (R1)

Wastewater effluent pollutant quality and demand for recycling wastewater quality may impact wastewater recycling demand. Higher wastewater recycling quality standards will reduce demand and boost the necessity for technology applications like UV.

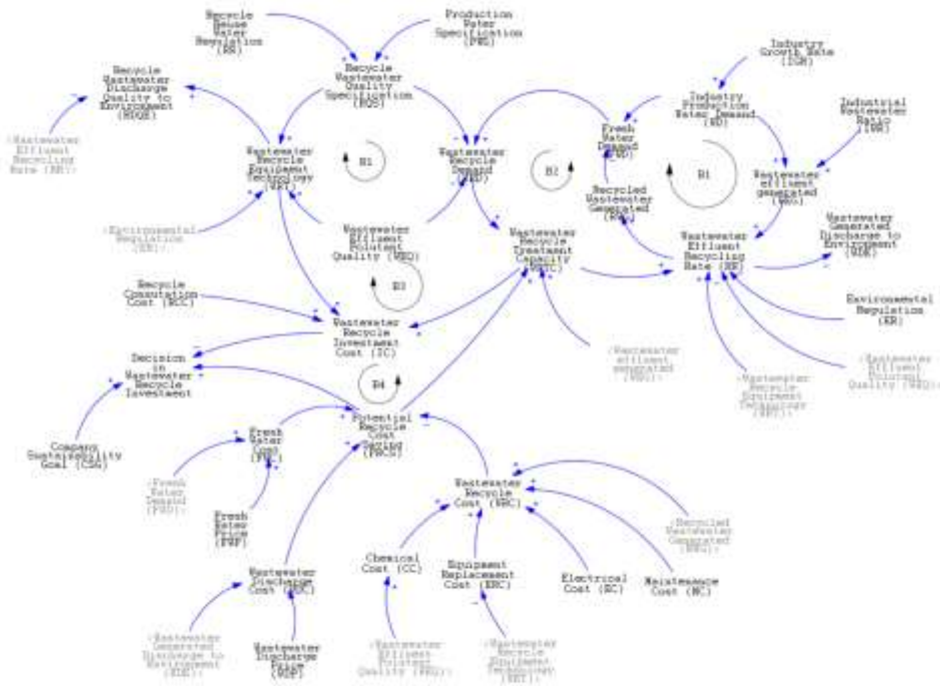

Fig 10. Wastewater Recycle Causal Loop Diagram in the Industrial Sector

C) Stock and Flow Diagram

Stock and flow diagrams will simulate and model the causal loop representation of every factor in wastewater recycling. Stocks are accumulated quantities, while the flow is the change in the quantity of stocks over time. Water stocks will be simulated, as will the cost of recycling wastewater. In this study, wastewater recycling costs were thought to be a possible source of revenue for water treatment providers. Potential cost savings from wastewater recycling in industry/customer will bring value to the water treatment supplier. In this study, the flow of Recycled Wastewater Generated (RWG) as m3/year and the Potential Recycling Cost Savings (PRCS) as Rp/year will be examined. During the conversion process from CLD to SFD, the model is simplified for this research to assist stakeholders, customers, and water treatment management businesses in determining the potential amount of water that might be reduced and the potential cost savings that an industrial client may obtain.

Figure 11 depicts a simplified Stock and Flow Diagram (SFD) derived from the previous Causal Loop Diagram (CLD) for the wastewater recycling process. This stock and flow diagram could be used to assess the business potential of the recycling process and the overall business potential for water recycling in Indonesia. This stock and flow diagram includes a mathematical model and an initial value. Auxiliary variables require an initial value, which is provided by combining the author’s experience creating wastewater recycling with data from industry sources. Several factors in this research will be reduced as ratios, and further technical investigation will be required in industrial applications to determine the ratio value. This study's initial value and value estimates are presented in Tables 1 and 2 of the appendix. Stock and Flow Diagram was developed and verified at vensim using model and unit check features to ensure the simulation could be conducted.

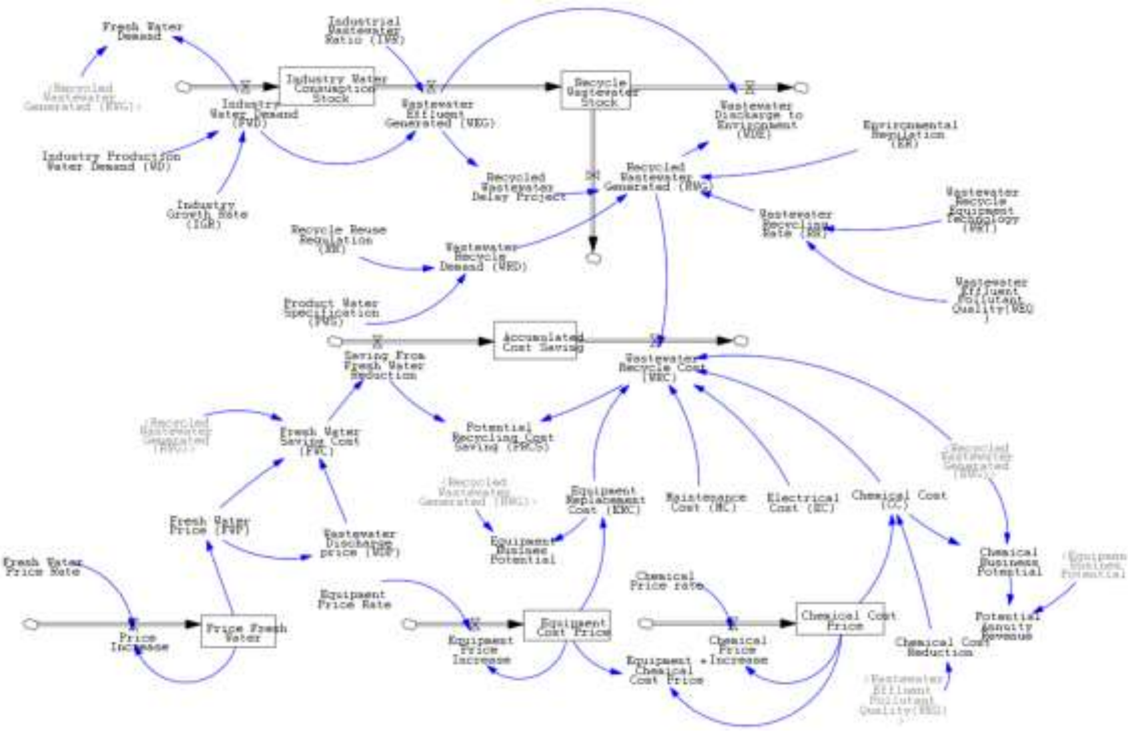

Fig 11. Stock and Flow Diagram of Industrial Wastewater Recycle

D) Model Simulation

According to Vensim simulations, wastewater discharge in Indonesia will be 21 billion m^3/year by 2035, with the possibility of being recycled to minimize freshwater use. In this study, recycled wastewater created from wastewater effluent is estimated to represent 30% of the baseline for industrial usage. Without wastewater recycling, demand for freshwater will continue to rise in response to industry water needs, as will the waste release to the environment as a result of wastewater effluent generation.

The implementation of wastewater recycling, as depicted in Figure 12, will reduce freshwater demand and wastewater discharges into the environment. The author added the delay variable to symbolize the delay in the wastewater recycling application project. The predicted annual freshwater demand decrease in 2035 might be 6 billion m^3.

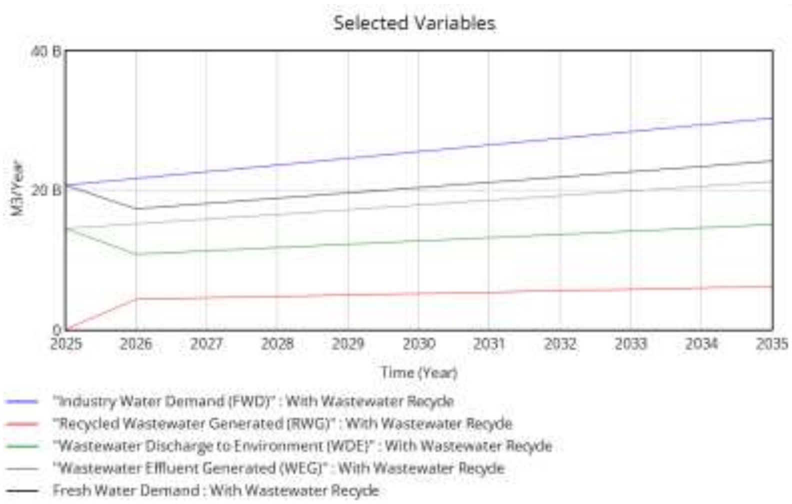

Fig 12. Water model simulation with wastewater recycling

a. Water Saving Potential Cost

Figure I3 simulates the possible water savings from using wastewater recycling compared to the costs of fresh water and wastewater recycling, as shown in Table 1. There is a greater chance of cost savings if wastewater recycling costs are kept below water-saving costs. Because water prices in Indonesia vary, the author used the water prices of Suryacipta Industrial Estate (SCI) Karawang and Greenland International Industrial Estate Cikarang (GIIC) for cost analysis and the water capacity of Suryacipta Industrial Estate for the study's modeling. Project delays are implemented, with an estimated start date of 1.5 years from the beginning of 2025.

Table 1. Price Comparison Between Surya Cipta and GIIC

Surya Cipta Industrial Estate Karawang	Greenland Industrial Estate Cikarang
0.7 USD/M3 + (0.7 x Freshwater)/M3	0.85 USD/M3 + (0.8 x Freshwater)/M3
Freshwater Price: Rp. 10.850 Wastewater discharge price: Rp. 7.595 Total price: Rp. 18.445/M3	Freshwater Price: Rp. 13.550 Wastewater discharge price: Rp. 10.840 Total price: Rp. 24.390/M3

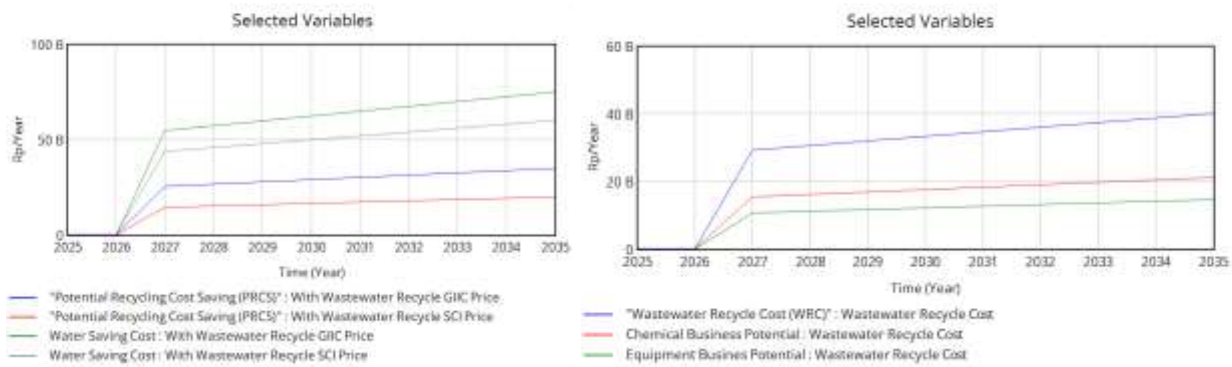

Fig 13. Comparison of potential cost saving and wastewater recycling cost

With the identical wastewater recycling cost, GIIC's potential recycling cost savings are greater than SCI's due to the higher water price. The expense of replacing chemicals and equipment is a major factor in wastewater recycling. Figure 13 shows the wastewater recycling cost variable. The largest expense for wastewater recycling that corresponds with the supplier of chemicals for water treatment is chemical. Data from the Suryacipta Industrial Area will be used in this instance to assess the feasibility of a wastewater recycling enterprise. According to this study, recycling wastewater could potentially increase water treatment companies' revenue by lowering production costs.

b. Accumulated Potential Saving Model for Investment

Vensim's accumulated cost savings may enable a particular customer to evaluate the wastewater recycling process investment over a ten-year period. Figure 14 shows the possible total cost savings of IDR 130 billion that could be achieved at Suryacipta Industrial Estate in Indonesia through wastewater recycling. Customers may use cumulative cost savings to compare capital expenditure to accumulated prospective cost savings. A simulation for a facility with an 800 m3/day industrial demand for water in Suryacipta Industrial Estate is shown in Figure 15, assuming no rise in the cost of fresh water, chemicals, equipment, or fixed water demand. Customers might recycle 168 m3/day or 7 m3/hour or cut their freshwater use by 21%.

Over ten years, the estimated overall cost reductions with the wastewater recycling capacity depicted in Figure 15 come to 2.5 billion rupiah. Given the present freshwater and wastewater recycling cost conditions, this simulation indicates that wastewater recycling plants will generate a longer return on investment. However, they need corporate policy and a commitment to sustainability to invest. In order to facilitate comprehension, the study will focus on variables that affect wastewater recycling operations while boosting those that affect annuity revenue or operational expenses. For example, companies that invest in recycling procedures will see a faster return on investment if the total cost of wastewater recycling is reduced.

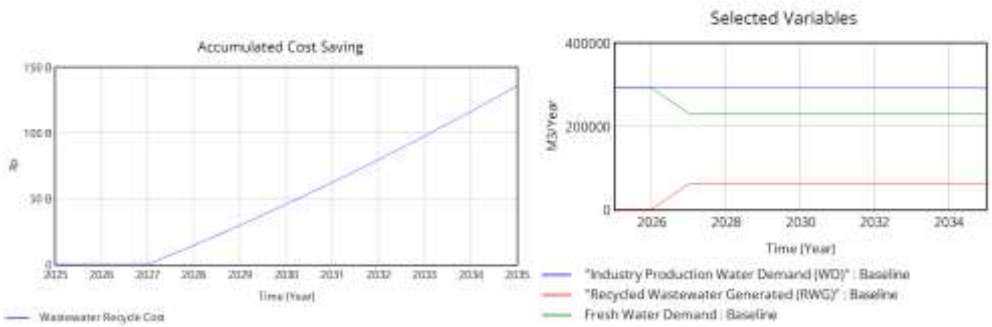

Fig 14. Accumulated Cost Saving and Customer simulation recycled wastewater Generated

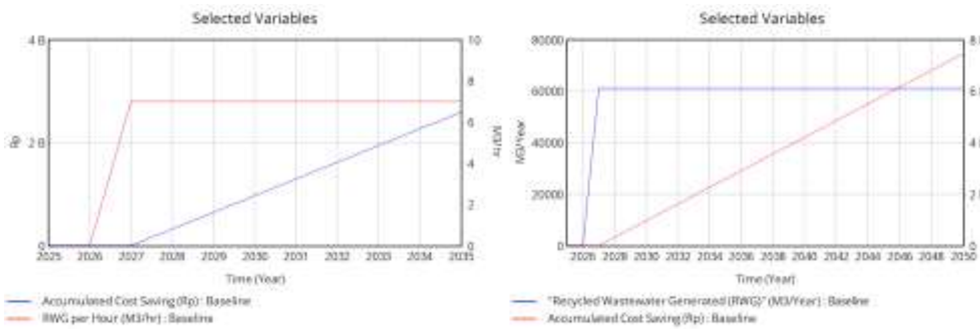

Fig 15. Customer simulation accumulated cost savings within 10 vs 25 years

c. Scenario Simulation

The purpose of this simulation is to model some of the variables that water treatment firms might use to help consumers save water as part of sustainability goals and to save money. Water treatment firms could use this simulation to assess pricing tactics and which sector to concentrate on in the wastewater recycling industry.

Table 2. Scenario Summary

	Scenario	Variable	Baseline (2025)	2028	2030	2032	2033	2034	2035
S1	Increase Wastewater Recycle Demand	Production water specification	0.5	0.6			0.7		
S2	Increase Wastewater Recycle Equipment Technology	Wastewater Recycle Equipment Technology	0.3	0.35			0.4		0.45
S3	Increase Wastewater Recycle Effluent Pollutant quality	Wastewater Effluent Pollutant quality	0.3	0.35			0.4		
S4	Tighten of environmental water quality regulations	Environmental Regulation (ER)	1.0		0.9				0.8
S5	Value Optimization (VO)+ER	S1+S2+S3+S4							
	Price Increase simulation (PI)	Freshwater price %	Freshwater price increases by 2% per year						
		Chemical cost price %	Chemical cost price increase by 5% per year.						
		Equipment cost price %	Equipment cost price increases by 5% per year.						
S6	VO+ER+PI	S1+S2+S3+S4+S5+S6							
	Price Increase simulation (PI)	Freshwater price %	Freshwater price increases by 2% per year						
		Chemical cost price %	Chemical cost price increases by 2.5% per year.						
		Equipment cost price %	Equipment cost price increases by 2.5% per year.						
S7	VO+ER+PI	S1+S2+S3+S4+S5+S6							

Researchers conduct simulations for all scenarios, and scenario S5 value optimization is the scenario when water treatment providers tailor improvements for customers in all variables as simulated using vensim. Using scenario 5 optimized value, potential wastewater recycle that could generated could increase by 58% from baseline in 2035, as shown in figure 16.

Fig 16. Scenario simulation recycled wastewater generated

Potential annuity revenue will rise if wastewater recycling costs rise, but potential recycling cost savings will turn negative and not provide customers with any financial benefit. Figure 17 illustrates how to sustain wastewater recycling businesses to positively keep prospective recycling cost savings. The freshwater cost variable positively correlates with possible cost savings, raising such savings. According to scenarios 6 and 7, the price of freshwater increased by 2% annually. This increase was caused by an increase in the USD to IDR conversion rate, brought on by the price of water for industrial estates based on USD prices. Additionally, the cost of the chemicals and equipment will rise 5% year in scenario 6 and 2.5% annually in scenario 7.

Scenario S6 demonstrates that water treatment companies must control the cost of chemicals and equipment replacement; if these costs rise by 5% annually before ten years, the economic impact of wastewater recycling will be negative. Scenario 7 demonstrates an economic benefit potential for recycling cost savings of up to 20 years if equipment and chemical prices are kept below 2.5% annually. The secret is to keep the cost of recycling wastewater below the cost of saving fresh water.

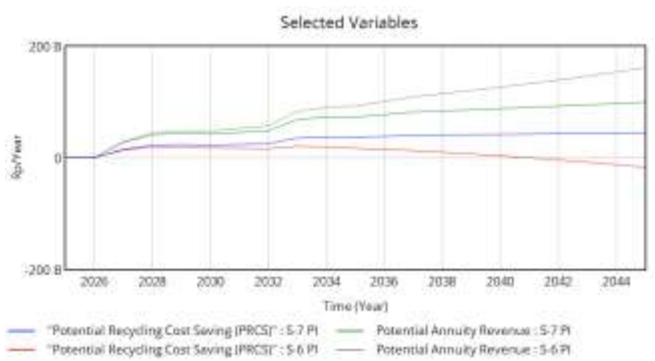

Fig 17. Potential Cost savings for customer and annuity revenue from chemical and equipment costs for water treatment companies

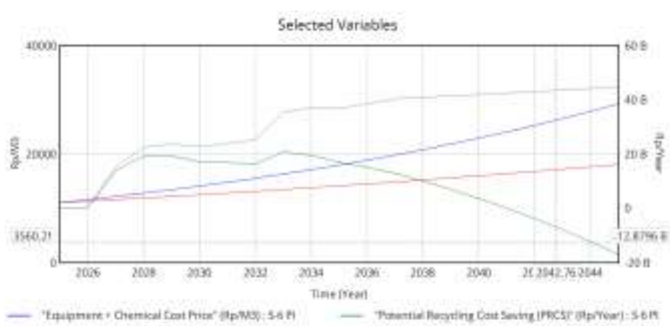

Fig 18. Equipment and chemical price simulation scenario

Using the Suryacipta Industrial Estate in Karawang, Scenario S-7 demonstrates that the potential annuity business for chemicals and machinery for wastewater recycling could result in potential cost savings of up to 45 billion rupiah in 2045 due to the decreased supply of fresh water and business potential from chemicals and equipment could reach up to 28 billion rupiah in 2045. According to a study by Cagno et al. (2022), the cost of recovery is still a significant element that requires government policy interventions to encourage the adoption of water reuse, particularly in non-industrial areas with water scarcity.\

IV. CONCLUSION

According to baseline simulations, 2.38 million m3/year of fresh water might be saved, and possible profits from the chemical and equipment industries could reach 26 billion rupiah in 2027, rising in tandem with industrial expansion. It shows that recycling wastewater in the industrial sector has a significant potential for generating income. Accumulated cost savings simulation from wastewater recycling shows that the return on investment of customers in wastewater recycling is a long time, within 10 to 24 years. Scenario simulation is used with scenario 7 to overcome this variable and challenges affecting the wastewater recycling business. This is done by optimizing the potential value delivered at scenarios 1, 2, and 3, anticipating changes in regulatory scenarios, and controlling wastewater recycling costs from increases in the price of chemicals and equipment. This will allow the wastewater recycling business to remain viable and provide the best value for customers while generating continuous revenue for water treatment companies.

Future studies on wastewater recycling utilizing system dynamics may also be developed for non-industrial sectors, including commercial spaces and buildings. A system dynamics method might also be developed in areas where water is limited to integrate the water, food, and energy nexus. Wastewater recycling products could be used in agriculture and as water supplies for power plants to generate electricity. According to a study by Nyoman et al. (2020), wastewater discharge may contain additional resources for other industries, such as metal and fiber; therefore, the implementation of wastewater resource recovery may be followed by another kind of possible investigation of a new sector. According to a study done in Iran (Keyhanpour et al., 2021), a system dynamics approach could also be developed to combine Indonesia's water, food, and energy nexus. This is especially important for areas where water is limited, and wastewater recycling products have the potential to be used in agriculture and as water sources for power plants that generate energy.

Appendix

Table 1. Numerical values for variables at stock and flow diagram

No	Variable Name	Unit	Initial Value	Note
1	Industrial Wastewater Ratio (IWR)	Dmnl	0.7	https://calculator.suryacipta.app/ **https://suryacipta.com/id/karawang/** Ratio of wastewater that will be produced from freshwater incoming from the industrial estate.
2	Industry Production Water Demand (WD)	M3/year	20.692.000.000 (Indonesia) 11,315,000 (Suryacipta Industrial Estate)	The demand for freshwater needed for the industry production process (m3/year) using a ratio of 0.7 and treated wastewater Statistik PPKL | SISKLHK https://suryacipta.com/id/karawang/
3	Industry Growth Rate (IGR)	Dmnl	4.64%	Industry yearly growth rate that could affect Industry Production Water Demand (%/year) Laju Pertumbuhan PDB Industri Manufaktur - Tabel Statistik - Badan Pusat Statistik Indonesia
4	Recycle Reuse Water Regulation (RR)	Dmnl	1	The value will be from 0-1, 1 if recycled wastewater use meets with regulation ratio will be 1, all wastewater could be recycled.
5	Production Water Specification (PWS)	Dmnl	0.5	For industry, wastewater recycling could be used for the below process - Cooling Tower - Boiler - Domestic Flushing - Production Process For this Research, assume 25% of wastewater recycled could be reused.
6	Environmental Regulation (ER)	Dmnl	1	The value will be from 0-1, 1 if wastewater discharge to environment use meets the regulation ratio will be 1.
7	Wastewater Effluent Pollutant Quality (WEQ)	Dmnl	0.3	Pollutant quality technical details could be referred to as Chemical Oxygen Demand and Total Dissolved Solid. The ratio will be assumed to be 0.3 from 0.0-0.5
8	Wastewater	Dmnl	0.3	Equipment Technology will affect how much Recycled can

	Recycle Equipment Technology (WRT)			generated. In this Research, the Recycle factor will be 60% from a ratio of 0.0-0.5
9	Fresh Water Price (FWP)	Rp/M3	10.850	https://calculator.suryacipta.app/ 0.7 USD/M3 (1 USD = Rp. 15.500)
10	Chemical Cost (CC)	Rp/M3	6.500	Chemical cost operation for wastewater recycling facility (Priadi et al., 2017)
11	Equipment Replacement Cost (ERC)	Rp/M3	4500	Cost for replacement equipment in wastewater recycle facility (Priadi et al., 2017)
12	Electrical Cost (EC)	Rp/M3	1.274	Electrical cost for wastewater recycles facility (Priadi et al., 2017)
13	Maintenance Cost (MC)	Rp/M3	37	Cost for maintenance for wastewater recycle (Priadi et al., 2017)
14	Wastewater Discharge Price	Rp/M3	7.595	https://calculator.suryacipta.app/ 0.7 x FWP

Table 2. Stock and Flow Diagram Mathematical Equation

No	Variable Name	Equation	Unit
1	Industry Water Demand (IWD)	Industry Production Water Demand + STEP (Industry Growth Rate, 2026 … 2035)	m^3/year
2	Industry water Consumption Stock	Fresh Water Demand (FWD) - Wastewater effluent Generated (WEG)	m3
3	Wastewater effluent Generated (WEG)	Fresh Water Demand (FWD) x Industrial Wastewater Ratio (IWR)	m3/year
4	Recycle wastewater stock	Wastewater effluent Generated (WEG) - Wastewater Generated Discharge to the environment (WDE)	m3
5	Recycled Wastewater Generated (RWG)	Wastewater Recycling Rate (RR) x Wastewater Effluent Generated (WEG) x Wastewater Recycle Demand (WRD) x Environmental Regulation (ER)	m^3/year
6	Wastewater Recycle Demand (WRD)	Product Water Specification (PWS) x Recycle Reuse Regulation (RR)"	Dmnl
7	Wastewater Effluent Recycling Rate (RR)	Wastewater Effluent Pollutant Quality(WEQ) + Wastewater Recycle Equipment Technology (WRT)"	Dmnl
8	Wastewater Generated Discharge to environment (WDE)	Wastewater Effluent Generated (WEG) - Recycled Wastewater Generated (RWG)	m3/year
9	Wastewater Recycle Cost (WRC)	Equipment Replacement Cost (ERC) + (Electrical Cost (EC) + Chemical Cost (CC) + Maintenance Cost (MC)) x Recycled Wastewater Generated (RWG)	Rp/year
10	Accumulated Cost saving	Water Saving Cost - Wastewater Recycle Cost (WRC)	m^3/year
11	Fresh Water Saving Cost (FWC)	Recycled Wastewater Generated (RWG) x (Fresh Water Price (FWP) + Wastewater Discharge price (WDP))	Rp/year
12	Potential Recycling Cost saving (PRCS)	Water Saving Cost - Wastewater Recycle Cost (WRC)	Rp/year
13	Fresh Water Demand (FWD)	Industry Water Demand (IWD) - Wastewater effluent Generated (WEG)	m3/year
14	Equipment Business Potential	Equipment Replacement Cost x Recycled Wastewater Generated (RWG)	Rp/year
15	Chemical Business Potential	Chemical Cost x Recycled Wastewater Generated (RWG)	Rp/year
16	Recycled wastewater delay project	Delay for project execution begins assuming 1.5 years for project execution DELAY FIXED("Wastewater Effluent Generated (WEG)", 1.5 , 0)	dmnl

V. REFERENCES

[1] Adhariani, D. (2020). *The Shape of Water: Analysis of Corporate Water Disclosure in Indonesia*.

[2] Aru Yudhantoro, W., Warno Utomo, S., & Nowo Martono, D. (2020). Water Reuse Planning for Fulfilment of Clean Water in Indonesia. *E3S Web of Conferences*, *202*. https://doi.org/10.1051/e3sconf/202020203002

[3] Bai, Y., Shan, F., Zhu, Y. yao, Xu, J. yi, Wu, Y. sheng, Luo, X. geng, Wu, Y. hu, Hu, H. Y., & Zhang, B. lin. (2020). Long-term performance and economic evaluation of full-scale MF and RO process – A case study of the Changi NEWater Project Phase 2 in Singapore. *Water Cycle*, *1*(August), 128–135. https://doi.org/10.1016/j.watcyc.2020.09.001

[4] Cagno, E., Garrone, P., Negri, M., & Rizzuni, A. (2022). Adoption of water reuse technologies: An assessment under different regulatory and operational scenarios. *Journal of Environmental Management*, *317*. https://doi.org/10.1016/j.jenvman.2022.115389

[5] Delgado, A., Rodriguez, D. J., Amadei, C. A., & Makino, M. (2021). Water in Circular Economy and Reselience (Wicer). *International Bank for Reconstruction and Development / The World Bank*.

[6] Ehalt MacEdo, H., Lehner, B., Nicell, J., Grill, G., Li, J., Limtong, A., & Shakya, R. (2022). Distribution and characteristics of wastewater treatment plants within the global river network. *Earth System Science Data*, *14*(2), 559–577. https://doi.org/10.5194/essd-14-559-2022

[7] Fagundes, T. S., & Marques, R. C. (2023). Challenges of recycled water pricing. *Utilities Policy*, *82*. https://doi.org/10.1016/j.jup.2023.101569

[8] FAO. (2022). The State of the World's Land and Water Resources for Food and Agriculture 2021 – Systems at breaking point. In *The State of the World's Land and Water Resources for Food and Agriculture 2021 – Systems at breaking point*. https://doi.org/10.4060/cb9910en

[9] HKI. (2023). *Members - Himpunan Kawasan Industri Indonesia (H K I)*. https://hki-industrialestate.com/members

[10] Keyhanpour, M. J., Musavi Jahromi, S. H., & Ebrahimi, H. (2021). System dynamics model of sustainable water resources management using the Nexus Water-Food-Energy approach. *Ain Shams Engineering Journal*, *12*(2), 1267–1281. https://doi.org/10.1016/j.asej.2020.07.029

[11] Kumar, S., Talan, A., Boyle, K., Ormeci, B., Drogui, P., & Tyagi, R. D. (2021). Water Recycling: Economic and Environmental Benefits. In *Biomass, Biofuels, Biochemicals: Circular Bioeconomy-Current Developments and Future Outlook* (pp. 91–120). Elsevier. https://doi.org/10.1016/B978-0-12-821878-5.00015-5

[12] Kuo, T. C., Hsu, N. Y., Wattimena, R., Hong, I. H., Chao, C. J., & Herlianto, J. (2021). Toward a circular economy: A system dynamic model of recycling framework for aseptic paper packaging waste in Indonesia. *Journal of Cleaner Production*, *301*, 126901. https://doi.org/10.1016/j.jclepro.2021.126901

[13] Liao, Z., Chen, Z., Xu, A., Gao, Q., Song, K., Liu, J., & Hu, H. Y. (2021). Wastewater treatment and reuse situations and influential factors in major Asian countries. *Journal of Environmental Management*, *282*. https://doi.org/10.1016/j.jenvman.2021.111976

[14] Meiryani, Huang, S. M., Soepriyanto, G., Audrelia, J., Fahlevi, M., Aljuaid, M., & Grabowska, S. (2022). An exploration of circular water management accountability: A case from Indonesia. *Heliyon*, *8*(9). https://doi.org/10.1016/j.heliyon.2022.e10556

[15] Morris, J. C., Georgiou, I., Guenther, E., & Caucci, S. (2021). Barriers in Implementation of Wastewater Reuse: Identifying the Way Forward in Closing the Loop. *Circular Economy and Sustainability*, *1*(1), 413–433. https://doi.org/10.1007/s43615-021-00018-z

[16] Morseletto, P., Mooren, C. E., & Munaretto, S. (2022). Circular Economy of Water: Definition, Strategies and Challenges. *Circular Economy and Sustainability*, *2*(4), 1463–1477. https://doi.org/10.1007/s43615-022-00165-x

[17] Naeem, K., Aloui, S., Zghibi, A., Mazzoni, A., Triki, C., & Elomri, A. (2024). A system dynamics approach to management of water resources in Qatar. *Sustainable Production and Consumption*, *46*(December 2023), 733–753. https://doi.org/10.1016/j.spc.2024.03.024

[18] Naeem, K., Zghibi, A., Elomri, A., Mazzoni, A., & Triki, C. (2023). A Literature Review on System Dynamics Modeling for Sustainable Management of Water Supply and Demand. *Sustainability (Switzerland)*, *15*(8), 1–24. https://doi.org/10.3390/su15086826

[19] National Development Planning Agency (Bappenas). (2020). Rpjmn 2020-2024. *National Mid-Term Development Plan 2020-2024*, 313. https://www.bappenas.go.id/id/data-dan...dan.../rpjmn-2015-2019/

[20] Nyoman, N., Marleni, N., & Raspati, G. S. (2020). A Critical Review of Wastewater Resource Recovery Implementation in Indonesia. *Journal of Civil Engineering Forum*, *6*(1), 89–102. https://doi.org/10.22146/jcef.52655

[21] Priadi, C. R., Suleeman, E., Darmajanti, L., Novriaty, S., Suwartha, N., Resnawati, R., Handayani, R., Putri, G. L., Felaza, E., & Tjahjono, T. (2017). Water recycling opportunity in the business sectors of Greater Jakarta, Indonesia. *International Journal of Technology*, *8*(6), 1031–1039. https://doi.org/10.14716/ijtech.v8i6.743

[22] Sterman, J. (2002). *Business Dynamics, System Thinking and Modeling for a Complex World Massachusetts Institute of Technology*. *January 2000*.

[23] Tortajada, C. (2020). Contributions of recycled wastewater to clean water and sanitation Sustainable Development Goals. *Npj Clean Water*, *3*(1). https://doi.org/10.1038/s41545-020-0069-3

[24] Worldbank. (2023). *Annual freshwater withdrawals, total (billion cubic meters) | Data*. https://data.worldbank.org/indicator/ER.H2O.FWTL.K3

[25] WWDR, T. U. N. (2023). *UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 2023 : partnerships and cooperation for water.* UNITED NATIONS.