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SUSTAINABLE WATER SERVICES FEE USING A SYSTEM DYNAMICS APPROACH IN JATIGEDE RESERVOIR

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ABSTRACT: Reservoir operation and maintenance costs consist of the water service fee from the beneficial water users, and the subsidy from the government. Sustainable operation and maintenance should keep the government subsidy at the minimum level while at the same time considering the willingness to pay from the water users. These two parameters of subsidy and water service fee form an interdependent feedback loop in determining operation and maintenance costs, that belong to the system dynamics phenomenon. This paper calculates the level of government subsidy and the water services fee in order to reach optimal water resources management using a system dynamics approach, in the Jatigede multipurpose reservoir in West Java – Indonesia. Jatigede Reservoir with a volume of 877 million m3 irrigates almost 90 thousand hectares of rice field, providing a public water supply of 3.5 m3/s, and a targeted energy generation of 110 MW. The methodology of using the system dynamics approach is starting with the identification of the interrelated parameters into a causal loop diagram, conversion into stock and flow diagram, and programming using Powersim. It is concluded that the system dynamics approach can reveal the optimal solution, a combination of minimum government subsidy and water services fee within the range of willingness to pay, that minimize the additional maintenance costs in the long term.

Keywords: Water Service Fee, System dynamics, sustainable management, Multipurpose reservoir.

1. INTRODUCTION

The annual potential of surface water resources in Indonesia is currently ± 2,780 billion cubic meters [1] and Indonesia ranks fifth in the world in terms of potential water reserves, but only 25% can be utilized for various needs such as irrigation, raw water, and industry.

The high potential of water resources is a gift, sustainable development, and management of dams in an effort to support the realization of water sovereignty that will support food and energy security. The development of water resources infrastructure is the government's effort to supply raw water, national energy security and support food security, while also efforts to reduce flood losses.

Jatigede Dam Project is one of the strategic projects in the field of water resources. By investing in development costs and other related matters, the Jatigede Reservoir is calculated to be able to provide benefits throughout its operating life. The sustainability of the function of the irrigation infrastructure determines the success of the management of water resources. To achieve sustainability, the operation and maintenance (O&M) aspects of the irrigation infrastructure are very important to guarantee the benefits of water services and protect the community from water damage, in addition to meeting the return on investment that was allocated at the time of development.

Water resources management costs consist of: a) information system costs; b) planning costs; c) construction implementation costs; d) operation and maintenance costs; and e) the costs of monitoring, evaluating, and empowering the community. After a reservoir has been built, the most important cost is operation and maintenance cost to operate and maintain the reservoir. Insufficient budget for operation and maintenance cost could make the failure of delivering the product as designed, and even worse might resulting permanent damage to the reservoir.

Jatigede Reservoir operation and maintenance cost come from two sources: 1) water users, and 2) government subsidy. According to the Integrated Water Resources Management (IWRM) principles, water users should pay for the water services they received. However, water users are having different abilities and willingness to pay. Water tariffs should be low enough, affordable within the willingness to pay from the water users, and on the other hand, enough to cover the operation and maintenance cost. Sustainable tariffs or water services fee is a balance between optimality, viability, fairness, and efficiency.

The objective of this paper is to find the optimal water services fee for each category of water users, as well as the government subsidy in order to reach sustainable financing of the operation and maintenance for Jatigede Reservoir.

2. MATERIAL AND METHODS

Jatigede Reservoir is one of the largest multipurpose reservoirs in Indonesia which is located on the island of Java, precisely in the province of West Java. The reservoir with inflow from the Cimanuk river has a capacity of 979.5 million cubic meters with the main function of irrigating 90 thousand hectares of irrigation area. This reservoir also serves to supply raw water 3.5 m^3/s and 110 MW hydroelectric power plant. Reservoir also serves raw water for the industry and supply industry directly from the reservoir. Besides, the reservoir also has a function to secure floods area covering 14 thousand hectares. The map of Jatigede reservoir location can be seen below.

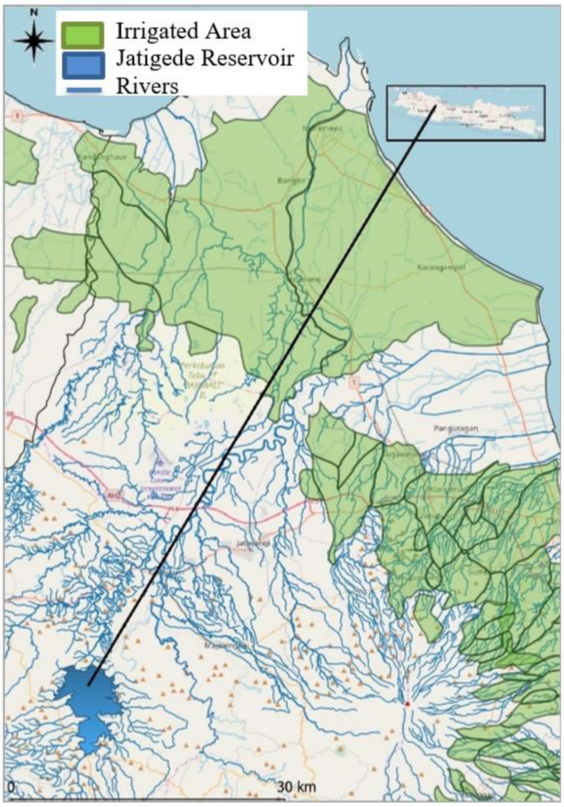

Fig 1. Map of Jatigede Reservoir Location and Location of Services

2.1 Economic Principles in Water Resources Management

An economic sense of the benefits of water can be defined as an assessment in units of money to measure satisfaction or welfare received by humans because of their choices [2]. Of course, this value cannot be found absolutely in the real world because water is an essential resource that has great externalities [3].

In determining the economic value of water use, the economic framework of Alfred Marshall [4] is used. In this framework of thinking welfare in the community is measured based on the surplus enjoyed by the two opposing groups, namely the producer and consumer groups [5].

Water resource management costs consist of several components. [6] states that costs include: maintenance operating costs, investment returns, opportunity costs, economic externalities, and environmental externalities. The opportunity cost according to [2] is the cost of the next best choice that is not so was taken. All of these costs can be called full costs.

2.1 Causal Loop Diagram (CLD)

The causal or fishbone diagram was first introduced by a Professor Kaoru Ishikawa from Tokyo University, therefore a causal diagram is also called an Ishikawa diagram or fishbone diagram. The purpose of making this causal diagram is to be able to show the root causes and the quality characteristics that are caused by those causal factors. Generally, a causal diagram shows 5 factors that are called the cause of an effect. The five factors are the man (human, labor), method (method), material (material), machine (machine), and environment (environment). This diagram is usually arranged based on information obtained from brainstorming. According to [7] Cause and effect analysis was created as tool for a quality control and to identify potential factors causing an overall effect which is caused by various phenomena understudy. Cause and effect diagrams are used for the following needs; 1) Help identify the root cause of a problem, 2) Help generates ideas for solutions to problems, and 3) Assist in a further investigation or search for facts.

Determination of tariffs is a causal process that can be simulated in a system dynamics model. There are three cycles: 1) The higher the rate charged to the community; the greater the community's funds will be obtained; 2) The higher the tariff charged to the community, the more reluctant the community will be to pay, causing the smaller amount of public funds to be obtained, and resulting in swelling of the required subsidies; 3) The lower the available O&M funds, the annual O&M will not be optimal, thus causing greater periodic maintenance costs, and resulting in the greater total costs in the long run.

2.2 System dynamic

[2] defines system as a collection of interrelated elements, each related to the other, and no part unrelated to the other is in [8] . Thinking systemically or system thinking its history begins by [9] with the science of cybernetics, with the presence of feedback

(feedbacks) that can be used to explain the behavior of humans, animals, and machines. Still, according to [10], system theory can be applied to technical, biological, and social system problems is explained by [11].

The heart of the system dynamics is system analysis. A system is defined as a set of elements that interact with each other with patterns of interaction that influence one another and determine one another. Problems with dynamic nature and have a feedback structure will be better if system dynamics is carried out. [12]. The benefit of this approach is to explain the structure of the system, the elements of the system that are interrelated. The link between structure and behavior depends on the concept of information and control feedback [13]. Causal loop diagrams represent the feedback mechanism, which amplifies (positive feedback loop) or negates (negative feedback loop)[14].

The system dynamics model in this study was developed using Powersim 8 software in order to obtain optimal domestic water tariffs to achieve the Annual Real O&M cost with specified subsidies. Powersim is a tool for modeling and simulation of dynamic systems. It can be used to study time-continuous progress in a great number of areas, for example, biology, economics, physics, and ecology. The modeling is done by constructing a Powersim diagram. This is done by choosing from the set of defined graphical symbols and placing them in suitable places. Elements influencing each other are then connected with arrows. Powersim is easy to understand and use even for people without great knowledge in mathematics, programming, and simulation. The integration is based on a "bathtub analogy" which doesn't demand knowledge about differential calculus.

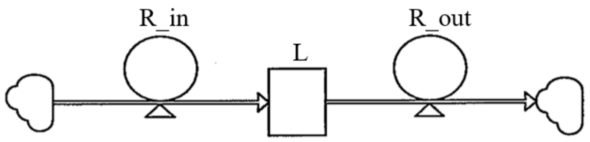

Fig 2. Bath Tub analogy

The state L (Level) in figure 2 is affected by an inflow R-in (Rate) and an outflow R-out. This corresponds to a bathtub where the water leve1 is affected by two taps, one that runs water into the bath and one that lets water out of the bath. Note that the state L is not entirely determined by the flows, but also by the initial value Lo. Note also that the state does not depend on the current flows, but on the accumulated flows from the past.

Mathematically is L determined in Eq. (1) and Eq. (2).

$$\begin{cases} \frac{dL}{dt} = R\_in(t) - R\_out(t) \\ L(0) = L_0 \end{cases} \tag{1}$$

$$L(t) = L_0 + \int_0^t R\_in(t) - R\_out(t)dt \tag{2}$$

In Powersim first-order systems of differential equations are modeled and simulated.

3. RESULT AND DISCUSSION

3.1 External Factor

Water pricing is affected by social and political conditions, besides supply and demand [15]. The value of water should also consider the externality effects of using water resources. In [17] externalities can be defined as the costs (or the benefits) associated with providing water service, but are outside the system and are not included in the cost (or benefits) of service [16].

External factors impact the willingness to pay. External factors might consist of: a) Ratio between income and expenditure, as the indicator of community purchasing power; b) regional income, as the indicator of the ability of subsidies, surface water scarcity which is an indicator of the amount of water in the region, and availability of groundwater which is an indicator of the large needs people will surface water. The higher the value of external factors means the higher the purchasing power of the community, or it can also indicate there is no other choice so that the community is willing to buy water from the Jatigede reservoir. Determination of the value of external factors was analyzed by considering another river basin those are Ciliwung - Cisadane (DKI), Citarum (West Java), Cimanuk - Cisanggarung (West Java), Bengawan Solo (Central Java), and Brantas (East Java).

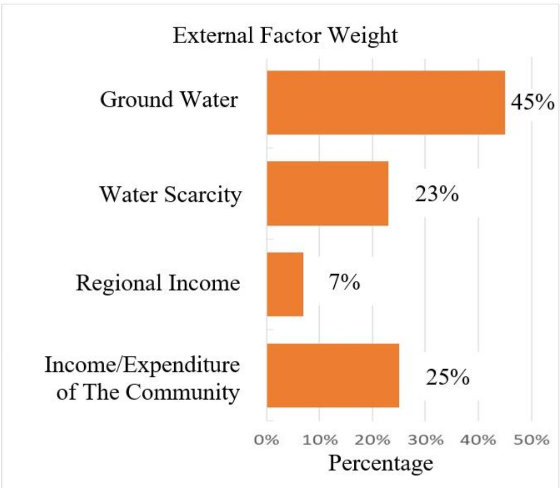

Fig 3. External Factor Weight Chart

3.2 Causal Loop Diagram

From the cause and effect diagram above, it can be seen that there is two balancing loops, namely DMI (Domestic, Municipal, and Industry) water loop and hydropower water loop. DMI water loop in the model would be separated into the raw water supply, raw water supply for industry and industrial water supply directly from the reservoir.

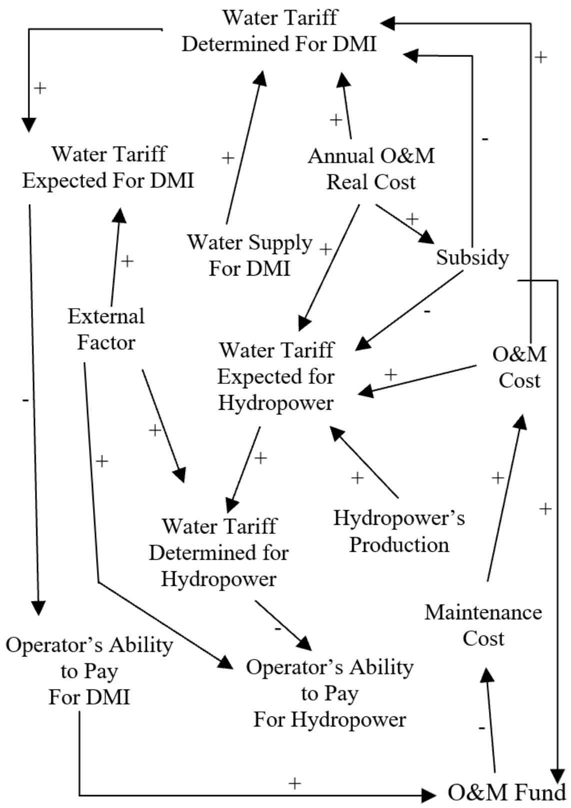

Fig 4. Causal Loop Diagram of This Study

In this study, the tariff of DMI is an interaction of the ability to pay the community, in this case, is the operator and public funds/operators that can be collected after subsidies from the government balanced with funds collected from hydropower.

From the causal loop diagram above, it is illustrated that the O&M Fund is a fund generated from the amount of water given to the operator which is expected to be a maximum of Annual Cost of O&M. Subsidies are interventions from the government and op costs are maintenance costs and O&M funds.

The expected tariff is a comparison between the Annual Cost of O&M minus Subsidies with production water volume. The greater the tariff expected, the greater the rate will be determined. The ability of the operator to pay is a factor of the tariff determined which is influenced by external factors. The higher the tariff set, the lower the operator's ability to pay. The ability to pay operators is directly proportional to the O&M Fund and the O&M Fund is inversely proportional to Maintenance Costs in the sense that the smaller the O&M Fund is available it will incur large Maintenance Costs. The number of maintenance costs will result in high O&M costs. High O&M costs result in the expected tariffs being large so the tariffs set will also be large and so on. This rotation is called a loop that will spin continuously towards balance.

3.2 Computer Model

Model input data, namely Annual O&M Real Cost to be achieved, Percentage of subsidies to be provided, graphs of relationship maintenance costs that arise if existing O&M Funds do not reach O&M Cost, water production plans in m^3/year for raw water, raw water for industry and demand industry supplied directly from reservoir, Annual Hydropower production in GWh/year, Reliability water production, Reliability hydropower production, water tariff reference is taken from other selected regional tariffs. The external factor analyzed is an indicator of the ability of the community to be willing to pay for water at a fixed rate calculated from the comparison of the tariff set with the desired tariff based on external factors. the structure of the model is presented in the following figure.

Data and assumptions used in this simulation are: Production of water from the Jatigede reservoir for raw water supply companies is 3,5 m^3/s, raw water supply for industry companies is 2 m^3/s, and supply for industry directly from reservoir 0,08 m^3/s. The reference rate used is the rate from Jatiluhur because the reservoir tariff is classified as the smallest. The reliability of all raw water production is set at 90%, and hydropower that depends on irrigation water is set at 80%. The analysis is carried out with several scenarios; reservoir normal operation with 0%-10% subsidy and reservoir dry operation with 0%-10% subsidy.

The simulation results for all scenarios show that the tariff for the raw water users reaches an optimal number. The simulation results show that the O&M Fund will reach 100% of the Annual Cost of O&M. The simulation shows that all tariffs fluctuate until they reach equilibrium. The willingness to pay also fluctuates in tandem with the fluctuation of the tariff until it stays at an optimal number. Graphs of tariff and willingness to pay are presented below.

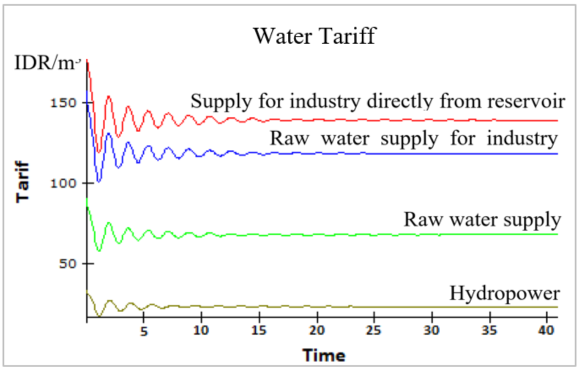

Fig 5. Graph of water tariff's iteration

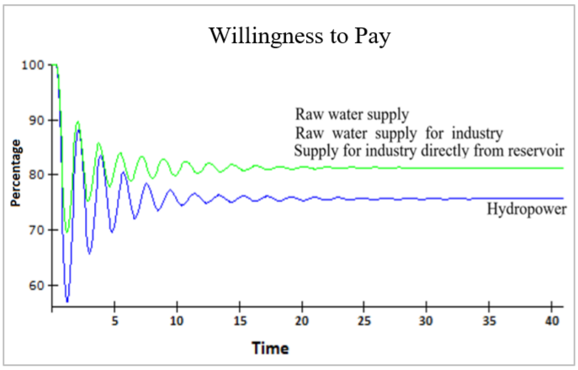

Fig 6. Graph of willingness to pay's iteration

The higher the subsidy is given, the lower the tariff will be achieved. A scenario for normal operation also gives lower tariffs than dry operation. The lowest tariff is achieved with normal operation and a 10% subsidy and the highest tariff is achieved with dry operation and 0% subsidy. The tariff table is presented below.

Table 1. Tariff of Raw Water from Jatigede Reservoir

	Reservoir Normal Operation		
Subsidy	0%	5%	10%
Raw Water (IDR/m3)	67.42	65.29	63.03
Raw Water for Industry (IDR/m3)	117.39	113.67	109.74
Industry supply Directly from Reservoir (IDR/m3)	137.88	133.51	128.89
Hydropower (IDR/KWh)	23.44	22.75	22.01
	Reservoir Dry Operation		
Subsidy	0%	5%	10%
Raw Water (IDR/m3)	68.15	66.02	63.78
Raw Water for Industry (IDR/m3)	118.65	114.95	111.05
Industry supply Directly from Reservoir (IDR/m3)	139.36	135.02	130.44
Hydropower (IDR/KWh)	23.67	22.99	22.26

Compared to other regional water tariffs, the optimal water tariff from the Jatigede reservoir with dry operation and 0% subsidy is the lowest water tariff. The tariff comparison chart is presented below.

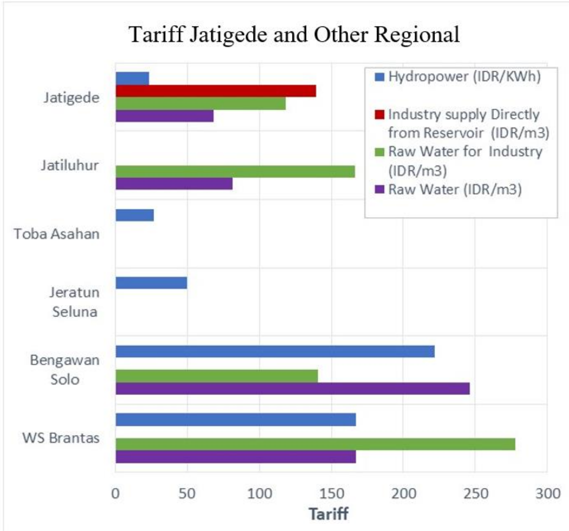

Fig 7. Tariff raw water of Jatigede Reservoir compared with raw water tariff of other regionals

4. CONCLUSIONS

The system dynamics modeling of the sustainable water services fee for Jatigede Reservoir concluded that:

1) A transparent and flexible system dynamics approach has provided a comprehensive picture of sustainable financing for the operation and maintenance of Jatigede Reservoir.
2) The resulting lowest tariffs are at 10% of the subsidy. The lowest tariff obtained for raw water is 63.03 IDR/m3, industrial raw water 109.74 IDR/m3, direct extraction industry 128.89 IDR/m3, and for hydropower 22.01 IDR/m3.
3) The scenario for normal reservoir operation provides lower tariffs than operation in dry conditions.
4) Optimal tariffs obtained for all scenarios reach 100% of annual real demand of operation and maintenance costs and prove to be the lowest water tariffs compared with water tariff in other river basins in Indonesia

5. ACKNOWLEDGMENTS

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