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The Role of Dams on Water, Food, and Energy Security Issues: A Global Review and Resolution for Indonesia

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***Abstract*— Surviving and struggling for lives are the major concerns of the people in the world. In order to survive, they highly depend upon water, food, and energy. Therefore, they are trying to povide to meet their needs. Increasing demand for water, food, and energy demand due to world population growth has directly contributed to focus on dams in many countries in the world. Hence, they play an important role in sustainable water resources management, such as flood control, industrial water supply, irrigation, fisheries, recreation, navigation, hydroelectricity, and other purposes. Predictedly, the number of dams will increase 51% of the total dams by 2050. This study aims to analyze the relationships among variables of water, food, and energy. Multiple linear regression analysis was used to identify the significance of interrelated relationships among variables of water consumption, energy consumption, irrigated areas, and the number of dams by using data from period 1960-2010. Meanwhile, number of dams had significant impact on energy consumption and the number of dams. This indicates that the development of dams will be contribute to increasing the ability to manage water resources and increasing energy consumption in various sectors in the world will have an impact on increasing water consumption. For Indonesia, currently focusing on food and energy securities.This study recommends that the construction of dams need accelerated. The urgency of water, food and energy securites has been the main driver for focusing investment on this facility as well as meeting the demands of providing other public infrastructure.**

***Keywords*— dams; water; irrigation; food security; energy security.**

I. INTRODUCTION

The world populations have increased rapidly since the beginning of the 20th century, from 2,5 billion in 1950 to 6,1 billion in 2000 and was at 7 billion in 2011 [1]. It is considered a driver of increased demand for water, food, and energy. According to the projected population growth scenario by the UN, the global population will reach 8,5 billion by 2030 and 9,7 billion by 2050 [1]. In response to global population growth, demand for water, food, and energy worldwide also increased rapidly [2].

Linearly, food consumption continues to increase in response to global population growth, but its development will be linked to modern agriculture. Reference [3] and Reference [4] indicates this that at the global aggregate level the food production of the world's population has exceeded population growth. However, at the same time, food production cannot meet the food needs in some countries in the world so that the problem of food security becomes inevitable. The absolute increase in food demand will be quite large as projected, especially in countries with large population growth (for example, countries in Asia will account for more than 50% of global population growth). Moreover, it should be noted that in recent decades the world food consumption per capita has increased. This impacts economic growth, individual wealth, and water consumption [5].

Reference [6] has projected that approximately 70% more food than the current amount (even nearly 100% in developing countries) will be needed by 2050 to cope with a 40% increase in the world population and to accommodate changes in global food consumption patterns. Of the additional amount of the food, some will be produced in irrigated areas that will require 11% more water than the current volume, most likely coming from storage reservoirs. On the other hand, about 19% of the world's electricity will be supplied by hydropower that is used in more than 150 countries [7].

On the other hand, over the past few decades, global energy consumption has been increasing linearly. Oil, coal, and gas are still the main sources of current energy statistically. However, these sources of energy lead to a steady increase in greenhouse gas emissions because they are not a source of renewable energy. Therefore, it has been warned that that it is vital to accelerate the development of clean energy sources, such as hydroelectric powers, which currently contribute only a fraction of total energy consumption [8].

The ever-increasing demand for water, energy, food, and biofuels due to population growth, as well as concerns related to carbon emissions and potential impacts on climate change, have contributed to the increasing attention of various parties to dams in many countries [9]. Dams have been recognized to play a broad role in human survival as they play an important role in water resources management and control. In this regard, dams are estimated to have contributed directly to 12-16% of global food production [7].

Since it was built in the early 3.000 BC that marked the major episodes of human civilization in Asia and Europe [10], for thousands of years, humans have built dams and reservoirs to regulate the spatial and temporal variability of water. Dams have been used for various purposes, including flood control, industrial water supply, irrigation, fisheries, recreation, navigation, and hydroelectric power [7], [11], [12]. With extensive function, dams are considered an important issue in the sustainable management of water resources in a sustainable manner. The management of these resources is expected to become more competitive today as the growth of the global population creates conflicts over the provision of water to generate energy and to ensure food security [11].

The amount and volume of large dam storage (dams higher than 15 m) have increased significantly worldwide in the last six decades [12], which currently amounts to approximately 32.000 dams [2]. As already mentioned, the growth of the world population and the increasing demand for water, food, and energy have affected the increase in the number of dams worldwide. Based on data compiled from [2], [13]-[16], development of water consumption, energy consumption, irrigated areas, and the number of dams from 1960-2010 are shown in Table 1.

TABLE I
THE DEVELOPMENT OF WATER CONSUMPTION, ENERGY CONSUMPTION, IRRIGATED AREAS, AND THE NUMBER OF DAMS FROM 1960-2010

Variable	Estimation					
	1960	1970	1980	1990	2000	2010
Water consumption (thousand km^3)	2.00	2.60	3.20	3.55	3.90	4.30
Energy consumption (thousand TWh)	0.68	1.18	1.70	2.16	2.66	3.47
Irrigated areas (million hectares)	160.9	184.1	220.7	257.7	287.6	317.7
Number of dams	9.056	14.968	22.361	27.559	30.773	32.473

Table 1 provides an understanding of why the increase in the number of dams is almost linear with the development of these variables. Using projection methods based on historical data, projected increases in water consumption, energy consumption, irrigated areas and the number of dams in the world by 2050 is shown in Figure 1.

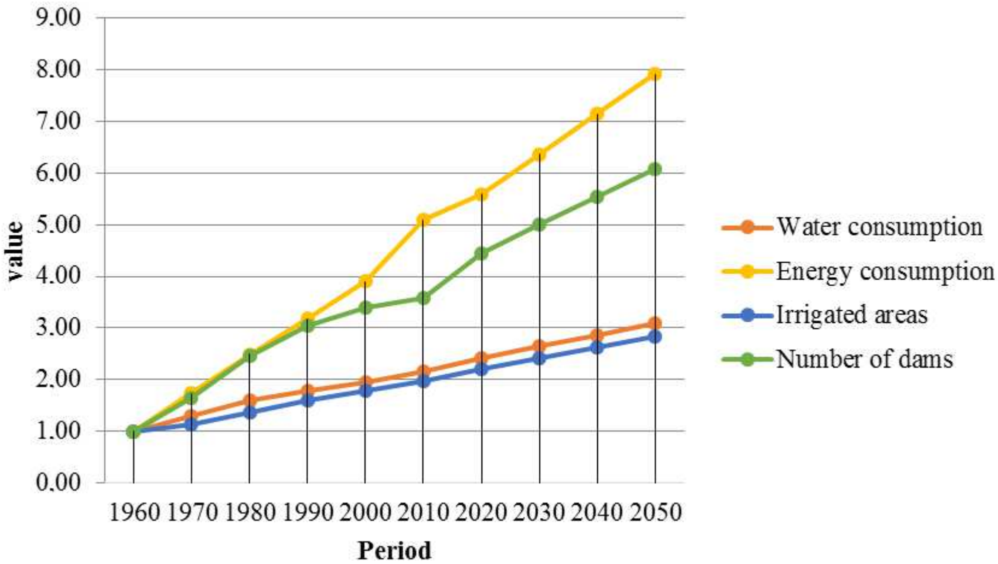

Fig. 1 Development and projection of water consumption, energy consumption, irrigated areas, and number of dams in the world

By using the year of 1960 as the initial value (value of 1), the development of each variable is calculated according to the relative value of each period (year) to the initial value as done by [2]. Based on this scenario, the development trends of all variables from 1960 to 2010 can be seen as shown in Figure 1. Projection of all variables for the period 2020-2050 shows that water consumption, food consumption, energy consumption, irrigated areas and the number of dams of the world will increase by 3,34; 7,91; 2,82 and 6,09 times respectively in 2050 when compared to 1960. These figures show a very significant increase because of the interrelationships between these variables.

Various sources have clearly shown the importance of the dam role in addressing the issue of food and energy resilience of the world. The dam is considered to have solved many of the world's population problems and has provided the basis for sustainable economic development. Reference [17] discloses some of the benefits to be derived from water resources management through dams, including the realization of food security for an ever-increasing population of the world, protection from floods and droughts in vulnerable areas and energy regeneration. This study aims to analyze the relationships among variables related to water, food, and energy issues of the world, including dams. This is considered important because there is a dependency on water and energy consumption, dams, and irrigation. However, the prioritization of significantly related variables to each of them becomes a necessity for decision-making in various dam, energy, and irrigation development programs around the world. Finally, more specifically this needs to be reflected on how each country views the importance of the role of the dam in ensuring their food and energy security.

II. Material and Method

A. Data

This study uses secondary data from the 1960-2010 period with a 5-year period ranging from previous research and published reports from various international organizations, including world water consumption [13], world energy consumption [15], [16], world's irrigated area [14], and number of world dams [2].

B. Analysis

All the variables used in this study (i.e., water consumption, energy consumption, irrigated areas and the number of dams) were standardized before analyzing by setting initial and relative values. Each of these variables is treated as a dependent variable in multiple regression analysis, allowing the identification of the relative importance of the four independent variables in controlling the dependent variable. If the standard coefficient value is higher, then the influence of independent variables to the dependent variable will be greater. The ranking order of the standard coefficients provides the basis for the relative importance of the independent variable to the dependent variable. Such a method is adapted from [2], which examined the relation between six variables, namely population, water, food, energy, dams, and reservoirs. In this study, population, food consumption, and reservoir capacity variables were not analyzed. However, irrigated areas are added to the analysis of a new variable. The hypothesis is then set equal for all variables, in which three independent variables are expected to have simultaneous effects on the dependent variable. In this case, there are four hypotheses tested. The significance level of the test (α) used was 0.05 with a 95% confidence interval.

III. Result and Discussion

A. Linear Regression Analysis

Based on data from 1960-2010 and projection periods up to 2050, the multiple regression analysis of water consumption variables, energy consumption, irrigated areas and a number of dams (by treating each variable as a dependent variable) are shown in Table 2. The standard coefficients and significance of variables respectively are shown in Table 3 and Table 4.

TABLE II
RESULT OF MULTIPLE REGRESSION ANALYSIS

No.	Hypothesis (Simultaneous Influence)		R-Square	Significance			
	Independent Variables	Dependent Variables		WC	EC	IA	ND
H_1	EC, IA, ND	WC	1.000	-	0.000	0.064	0.000
H_2	WC, IA, ND	EC	0.999	0.000	-	0.000	0.000
H_3	WC, EC, ND	IA	0.999	0.064	0.000	-	0.007
H_4	WC, EC, IA	ND	0.999	0.000	0.000	0.007	-

Remarks: WC = Water Consumption
IA = Irrigated Area
EC = Energy Consumption
ND = Number of Dams

Almost all independent variables relate significantly to the dependent variable, except the Irrigated Area (IA) variable that is not significantly related to Water Consumption (WC) and vice versa, the Water Consumption (WC) variable is not significantly related to the Irrigated Area (IA), as shown in Table 2. It is understandable that irrigated areas do not fully use the water consumed by the inhabitants of the earth. Although 70% of the world's freshwater use is destined for irrigation to produce 40% of global food [3], [17], [18], the fact that the number of irrigated areas in the world do not fully consume freshwater globally because of this consumption is also intended for the needs of other residents such as industry, power generator, fisheries, recreation and others [11], [12].

TABLE III
STANDARD COEFFICIENT OF REGRESSION ANALYSIS

Dependent Variables	Independent Variables			
	WC	EC	IA	NB
WC	-	0.550	-0.252	0.703
EC	1.248	-	0.674	-0.924
IA	-0.838	0.990	-	0.850
NB	1.274	-0.739	0.463	-

TABLE IV
SIGNIFICANCE BETWEEN VARIABLES

Variables	Significant Variables	
Water consumption	Number of dams	Energy consumption
Energy consumption	Water consumption	Irrigated area
Irrigated area	Energy consumption	Number of dams
Number of dams	Water consumption	Irrigated area

In general, all independent variables are interrelated significantly to the dependent variable, as shown in Table 3 and Table 4. If the standard coefficient value is higher, then the influence of independent variables to the dependent variable is greater [2]. Water consumption was dominantly the most significant influence on energy consumption (standard coefficient 1,248) and some dams (standard coefficient 1,274). The number of dams dominates the effect on water consumption, followed by energy consumption. This supports the results of the study of Chen et al. [2], which indicates that dam development will help improve water resources management capabilities, and increased energy consumption in various sectors of the world will impact on increased water consumption. Of the 2815 large dams documented by Chen et al. [2], 39% built for hydropower, 29% for irrigation, 14% for flood control, 8% for water supply and 10% for other uses (e.g., navigation and recreation). This statistic clearly shows that irrigation is the two most important considerations for the construction of large dams worldwide so far.

B. Issues Related to World's Food and Energy Security

Due to unavoidable future population growth, serious problems such as water, food and energy shortages can occur if development strategies are not properly implemented [19]. In the face of continued population growth in developing countries and underdeveloped economies, the need for the construction of additional dams (especially large dams) in the next few decades becomes inevitable [20]. The dam constructions will be an effective way to address future economic and social development issues.

The relationship between rapid economic expansion and the construction of large dams in various countries of the world (especially in developing countries) indicates that large dams can help alleviate the problem of energy shortages and play an important role in economic development. The World Bank has noted that hydropower dams have a role in water resources management, including water allocation, flood management, and drought. The construction of dams, along with other infrastructure, will enhance the ability of the world's population in planning and water resources management, particularly related to food and energy security issues [8].

The efforts to reduce the impact of floods, secure water supplies, and provide hydropower have benefited the world's population in many ways, allowing for improved human health, expansion of food production, and economic growth [7]. With the increasing need for water, energy, and food, the dam development in the effort to provide much-needed services is expected to continue in the future [9]. The results of this study clearly show that the dam plays an important role in the development of the global socio-economic primarily related to its role in ensuring water supply for consumption needs by the world's population and the provision of energy. These results support the findings of [21] who reported that the construction of dams in the 20th century coincided with economic development on a national and regional scale. The contribution of large-scale infrastructure (including dams) to human development should not be ignored [22], and most economic development around the world has been secured by the use of water resources, including hydropower [23].

C. Resolution for Indonesia

Based on data from the Ministry of Public Works (PU), Republic of Indonesia (2015), the number of dams in Indonesia is 209 dams with technical parameters, and their utilization are shown in Table 5.

TABLE V
DAMS IN INDONESIA AND THEIR UTILIZATION

No.	Parameters	UoM	Values
1	Number of dams	unit	209.00
2	Volume of dam	km^3	1,374,972.57
3	Reservoir capacities	km^3	15,625,989.03
4	Puddle areas	km^2	1,036,770.39
5	Irrigation benefits	hectare	827,905.90
6	Hydropower benefits	MV	5,833.43
7	Raw water benefits	m^3/second	1,693.21
8	Water catchment	km^2	49,204.88

Based on Table 5, it is noted that the number of dams in Indonesia only accounts for about 0,64% of the total of dams in the world, while the irrigated area of the dams in Indonesia only accounts for about 0,51% of the total area irrigated by dams worldwide (compared to number of dams and the world's irrigated areas of 2010 in Table 1). This amount is still few compared to the potential of water resources management in Indonesia is quite large (especially lakes and rivers).

Reference [24] identified the potential problems of dam constructions in Indonesia on two main issues: (1) the impact of dam constructions, and (2) post-construction or utilization period of the dams. At the stage of utilization, there are still other issues such as (1) potential construction failures that will threaten residents living downstream of dams, and (2) problems related to the threat of sustainability of dam functions. This is only part of the potential other problems that will arise due to dam constructions.

After the last few decades to date, the dam construction activities are still considered far from satisfactory in many developing countries (including Indonesia). The need for more dams remains enormous, especially in its development in various regions of the world. Population growth, the pace of urbanization and industrialization, and the urgent need to improve the standards and quality of the poor life have urged governments and relevant stakeholders to build these facilities [17]. Reference [8] has noted the multidimensional role of dams as a hydropower plant in poverty alleviation and sustainable development in developing countries.

In developing countries, it can be observed that reservoir capacity accumulation increased throughout the year before 1990, but this growth rate seems to decline thereafter. This slower rate of growth may reflect the environmental and social problems associated with dam building in conjunction with the financial constraints experienced by these countries [8]. Although total installed hydropower capacity per year has increased in recent years, the number of dams completed per year has decreased [2]. This is an indication that in recent years, dams have been designed and built with greater power generation capacity. The installed capacity of hydropower plants in developing countries (especially BRICS) has increased rapidly in recent decades, while in developed and an underdeveloped country has only increased slowly [25]. Besides, in high-ranking countries regarding large dams (such as Canada, Spain, Norway, Japan, and Sweden), the rate of exploitation of hydropower is very high and hydroelectric power is a major part of energy consumption [7].

Regarding dam constructions, it should be noted that the above countries are developed or developing countries that have rapid economic expansion. Intuitively, energy and food production is the most important driving force for a country's economic growth. As a result, the rapid economic expansion will have an impact on large energy consumption, while energy scarcity remains a problem concerning continued economic developments. Therefore, the role of hydropower in industrialization in China, India, Russia, Brazil, Japan, and South Korea, for example, has been seriously highlighted recently [23].

Indonesia can learn from the success of countries that have harnessed hydropower through dam functionalization. Achieving water security, food, and energy security to improve population and economic development is a major global challenge facing the world community today, including Indonesia. The complication of this challenge is the high level of interconnection between the water, food, and energy sectors, as evidenced by the high level of food and energy price correlations and the strong dependence of food production on water availability [26].

IV. CONCLUSIONS

The increase in world population has resulted in increased consumption of water, food, and energy. In response to these developments, the role of dams has been recognized as contributing to the fulfillment of water, food, and energy needs of the world's population. This study has successfully identified the interrelated variables significantly in response to this water, food, and energy security issues. Water consumption dominates the most significant influence on energy consumption and the number of dams. Meanwhile, the number of dams dominates the effect on water consumption, followed by energy consumption. It indicates that dam development will help improve water resources management capabilities, and increased energy consumption in various sectors of the world will impact on increased water consumption. The results of this study clearly show that the dam plays an important role in the development of the global socio-economic primarily related to its role in ensuring water supply for consumption needs by the world's population and the provision of energy.

As a resolution, Indonesia can learn from experience and practice in various countries that have successfully optimized the function of the dams. Indeed, there is little investment required to build dams (especially large dams). However, the urgent need to create dams as a guarantee for water security, food, and energy security is expected to be a key driver to focus investment on this facility, in addition to meeting the demands of other public infrastructure provision.

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