Water-energy nexus development for sustainable water management in Indonesia

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Water-energy nexus development for sustainable water management in Indonesia

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Abstract. This paper is a review of the development of simulation model for water-energy nexus in achieving sustainable water management in Indonesia. It is important to understand complex interconnection of water and energy to create strategy since Indonesia is facing the decrease of resources and increase of demand. A system dynamic simulation model is a reliable tool to simulate the relationship between water and energy. This study objective is to develop a conceptual model that can determine the amount of demand, supply, or import of water and energy. The method used is a Vensim (Ventana Simulation Environment) program. This conceptual water-energy nexus framework could further being tested to calculate the balance of water and energy element and creating sustainable resource management plans.

Keywords: Water-energy nexus, hydropower, system dynamic model, conceptual framework

1. Introduction

The word 'nexus' is interpreted as a process to connect actions of various stakeholders from different sectors for achieving sustainable development. The concept of nexus is in alignment with the concept of integrated water resource management (IWRM) [1]. Although, while IWRM is water sector oriented and constraints its interaction with other sectors, nexus is more opened to any other sectors, by encouraging efficiency in resource use. Activities on water–energy nexus varied from water for energy to energy for water. Examples of utilizing water for producing energy include generation of hydropower and cooling water utilized in coal and thermal power plants. Energy consumption examples included pumping groundwater for irrigation and treating wastewater using electricity. There is an example from the Spanish agricultural irrigation water sector that showed elevating requirements of energy [2]. Also, some studies on waste water treatment plant from a life cycle point of view [3,4]. The interconnections between water and energy sectors can be illustrated in concept, yet the feedback connections are complicated and influenced by external factors [5]. There are many studies regarding the water-energy-food (WEF) nexus simulation models to calculate the quantity of nexus on local, regional, and national scales such as NexSym [6], MuSIASEM [7], and WEF Nexus Tool 2.0 [8], respectively. However, studies on water-energy nexus are limited, let alone its simulation model. Therefore, this study will adopt the concepts from the WEF existing models, and developed a conceptual framework of nexus model in national-scale. Future studies will use the model to calculate the quantity of resource consumption and production. After that, calculate the resource sustainability in future, on national scale.

2. Water for Energy and Energy Consumption

Hydropower is one type of energy supply in Indonesia. In 2018, it is number 4 (four) among the energy source types after oil, coal and gas [9] (Figure 1). As an energy source, hydropower in Indonesia has a big opportunity to be expanded. The potential availability of raw water in Indonesia is 3.9 trillion m^3, although it has an uneven distribution. This uneven distribution also occurs in population, where impacted in wide range of water availability in m^3/capita/year among 5 (five) big islands (Table 1) [10]. Moreover, it is only approximately 15 billion m3 or 63.5 m^3/cap is stored in the reservoir. This number is much lower than Thailand (1277 m^3/cap). Raw water supply from regional drinking water supply system (SPAM) analysis from year 2015-2019 shows total raw water capacity of approximately 13.79 m^3/s [11].

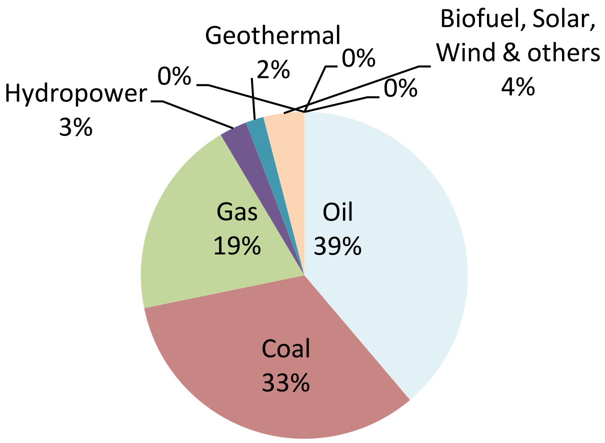

Figure 1. Primary Energy Supply in Indonesia year 2018 [9]

Table 1. Raw water availability in Indonesia

Island	Total Raw Water Potential	
	billion m^3/yr	1000 m^3/cap/yr
Sumatera	840.7	16.73
Jawa	164	1.21
Bali & Nusa Tenggara	49.6	3.88
Kalimantan	1314	95.9
Sulawesi	299.2	17.51
Maluku	176.7	71.1
Papua	1062.1	299.5
Total	3906.5	16.6

Source: [10]

Hydropower contribution in Electricity supply is only 6% of the Indonesia's power generating capacity [12]. In 2019, there are 238 dams with total storage of 14.415 billion m^3. Within this dams, there are 29 dams that were newly constructed (See Table 2) adding around 7.69 m^3/s raw water potential. These reservoirs have a total hydropower potential of 142.59 MW. In order to increase hydropower

potential, number of dams will be targeted to be built by 2022 is 274 dams, with total storage of 19.137 billion m3. Hence in 2020, hydropower potential will be 406 MW [11].
The energy consumption in domestic (household) and industrial sector by 2018 is 334.47 and 151.21 million BOE, respectively [9]. According to Center for Data and Information Technology Energy and Mineral Resources (CDI-EMR), the present problem of energy data is the unavailability of demand-sida data. Therefore, the energy consumption data are derived from the sales data. the The energy consumption trend shows that there is an increase in both sectors since the last decade (see Figure 1) about1.6 % for domestic and 10 % for industrial sector.

Table 2. Dams in Construction

No	Island	Province	Location	Raw water potential (m^3/s)
1	Sumatera	Aceh	Rajui	0.2
2			Payaseunara	0.48
3			Keureuto	1.14
4			Rukoh	-
5			Tiro	-
6	Java	West Java	Jatigede	3.5
7			Kuningan	0.3
8			Ciawi & Sukamani	-
9		East Java	Bajulmati	0.11
10			Nipah	0.2
11			Bendo	0.37
12			Gongseng	0.3
13			Tukul	0.35
14			Tugu	0.4
15		Central Java	Jatibarang	2.4
16			Gondang	0.2
17			Pidekso	0.3
18			Logung	0.2
19	Kalimantan	East kalimantan	Marangkayu	0.45
20			Teritip	0.25
21		South Kalimantan	Tapin	0.5
22	Sulawesi	South Sulawesi	Karalloe	0.4
23		North Sulawesi	Kuwil Kawangkoan	4.5
24			Lolak	0.5
25	Nusatenggara	East Nusa Tenggara	Tanju and Mila	0.05
26			Raknamo	0.1
27			Rotiklod	0.03
28			Bintang Bano	0.55
29		West Nusa Tenggara	Titab	0.35

Source: [11]

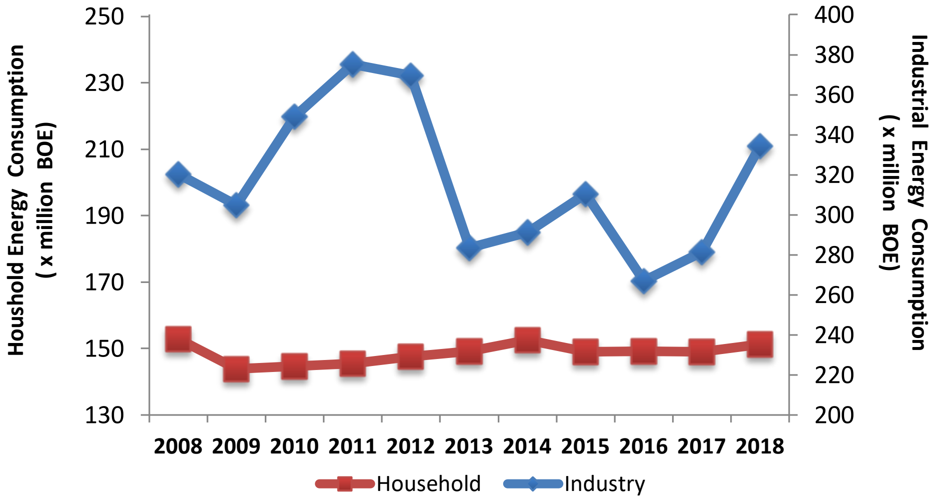

Figure 2. Energy consumption for household and industrial sector year 2008 to 2018 [9]. Note: BOE (barrel of oil equivalent) is a unit of energy based on the approximate energy released by burning 1 barrel (158.9873 lt) of crude oil [9]

Table 3. Projection of Water for Energy Demand

Scenario	Unit	2020	2030	2040	2050
Population	Million	261.5	284.4	299.2	307
Total energy demand	KWh/cap/year	8839	15701	25702	35820
Electricity as a % of total		16.9	20	23.8	30
Electricity demand	KWh/cap/year	1494	3140	6117	10746
Installed electricity capacity total energy demand	GW	95	198	400	626
Electricity demand	TWh per year	405	929	1915	3471
Water demand intensity	m^3/MWh	11	9	7.5	6.7
Water demand	M^3/s	141	265	455	737

GW=gigawatt, KWh=megawatt-hour, m^3=cubic meter, s=second, TWh=terawatt-hour
Source: [13]

The long-term prediction (until 2050) of water demand for energy until was predicted by Ibrahim [13], see Table 3.

3. Conceptual Framework of Water-Energy (WE) Modeling

System Dynamics (SD) modelling is based on the theory of nonlinear dynamics and control of feedback [14]. It can be utilized to dynamic system at spatial and temporal variation [15]. SD model begins with a conceptual model in which the primary interactions among the elements in the system are defined qualitatively. Feedback analysis among the elements is realized according to the approach of 'indirect demand' and 'actual availability' [16]. As an illustration of this feedback analysis, for example, the treated water (actual availability) depends on the energy for water (indirect demand), and the water for energy is determined based on the required energy production. The conceptual diagrams of the water-energy (WE) nexus model is shown in Figure 3. It was modified from the conceptual framework of the water-energy-food (WEF) nexus simulation model (WEFSiM) developed by Wicaksono [16].

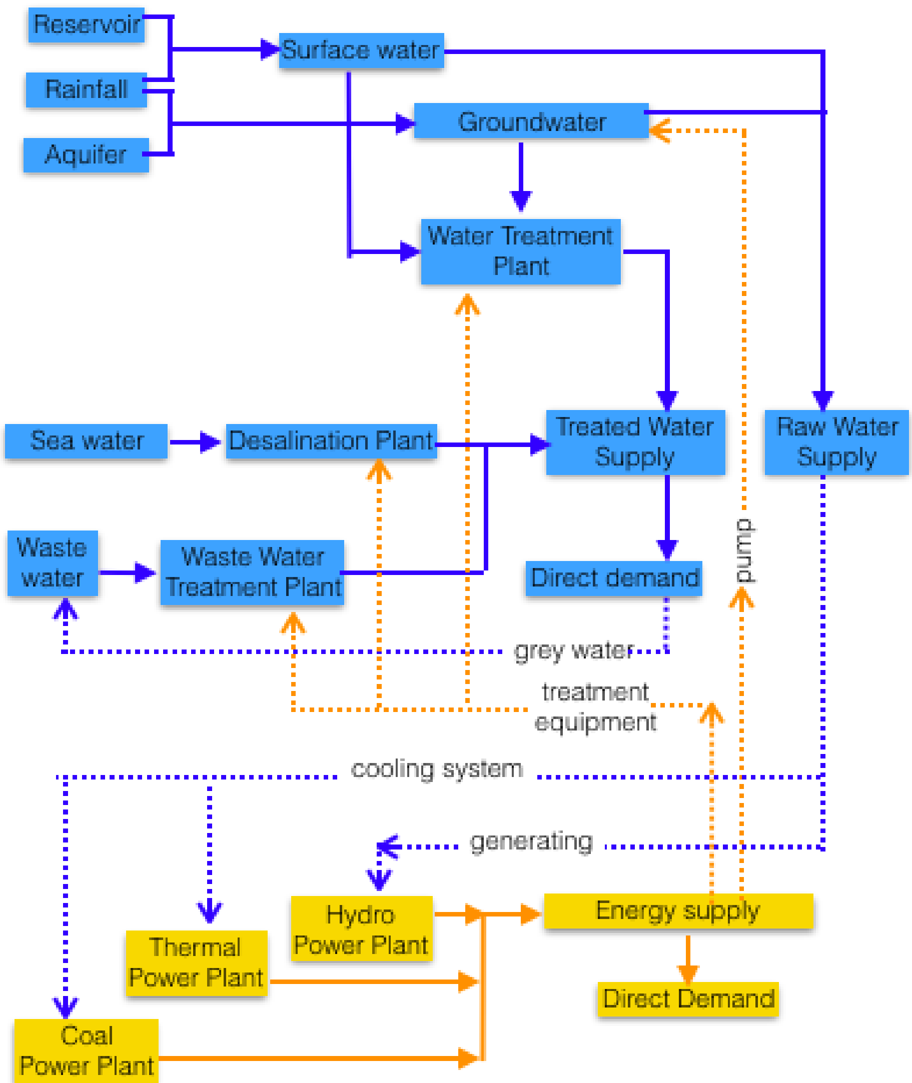

Figure 3. Conceptual framework of water-energy nexus simulation model, modified from WEF nexus simulation model (WEFSiM) [16]

The description of the feedback connections are as follows:

a. The raw water supply consists of surface water (reservoir, rainfall), groundwater (aquifer) , seawater and wastewater.

The direct demand for raw water are defined as follows:

1. The need to deliver water from surface water and groundwater to water treatment plant so that it can be used by industrial as well as municipal users.
2. The need to deliver sea water to desalination plant
3. The need to deliver waste water to wastewater treatment plant

The indirect demand for raw water are explained as follows:

4. Cooling water for thermal and coal power plant
5. Raw water supply for generating power in hydro power plant
6. Grey water as waste water for wastewater treatment plant

b. Electric energy is generated by hydropower plant, thermal power plant and coal power plant. The direct demand for energy from industrial and municipal (domestic or household sector) users. The indirect demand are energy for water described as follows:
   1. Pumping operation for groundwater abstraction
   2. Treatment equipment or machineries for wastewater treatment plant, water treatment plant and desalination plant

4. Conclusion

The water-energy (WE) nexus conceptual model was developed by modifying the existing developed water-energy-food nexus conceptual model. The WE nexus model consists of feedback connection of water for energy and energy for water elements. By understanding the framework of WE nexus, then the equations of the simulation model that consists of single- and multi objective algorithms to provide a decisions for resource supply and allocation could be performed. Therefore, next phase of this study is to see the impact of climate change in future. Case study of Yogyakarta Province and Bali Province will be utilized under drought season scenario. Furthermore, the simulation result will be adopted for the assessment study to analyse the sustainability of water management (at provincial level) applied in Indonesia.

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