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Integrated Model for Water, Food, Energy, and Human Development

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Abstract. Water, Food, and Energy (WFE) are basic needs crucial to human survival but also pervade many aspects of human development. Systemically, they are vastly interdependent. A system dynamics model was constructed to evaluate the dynamics behavior of WFE systems and their linkages to human development. The model was constructed, calibrated and tested against Indonesia national data on yearly basis from 1990 to 2015. System model comprising five modules, W-F-E sectors, demographic and human development. Analysis of error using Mean-Square Error (MSE), Root Means Square Percent Error (RMSPE), and Inequality statistics were used for model behavioral test. Preliminary results show that some variable like population size, GDP per capita, and Human Development Index (HDI) match historical trends and have low RMSPE (less than 10%). However, some variables pose greater error like Industrial water demands so it need to be reconstructed. Energy and Food module are being constructed. As part of the future work, once the model is fully constructed, it will be applied to assess the impact of a range of policy scenarios and implications on WFE and human development.

Keywords: water-food-energy system, human development index, system dynamics model.

1 Introduction

Water, Food, and Energy (WFE) are basic needs crucial to human survival but also pervade many aspects of human development. Systemically, they are vastly interdependent, and hence an effort to secure one sector may destabilizes others [1–3]. It is therefore highly important to understand the complex interactions within and among these sectors to inform better policies formation on securing these basic needs and sustainably improving human development.

In this paper, we constructed a System Dynamics (SD) model to be use as a tool to evaluate the dynamics behaviours of WFE systems and their linkages to human development. We chose Indonesia for a case study for the following reasons:

- The government of Indonesia has been actively pursuing sustainable development agendas to meet national WFE development targets set in 2019 i.e. in the water sector, the targets are improving access to drinking water and sanitation to 100% and rehabilitating 5.5 million ha of critical land in forest management units and priority watersheds; in the energy sector, the targets are increasing electrification ratio to 96.6%, reaching 10-16% of renewable energy share in the energy mix, increasing geothermal by 122%, biodiesel by 80%, hydropower by 27%, and biomass by 45%, and in the food sector, the targets are increasing calorie intake to 2150 kCal, expanding agricultural land by 300,000 ha, increasing rice production by 26%, soy 109%, sugar 46%, and beef 67% [4].
- The study can be used to inform policy makers the impact of a range of policy scenarios and implications on WFE security and human development so they can be aware of consequences when formulating the next 2020-2025 medium-development plan.

2 Methods

We used system dynamics modelling technique to evaluate the dynamics behaviour of WFE systems and human development. A SD model of WFE and Human Development or in short a WFE-HD model was first constructed using the following sub-system models:

- Water sector module – This simulates water supply-demand balance as a function of income per capita, population size, energy generation, and agricultural land development. An earlier developed model [5,6] has been tailored to facilitate its integration into WFE-HD model.
- Food sector module – This simulates major food crops production as a functions of crop productivity and harvested area and crops consumptions as a function of average daily per capita consumption, population size, and income per capita.
- Energy sector module – This module comprising fossil fuel reserved stocks as a function of discovery rate and production rate, renewable energy production as a function of installed powerplant capacities, i.e wind power plant, solar power plant, hydropower, and geothermal power plant. The module also simulates total primary energy consumption as a function of GDP.
- Human development module – this module makes use of Human Development Index (HDI), a composite index constructed by Mahbub ul Haq [7] to characterize human development. HDI is calculated as function of life expectancy at birth, mean and expected years of schooling, and income per capita [8]. Income per capita may be represented by Gross domestic product (GDP) per total population. GDP is computed using Solow growth model [9] in the form of Cobb-Douglas function [10].
- Demography module – This simulates population size as a function of birth rate, mortality rate, and migration rate.

Figure 1 shows the interactions between different modules. Model of subsystems were constructed, calibrated, and tested separately before they were assembled into an integrated model. National data collected from several sources, i.e. Indonesia Statistics[11], United Nation Human Development Report (UN HDR) [12], World Bank [13], and British Petroleum (BP) Statistical Review of World Energy [14]. The collected historical data were used for model validation. Mean Square-Error (MSE), Root Means Square Percent Error (RMSPE), and inequality statistics were used to measure model fit [15]. The model was developed for national scale and simulated at yearly basis from 1990 to 2015.

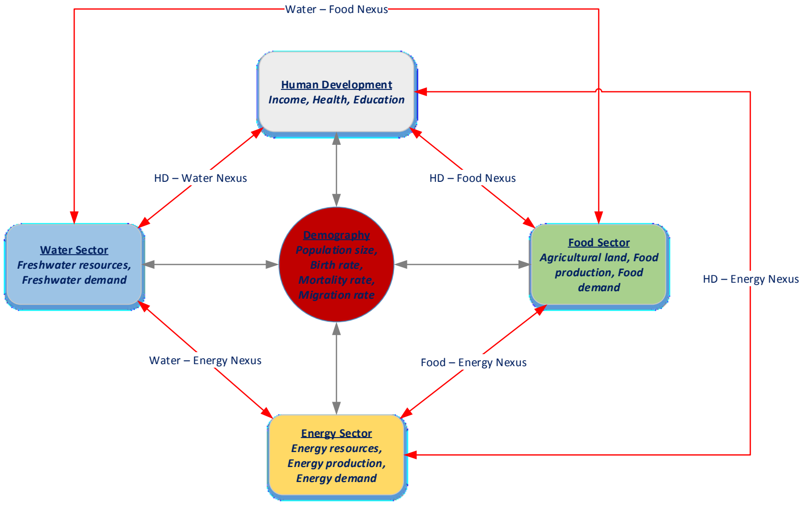

Figure 1 Model Framework of WFE-HD Nexus

3 Preliminary Results and Discussion

Figure 2 (a-d) shows preliminary results of total population, GDP per capita, HDI, and freshwater demands plotted along with the historical or reference data. Figure 2(e) shows preliminary results of fossil based energy production and primary energy consumption. The corresponding MSE, RMSPE and inequality statistics are given in Table 2. It is shown that only total population and HDI have lowest error (RMSPE <5%) so they closely match actual data. GDP per capita has RMSPE 8.39% due to big different of simulated and actual data at the mid simulation year (2000-2012). However, overall the model shows similar trends with actual or reference data. Water demands for agriculture, industry and domestic are increase where agricultural activity use the most water. Energy produced by fossil fuels is also increase at almost the similar rate with energy consumption.

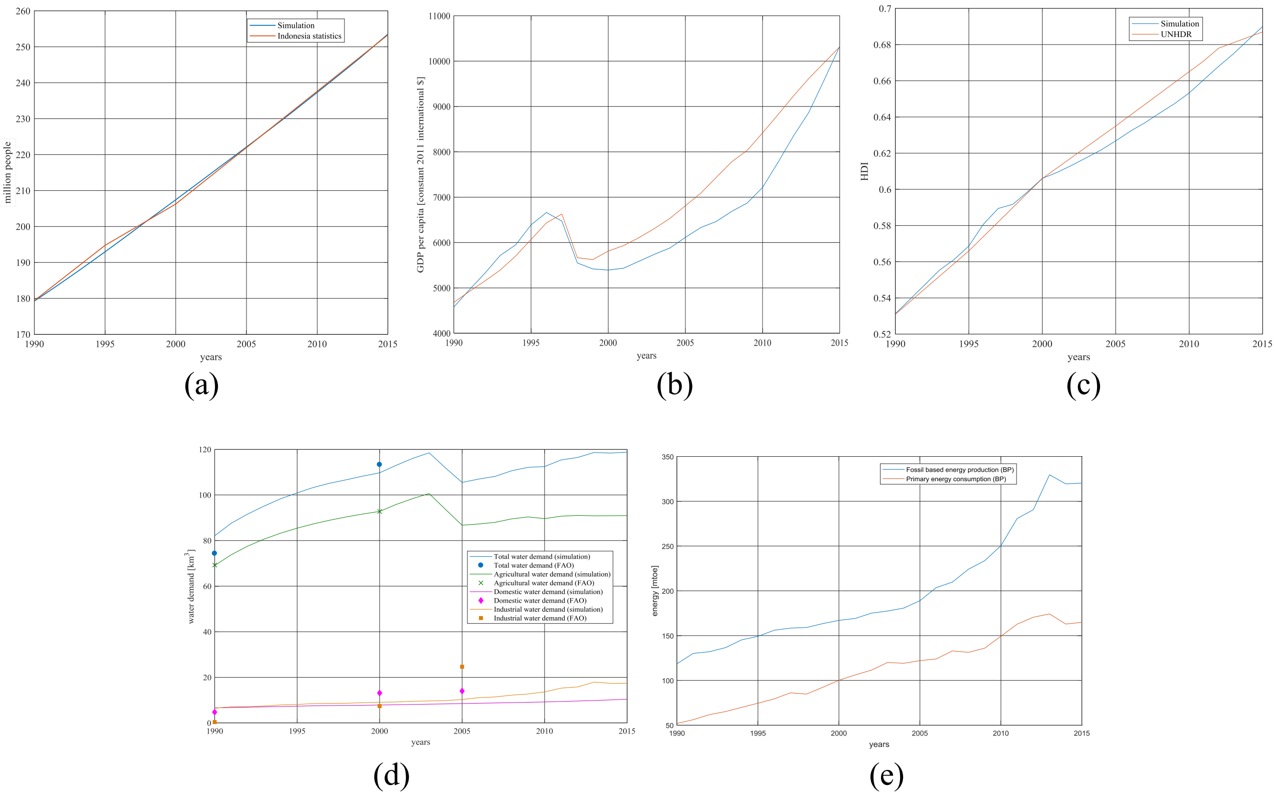

Figure 2 Simulation results for: (a) population, (b) GDP per capita, (c) HDI, (d) freshwater demands, (e) energy production and consumption

Table 2 Model Error Analysis

Variable	RMSPE [%]	MSE [units^2]	Inequality Statistics		
			U^M	U^S	U^C
Total population [million people]	0.38	0.57	0.07	0.10	0.83
GDP per capita [2011 US$]	8.36	4.02×10^5	0.43	0.09	0.48
HDI	1.03	4.4×10^{-5}	0.20	0.34	0.46
Total water demand [km^3]	7.69	36.36	0.12	0.88	0
Domestic water demand [km^3]	39.66	20.50	0.43	0.56	0.01
Industrial water demand [km^3]	922.95	82.05	0.06	0.9	0.04
Agricultural water demand [km^3]	0.2048	0.02	0.40	0.60	0

4 Conclusions and Future Works

A system dynamic model of water, food, energy systems and human development is being constructed and tested against national data. Preliminary results show an increase in demand for water, energy, and food mainly due to the increase in population size and income per capita.
Our model is still in the construction stage hence, several main components such as renewable energy production, energy demand from industry and transportation sector, production and consumptions of food crops, are being developed and added to the main model. Once the model has been completely constructed we will carry out sensitivity and uncertainty analysis and will evaluate different policy scenarios to support decision making for the development of WFE to improve human development in Indonesia.

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