WEFSiM: A Model for Water–Energy–Food Nexus Simulation and Optimization

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Abstract

A Water-Energy-Food Nexus Simulation Model (WEFSiM) is proposed to quantify the nation-wide resources sustainability. WEFSiM considers the feedback connections between water, energy, and food sectors in a single framework. The optimization module provides more alternatives for resource management planning. The effect of a new energy plan in South Korea (Energy 2030) is simulated in a nexus perspective.

Keywords

Nexus simulation and optimization • WEF nexus • WEFSiM

1 Introduction

Water-Energy-Food nexus (WEF nexus) is a novel concept for resource management that considers the feedback connections among sectors in a single framework (Hoff 2011). Recently, several computer models have been developed and applied to simulate this concept. In this study, a Water-Energy-Food Nexus Simulation Model (WEFSiM) is introduced to simulate the feedback analysis and calculate the demand and supply of WEF resources on a nation-wide scale based on a system dynamics approach. Being different with other simulation models, the feedback analysis in WEFSiM is also utilized to identify the critical factors that affecting the availability of specific resources (e.g., food production can be affected by either land, water, or energy availability). Various types of water resources, power plants, and foods are implemented in the model to provide a detail simulation. Moreover, the optimization module is implemented to provide optimal decisions of resource allocation to maximize supplying reliability. The optimization scheme is expected to assist stakeholders to decide the suitable policy and management plan.

As one of the most energy-consuming countries, South Korea relies on the thermal (64%) and nuclear (34%) plants to fulfill the energy demand, while only 2% is supplied from the renewable energy (U.S. Energy Information and Administration 2015). The thermal and nuclear power plants produce greenhouse gases and consume a significant amount of water to generate electricity. South Korea government is planning to increase the usage of renewable energy up to 20% of total electricity production by 2030 while reducing the thermal and nuclear plants (Lee 2017). Here, this new energy plan is simulated using WEFSiM to evaluate the effect of this plan to other sectors.

The simulation results revealed that the implementation of the new energy plan (Energy 2030) in South Korea reduces the water consumption overall. The results showed that the reserved water could be supplied to the food sector to enhance food production. Furthermore, the optimization analysis provides several combinations of user priority and water allocation strategies to improve overall resource sustainability.

2 Materials and Methods

WEFSiM is developed based on a conceptual scheme in Fig. 1 that represents the possible connection between water, energy, and food sectors. In general, the water is calculated as a direct demand to municipal and industrial users, while calculated as indirect demand when it becomes irrigation water or cooling water in a power plant. Energy is used for pumping, processing (treating), and distributing water to municipal and industrial users, and it is needed to produce fertilizers and pesticides, and pump irrigation water into

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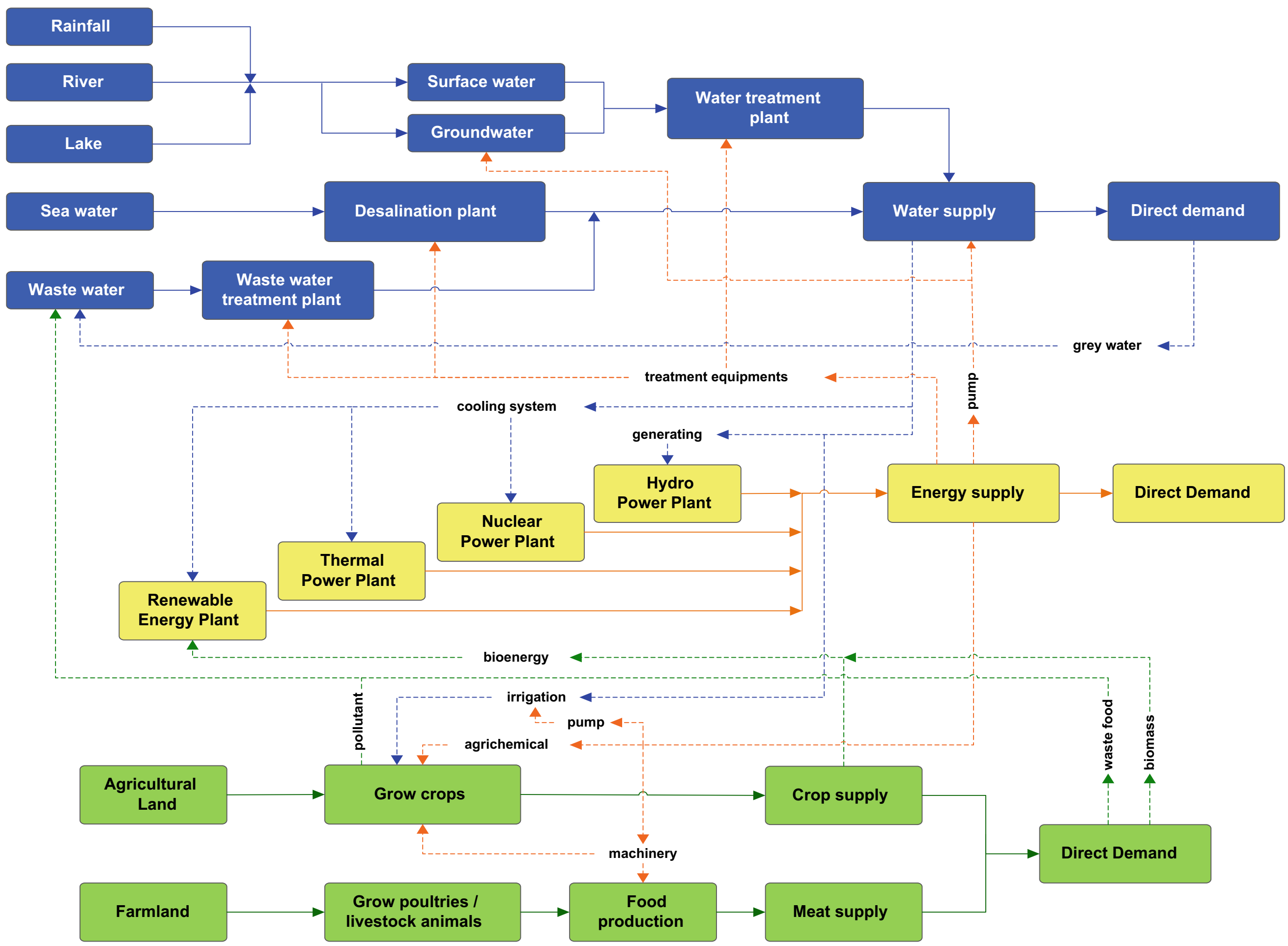


Fig. 1 Conceptual scheme of WEFSiM

agricultural areas. On the other hand, agricultural products can be transformed into bioenergy.

In this study, the interconnections among elements are represented/quantified by an intensity value that determines the indirect amount of a resource required to produce a particular resource. The interlinkage among the resources is simulated using a system dynamics approach, so-called feedback analysis. In addition, an optimization module is implemented in WEFSiM using a genetic algorithm (GA). The optimization is executed to maximize the resources reliability index by optimizing 21 decision variables.

A database that is composed of various information of the water, energy, and food sectors, as well as population, socioeconomic, and climate-related data was also developed to supply input data for the simulation model. Data was collected from open-access references and summarized in a spreadsheet format to be linked directly to WEFSiM. The collected data was also used as a reference in model calibration and projection of future condition.

In this study, three scenarios are developed to predict the conditions in the next 20 years. The first scenario is the base condition assuming the projection of current trends. The second scenario represents the new energy plan in South Korea (Energy 2030). In this plan, renewable energy production is assumed to increase linearly, while the nuclear power generation is decreasing and finally closed without further construction (see Fig. 2). The third scenario is an

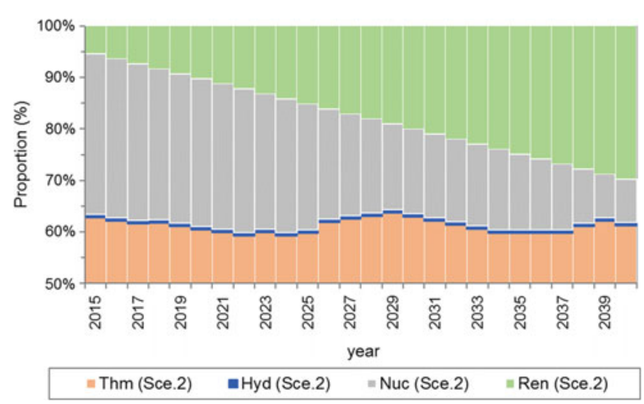


Fig. 2 New energy plan in South Korea

optimization of scenario 2 with the objective to find better-supplying reliability. In the first and second scenarios, the priority order of water and energy users has been predefined, i.e., municipal–industry–energy–food, and municipal–water–industry–food, respectively. Meanwhile, the priority order in the third scenario will be determined based on the optimization results.

3 Results and Discussion

For the base scenario, South Korea is predicted not to experience any energy shortage (Fig. 3b), but some significant droughts might occur in the future, and subsequently affect food availability (Fig. 3a, c). It can be seen that water availability consequently affects food production, especially the crop-based food sector since they depend on irrigation. The limitation of the available agricultural area also limits the self-sufficiency of food, so it is unable to fulfill the food demands and requires importation from outside.

The implementation of a new energy plan can reduce the consumption of water for energy sector by 4.7% (Fig. 4). The reduction is not significant because the thermal power (another water-intensive power plant) still dominates the energy supply. However, the reserved water can be used to supply additional water for food sector although it only slightly increases food production since the excess water is only 0.3% of the total indirect demand water for food. Hence, the reliability index between scenario 1 and scenario 2 is not significantly different (Fig. 5). Here, the optimization is performed to improve system reliability by optimizing the resources allocation.

The optimization results showed enhanced resource reliability by optimizing the combination of priority index and water allocation. The optimization results placed the water and energy users at the same priority level, which means they should be considered simultaneously and equally in the resources allocation process. The results show a slight decrement in the water supply for municipal and energy sectors but increases for food production. Hence, the food reliability index is increasing, but the water reliability index is slightly decreasing. However, the reduction of water supply for energy does not affect the energy reliability index because of the implementation of a renewable energy plan that consumes less water.

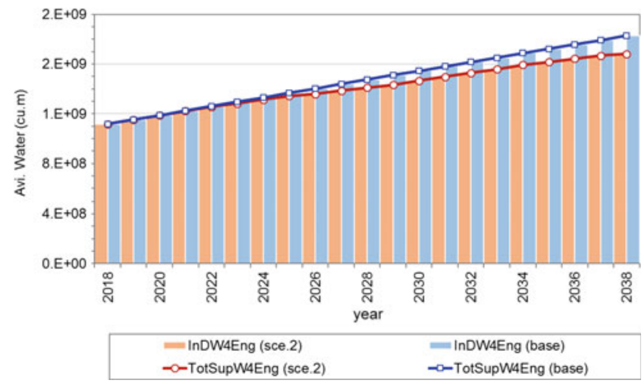
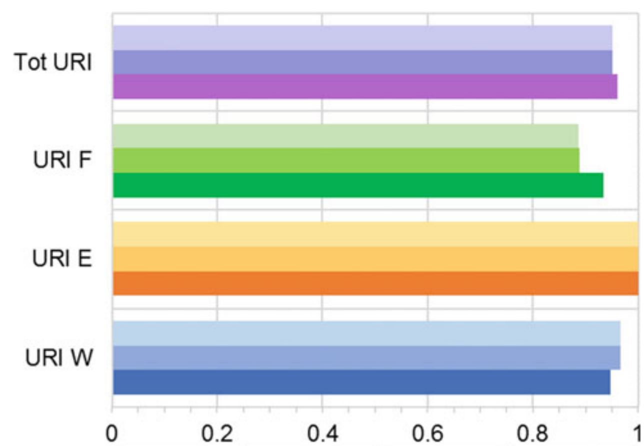


Fig. 4 Water consumption for the energy sector



	URI W	URI E	URI F	Tot URI
sce.1	0.966	1.000	0.887	0.951
sce.2	0.966	1.000	0.888	0.951
sce.3	0.948	1.000	0.933	0.961

Fig. 5 Reliability index

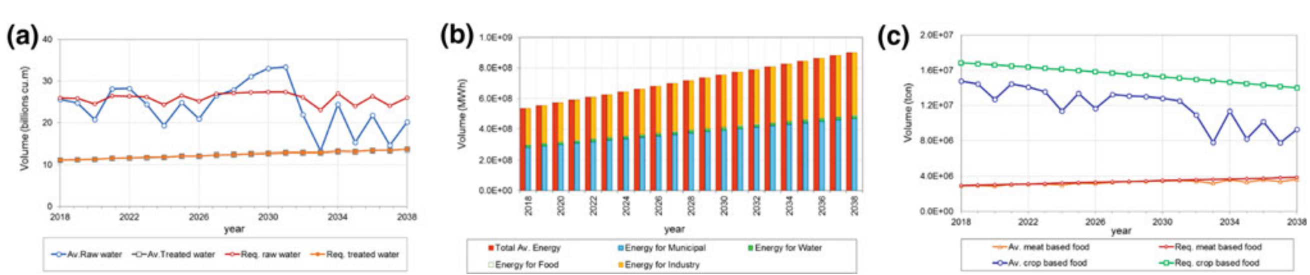


Fig. 3 Projection of **a** water, **b** energy, and **c** food demand and availability in the base condition

4 Conclusion

This study proposes a new simulation model that simulates the interconnections between water, energy, and food sectors using a nexus concept. Based on the analysis of the simulation results, WEFSiM is able to simulate the interconnections and quantify the resources supply, demand, and reliability. The results can be used to identify the critical factors affecting certain element and evaluate the effect of a change of an element on other elements. Here, this concept is used to evaluate the implementation of a new energy plan in South Korea to other sectors. In this scenario, the new energy plan has a beneficial impact on reducing water consumption in the energy sector and used it to increase food production. The optimization module could provide some alternatives to increase resources sustainability. In this study, the best result is obtained by slightly decreasing the water supply for municipal and energy, and allocating it for food production. By implementing this alternative, the food and total reliability index can be increased without sacrificing other resources significantly. The optimization module is a helpful tool to provide optimal strategies in creating resource management plan.

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References

Hoff, H. (2011). *Understanding the Nexus*. Stockholm: Stockholm Environment Institute.

Lee, W. (2017). *2030 Energy Masterplan of South Korea*. Chuncheon, Republic of Korea: Research Institute for Gangwon.

U.S. Energy Information and Administration. (2015, July 15). *International energy statistics: Total primary energy production 2013*. Retrieved from U.S. Energy Information and Administration: http://www.eia.gov/beta/international/data/browser/.