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Evaluation of food processing with the management of food, water, and energy nexus in Baghdad, Iraq

Ghulam YASIN[1], Widodo BRONTOWIYONO[2*], Maria Jade Catalan OPULENCIA[3], Sandhir SHARMA[4], Mohammed Nader SHALABY[5], Mohaimen AL-THAMIR[6], Abduladheem Turki JALIL[7], Abdullah Hasan JABBAR[8], Acim Heri ISWANTO[9]

Abstract

Efficient use of water and energy is crucial in food processing. One of the major problems in the food processing is the creation of food waste. Reducing food waste is essential to fill the global food gap and help reduce water and energy gaps around the world. Also, efficient use of water and energy in food processing is crucial. Examining scientific sources, it seems that Nexus thinking can be considered as the key to reducing food waste. Proper planning and management of limited water, energy, and food resources to meet society's economic and social needs for sustainable development is always a challenging issue. In this paper, considering the two thermal power plants with coal fuel and natural gas fuel in Baghdad, the relationship between food production, water consumption, energy production, and CO_2 emissions has been investigated. Considering three periods (5 years) and estimating demand and forecasting energy and food production, Nexus has been studied between water, food, and energy parameters. During these three periods, the amount of natural gas consumption has increased by 13.13%, 25.7%, and 28.79% compared to the total energy. Also, in the optimal case, the cost of the system is $ 5.65 billion.

Keywords: agricultural sector; food crisis; food, water, and energy nexus; sustainable development; economic and social needs.

Practical Application: In the current study, the relationship between food production, food processing, water consumption, energy production, and CO2 emissions has been investigated.

1 Introduction

Global forecasts show that demand for freshwater, energy, and food will increase in the coming decades due to water scarcity, technological advancement, resource depletion, growing demand for food and diverse diets, population growth, economic development, climate change, and urbanization (Norouzi & Kalantari, 2020). Currently, agriculture, with a consumption of about 70% of the total freshwater resources in the world, is the largest consumer of water (Barreira et al., 2021; Afshar et al., 2021; Molajou et al., 2021a). Water is used to produce agricultural products and the entire food and agricultural supply chain, as well as to produce, transport, and use all forms of energy. At the same time, food production and supply chains consume about 30% of the world's total energy. This situation is expected to intensify in the near future, as it is predicted that by 2050, due to a greater supply of nutrients and better quality, 60% more food will be produced (Burzyńska, 2019; Molajou et al., 2021b).

30 to 40% of the world's food waste wastes water and energy resources by endangering the world's food security. While competition in obtaining these resources is becoming a major issue. Therefore, the existence of Nexus thinking can be considered as the key to reducing food waste. The key to Nexus thinking is the interaction between WEF (Water, energy, and food) security. Water, energy, and food systems are so interconnected that acting on one often affects the other (Elagib & Al-Saidi, 2020).

Therefore, integrated methods for analysis, planning and decision making must be used. Strong correlation and connection between water resources-energy-food and their close relationship with environmental issues, climate change, economic, social, policy, etc. requires the cooperation of stakeholders, so that systematic management among these sectors in order to Achieving Nexus goals and sustainable development is essential. Planning and policy-making between the departments and organizations involved to achieve a common ground requires creating a dialogue between stakeholders and organizing conflicting goals in order to create cooperation and reduce interventions (Al-Saidi & Hussein, 2021; Qian & Liang, 2021). Promoting Nexus thinking as an approach to developing innovative ideas, problem analysis, solution development, lifestyle paradigm shift towards

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[1] *Bahauddin Zakariya University, Multan, Pakistan*
[2] *Department of Environmental Engineering, Centre for Environmental Studies, Islamic University of Indonesia, Yogyakarta, Indonesia*
[3] *Ajman University, Ajman, United Arab Emirates*
[4] *Chitkara University, Chandigarh, Punjab, India*
[5] *Suez Canal University, Ismailia, Egypt*
[6] *Al-Ayen University, Nasiriyah, Thi-Qar, Iraq*
[7] *Al-Mustaqbal University College, Hilla, Babylon, Iraq*
[8] *Sawa University, Samawah, Al-Muthanaa, Iraq*
[9] *University of Pembangunan Nasional Veteran Jakarta, Jakarta, Indonesia*
*Corresponding author: widodo.bronto@uii.ac.id

sustainable development, very sounds promising (Zarei, 2020; Sarkodie & Owusu, 2020).

Food waste is one of the main obstacles to achieving food security and fighting poverty. Food waste has negative environmental effects, such as increased emissions of greenhouse gases (CO2, methane and nitrogen compounds) that contaminate ecosystems by decomposing food. Food accounts for 31% of total greenhouse gas emissions (van Gevelt, 2020).

The main causes of waste and food waste in industries and at the household level are very complex. For example, the mismatch between industry approaches to food safety and food waste management versus public relations can cause significant anxiety for consumers who hear different messages from policies and the media (Ramos & Nascimento, 2020). Attempts to reduce waste at these two levels often run counter to organizational-based safety regulations, leading to significant tensions for farmers, processors, retailers and consumers. Given the above, analyzing the relationships between relationships and the role of institutions and policies to effectively control this resource competition requires a lot of Nexus thinking (Cansino-Loeza & Ponce-Ortega, 2021). In addition, there is a current global debate on the goals of sustainable development, taking into account all three dimensions of water, energy and food, as well as human well-being (Rabêlo et al., 2021; Pouladi et al., 2019, 2020).

Forecasts show that by 2050, more than twice the current amount of food must be produced to meet human food needs. About a third of food production is wasted in the life cycle of the food system. Food waste means wasting land, water, energy and agricultural products through the value chain of food production (Arifjanov et al., 2021). Reducing food waste is critical to bridging the global food gap and helping to reduce water and energy gaps around the world. Also, efficient use of water and energy in food processing is crucial. Challenges require the participation of governments, policymakers, farmers, the food industry, retailers and consumers to reduce waste (Galhardo et al., 2021).

The world's energy consumption has also been on the rise so that by 2035 it will increase by nearly 50% and in 2050 by 80% (Zhang et al., 2020). Water supply costs are also projected to increase by about 50% by 2025 in developing countries and 18% in developed countries (Borghi et al., 2020). With the expansion of the perception of resources, the need for new methods in identifying and analyzing the relationships between different sources for the sustainability of valuable resources of water, soil, energy, etc., has become particularly important (Ferreira et al., 2022).

Different societies face many challenges in managing water crises, including political, economic, and social. Water, energy, and food resources management are applied through appropriate management measures and effective legislation in various parts of the environmental, economic, social, political, and administrative systems (Li & Ma, 2020). Finally, it leads to adjustment and improves the exploitation of the three components (Psomas et al., 2021).

Water security is an acceptable quantity and quality of water for health, livelihood, sustainable production, and ecosystem with an acceptable level of water risks for people, the environment, and the economy (Norouzi, 2022). Demand for food, water, and energy is projected to increase by about 30 to 50% over the next 20 years, while economic inequalities and short-term solutions to boost production and consumption provide long-term sustainability (Yu et al., 2020; Radmehr et al., 2021; Scardigno, 2020). Nexus approaches water, energy, and food; an overview of it is sustainability that seeks to strike a balance between different goals, interests, and needs of people and the environment (Wu et al., 2021).

2 Material and methods

This section reviews the development of the water, energy, and food nexus management optimization model in three socio-economic periods in Baghdad. The system under study includes two thermal power plants (coal) and (natural gas) to generate electricity in three (five-year) planning periods. This system supplies the water needed to generate electricity from surface water, groundwater, and recycled water sources. The generated electricity is used to transport water needed for power plants, produce food, and meet social and economic needs. Recycled water is not used in food production due to health issues. In the process of generating electricity and food, greenhouse gases, especially CO_2, are emitted.

2.1 Decision variables

The decision variables of the optimization model include the value energy of coal and natural gas resources, power plant capacity to generate electricity, amount of surface and groundwater required for material production food, the amount of surface and groundwater and recycled water needed to generate electricity, and social and economic demands for water production, food and energy are examined over several periods.

2.2 The objective function

The goal of optimizing the WEF management model is to minimize the system's total cost, which includes the costs (Yan et al., 2020). Equation 1 shows the general relationship of the parameters, then each of the parameters is explained in detail.

$$Min\, f = a + b + c + d + e \tag{1}$$

In this equation, (a) is the cost of providing energy to generate electricity, (b) electricity generation costs, (c) water supply costs, (d) food production costs, and (e) it is also the cost of reducing CO_2 emissions. Energy supply costs for electricity generation (a) are obtained using Equation 2.

$$a = \sum_{j=1}^{m}\sum_{t=1}^{k} ES_{jt} ESC_{jt} \tag{2}$$

(j) type of energy supply and energy source used in power plants, (m) the number of energy supplies and power plants, (k) is the number of planning periods, ES_{jt} Power supply (j) in the planning period t (PJ), ESC_{jt} average energy supply costs j in the planning period t (PJ/million dollars) (Zhang & Vesselinov, 2017). Electricity generation costs (b) are obtained using Equation 3.

$$b = \sum_{j=1}^{m} FC_j + \sum_{j=1}^{m}\sum_{t=1}^{k} X_{jt} PC_{jt} \tag{3}$$

(FC_j) fixed costs of j power plant (million dollars), (X_{jt}) the amount of energy production of the power plant using energy j in the planning period t (PJ) and (PC_{jt}) Average operating costs for power generation at power plant j in the planning period t (PJ/million dollars). Water supply costs for electricity and food production (c) are obtained using Equation (4).

$$c = \sum_{t=1}^{k} (GW_t^F CGW_t^F + SW_t^F CSW_t^F) + \sum_{j=1}^{m}\sum_{t=1}^{k} (GW_{jt}^e CGW_{jt}^e + SW_{jt}^e CSW_{jt}^e + RW_{jt}^e CRW_{jt}^e) \tag{4}$$

GW_t^F and SW_t^F the amount of groundwater and surface water used for food production in period t (gal), CGW_t^F and CSW_t^F the costs of groundwater and surface water supply used for food production in the period t (gal/$), SW_{jt}^e, GW_{jt}^e and RW_{jt}^e the amount of groundwater, surface and recycled water used in power plant j in period t (gal), CSW_{jt}^e, CGW_{jt}^e and CRW_{jt}^e groundwater, surface and recycling water supply costs for the power plant, respectively j in period t (gal/$).

Food production costs (d) are obtained using Equation 5.

$$d = \sum_{t=1}^{k} CFO_t FO_t \tag{5}$$

FO_t the amount of food produced in the planning period (ton), and CFO_t cost per unit of food production in period t (million $/ton). CO_2 emission reduction costs (e) are also obtained using Equation 6.

$$e = \sum_{j=1}^{m}\sum_{t=1}^{k} CEA_t CC_{jt} X_{jt} + \sum_{t=1}^{k} CFA_t FO_t FF_t \tag{6}$$

CEA_t costs of CO_2 reduction in electricity generation period t ($/kg), CFA_t costs of CO_2 reduction in food production period t ($/ton), CC_{jt} CO_2 emission unit per unit of electricity generation in period t (million Kg/PJ) FF_t also CO_2 emission unit per food production unit in period t (ton/ton).

2.3 Optimization model solution method

Because all equations and relationships between decision variables in objective functions and constraints are linear, the optimization model is linear, and using methods based on linear programming (Simplex algorithm) is solved (Karamian et al., 2021).

3 Results and discussion

Parameters related to cost, fixed values , and model constraints in three 5-year periods are given in Tables 1-3. In addition, the fixed costs of generating electricity at coal and natural gas plants are $ 59 million and $ 69 million, respectively. The water required for each unit of electricity generated in coal and natural gas power plants is 0.31 gal/KWh and 0.39 gal/KWh, respectively. Water losses in coal and natural gas power plants as well as in food production are 9, 14, and 13%, respectively. The average efficiency of CO_2 reduction in coal and natural gas power plants during the three planning periods is constant and equal to 79 and 86%. Also, the amount of CO_2 emissions per unit of food production in the three programming cycles is constant and equal to 0.51 ton/ton.

Tables 1-3 provides information on resource constraints, the cost of providing effective parameters, and optimization model constants over three consecutive five-year periods.

3.1 Optimal model results

The answers to the water, energy, and food optimization model for energy and water systems are presented in Figures 1-2. The optimal values of food production in the three planning periods were equal to 59,000, 68,000, and 75,000 tons, which is in accordance with the values of social and economic demand for food Table 1. The optimal quantities of electricity generated in the three periods were equal to 100.91, 111.12, and 123.81 PJ, respectively, which is slightly higher than the socio-economic demand for electricity, which is given in Table 1. Excess electricity generated for food production as well as the collection, refining, and water delivery is used. In terms of energy supply, the results showed that it is better than the main source of energy in line with planning is coal with lower supply costs, but in the second and third periods, the amount of natural gas used has increased. The ratio of natural gas to total energy supplied in the first, second, and third periods will increase by 13.13%, 25.7%, and 28.79%,

Table 1. Parameter values related to resource constraints.

Parameters	Consecutive five-year periods, A		
	A = 1	A = 2	A = 3
Electricity demand (PJ)	99	109	122
Food demand (ton)	59000	68000	75000
Accessible to coal (PJ)	266	249	228
Access to natural gas (PJ)	132	119	107
Maximum groundwater in access (billion gal)	48	45	42
The maximum amount of available surface water (billion gal)	29	28	26
The maximum amount of recyclable water (billion gal)	27	25	22
Maximum CO2 emissions (million tons)	14.3	-	-

Table 2. Costs of energy supply, water, electricity generation, food production, and CO_2 reduction in three 5-year periods.

Parameters	Consecutive five-year periods, A		
	A = 1	A = 2	A = 3
Average operating costs for coal energy supply (million \$/PJ)	2.81	3.11	3.25
Average operating costs for natural gas energy supply (million \$/PJ)	4.68	4.95	5.31
Average operating costs for power generation at coal power plants (million \$/PJ)	0.14	0.16	0.21
Average operating costs for electricity generation in natural gas power plants (million \$/PJ)	0.49	0.53	0.56
Food production unit costs (\$/ton)	151.2	163.4	178.9
CO_2 reduction costs for electricity generation (\$/million kg)	11900	13800	15700
CO_2 reduction costs for food production (\$/ton)	11.1	12.1	13.2
Groundwater supply costs for food production (\$/10^3 gal)	2.01	2.38	2.87
Costs of surface water supply for food production (\$/10^3 gal)	2.31	2.61	3.28
Groundwater supply costs for electricity generation of coal power plants (\$/10^3 gal)	2.05	2.51	3.01
Groundwater supply costs for electricity generation of natural gas power plants (\$/10^3 gal)	1.86	2.22	2.73
Costs of surface water supply for electricity generation of coal power plant (\$/10^3 gal)	1.84	2.21	2.59
Costs of surface water supply for electricity generation of natural gas power plant (\$/10^3 gal)	2.09	2.71	3.18
Costs of providing recycled water resources to generate electricity for the coal power plant (\$/10^3 gal)	4.18	4.41	4.57
Costs of supplying recycled water resources to generate electricity for natural gas power plants (\$/10^3 gal)	4.38	4.51	4.69

Table 3. Constraints and constants of the optimization model.

Parameters	Consecutive five-year periods, A		
	A = 1	A = 2	A = 3
Need an energy unit to produce food (10^{-6} PJ/ton)	2.49	2.66	2.81
Need for an energy unit to collect, treat and deliver water (KWh/1000 gal)	3.49	3.71	3.89
Water needed to produce food (gal/ton)	655000	681000	702000
Most electricity is available for food production (PJ)	0.22	0.24	0.25
Most electricity is available for water collection, treatment, and delivery (PJ)	1.03	1.19	1.31
Energy carrier unit on electricity generation unit in coal power plant (PJ/PJ)	3.17	2.98	2.88
Energy carrier unit on electricity generation unit in natural gas power plant (PJ/PJ)	2.55	2.37	2.28
CO_2 emissions per generation of electricity in a coal-fired power plant (million kg/PJ)	258.1	250.35	244.88
CO_2 emissions in exchange for electricity generation in a natural gas power plant (million kg/PJ)	149.34	146.45	144.3

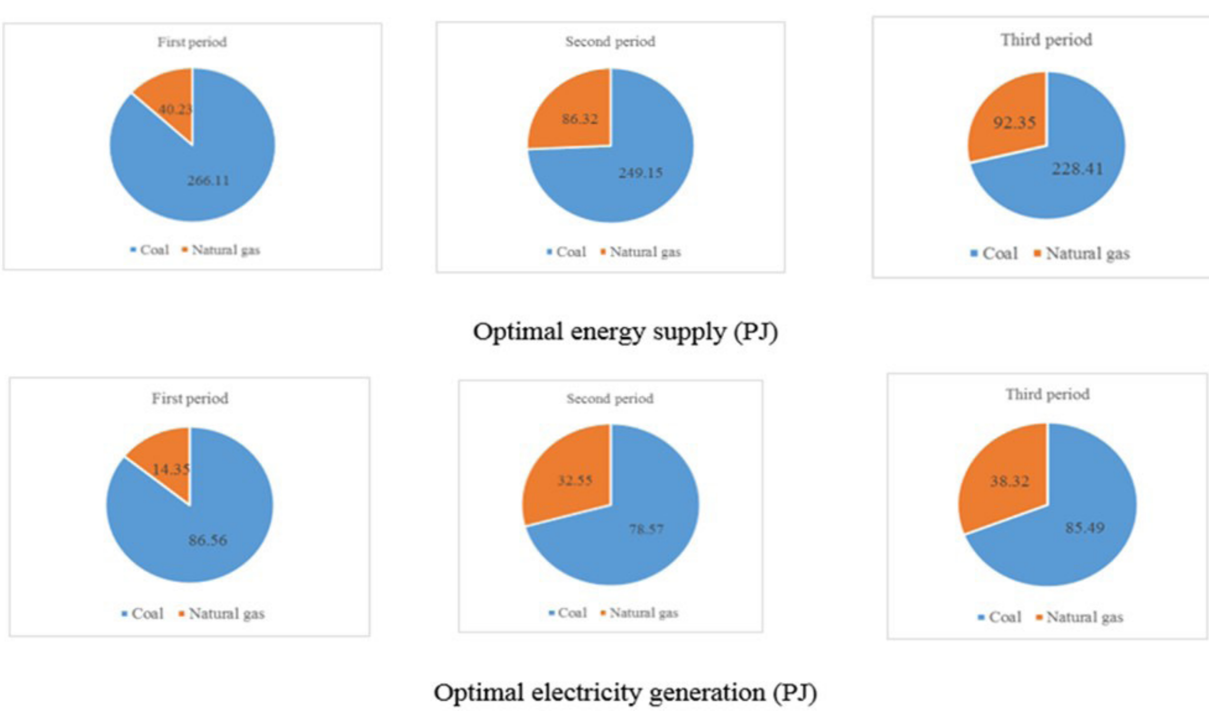

Figure 1. Optimal amounts of energy and electricity supply in three planning periods.

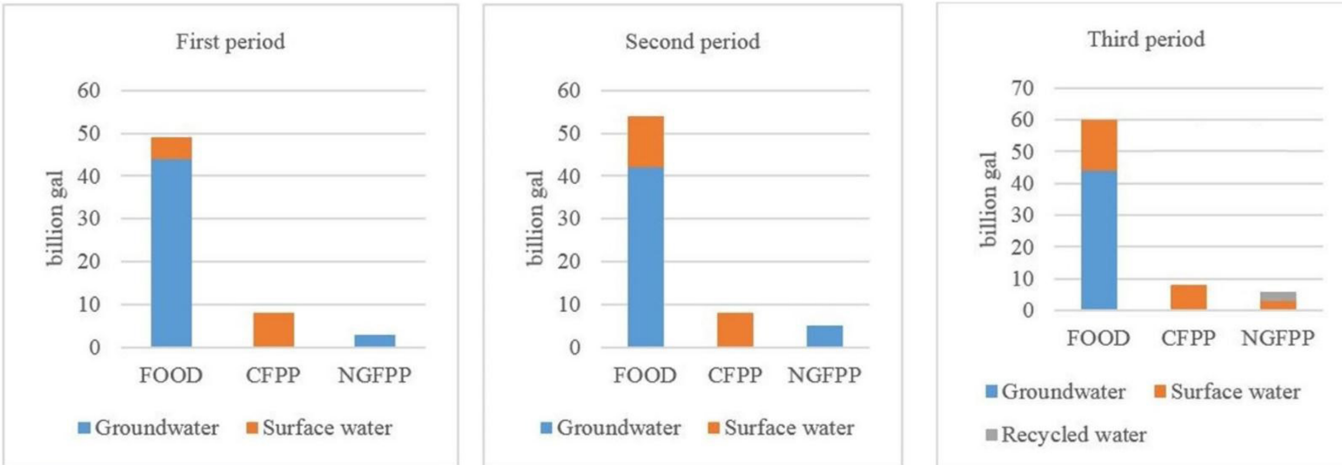

Figure 2. Optimal amounts of water allocated for food and electricity production.

respectively, indicating environmental constraints. Therefore, according to the amount of natural gas sources in power plants, the amount of energy produced will increase from the first to the third period. Figure 1.

In examining the two sources of water and energy, it is necessary to note that more water resources are used in food production than in energy production. Recycled water is also not used in food production due to health issues. The results presented in Figure 2 showed that the majority of groundwater is used in food production, except for a small percentage in natural gas power plants. Maximum reduction of available groundwater resources has led to different water-efficient patterns for food production in the three periods. The study of the allocation values of surface water resources and groundwater as well as recycled water is shown in Figure 2. Available water resources and the cost of water supply in different power plants play an important role in allocating the required water resources for power plants. Figure 2 uses these acronyms: Food Production (FOOD), Natural Gas Fuel Power Plant (NGFPP), Coal Fuel Thermal Power Plant (CFPP).

Optimally, the total cost of the system under consideration was \$ 5.65 billion, of which \$ 3.22 billion for energy supply, \$ 1.2 billion for CO_2 emissions reduction, and other relatively small costs. The results obtained in this section will play an important role in defining scenarios and determining planning policies in the study area.

4 Conclusion

This paper integrated the model framework for optimizing the water, energy, and food nexus. The introduced model was multi-cycle, and since all the relations of this model are linear, it is solved using the linear programming method. The various components of the model link management include energy planning, electricity generation, water supply and demand, food production, and control of greenhouse gas emissions. This model can simultaneously examine the interactions between the water, energy, and food sectors and evaluate the impact of different social and economic strategies and policies on decision-making in each sector and the system as a whole. The results of the studies in this paper show that the model of optimizing the relationship between water, energy, and food can help decision-makers and stakeholders in an area to assess the shortcomings of complex interactions between the water, energy, and food sectors, in this way, for integrated management of water, energy, and food, make informed decisions in the direction of sustainable development. The total cost of the optimized system was estimated at \$ 5.65 billion

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