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Sustainability assessment of food industry with the approach of water, energy and food nexus

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Abstract

The development of the food industry, along with the protection of water and energy resources, is crucial for sustainable economic growth and human well-being. Water, energy and food nexus approaches can help reduce food waste and other resources by adopting policies and regulations based on comprehensive information and Nexus that promote the use of more efficient production technologies in terms of water and energy consumption against food waste. This paper aims to identify the potential of integrated management of food industry, water and energy in Sulaimaniyah. In this paper, the WEAP planning system, as well as Excel software, have been used. Also, five scenarios were proposed that predicted the level of food demand and shortage of water and energy resources from 2021 to 2025. Considering the simultaneous development of food industry and agriculture, scenario 5 was selected as the best scenario. In this scenario, simultaneous management of water and energy demand is also considered to increase food production. In scenario 5, the amount of water supply is 94.85%, which indicates that it is more effective than in scenarios 3 and 4. Also, in scenario 5, with the increase in surface water use and full use of electric pumps instead of diesel, the amount of energy required to pump water from the aquifer is 55% and 49% less than in scenarios 3 and 4 respectively.

Keywords: supply and demand management; water-food-energy nexus; WEAP; Sulaimaniyah.

Practical Application: In the current study it was tried to identify the potential of integrated management of food industry, water and energy in Sulaimaniyah.

1 Introduction

The main challenge is to reduce the water and energy used, increase the efficiency of water and energy consumption in food industry processes. Another key issue is the production of significant volumes of waste as a by-product during processing (Ramírez et al., 2021). Significant quantities of products are discarded due to non-fulfillment of quality criteria for consumption. Waste transfer, storage, handling, processing, packaging, distribution and marketing are also significant (Zheng et al., 2022; Molajou et al., 2021a). Water footprint is a measure of the volume of fresh water that is used in the entire food chain from production to waste disposal, including the use of rainwater (green water), groundwater or surface water (blue water) resulting in water. Sewage flows (gray water). The microbial load and pathogenicity of gray water in its treatment should be carefully considered and the limitations of reuse should be considered (Cruz et al., 2019; Molajou et al., 2021b).

Food waste occurs in five main stages of the food system life cycle, including: a) production, b) processing, c) distribution, d) consumption, and e) after consumption, in which stages prevention should be sought and there were solutions (Ferrari et al., 2021). Considering these stages, and their relationships in the form of Nexus thinking and considering the complexities and entanglements and paying attention to the boundaries, the interaction between water, energy, soil and air factors in a dual and multiple way and being affected by issues of climate change, with a very wide range of views that is characteristic of Nexus thinking, the issue of reducing food waste can be studied and evaluated with a comprehensive and forward-looking approach (Cunha et al., 2020; Afshar et al., 2021).

Resources and resources such as water, energy, manpower and raw materials and inputs are used in the form of flows and

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cycles in the form of human actions that create goods and services to meet different levels of human needs (Jacintho et al., 2020). In relation to the food production chain, these measures go through 5 stages of the food system life cycle, which starts from on-farm production and ends after consumption (Mroue et al., 2019). The nature in which goods and services are provided and in different modes of the system, each of which leads to positive and negative consequences (Karnib & Alameh, 2020).

Considering food production as an example, coercion, such as increasing market demand for food, is introduced through agriculture and puts pressure on the environment in the form of air, water and soil pollution, and energy and water consumption (Olawuyi, 2020). These can change environmental conditions such as the quality or quality of air, land, water and ecological systems. Changes in the situation can lead to positive and negative effects on society (Roidt & Avellán, 2019). These effects include benefits such as increasing food supply at reasonable prices, but may also include social and environmental costs such as safety and health risks, loss of ecosystems or reduced farm incomes, and increased vulnerability due to reduced natural resource productivity would have existed (Rezaei & Vadiati, 2020; Pouladi et al., 2019; Pouladi et al., 2020).

Individuals and households are the front line of food waste in two stages of consumption and after consumption. Consumer behavior with food entering the household is a major challenge. The main problem in some areas is the accumulation of food at home. Freezing leftover food significantly reduces greenhouse gas emissions (Kumar Rai, 2021; Li et al., 2019). One of the challenges in this regard is the development of socio-economic values and cultural norms regarding the more efficient use of available food and reducing the potential for food waste (Abulibdeh & Zaidan, 2020).

WEFN (water, energy and food nexus) approaches can help reduce food waste and other resources by adopting policies and regulations based on comprehensive and coherent information that promotes the use of more efficient production technologies and reduces waste and changes consumer behavior towards food waste (Telfah et al., 2021). In the meantime, it seems that Nexus thinking can be considered as the key to reducing food waste. Promoting nexus thinking as an approach to developing innovative ideas, problem analysis, developing and evaluating solutions, changing lifestyle paradigms for sustainable development, reducing waste, and improving water and energy consumption in the food production chain it seems (Wu et al., 2020). In any case, potential solutions need further research, and the lack of sufficient and reliable data on the exact amount of food waste at each stage of the chain can limit planning and preventive and recycling measures, nationally and globally (Wang et al., 2022; Terrapon-Pfaff et al., 2018).

2 Material and methods

In recent decades, systems analysis techniques in water resources planning and management have attracted the attention of many researchers in this field. The types of models used in such problems are classified into three categories: simulation, optimization, and a combination of simulation and optimization (Batlle-Bayer et al., 2020). Simulation models are based on the phrase "if ... then ..." and this means that the question is, what will most likely happen at any time and in one or more places under a design with an exploitation policy? The advantage of simulation methods is their ability to solve the challenges of analyzing water resources systems, which have nonlinear relations and constraints (Wolde et al., 2021). While optimization methods rarely have the ability to address them. Since the supply of water needs according to the type of drinking, industry, and agriculture has a periodic pattern, it should be the basis of simulation and water policies (Sadeghi et al., 2020).

The present paper prioritizes the demand for resource utilization with drinking, environmental, industrial, and agricultural, respectively. The key to the success of mathematical models is to simultaneously address the biophysical and socio-economic aspects. WEAP is comprehensive and flexible software for integrated water resources management for linking hydrological, energy, and water and energy-consuming data (Simpson & Jewitt, 2019). In the present paper, by using two tools, WEAP and Excel, and defining the scenarios in general, conditions have been provided for simultaneously advancing the goals of the three sections and reducing conflicting interventions between them. These two tools simultaneously exchange data dynamically, and the necessary analysis to identify the optimal scenario and show the impact of applied techniques in each guide the user to choose a more sustainable approach (Cabello et al., 2021).

2.1 Modeling of water resources and their supply system

Allocation of water resources among agricultural, urban, industrial, and environmental applicants requires a comprehensive review of the assumptions of available water resources, demand, water quality, and ecology. Water Evaluation and Planning (WEAP) by the Stockholm Environment Institute (SEI) was designed and developed; it helps to gather a set of problems in a powerful scientific tool (Huang et al., 2020). WEAP is a tool that coordinates and displays watershed opportunities and challenges in the form of a simulator for integrated water policy analysis and planning. The results obtained from this tool are useful for examining different scenarios of management and the development of supply systems.

2.2 Scenario analysis

Proposed scenarios for water, food, and energy sectors are analyzed according to the amount of demand, scarcity, percentage of supply-demand, groundwater supply, reliability index, and compatibility with environmental and social goals.

3 Results and discussion

This section presents five scenarios for forecasting and managing the demand and shortage of water and energy resources until 2025 in the city of Sulaymaniyah. Finally, the best scenario has been selected by comparing the scenarios and the conditions of the region and considering the long-term goals for the development of agriculture and industry.

3.1 Scenario 1: reference

This scenario examines the results of the continuation of the current management process until the end of 2025. Considering the negative index of population changes, using modern irrigation systems and increasing irrigation efficiency is quite reasonable. The water demand of each sector in 2021 is presented in Table 1. Information on water demand and supply forecasts from 2021 to 2025 is presented in Table 2. In 2021, about 40% of agricultural lands in the region will use modern irrigation methods. According to plans, by 2025, 100% of agricultural lands will use modern irrigation.

3.2 Scenario 2: population growth

Population growth is one of the uncertainties in the management of urban and water resources. Due to the water shortage predicted in 2025 in the reference scenario in which the population growth index was negative and equal to 0.84, It is asked if during the period, contrary to the trend of the reference scenario, the population growth index is upward and positive; is the amount of available water resources and the extent of harvesting from them the answer to the city's water demand? The results of the WEAP analysis of this scenario answered this question in the negative. Except for the rate of population change, other input parameters in this scenario are similar to the reference scenario. Table 3 examines demand and water shortage changes over five years, with all parameters remaining constant except population growth. In the second scenario, water shortage will be more noticeable than in the reference scenario.

3.3 Scenario 3: co-development of industry and agriculture

The key assumptions in the third scenario are consistent with the first scenario, and only the level of activity has changed in agriculture and industry. The changes are presented in Table 4 according to the plans made by the district officials.

Table 1. The amount of water demand in each sector in 2021.

Demand site	Water demand (million cubic meters)
Agriculture	528.3
Urban and home	44.2
Industrial	15.8
Total	588.3

Tables 5, 6, and 7 present the current cultivation rate of agricultural products and forecast the amount of cultivation until 2025, as well as the water consumption of each crop during five years. Finally, water demand and shortage are examined in scenario 3.

3.4 Scenario 4: demand management in the simultaneous development of agriculture and industry

The severe shortage of water in the third scenario, especially in the agricultural site, is evidence of the need for prudent action. Therefore, it is necessary to maintain the levels and the activity of each point of demand according to scenario 3 to use the techniques of demand management in the agricultural sector as scenario number four, more than previous scenarios. It is noteworthy that scenario 4, with the exception of the agricultural sector, has inherited the characteristics of scenario 3 because it seeks to intensify the demand management leverage. Designing a model for cultivating agricultural products in accordance with the needs, climatic and geographical conditions of the study area while considering the challenge of water shortage, in addition to increasing the productivity of soil and water resources, can also play an effective role in organizing the market conditions of agricultural products. Barley has the highest level of cultivation and water footprint among agricultural products, which is a negative point due to the water crisis in the region. One of the lowest amounts of water used belongs to corn. This product has a high production performance compared to others and, as a result, is one of the recommended products for future cultivation in this city. Pomegranate also has a significant water footprint compared to other products. Products such as cantaloupe, watermelon, and cucumber have much less water footprint than most agricultural and horticultural products; therefore, pomegranate can be replaced with these crops. Table 8 presents some suitable alternative crops to the conditions of the region and its water consumption.

Table 9 provides information on agricultural reform patterns, and Table 10 provides water consumption in Scenario 4.

Analyzes show that improvement in cultivation patterns and the simultaneous development of agricultural lands and industry lead to increased productivity and cost savings in groundwater consumption. More investors will be willing to enter this sector following this increase in production (essentially profitability).

Table 2. Demand, shortage and percentage of water supply in the reference scenario for each year (cubic meters).

Variable	2021	2022	2023	2024	2025	Total
Demand (m^3)	588352125	403352821	332851625	221325822	241365952	1787248345
Shortage (m^3)	57658508	7260350	0	0	3000	64921858
Supply (%)	90.2	98.2	100	100	99.99	97.67

Table 3. Demand, shortage (cubic meters) and percentage of water supply in the second scenario.

Variable	2021	2022	2023	2024	2025	Total
Demand (m^3)	588352125	403879221	334558214	224208423	246078420	1797076403
Shortage (m^3)	57658508	7364598	0	0	3000	65026106
Supply (%)	90.2	98.2	100	100	99.99	96.38

3.5 Scenario 5: integrated supply and demand management for the simultaneous development of industry and agriculture

In this scenario, while maintaining the cultivation pattern modifications in accordance with the fourth scenario, in the supply sector, a new water source for agriculture is provided by defining reservoirs and runoff from up to 66,000 cubic meters and the water shortage of this high-consumption site is limited. This scenario inherits all the information from scenario number 4, except in the case of runoff collection tanks and allocation from that source. Table 11 shows the values for scenario 5.

Table 4. Regional change plans over a 5-year period.

Planned changes	2021	2025
Water loss (%)	38	28
Access to surface water (million cubic meters)	0	12
Water storage tanks (cubic meters)	38000	71000
Horticultural products (tons)	9898	11223
Crop production (tons)	49878	55345

Table 5. The amount of horticultural and agricultural production for each year in scenario 3.

Year Crop name	2021	2022	2023	2024	2025
Wheat (ton)	34250	37380	43425	50250	55350
Barley (ton)	29871	32350	36745	40200	43352
Corn (ton)	232698	262300	278020	295253	310150
Forage corn (ton)	29889	31200	31825	33200	35215
Watermelon (ton)	33252	35250	36780	39200	41600
Cucumber (ton)	44825	46780	49200	52320	54640
Pomegranate (ton)	2015	2215	2417	2533	2780
Canola (ton)	5125	6780	8925	10325	13112
Cantaloupe (ton)	744345	783250	815235	833452	852150
Total (ton)	1156270	1237505	1302572	1356732	1408349

Table 6. Current cultivation pattern and characteristics of each crop.

Crop name	Crop performance (tons in Hectares)	Water consumption (cubic meters per ton)
Wheat	5	2200
Barley	4	2300
Corn	4.5	420
Forage corn	59	1300
Watermelon	44	420
Cucumber	32	480
Pomegranate	13	2100
Canola	4.7	240
Cantaloupe	46	370

3.6 Energy modeling

Since the main source of water in the region is groundwater, it is natural that a lot of energy is used to extract it from the aquifer and pump it. The efficiency of the electric pump type is 40%, and the diesel type is 15%. It should be noted that in scenarios 1 to 3, 50% of the pumps are electric. In Scenario 4, 75%, and in Scenario 5, all motors are electric pumps. Figure 1 shows the power consumption for pumping water in scenarios 3, 4, and 5.

In contrast to scenarios 1 and 2, with the increase of agricultural and industrial lands in scenario 3, the demand for water and electricity is increasing. In Scenario 4, although 75% of the existing wells are equipped with electric pumps, the cultivation pattern modification has been able to overcome the management of water and energy demand. In scenario 5, considering the integrated management, the problem of demand and consumption of water and energy is solved simultaneously. In Scenario 5, the energy required to pump groundwater is reduced by increasing the use of surface water. The amount of energy required to pump water in scenarios 5 is 55% and 49% less than in scenarios 3 and 4.

3.7 Summary of scenarios

According to the reference scenario results, the continuation of the current water management process will lead to water and food insecurity. Therefore, the basic solution is a gradual transition from the era of supply management to the simultaneous management of supply and demand, and finally, the management of demand in the future. Scenario analysis 3 to 5 is presented in accordance with Figures 2 to 4.

Examination of the above figures shows; that among the three development scenarios in the present paper (3, 4, and 5)

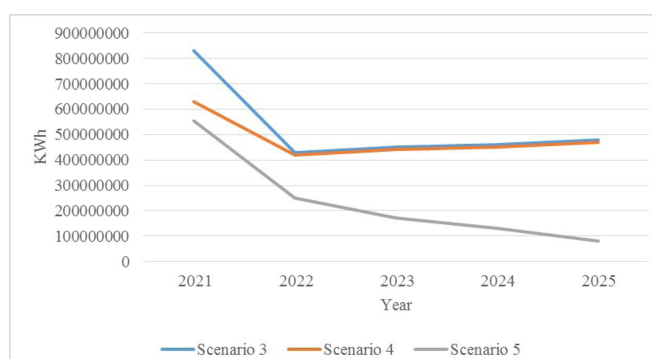

Figure 1. Power consumption for water pumping in scenarios 3, 4, and 5.

Table 7. Demand, shortage (cubic meters) and percentage of water supply in the third scenario.

Variable	2021	2022	2023	2024	2025	Total
Demand (m^3)	588352125	1673865235	1783135425	2016914325	2354584742	8416851852
Shortage (m^3)	57658508	264670707	386940387	502211666	631028710	1842509978
Supply (%)	90.2	84.18	78.3	75.1	73.2	78.1

Table 8. Alternative crops and water consumption.

Crop name	Production per hectare (tons)	Crop water consumption (cubic meters per hectare)
Pea	2.35	4150
Onion	75	7680
Medicinal herbs	2.1	8430
Potato	46	6835
Lentils	0.4	3990

Table 9. Proposed share of each crop in the agricultural reform pattern of cultivated lands each year.

Year Crop name	2021	2022	2023	2024	2025
Wheat (%)	30.29	24.84	22.32	18.14	16.12
Barley (%)	35.44	27.32	26.31	22.44	19.81
Corn (%)	16.11	13.32	11.25	9.98	7.85
Forage corn (%)	9.34	8.32	7.63	6.23	5.12
Watermelon (%)	1.52	1.54	1.21	1.63	1.45
Cucumber (%)	4.22	3.12	2.99	4.03	4.86
Cantaloupe (%)	1.23	1.89	2.45	3.66	4.89
Canola (%)	1.85	3.22	5.02	6.22	7.13
Pea (%)	0	1.75	2.73	4.25	7.88
Onion (%)	0	5.35	6.35	8.02	7.12
Medicinal herbs (%)	0	5.86	7.25	8.95	9.95
Potato (%)	0	2.36	3.12	4.21	4.38
Lentils (%)	0	1.11	1.37	2.24	3.44
Total (%)	100	100	100	100	100

Table 10. Demand, shortage (cubic meters) and percentage of water supply in the fourth scenario.

Variable	2021	2022	2023	2024	2025	Total
Demand (m^3)	588352125	1594845436	1682134324	1976713316	2254534722	8096579923
Shortage (m^3)	57658508	185650908	285939286	462010657	530978690	1522238049
Supply (%)	90.2	88.36	83	76.62	76.44	81.19

Table 11. Demand, shortage (cubic meters) and percentage of water supply in the fifth scenario.

Variable	2021	2022	2023	2024	2025	Total
Demand (m^3)	588352125	612352847	658956785	703598355	788356748	3351616860
Shortage (m^3)	57658508	32341208	18531252	28534266	35267892	172333126
Supply (%)	90.2	94.71	97.18	95.94	95.52	94.85

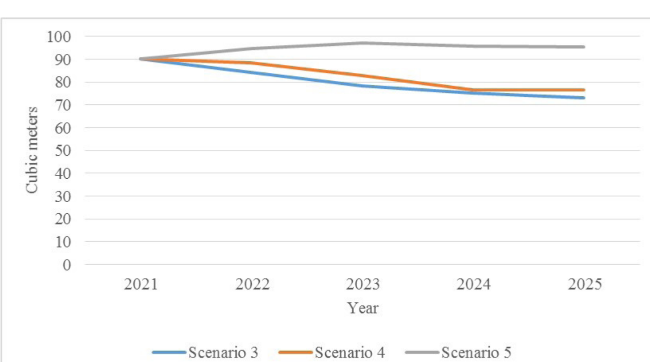

Figure 2. Comparison of water supply percentage in scenarios 3, 4, and 5.

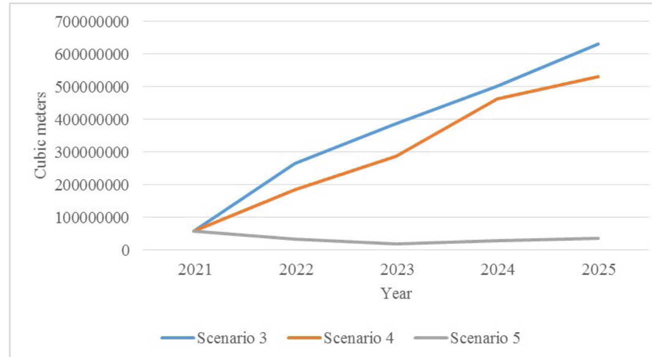

Figure 3. Comparison of water shortage in scenarios 3, 4, and 5.

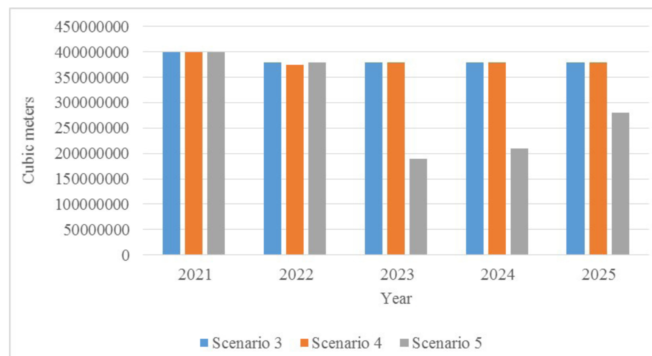

Figure 4. Aquifer withdrawals in scenarios 3, 4, and 5.

is the only scenario number 5 strategy that can provide the most protection of the aquifer reserve in addition to the growth of agriculture and industry. Reliability calculations in WEAP showed; that all defined scenarios equally provide supply and demand stability in the urban and industrial sectors. But in the agricultural sector, which is the largest consumer of water, scenario 5 is the most socially sustainable due to the simultaneous use of supply and demand management techniques.

4 Conclusion

This paper was conducted to investigate the water-energy-food nexus in the Iraqi city of Sulaymaniyah. 5 scenarios were considered to examine the conditions and determine the demand and shortage of each parameter. The first scenario, called the reference scenario, considers the current resource management to continue until 2025 and considers the amount of population to decrease according to the forecasts. In the second scenario, the amount of population is considered to increase, unlike in the first scenario. In the third scenario, according to the plans of regional officials, the amount of agricultural and industrial production has increased. In the fourth scenario, with the increase in demand for water and energy in the third scenario, the issue of modifying the cultivation pattern is raised. Finally, in scenario 5, the issue of combining demand and resource management and the use of surface water as much as possible is raised. Given the region's conditions and the need to develop the agricultural and industrial sectors, the best scenario to provide resources is scenario 5. In scenario 5, the average water supply is 94.85%, which is more than in scenarios 3 and 4. Also, energy consumption for pumping water in scenario 5 is 55% less than in scenario 3 and 49% in scenario 4.

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