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ASSESSING THE SUSTAINABILITY OF CROP PRODUCTION IN THE GEDIZ BASIN, TURKEY: A WATER, ENERGY, AND FOOD NEXUS APPROACH

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ABSTRACT

This study assesses the sustainability of crop production system in Gediz Basin, Turkey and develops forward-looking scenarios for optimal utilization and sustainable allocation of its resources using the water, energy, and food (WEF) Nexus holistic systems approach. Gediz basin data for the year 2014 are used to analyze the current situation and to develop future scenarios, including climate change, urbanization, changes in water sources, and technological developments in the field of agricultural production. The study results indicate that reduction in land availability as a consequence of urbanization and increased water scarcity due to climate change are inevitable. Moreover, sustainably maintaining current levels of agricultural production requires that serious consideration be given to the selection of drought resistant varieties and new farming practices, such as direct planting to reduce energy use and drip irrigation systems to save water.

KEYWORDS:
Crop production, water requirement, fuel consumption, climate change, land use**,** agricultural technologies

INTRODUCTION

Globally, agriculture accounts for about 70% of water use [1]. Agriculture is also an important input for energy production. With water and energy as inputs, it is possible to manufacture bio-energy products or to recycle energy through biomass [2, 3]. Thus, water, energy, and food resource systems are tightly interconnected and interdependent [4]. As it is increasingly apparent through sudden changes in weather patterns, rainfall amounts, and temperature increases, climate change will continue to affect agricultural production levels, bringing forward risks that cannot be overlooked: increased environmental awareness in agricultural operations necessitates the use of machinery and technologies with more intricate applications [5].

With growing pressures to produce food for growing populations globally, there is a need for better understanding and quantifying its interlinkages with water and energy systems [6, 7, 8, 9]. Water assets vary around the world, even within regions of a given country [10]. With regard to quality, water can be categorized into three categories: blue, green, and grey. As a result of this classification, a map of water assets of 50 countries around the world was drawn and virtual water flow maps were created between countries. As sources of irrigation, blue and green water have an important role in agriculture. Blue water is defined as the rivers, lakes, underground, and aquifer water. Green water is accepted as rainfall water stored in the soil. Grey water is defined as water that is somewhat polluted, i.e. waste water, but which can be brought to utilizable standards by processing [11]. Through food trade, virtual water gets imported and exported: the export of water and the physical utilization of water resources by the exporting country saves water for the importing country [12]. In this sense, on a global scale, Japan has 134 Gm^3/year (80% green, 9% blue, and 12% grey water). Mexico and Italy follow at 83 and 54 Gm^3/year, respectively, as water saving countries [13].

Turkey, United States of America, India, Australia, Uzbekistan, and China, make up 49% of the virtual global blue water export [13]. It has been stated that these countries are, albeit partially, distressed when it comes to water [14, 15, 16]. In light of this information, the sustainability and efficiency of using limited water resources in the face of such copious amounts of virtual water exports can be questioned [13]. Moving from a global context to the national level, countries need to identify policies, which would ensure the optimal use of existing natural resources as it plans for meeting food demands of its future populations [17]. Accordingly, it is also needed to understand the regional and transboundary impact of such policies [18, 19].

The main objectives of this study were to determine the sustainability of the current agricultural system in the Gediz Basin, Turkey; and develop sustainable allocation and forward-looking scenarios for optimal utilization of its resources using the WEF Nexus holistic system approach.

MATERIALS AND METHODS

Gediz Basin. The Turkish Ministry of Food, Agriculture, and Livestock identifies thirty distinct basins, with lists of crops and cropping patterns for each, based on soil and climate conditions, among others. The Gediz basin includes 26 towns as depicted in Figure 1.

The Gediz Basin covers 1.922 % of the total area of Turkey and is part of the Aegean region and Mediterranean rainfall regimes, which are characterized by hot dry summers and cool winters. The average annual rainfall is about 500 mm, with extremes of 300 mm and 850 mm having occurred in the past. The total agricultural land in the basin is about 1774 km^2.

Data. The basin produces a variety of field crops, vegetables, and fruits; the list of crops and the production and yield for each crop, fertilizer needs, and financial values are provided from the database of the Turkish Statistical Institute [20] and tabulated in Table 1 for only top fifteen crops in terms of the land that they are grown and water consumption.

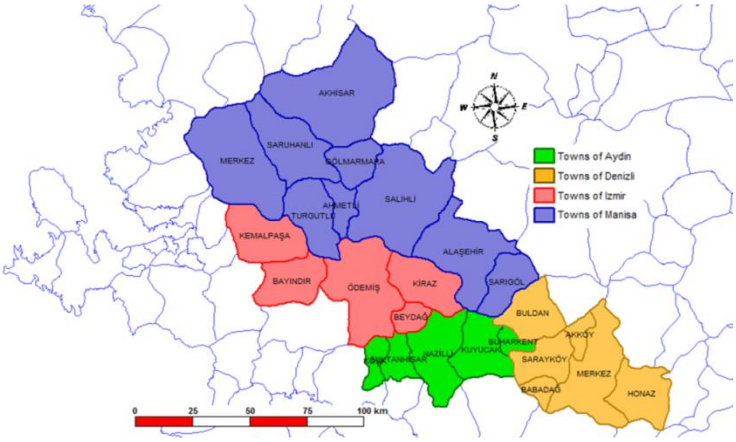

FIGURE 1
Gediz basin and its boundaries along with towns within the basin

TABLE 1
Data for the top fifteen crops grown in the basin [20]

Field crop	Area grown (ha)	Production (Tons)	Yield (Tons/ha)	Seasonal water req. (m^3/ha)	Irrigation req. (m^3/ha)	Nitrogen req. (kg/ha)	Phosphorus req. (kg/ha)	Potassium req. (kg/ha)	Gasoline consumption (L/ha)	Financial value (TL/ton)
Barley	31057.4	85380.0	2.75	4709.1	419.3	90	40	0	47.8	620
Clover	13100.0	745587.0	56.92	10143.8	7293.1	132.1	75	75	43	520
Corn	42049.2	444066.8	10.56	2530	1794.9	272.7	166.6	0	159.1	620
Corn for silage	43709.4	2325906.0	53.21	2530	1794.9	272.7	166.6	0	131	280
Cotton	13134.7	73967.0	5.63	7140	6492.7	185.4	125	0	222.0	1470
Potato	9652.8	353071.0	36.58	7647.3	7000	187.6	78	30	315.1	1160
Tobacco	14318.8	9671.0	0.68	2354.7	1707.4	76.8	30	0	70.4	11750
Vetch	11057.6	151566.0	13.71	4836.1	2312.9	50	50	0	76.7	450
Wheat	86989.2	301762.0	3.47	4836.1	1182.9	120	40	0	65.6	740
Tomato	14643.1	975484.0	66.62	4028.5	2849.5	136.1	73.1	37.7	180.46	450
Cherry	18392.1	72513.0	3.94	2094.4	1084.5	187.5	180.2	166.1	267.93	3530
Fig	20827.0	91688.0	4.40	6250	0	41.5	55.4	55.4	141.3	2580
Olive	126956.3	311187.0	2.45	8928.4	0	90	72	50.93	50.93	2560
Raisins	58593.2	1041554.0	17.78	6584.5	5396	172.85	153	90	171.07	1540
Table grape	25376.5	499661.0	19.69	6584.5	5396	55.8	51.5	41.6	225.55	1540

TABLE 2
Energy consumption for different sources of water

Energy need for water (kWh/m^3)	
Groundwater	0.4068
Surface water by GDSHW	0.209
Groundwater by Solar Energy Solar	0.406

TABLE 3
Carbon emissions of different sources

Carbon emissions of different sources	
Diesel gasoline*	0.002357 tons CO_2/L or 778 g CO_2/kWh
N, P and K fertilizers**	0.0026 tons/ kg
Hydroelectric power***	24 g CO_2/kWh
Solar panel toproof***	32 CO_2/kWh

* and *** [25, 26]; **: [24]

This study also uses data provided by recent studies [21] which include the water requirements for all crops grown in a basin neighbouring the Gediz basin, which has the climatic and soil conditions. The study includes seasonal water requirements along with the irrigation amounts for crops, vegetables, and fruits using two different methods: Penman-Monteith and Blaney-Criddle. Fuel consumption is the only energy input considered, which reflects the reality of the main energy source for agriculture in Turkey. Data for tractor use or time (hr/ha)spent using tractors and fuel consumption for each crop, vegetable and fruit, are determined and tabulated along with the tractor use for farming operations [22, 23].

Water in the basin is provided from two sources; it is either pumped from deep wells, or drawn from the General Directorate of State Hydraulic Works (GDSHW). GDSHW delivers surface water to farmers through concrete channels, mostly by flow of gravity. The energy consumption for different sources of water in the basin was calculated for per cubic meter (Table2). Carbon emission values are given in Table3 [24, 25, 26].

Water-Energy-Food (WEF) Nexus Concept and Methodology. Water, energy, and food are inextricably linked to one another which require a methodology for studying the tradeoffs between decisions made within the three resource systems. Water is the most important input for agricultural crop production, but is also needed to produce energy. On the other hand, energy is required for many agricultural operations in the field, including the transport of agricultural goods, and pumping ground and surface water. The lack or intensive use of any of these sources triggers decline in the others and may jeopardize their security. Hence, a certain balance among the three should be insured to maintain the security level of each [4, 27, 28]. Consequently, to improve our understanding of the three interconnected resources, there is a need to quantify their interlinkages through data-driven and quantitative modeling approaches [28, 29]. Much research in recent years has focused on modelling based on WEF Nexus Concept. Most of them focused on management of a single resource such as water resources, energy systems or planning of agricultural production, or two resources such as water-energy nexus [30, 31, 32, 33, 34, 35]. There are also some studies focused on modeling of resource allocation on water, energy and food resources [36, 37, 38, 39, 40, 41].

WEF Nexus based modeling can increase consistency of decision-making that put forth sustainable resource allocation policies. In previous studies, WEF Nexus Tool 2.0 has been developed as a common platform to evaluate scenarios that aim to identify strategies for sustainable resource allocation [36, 39]. The tool provides ability to create variable scenarios under different conditions of water, energy and food resources. Although the analyses of resources produce outputs as requirements-consumptions of resources and Carbon emissions at the national level, basin level scenarios are needed to be created to obtain region specific interactions of resources.

Scenarios are created to represent different variations of water and energy inputs for products grown in the basin and are able to calculate the following outputs for each scenario;

- Water requirements
- Land requirements
- Energy requirements
- Carbon emissions
- Financial costs

For this purpose, a master excel sheet was modified for each scenario by including possible changes in land size resulting from urbanization, water requirements affected by climate change projections, expected changes in water portfolios for agriculture (surface or ground water) and technologies for pumping water from underground sources. The WEF Nexus block diagram, with the input-output entities calculated for the development

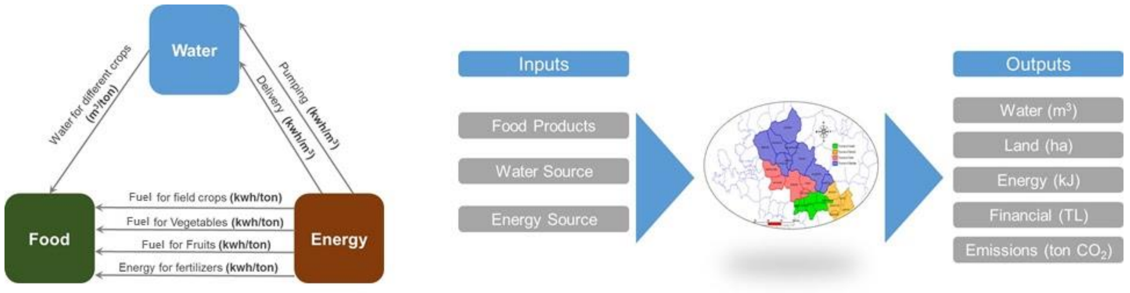

FIGURE 2
WEF Nexus block diagram (left) and Input-output entities considered for the development of different scenarios in the Gediz Basin

of different scenarios in the Gediz Basin are depicted in Figure 2.

Water (W). Water requirement is a result of crop production [42]: each crop requires a certain amount of water, consisting of blue (provided by irrigation) or green water (available water in the soil) [43].

$$Wi = Li * (W_s - 10*W_a) \quad (1)$$

where;

Wi= amount of total water needed for a specific crop (m^3)

Li= Land allocated to the certain crop (ha)

W_s= Seasonal water requirement for the crop (m^3/ha)

W_a= Water available to the crop (mm)

The total amount of water (Wi) needed to grow all crops in the basin is fulfilled from different sources: surface, underground, or desalinated. In this study, only surface and groundwater sources are considered. The formulation of total amount of water based on the water source equals the amount needed for plant growth is formulated as below.

$$W = \Sigma Wi = SW + GW \quad (2)$$

where,

SW= Surface water (m^3)

GW= Ground water (m^3)

Land (L). Land is the total area in ha and the sum of the land allocated to grow specific crops, vegetables and fruits in the basin.

$$\mathbf{L} = \sum [\, DOM_i \text{ (ton) X Li(ha/ton)} \,] \quad (3)$$

where,

L = Total land needed to grow locally produced food products.

DOMi= Production (tons)

L_i = Land required to growth a unit amount of crop (ha/ton)

Energy (E). Energy needed in the basin is for farming operations in the field, transportation, fertilizer use, and pumping water from different sources [4, 44]. It is calculated as following;

$$E = E_1 + E_2 \quad (4)$$

E= Total domestic energy needed for the scenario (kJ)

E_1 = Energy needed for either pumping or treating water for irrigation (kJ)

E_2 = Energy needed for tillage, harvest, fertilizer production, and local transport (kJ)

Depending on the choice of water supply source, whether conventional or non-conventional, respective energy costs can be calculated (E_1). Whether surface or ground water pumping, treated, waste, or desalinated water, each would have its respective energy footprint depending on the domestically available plants and their efficiencies. Depending on the amount of water needed for the growth of the created food self-sufficiency scenario and sources of water identified to secure those needs, respective energy values can be calculated.

$$E_1 = E_{GWe} + E_{GWs} + E_{SW} \quad (5)$$

E_{GW} = Total energy needed for pumping water from deep well pumps using electricity (kJ)

$$E_{GWe}\text{ (kJ)} = S_{GWE}\text{ (kJ/m}^3\text{) x } [\alpha_w \text{ x W (m}^3)] \quad (6)$$

E_{GWs} = Total energy needed for pumping water from deep well pumps using solar energy (kJ)

$$E_{GWs}\text{ (kJ)} = S_{GWS}\text{ (kJ/m}^3\text{) x } [\gamma_w \text{x W (m}^3)] \quad (7)$$

$E_{SW.}$ = Total energy needed for pumping surface water (kJ)

$$E_{SW}\text{ (kJ)} = S_{SW}\text{ (kJ/m}^3\text{) } [\delta_w \text{x W (m}^3)] \quad (8)$$

where,

S_{GWE}, S_{GWS} and S_{SW} are specific energy requirements in kJ per unit volume of water in m^3 and, α_w, γ_w and δ_w are the coefficients in decimals

The second part of "energy costs" (E_2) is calculated as the sum of the energy needed for tillage, fertilizer production, harvesting and local transport. This calculation is made for each crop separately.

$$E_2 = E_{farming} + E_{transport} + E_{fert.} \quad (9)$$

where,

$E_{farming}$(kJ)=Total energy needed for farming operations

$E_{farming}$(kJ)= Total energy needed for local transport and

$$E_{fert.\ T}\text{ (kJ)} = \sum [E_{fert.\ (i)}\text{ (kJ/kg) x } FERT._{(i)}\text{ (kg/ton) x } DOM_i\text{(ton)}] \quad (10)$$

where,

$E_{fert.\ T}$ (kJ)=Total energy needed for producing the required amount of fertilizer
$E_{fert.(i)}$ (kJ/kg) = Energy required for producing a kg of fertilizer (depends on type of fertilizer)
$FERT._{(i)}$ (kg/ton) = Amount of fertilizer applied per ton of product (i) produced.

The total energy needed for farming is the sum of the energy requirements for all crops in the region and is calculated by finding the fuel consumption to grow a given crop, for example cotton, starting with soil tillage and ending with harvest and transportation. Field operations vary from one crop to another as each crop, vegetable and fruit has its own characteristics that alter farming operations. Vegetable and fruit production in Turkey generally, and in the Gediz Basin specifically, are mostly labor dependent; the farming operations for field crops are mostly mechanized. Fruits and vegetables are more labor dependent and harvested by pickers or other special harvesters. In this study, farming operations such as tillage by plough, harrowing (seedbed preparation equipment), planting or transplanting, spraying, fertilizer distribution, hoeing and irrigation operations, and harvesting for each crop, vegetable and fruit are considered. In this respect, there are different ways to calculate the fuel consumed by tractors, which is based on the yearly use of tractors for farming or transport operations, as in the equation below.

$$Q_{avg} = 0.223 .P_{pto} \quad (11)$$

where $O_{avg}$is: average diesel fuel consumption and $P_{pto}$is: rated pto power

This equation is valid for tractors such as those used in the Gediz basin, which run between 700 and 1000 hours per year. The rated Power take-off (P_{pto}) is a factor of tractor power and usually assumed to be 80% of tractor power, considering losses in transmission systems, etc.

Calculation of fuel consumption uses equation (11), the time spent for growing a specific crop must be known, so that the multiplication of time spent in total per unit area will result in total fuel consumption per unit land in liters.

$$C_g= Q_{avg} .T_{farming} . L \quad (12)$$

where,
C_g= Diesel fuel consumption for a specific crop (L)
$T_{farming}$= Time spent per unit of land for farming operations for a specific crop (h/ha)
L= Land allocated to specific crop (ha)

While the machinery parks of the farms in towns of the Gediz basin are similar, average tractor power varies from one town to another. However, differences are not great: tractor power distribution data obtained from the Turkish Statistical Institute for the year 2014 were used to calculate the fuel consumption. The rated Pto power was matched with the crops grown in each town and fuel consumption for each crop at a specific town was calculated. The time spent (hours) per hectare for each crop was obtained from a study conducted in Turkey [45]. The data, in terms of time spent per hectare using tractors, were updated in accordance with the many technological developments that have occurred, such as the use of new equipment or machinery in farming operations in the region, since the study was published.

Carbon footprint (C). Each of the mentioned energies consumed, as noted above, have their respective carbon footprints. Whether for energy consumed to secure water for irrigation or for other production and transportation practices, carbon is emitted into the atmosphere [39]. The carbon emission calculations based on the activities are formulated as in the following:

$$C = C_1 + C_2 \quad (13)$$

$$C_1 = C_{GWe}+ C_{GWs} + C_{SW} \quad (14)$$

$$C_2 = C_{farming}+ C_{transport}+ C_{fert} \quad (15)$$

As parallel to energy consumption, carbon emissions are quantified as the following,

$$C_1 = C_{GWe}+ C_{GWs} + C_{SW}= E_{GW}(kJ) \text{ x (ton } CO_2/kJ)+E_{GWs} (kJ) \text{ x (ton } CO_2/kJ)+E_{SW}(kJ) \text{ x (ton } CO_2/kJ) \quad (16)$$

$$C_2 = E_{till.\ T} (kJ) \text{ x (ton } CO_2/kJ)+E_{transport} (kJ) \text{ x (ton } CO_2/kJ)+E_{fert.} (kJ) \text{ x (ton } CO_2/kJ) \quad (17)$$

Financial Value. $LFV(TL) =\Sigma [Prod_i (ton) X Pri_i (TL/ton)]$ (18)
$Prod_i$ (ton) = Total production of a product (i) locally.
Pri_i (TL/ton) = Selling market price of product (i).
LFV(TL) = Total value of production of locally produced product

Sustainability Index. The sustainability of a scenario to be developed in this study will be defined by calculating its “sustainability index” as follows:

Water Index =WI = Wi /Wa (19)
Land Index = LI = Li / La (20)
Local Energy Index = EI = Ei /Ea (21)
Local Carbon Index =CI = Ci /Ca (22)
Financial Index = FI =Fi /Fa (23)
Energy IMP Index = EIMP I = E IMPi /E IMPa (24)
Carbon IMP Index = CIMP I = C IMPi / C IMPa (25)

Wi = The total water needed for scenario i
Li = The total land area needed for scenario i
Ei = The total local energy needed for scenario i
Ci = The total local carbon emitted by scenario i
Fi = The total finances for scenario I = Flocal + Fimport (local and import)
E IMPi=The total local energy needed for scenario i
C IMPi=The total local carbon emitted by scenario i
Wa = Total max acceptable water extracted and produced by available water resources for agricultural production

La = Max acceptable/arable local land use
Ea = Max acceptable energy use = a cap could be put on max energy generation and use for agricultural production. It is influenced by current capacities, and decision of upgrade.
Ca = Max acceptable carbon emissions = a cap put by a government to cut carbon emitted
Fa = Max acceptable limits for expenditures to supply food locally and through imports
E IMPa= Max energy consumed through transporting imported food products
C IMPa = Max carbon emitted through transporting imported food products

Therefore, the scenario with the lowest score would be most sustainable, as defined by the decision maker.

Scenario i: S.I. i = $[WI_i(100\text{-}I_W) + LI_i(100\text{-}I_L) + EI_i\,(100\text{-}I_E) + CI_i\,(100\text{-}I_C) + FI_i\,(100\text{-}I_F) + EIMP\,I_i\,(100\text{-}I_{EIMP}) + CIMP\,I_i\,(100\text{-}I_{CIMP})]\,/100$ (26)

$I_W + I_L + I_E + I_C + I_F + I_{EIMP} + I_{CIMP} = 100$ (27)

I_W = Importance factor assigned for the water assessment parameter
I_L = Importance factor assigned for the land assessment parameter
I_E = Importance factor assigned for the energy assessment parameter
I_C = Importance factor assigned for the carbon assessment parameter
I_F = Importance factor assigned for the financial assessment parameter
I_{EIMP} = Importance factor assigned for 'energy for global transport' assessment parameter
I_{CIMP} = Importance factor assigned for 'carbon emissions due to global transport' assessment parameter

Crop related phenomena include land, water, and fertilizer needs; energy used for farming operations, transport and pumping water (from surface or groundwater sources); and carbon emissions, as obtained for the food production. Hence, the effect of each crop on sources, energy, and carbon emission is investigated separately and using a special analysis called "parameter relative sensitivity analysis." The parameter relative sensitivity analysis determines the effect of changing each input parameter on different outputs and for this purpose, using the equation:

$$S_r = \left(\frac{O - O_b}{P_{b\pm\Delta} - P_b}\right)\frac{P_b}{O_b} \quad (28)$$

In this equation, S_r is the relative sensitivity value, O the new output, O_b the output of base scenario, P the new parameter value, and P_b the base parameter value in base scenario. "b" is the base average value and Δ represents the change in parameter value from base [46].

Development of Future Scenarios. Future scenarios using the WEF Nexus concept were created and then divided into two parts: near future (present to the year 2020), and long term (years 2030, 2040 and 2050).

In the last two decades, the region survived one drought and one rainy year: these were considered the extremes and are assumed to happen in the region in the future. The normal year data, in terms of seasonal water and irrigation requirements, were correlated to the data of extreme years, as shown in Figure 3. For these scenarios, the water requirement data of normal year were replaced based on the regression models as shown in the Figures.

In the long term scenarios, urbanization, climate change, and technological developments were considered. The trend in urbanization was calculated based on the data released by the Turkish Statistical Institute and the total land used for agriculture data from 2000 thru 2014. It was found that the land area for agriculture, as a general trend, decreases annually in the basin. The changes in local costs are depicted for near future and long term scenarios. As seen from the Figure, local costs go down as a natural result of reduction in land. This also means that self-sufficiency in each crop declines and the export of some crops from the basin will be jeopardized (Figure 4).

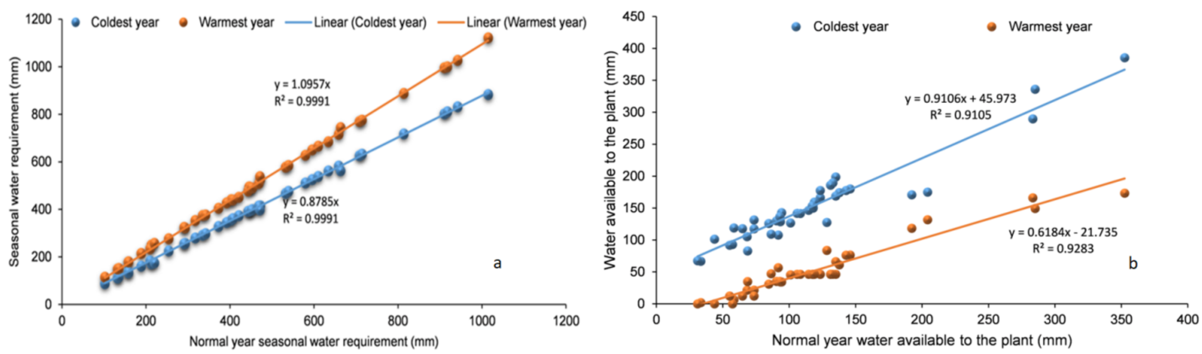

FIGURE 3
Relationship between normal year seasonal water requirement with the coldest and hottest year (a)
Relationship between normal year water available to the plant and with the coldest and hottest year (b)

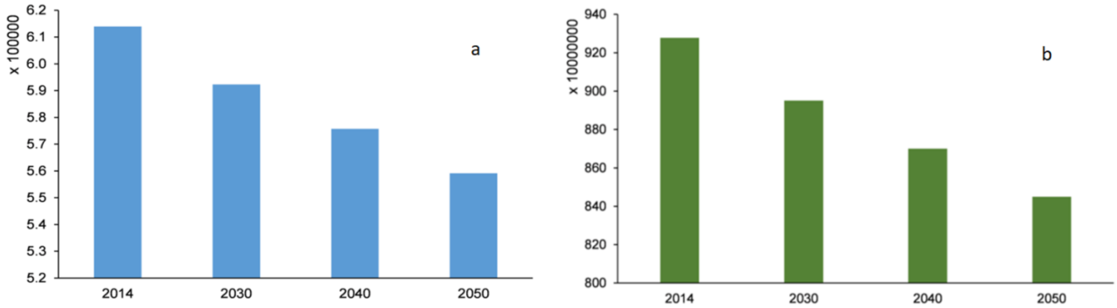

FIGURE 4
Changes in land size (ha) (a) and changes in the cost of production (TL) (b) in the long term scenarios

TABLE 4
Codes and Explanations of the Scenarios

Scenario code	Explanation
NFNSSE0	This is the based scenario that included only normal years. The ratio of surface and groundwater was 43 and 57%, respectively. No solar energy was considered in this scenario.
NFNSSE5	This scenario is the same as above, except the solar energy. It was considered that 5% of the total is pumped using solar energy
NFHSSE0	The hottest season was considered, hence the water requirement data was set along with the irrigation requirement for each crops. No solar energy was considered.
NFHSSE5	This is the same as scenario except the solar energy use. The level of solar energy to pump groundwater was set to 5%.
NFCSSE0 and NFCSSE5	The coldest season included a different set of data than the normal and hot season and was created without and with 5% solar energy, as was the case in the above scenarios.
UCSSE0	Solar energy use was not assumed in this scenario while the ratio of surface and groundwater was 43 and 57%, respectively. Rainy year data were used in terms of the seasonal water requirement and for irrigation purposes. The land size was reduced 3.52 % as compared to year 2014 which was 613917.20 ha
UCSSE5	Same as the above scenario except 5% of the water was assumed to be pumped from underground by using solar energy panels
UCSSW53SE0	In this scenario, the ratio of the surface water was increased to 53%, cold season data were considered along with no use of solar energy
UCSSW53SE5	The same as above scenario except the solar energy use in irrigation water was assumed to be 5%
UHSSE0	Same as scenario UCSSE0 except hottest year seasonal water requirement data were considered
UHSSE5	Same as above except the solar energy use for pumping water was considered at 5% level of the water used for irrigation
UHSSSW53SE0	Same as scenario 2030UCSSW53SE0except the surface water ratio was increased to 53%
UHSSSW53SE5	Same as above except 5% solar energy use was assigned

The four digit numbers in front of the scenario codes in figures refer to the year, NF refers to Near Future

This reduction was calculated to be 3.52, 6.22 and 8.92 % of the base year (2014), for the years 2030, 2040 and 2050, respectively. As in the near future scenarios, extreme precipitation years were considered since it is assumed that climate change in the long term will be between these two extremes. In some scenarios, the surface water use ratio increased to 53%, since the General Directorate of Hydraulics Works plans to put forward some new projects in the region that will increase the use of surface water. The increase from 43 to 53% was calculated based on the declared numbers of the institute. Beyond that, urbanization, climate change, and solar energy use rates were assumed to increase over the long term. This was added into scenarios as different percentages: 5% in 2030, 10% in 2040, and 15% in 2050. Including the near future scenarios, a total of 45 scenarios were developed in the study. Detailed information for each scenario is given in Table 4.

RESULTS AND DISCUSSION

As of 2014, the total land used for plant production in the basin is calculated to be 613917.2 ha, and the total water requirement is 1337.5 hm^3. For the WEF Nexus study, crops were divided into two groups to allow crops that govern the land and water needs to be easily analyzed and discussed separately. After sorting the data, the top 15 crops, accounting for 86.3 % of the land use and 79.4% of total water, were separated from the other 80 crops, vegetables, and fruits and then used for further analysis using WEF Nexus concept. The relative sensitivity analysis in this study was carried out only for the year 2014 and for the top 15 crops, by

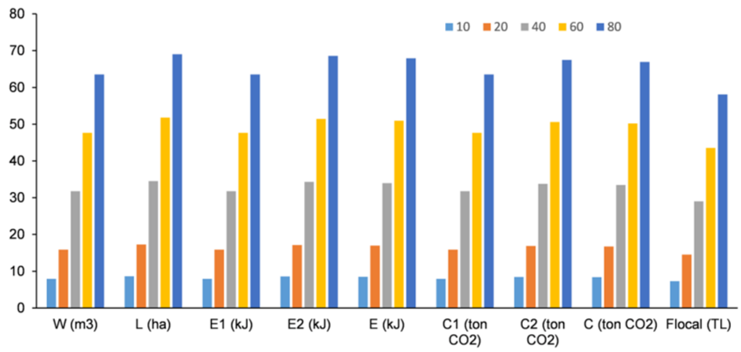

FIGURE 5
Percent changes in water, land, energy, carbon emission and local cost as a result of increasing self-sufficiency in the top 15 crops from 10 thru 80 %

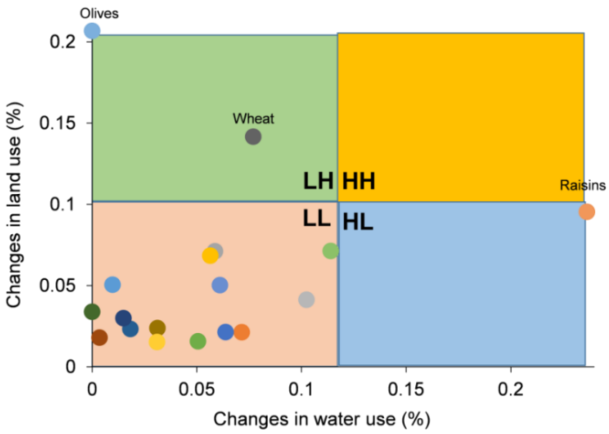

FIGURE 6
Percent changes in water use and land as a result of 20 increase in self-sufficiency of top fifteen crops, average of 22 field crops, 38 vegetables and 20 fruits

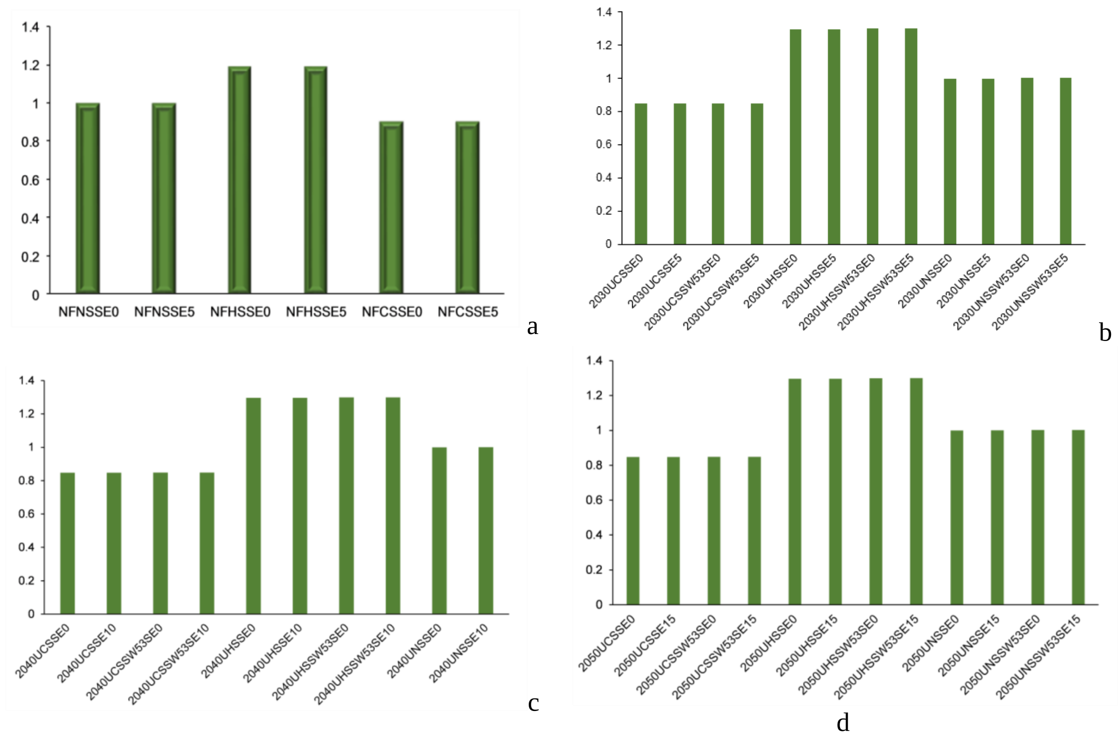

FIGURE 7
Sustainability index comparison for the near future (a), 2030 (b), 2040 (c) and 2050 (d) scenarios

increasing the self-sufficiency from 10 to 80%. The total changes can be seen in Figure 5.

The results are valuable in terms of crop management in the basin. If any change occurs in the future, changes in need for sources can readily be obtained. Another schematic view of the top 15 crops and the average of the other vegetables and fruits (total of 18 data) can be seen in Figure 6, which is divided into four equal areas by considering the ranges of the X and Y axis. As seen from the Figure, most of the crops accumulate in the regions of low land and water values, while some extreme crops such as raisins, wheat, and olives are out of the accumulated region.

The comparison of all near future scenarios can only be made from the point of the sustainability index, which requires importance factors that should be assumed for the evaluations. The sustainability index values were calculated for the long term scenarios; the results are given in Figures 7 for near future scenarios (a) and the years 2030 (b), 2040 (c) and 2050 (d). The calculations were achieved separately for each year, and normal season water requirements data was assumed to be the base scenario. Figure was drawn based on the importance factor of 0.3 for water and land while the energy parameter was assumed to be 0.2. The carbon and financial assessment parameters were also kept at the same level (0.1). The lowest sustainability indexes are obtained for the coldest seasons, making more sustainable and favorable scenarios. Normal season scenarios follow this scenario, while the hot season scenario is less favorable: the sustainability indexes are higher than the other scenarios. These reductions in the land of the basin, as stated in above, would be 3.52%, 6.22% and 8.92% for 2030, 2040 and 2050, respectively. Based on the linear relationship between land use and food production in this study, it can be expected that the self-sufficiency of each crop will decrease at the same rate as the land reduces, assuming the land reductions will be equally distributed in all crops in the basin.

On the other hand, the population growth in both the basin, and in Turkey as a whole, will enlarge the gap in a country’s ability to feed its people and may result in a reduction in self-sufficiencies such that Turkey may become a food importing country. The results tabulated in the Tables above for these scenarios are discussed below. The trend for each year is the same as other years, and a rainy year is always a favorable year in terms of water need. The increased precipitation in such a year not only reduces the evapotranspiration from the plants, but also reduces irrigation needs and saving significant amounts of water. Increasing the surface water use in all long term scenarios did not change the sustainability index. This trend is the same when solar energy use was increased in the basin. Even though the sustainability index does not change, increased surface water use in the basin will help significantly increase ground water levels. The studies conducted in the region indicate that the groundwater pumping depth increases year by year [47, 48].

A comparison among near future and long term scenarios should be considered, along with the changes in self-sufficiency values. For example, the same scenarios in 2030, 2040 and 2050 seem to reveal similar sustainability index values. However, even though the sustainability index values are similar, self-sufficiency declines if the time period is extended from 2030 to 2050. Hence, it could be said that changes in urbanization, along with climate change (drought seasons), make each scenario less sustainable as compared to the sustainability of 2014. A decrease in self-sufficiency by years can be avoided by growing drought resistant crop varieties and changing farming practices, such as direct seeding application, known as zero tillage. This application will significantly reduce fuel consumption, which in turn reduces carbon emission. Precision farming practices, such as variable rate fertilizer distribution, can also help to reduce the fertilizer input costs in agricultural production and cause less pollution in groundwater sources from consequent reduction in chemical drainage. There is an opportunity to reduce water use significantly in agricultural production by employing drip irrigation for many crop products in the region. It is believed that this will help save significant amounts of water in the basin.

Another issue with the basin is land fragmentation, an unsolved phenomenon for the entire country [23]. The number of parcels owned by one farmer ranges between 4 and 25, while the average land size is about 0.75 ha [22]. This situation is considered to be an important obstacle as it reduces efficiency in farming applications. Based on the linear relationship in the WEF Nexus study, it could be expected that the self-sufficiency of each crop will decrease at the same rates that land area is reduced, assuming the land reductions are equally distributed across all crops in the basin. On the other hand, the population growth in both the basin and Turkey may enlarge the gap for the country to feed its own people and result in reduced self-sufficiency.

CONCLUSIONS

The following can be concluded from the study:

1. The source of energy for crop production in the basin is petroleum, used for farming operations, transport, pumping surface water and fertilizer production. Solar energy seems to be an appropriate source, especially for pumping

groundwater. It is expected to become widespread not only in the basin, but nationwide.

2. The crop pattern in the region is an effective parameter for land allocation and water demand. Olive, wheat, and raisin production are considered the governing crops in the basin. Future changes in crop patterns may cause a shift toward increased water need and/or land allocations. Hence, the management in the basin requires acknowledgement of linkages between natural resources and quantification of these linkages.

3. Self-sufficiency and sustainability in the basin are likely to worsen in the long term, compared to the year 2014.

4. The reduction in available land for agriculture, as a consequence of urbanization and water scarcity due to climate change, is inevitable. In order to maintain sustainability at the current level, varieties resistant to drought should be selected and some new farming practices (direct planting and drip irrigation systems) should be seriously considered and adopted.

5. Environmentally friendly applications in agriculture are believed to reduce energy inputs, and result in less pollution. These applications could be described as the implementation of precision farming in agricultural operations along with the use of solar energy to reduce carbon emissions.

6. The WEF Nexus concept is well suited to study the basins in Turkey. Applying the concept to the other basins is of importance and the entire country profile can be obtained and then WEF Nexus concept, including importing materials from other countries (virtual water), applied and nationwide WEF study will be conducted.

7. Adding crop yields that reflect the use of different amounts of water during their growth is expected to bring non-linearity to the WEF Nexus concept: many crops respond to water used in a non-linear way. Excessive water use and water at certain levels can result in the same yield, but with differences in the amounts of water saved. The reflection of this issue in WEF Nexus work will also make other parameters non-linear. It is believed that this issue is worth studying.

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