Appl Water Sci (2017) 7:2857–2868
DOI 10.1007/s13201-017-0551-3

ORIGINAL ARTICLE

Water–food–energy nexus index: analysis of water–energy–food nexus of crop's production system applying the indicators approach

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Received: 25 November 2015 / Accepted: 27 February 2017 / Published online: 22 March 2017

Abstract Analysis the water–food–energy nexus is the first step to assess the decision maker in developing and evaluating national strategies that take into account the nexus. The main objective of the current research is providing a method for the decision makers to analysis the water–food–energy nexus of the crop production system at the national level and carrying out a quantitative assessment of it. Through the proposed method, indicators considering the water and energy consumption, mass productivity, and economic productivity were suggested. Based on these indicators a water–food–energy nexus index (WFENI) was performed. The study showed that the calculated WFENI of the Egyptian summer crops have scores that range from 0.21 to 0.79. Comparing to onion (the highest scoring WFENI, the best score), rice has the lowest WFENI among the summer food crops. Analysis of the water–food–energy nexus of forty-two Egyptian crops in year 2010 was caried out (energy consumed for irrigation represent 7.4% of the total energy footprint), respectively. WEFN index can be applied to developed strategies for the optimal cropping pattern that minimizing the water and energy consumption and maximizing their productivity. It can be applied as a holistic tool to evaluate the progress in the water and agricultural national strategies. Moreover, WFENI could be applied yearly to evaluate the performance of the water-food-energy nexus managmant.

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Keywords Water · Energy · Food · Nexus · Index · Productivity · Consumption

Introduction

The world's food, water and energy resources are nowadays experiencing significant stress and it is expected rapidly increasing demands for these resources in the coming years Water, energy, and food will become scarce in future (Bizikova et al. 2013; Hoff 2011). With limited resources, inadequate energy supply, and growing water stress, the challenge of providing enough water and energy to grow enough food for the growing population will be faced (Bizikova et al. 2013; Hoff 2011). Water, energy and food are vital for human well-being, poverty decline and sustainable expansion (FAO 2014 and Food and Agriculture Organization of the United Nations (FAO) 2014). An approach based on the water–food–energy nexus helps explain the complex and dynamic interrelationships involved and provides support for decisions to allocate the limited resources. It can do this by offering an informed and clear framework for determining and undertaking trade-offs to meet increasing demand without threatening sustainability (Bonn 2011).

Food, water, and energy are interconnected. Managing one of them cannot be considered in isolation but should be seen as part of an integrated system (Giampietro et al. 2013). The interactions among water, food, and energy are numerous and substantial. Water is used for food production (i.e. irrigation of food and feed crops and food processing). Water is used for energy production (i.e. cooling of thermoelectric power-plants, hydroelectric power-plants). Energy is used throughout the food supply chain, from the manufacture and application of agricultural inputs, such as fertilizers and irrigation, processing, and distribution services. Energy is used for food production (i.e. production of fertilizers, operation of machines, pumping irrigation water). Energy is used for water production (i.e. pumping and extraction of water, water and west water treatment, desalination). To meet increasing water demand, a substantial amount of energy is needed for pumping, treating and delivering water (Rutschmann 2013).

Due to the interaction among the three sectors, any strategy that focuses on one sector without considering its interconnections with other sectors may lead to acute unpremeditated consequences (Bizikova et al. 2013). Therefore, it is necessary to take a nexus approach when developing strategies. The nexus approach illustrates how and where the three systems interconnect (Hanlon et al. 2013). Using a nexus approach to steward water resources sustainably in energy supply chains and food supply chains is seen as a promising approach (Allan et al. 2015).

Recently, researchers, organization, and decision makers have considered the significance of the multifaceted relationships between water, energy, and food (Arent et al. 2011; Siddiqi and Anadon 2011; Bizikova et al. 2013; Gulati et al. 2013; Lele et al. 2013; Peyman et al. 2013; Finley and Seiber 2016; Biggs et al. 2015; Nielsen et al. 2015; El Gafy et al. 2017; Keairns et al. 2016; Paul and Tenaiji 2016). The nexus is broadly considered as a suggesting approach to settling the sustainable management of natural resources and ecosystems with the needs of development, including the growing demand for energy, food, and water (Bonn 2011; FAO 2014). The nexus approach allows for more integrated and effective policy-making, planning, monitoring and evaluation related to the different nexus sectors (Giampietro et al. 2013).

A set of comparative performance indices were applied to evaluate water sustainability and progress and priorities for water policies intervention. Among of them are the water availability index, the Water scarcity index, the Water Resources Vulnerability Index, Social Water Stress Index, Water Stress Indicator (WSI), and the Water Poverty Index (WPI) (Molle and Peter 2003; Juwana et al. 2010; Brown 2011; The United Nations Educational, Scientific and Cultural Organization (UNESCO) 2014; El-Gafy 2015). However, there is a need to produce an index that considers the water and energy and not concentrate only in one sector such as the previous indices.

The objective of the current research is providing a method to decision makers to analysis Water–food–Energy Nexus (WFEN) of the crop's production system. The current research applies the proposed method to analysis the water–food–energy nexus of 42 Egyptian food crops under different crop categories (cereal, legumes, sugar crops, oil crops, vegetable, and fruit).

Methodology

Through the current research the following were carried out: (1) six indicators, as illustrated in Fig. 1, were proposed to be applied as a tool to quantify the nexus and help in drawing strategies in the area of the crop production system, (2) based on these indicators, a Water–food–Energy Nexus Index (WFENI) was performed, and (3) WFEN and WFENI of 42 Egyptian main crops in Egypt were determined based on the performed WFENI and its indicators. WEFNI can be applied to developed strategies for the optimal cropping pattern that minimizing the water and energy consumption and maximizing their productivity. WEFNI can be applied as a holistic tool to evaluate the progress in the water and agricultural national strategies.

Water and energy consumption indicators

Indicator (1): water consumption indicator ($W_{c,t}$), is the water consumption per hectare of crop c at time t.

Indicator (2): Energy consumption indicator (E_c), is the energy consumption per hectare of crop c. Energy consumption for the crop food production can be categorized into direct and indirect energy use. Crop production uses energy directly as fuel or electricity to operate machinery and equipment and indirectly as in the energy consumed in producing the fertilizers and chemicals used in the farm [Zahedi et al. 2015]. E_c is calculated applying Eq. 1.

$$E_{c,t} = \sum \begin{array}{l} q_h h_{(c,t)} + q_m m_{(c,t)} + q_d d_{(c,t)} + q_f f_{(c,t)} \\ + q_p p_{(c,t)} + q_s s_{(c,t)} + q_w w_{(c,t)} \end{array} \quad (1)$$

where: q_h, q_m, q_d, q_f, q_p, q_s, *and* q_w are the energy equivalents of human labor (J/h), machinery (J/h), diesel oil (J/L), fertilizer (J/kg), pesticides (J/kg), seeds (J/kg), and irrigated water (J/m^3) inputs in crop c production. $h_{(c,t)}$, $m_{(m,t)}$, $d_{(d,t)}$,

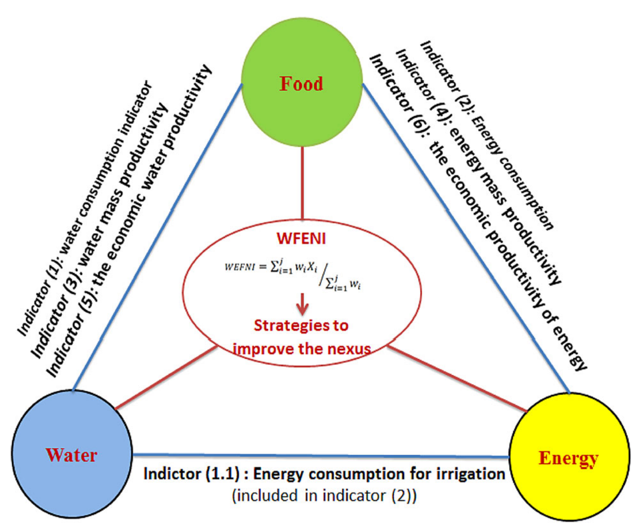

Fig. 1 Water–food–energy assessment method

$f_{(c,t)}$, $p_{(c,t)}$, $s_{(c,t)}$, and $w_{(c,t)}$ are human labor (h/ha), machinery (h/ha), diesel fuel (L/ha), electricity (kWh/ha), fertilizer (kg/ha), pesticides (kg/ha), seeds (kg/ha), irrigated water (m^3/ha) inputs in crop c production at time t.

Water and energy mass productivity indicators

Indicator (3): water mass productivity at time t ($W_{\mathrm{pro},t}$, ton/m^3) is calculated applying Eq. (2).

$$W_{\mathrm{pro},t} = {Y_{c,t}}/{w_{c,t}} \tag{2}$$

where: $Y_{c,t}$ is the yield of crop c (ton/ha) at time t, $w_{c,t}$ is the water consumption per hectar of crop c (m^3/ha) at time t.

Indicator (4): energy mass productivity at time t ($E_{\mathrm{pro},t}$, ton/J) is calculated applying Eq. (3).

$$E_{\mathrm{pro},t} = {Y_{c,t}}/{E_{c,t}} \tag{3}$$

where: $E_{c,t}$ is the energy consumption per ha of crop c at time t (J/ha).

Water and energy economic productivity indicators

Indicator (5): the economic water productivity of irrigation water at time t ($W_{EV,t}$, \$/m^3) is calculated applying Eqs. 4.

$$W_{EV,t} = N_{c,t} - C_{c,t}/w_{c,t} \tag{4}$$

where: Nc,t is the return per ha from crop c (\$/ha) at time t and $C_{c,t}$ is the cost of inputs used per ha for cultivating crop c at time t.

Indicator (6): the economic productivity of energy c at time t ($E_{EV,t}$,\$/J) is calculated applying Eqs. 5.

$$E_{EV,t} = N_{c,t} - C_{c,t}/E_{c,t} \tag{5}$$

Water–food–energy nexus index

Through the current research a preliminary WFENI was proposed. The index gives a picture to the decision makers about the performance of the water–food–energy nexus management. WFENI is calculated applying Eq. 6:

$$WEFNI_t = \sum_{i=1}^{n} w_i X_i \Big/ \sum_{i=1}^{n} w_i \tag{6}$$

The indicators of WFENI were normalized to exclude the inflection of different dimensions applying the Min–Max normalization technique applying Eqs. 7 and 8 approach as (Juwana et al. 2010). Equation 7 is used when the $\mathrm{Min}(x_i)$ of the indicator is the least preferred value and $\mathrm{Max}(x_i)$ is the most preferred value, where Eq. 8 is used for the opposite situation.

$$X_i = \frac{x_i - \mathrm{Min}(x_i)}{\mathrm{Max}(x_i) - \mathrm{Min}(x_i)} \tag{7}$$

$$X_i = \frac{\mathrm{Max}(x_i) - x_i}{\mathrm{Max}(x_i) - \mathrm{Min}(x_i)} \tag{8}$$

where: X_i refers to normalized indicator,x_i actual value of the indicator, $\mathrm{Min}(x_i)$ and $\mathrm{Max}(x_i)$ are the minimum and maximum values of the indicator, w_i is the weight applied to each indicator and n is the number of WFENI indicators. The highest value 1 is taken to be the best situation while 0 is the worst.

Total water and energy consumption footprint

Total water (W_t, m^3/year) of the crops production per year is calculated according to Eq. 9.

$$W_t = \sum_{c=1}^{v} A_{c,t} \times w_{c,t} \tag{9}$$

Total energy (E_t, J/year) of the crop production per year is calculated according to Eq. 10 v is the number of crops under study.

$$E_t = \sum_{c=1}^{v} A_{c,t} \times E_{c,t} \tag{10}$$

where: $A_{c,t}$ is the cultivated area of crop c at time t.

Case study

Agriculture consumes the largest amount of the available water in Egypt, with its share exceeding 85% of the total demand for water. Energy used for agricultural is used for pumping irrigation water, producing fertilizers and pesticides, operation of machines, and transportation. Through the current research the water–food–Energy nexus of 42 Egyptian food crops was analyzed. The determination method of WFENI and its indicators for the case study was summarized in Table 1.

Results and discussion

Determination of the proposed indicators for the case study

Calculated water and energy consumption indicators

The calculated water and energy consumption per hectare indicators, indicators 1 and 2, are illustrated in Fig. 2. The energy of human labor, machinery, diesel oil, fertilizer, pesticides, and irrigated water inputs per hectare in the crop's production system are consider in the calculation of energy consumption. Annex a Table 5.a illustrates the different energy inputs per hectare for the studied crops.

Table 1 The determination method of water–food–Energy nexus index and its indicators for the case study

Indicator no.	Indicator/index	Method of determination	
1	Water consumption per ha of crop c (w_c, m^3/ha)	Collected data	Water consumption per ha of each crop (w_c, m^3/ha) in Egypt were collected form CAPMAS (2010); CAPMAS (2011); Water Management Research Institute (WMRI) (2013); EAS (2014)
2	Energy consumption per ha of crop c (E_c, J/ha)	Applying Eq. (1)	Previous studies are used as a reference for the determination of the energy equivalent of q_h, q_m, q_d, q_f, q_p, and q_s, same approach as Yousefi et al. (2016);Zahedi et al. (2015); Brar et al. (2015); Mohammadi et al. (2015); Mirasi et al. 2014; Peyman et al. (2013); Rafiee et al. (2010); Zarini et al. (2013); Bilalisl et al. (2013); Ibrahim and Ibrahim, (2012); Umar and Ibrahim (2012); Avval et al. (2011); Namdari et al. (2011); Soliman (2003); Canning et al. (2010); Yaldiz et al. (1993) The energy equivalents of irrigation water (The energy equivalent is the energy required to left 1 m3 of water) q_w (J/m^3), is calculated applying Eq. 11: $q_w = E_p/W$ (11) Where: E_P is the pumping input energy (J), W (m^3) is the total water consumed for the food production $E_p = \sum_{j=1}^{r} P_j \times k \times h/\mathrm{eff}_j$ (12) where, P_j (hp) is the power of pump j, k is a factor to convert the hp to MJ/h; k is equal to 0.756, h is the pumping hours per year (it is assumed that the pump works 1.25 h/day), the eff_j is the efficiency of pump j (it is assumed that the efficiency of the pump is 45%,), and r is the number of the irrigation pumps in Egypt. The data of the P_j and r, as shown in Table 2, were collected from Economic Affairs Sector at Ministry of Agriculture and Land Reclamation of Egypt (Economic Affairs Sector (EAS) 2013) $h_{(c)}$, $m_{(c)}$, $d_{(c)}$, $f_{(c)}$, $p_{(c)}$, $s_{(c)}$, and $w_{(c)}$ [The human labor (h/ha), machinery (h/ha), diesel fuel (L/ha), fertilizer (kg/ha), pesticides (kg/ha), seeds (kg/ha), irrigated water (m^3/ha)] inputs in crop c production in quantity per ha were determined as following: $h_{(c)}$ were collected from Economic Affairs Sector EAS (1989) $m_{(c)}$ were collected through personal interviews with farmers $d_{(c)}$ (L/ha), the machine fuel consumption for cultivating one ha of crops c, is calculated applying Eq. 13: $d(d) = M_{hc} \times D_{Lc}$ (15) D_{Lc} (L/h), the machine fuel consumption per hour, is calculated applying Eq. 14 (Food and Agriculture Organization of the United Nations (FAO) 1992) $D_{Lc} = K \times HP \times LF/KPL$ (16) where: M_{hc} is the machine working hours for cultivating hectare of crop c (h/ha), K is the kg of fuel used per brake (Kg/kWh), LF is the load factor in percent, and KPL is the weight of fuel in (kg/L). Data of weighted average of the machine hours power (HP) where collected from (Economic Affairs Sector at Ministry of Agriculture and Land Reclamation of Egypt (Economic Affairs Sector (EAS) 2013). Data of K, LF, and KPL where collected from FAO (1992) $f_{(c)}$, The weighted average value for fertilizer quantity (nitrogen, phosphate, and potassium) per hectare used for each crop were calculated based on data collected form Economic Affairs Sector (EAS) (2014) and Economic Affairs Sector (EAS) (2014) $p_{(c)}$ and $s_{(s)}$ have not been considered through the current research
3	Water mass productivity	Applying Eqs. (2)	Y_c—yield of crop c (ton/ha)—collected from Central Agency for Public Mobilization and Statistics (CAPMAS) 2010 and Central Agency for Public Mobilization and Statistics (CAPMAS) 2011 w_c, water consumption per hectare of crop c (m^3/ha), collected from Central Agency for Public Mobilization and Statistics (CAPMAS) 2010 and Central Agency for Public Mobilization and Statistics (CAPMAS) 2011 E_c—energy consumption per hectare of crop c. calculated as described above

Table 1 continued

Indicator no.	Indicator/index	Method of determination	
4	Energy mass productivity	Applying Eqs. (3)	
5	Water economic productivity	Applying Eqs. (4)	
6	Energy economic productivity	Applying Eqs. (5)	
	Water-Food-Energy Nexus Index	Applying Eqs. (6, 7, 8)	According to the weights w_i in Eqs. 8 and 9, equal values are given in this study for the different crops
	Total water consumption	Applying Eqs. (9)	
	Total energy consumption	Applying Eqs. (10)	

Table 2 Numbers of irrigation pumps according to their powers

	Estimated average power (*Hp*)						
Area	5	7.5	11	13.5	20.5	35.5	45
Lower Egypt	112050	273816	72627	70079	41514	11373	11114
Middle Egypt	37099	67457	37756	23081	5941	1410	2422
Upper Egypt	10864	27911	13106	16269	7397	6270	5218
Outside the valley	973	3658	4108	10082	5457	370	424
Total	160986	372842	127597	119511	60309	19423	19178

Sources (Economic Affairs Sector (EAS) 2013)

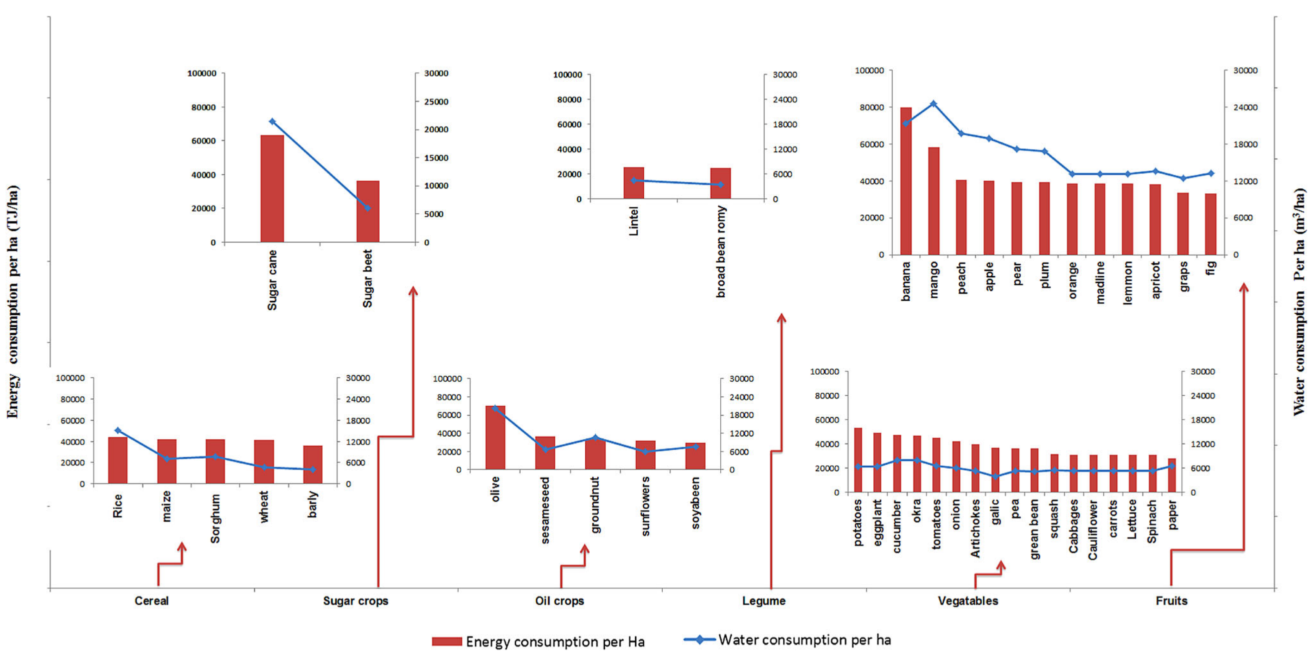

Fig. 2 Water–energy–food nexus: water and energy consumption indicators of the main food crops at the study year (The energy of human labor, machinery, diesel oil, fertilizer, pesticides, and irrigated water inputs per hectare in the crop's production system were illustrated in Annex a Table 1)

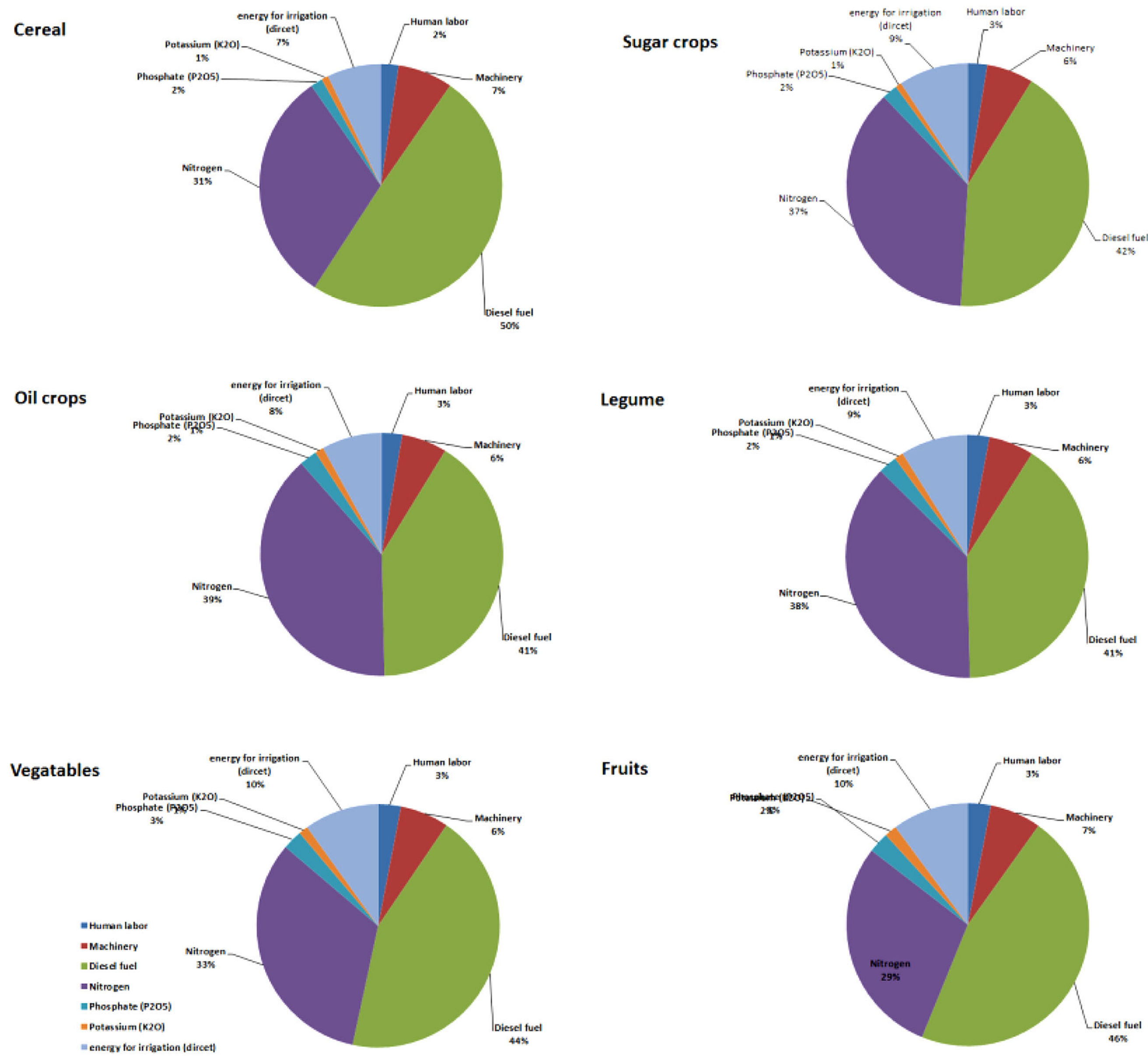

Fig. 3 Contribution of agricultural inputs categories to the total energy used for the food crops production

According to the energy used for irrigation, as shown in Fig. 3, the energy used for irrigating one hectare of fruits, sugar crops, oil crops, cereal, and vegetables represent 14, 11, 10, 7, and 6% of the total energy use for the production of each category, respectively. Rice, sugar can, lintel, okra, olive, and mango are the highest energy consumption for irrigation in the cereal, sugar, legume, oil, vegetables, and fruits categories, respectively, as shown in Table 5.

Calculated water and energy productivity indicators

The calculated water and energy productivity indicators, indicators 3 and 4, are illustrated in Fig. 4. As shown in Fig. 4, having the highest water productivity does mean that the crop should have the highest energy productivity. As an example, potato is the highest energy productivity crop in the vegetable category while garlic is the highest water productivity one in this category.

Calculated economic water and energy productivity indicators

Economic water and energy productivity indicators of summer crops are shown in Fig. 5. As shown in the previous figure, onion has the highest economy productivity among the summer crops. Due to the data availability for some crops, a complete analysis of the economic indicators did not conceder through the current research.

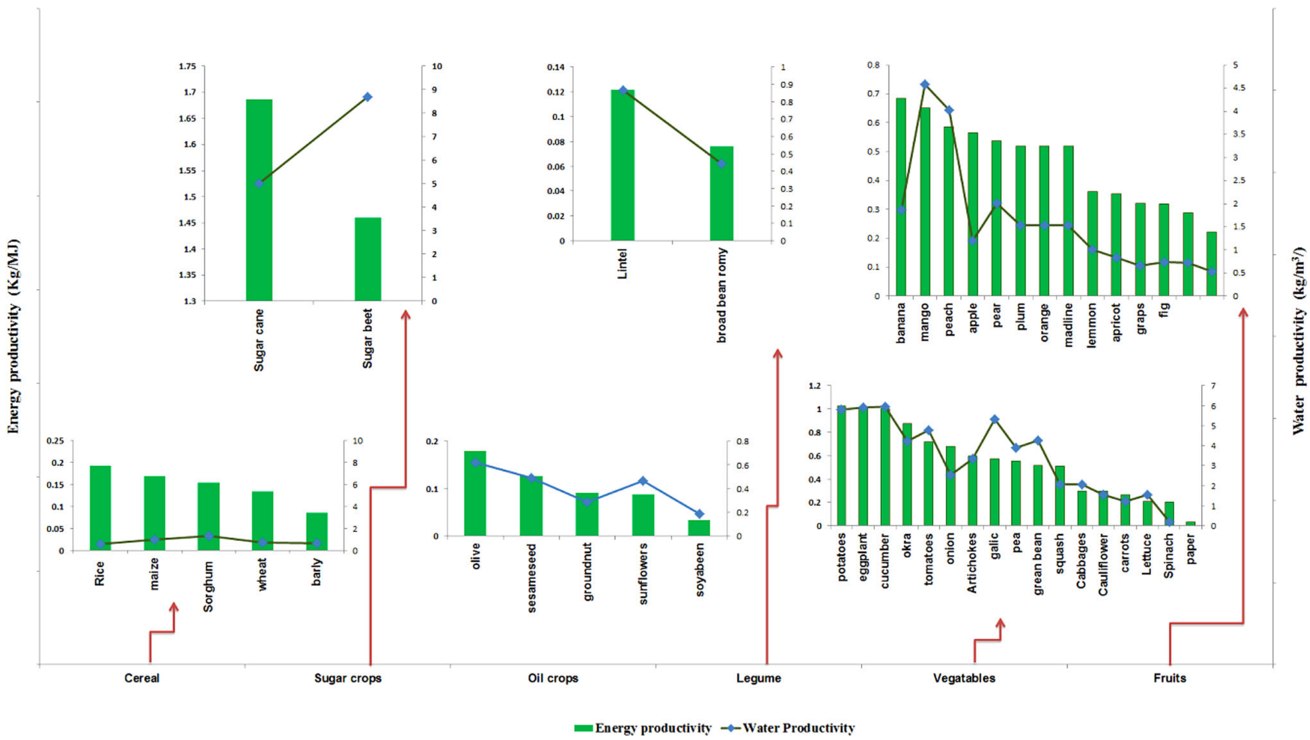

Fig. 4 Water–energy–food nexus: Water and energy mass productivity indicators of the main food crops at the study year

Table 3 Food–water–energy nexus index of a number of studied food crops and its normalized indicators

Crop	Consumption		Mass productivity		Economic productivity		WFENI
	Energy	Water	Energy	Water	Energy	Water	
Onion	0.60	0.95	0.39	0.80	1.00	1.00	0.79
Tomato	0.52	0.92	0.51	1.00	0.54	0.53	0.67
Pepper	1.00	0.92	0.34	0.41	0.32	0.18	0.53
Potato	0.28	0.93	0.29	0.71	0.38	0.48	0.51
Quintalob	0.31	0.86	0.37	0.77	0.17	0.19	0.45
Pea	0.77	1.00	0.16	0.32	0.20	0.21	0.44
Okra	0.46	0.83	0.14	0.24	0.53	0.45	0.44
Watermelon	0.31	0.85	0.33	0.67	0.22	0.23	0.44
Zucchini	0.91	0.99	0.11	0.18	0.20	0.16	0.42
Peanut	0.85	0.67	0.04	0.02	0.44	0.17	0.36
Sugarcane[a]	0.00	0.00	1.00	0.84	0.23	0.07	0.36
Soybean	0.96	0.85	0.06	0.05	0.08	0.03	0.34
Sunflower	0.90	0.95	0.03	0.05	0.00	0.00	0.32
Eggplant	0.40	0.93	0.10	0.23	0.12	0.16	0.32
Maize	0.60	0.88	0.08	0.14	0.05	0.05	0.30
Sesame	0.76	0.91	0.00	0.00	0.07	0.05	0.30
Sorghum	0.60	0.85	0.06	0.10	0.02	0.02	0.27
Cucumber	0.46	0.83	0.00	0.00	0.08	0.08	0.24
Rice	0.55	0.39	0.10	0.07	0.12	0.02	0.21

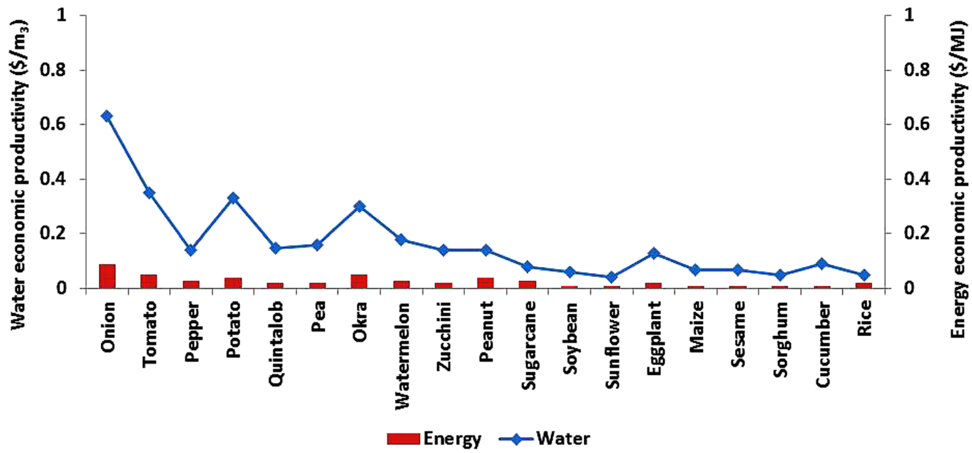

Fig. 5 Water–energy–food nexus: water and energy economic productivity indicators of the main food crops at the study year

WEFNI of the main food crops

The WFENI of summer crops, as an example, were calculated. The indicators of the water–energy consumption, mass, and economic productivity, as illustrated in Table 3, of the summer crops were first calculated. Based on the previous indicators, the WFENI of the summer crops for year 2010 were determined, Table 3. A comparative analysis among the crops base on their WFENI was carried out. The study showed that the calculated WFENI of the summer crops have scores that range from 0.21 to 0.79, as shown in Table 3. Comparing to onion (the highest scoring WFENI), rice has the lowest WFENI among the summer crops. WFENI could be applied yearly to evaluate the performance of the water–food–energy nexus management. WEFN index can be applied to developed strategies for the optimal cropping pattern that minimizing the water and energy consumption and maximizing their productivity.

Analysis of Water-Food-Energy nexus of the studied food crops in 2010

The WFEN of each food crop under study was determined, Table 4. The analysis of The WFEN of the food crops' production and consumption for year 2010 showed that:

- The total production of the food crops is about 71 Mt (29% cearal, 33% sugar, 0.40% oil, 0.40% legume, 26% vegetables, 11% fruits).
- The water and energy consumption for cultivating the studied food crops in 2010 (study year) was about 41 Billion Cubic Meter (BCM) (54% cereal, 17% vegetables, 14% fruits, 10% sugar crops, 2.4% oil crops, and 1% legume) and 2,14,217 TJ (59% for cereal, 23 vegetables, 8% fruits, 2% oil crops, 1% legumes), respectively.
- The energy consumed for irrigation is about 15,800 TJ which is representing about 7.4% of the total energy of the studied crops.

Conclusion

The current research is providing a method to decision makers to analysis the Water-food-Energy Nexus (WFEN) of the crop's production system. The research applied Water–Food–Energy Nexus Index (WFENI) that considers the water and energy and not concentrated only in one sector. This index integrates a number of aspects that refract major concerns in the nexus. Where, WFENI composite indicators for Water-Energy consumption (the energy of human labor, machinery, diesel oil, fertilizer, pesticides, and irrigated water inputs in the crop's production system were considered), water–energy mass productivity, and water–energy economic productivity.

WFENI and its indicators were applied to analysis the water–food–energy nexus of the crop production system of 42 Egyptian main food crops cultivated in year 2010 in Egypt.

The study showed that the calculated WFENI of the Egyptian crops have scores that range from 0.13 to 0.88. Comparing to Sugar beet (the highest scoring WFENI) olive has the lowest WFENI among the 42 food crops. The WFE nexus of each food crop under study was determined. The WFE nexus analysis of the food crops' production and consumption for year 2010 shown that: the total production of the food crops is about 71 Mt, The water and energy consumption for cultivating the studied food crops in 2010 (study year) were about 41 BCM and 2,14,217 TJ, respectively. The energy consumed for irrigation is about 15,800 TJ which is representing about 7.4% of the total energy of the studied crops.

Table 4 Total food–water–energy nexus of the studied food crops in 2010

Crop	Production M ton	Water con. BCM	Energy con. TJ	Energy con. for irrigation TJ
Wheat	8.50	6.31	55,269	2412
Rice	4.33	7.64	22,284	2918
Barley	0.12	0.16	1424	61
Maize	7.03	7.04	41,729	2690
Sorghum	0.70	0.94	5235	360
Sugar cane	15.71	3.15	9324	1202
Sugar beet	7.84	0.89	5382	339
Soya been	0.04	0.08	319	31
Groundnut	0.14	0.50	1585	192
Sunflowers	0.04	0.08	416	30
Sesame seed	0.05	0.30	1681	117
Broad bean	0.17	0.20	1458	78
Lentil	0.10	0.21	1248	82
Potatoes	3.64	0.86	7235	330
Onion	2.21	0.46	3225	176
Garlic	0.30	0.06	548	22
Tomatoes	8.09	1.37	9082	525
Green bean	0.34	0.16	1117	61
Pea	0.23	0.11	748	41
Artichokes	0.20	0.05	400	20
Cucumber	0.80	3.15	18,814	1203
Squash	0.07	0.06	327	176
Eggplant	1.16	0.74	5736	285
Okra	0.11	0.08	444	29
Cauliflower	0.11	0.02	114	7
Carrots	0.16	0.03	158	10
Cabbages	0.52	0.09	513	34
Paper	0.73	0.28	1200	108
Lettuce	0.11	0.03	157	10
Spinach	0.05	0.01	84	5
Orange	2.60	1.70	5018	651
Mandarin	0.84	0.55	1632	212
Lemmon	0.30	0.19	574	74
Apple	0.62	0.38	796	144
Grapes	0.72	0.71	1933	272
Banana	1.07	0.53	1992	203
Mango	0.60	1.13	2678	433
Apricot	0.10	0.10	265	36
Pear	0.04	0.05	125	21
Peach	0.41	0.62	1276	238
Plum	0.01	0.02	39	6
Fig	0.19	0.25	634	97
Total	71.11	41.32	2,14,217	15,944

Understanding WFE nexus allows for more integrated planning, development, policy-making, monitoring and evaluation related to the nexus sectors. The water food energy nexus should be considered when developing development projects. The WFE nexus should be considered when developing the stagey of the country and not

Table 5 Annex a calculated energy inputs per hectare of the studies food crops

Crops	Human labor	Machinery	Diesel fuel	Fertilizers			Energy con. for irrigation per ha
				Nitrogen	Phosphate	Potassium	
Wheat	1003	3284	22,276	12212	498	637	1820
Rice	1059	3284	22,276	11344	405	0	5777
Barley	687	3284	22,276	6977	529	637	1547
maize	1077	2389	16,200	18400	934	637	2730
Sorghum	1040	2836	19,238	15333	934	0	2912
Sugar cane	2024	2389	16,200	32200	1867	637	8189
Sugar beet	1207	2389	16,200	12727	934	637	2293
Soya been	1040	2836	19,238	2300	700	637	2927
Groundnut	910	2836	19,238	4907	934	637	4053
Sunflowers	780	2836	19,238	4907	934	637	2308
Sesame seed	1096	2836	19,238	9660	685	637	2545
Broad bean	761	2389	16,200	3067	700	637	1345
Lentil	1003	2389	16,200	3067	700	637	1687
Potatoes	984	2389	16,200	26680	1867	3053	2447
onion	1189	2389	16,200	18400	1058	796	2310
Garlic	2043	2389	16,200	12727	654	1646	1471
Tomatoes	576	2389	16,200	18860	1867	2549	2530
Green bean	1040	2389	16,200	12267	934	1274	1979
Pea	1151	2389	16,200	12267	934	1274	2005
Artichokes	631	2389	16,200	15640	934	1911	2005
Cucumber	799	2389	16,200	19167	4668	1062	3027
Squash	1003	2389	16,200	4600	4668	398	2081
Eggplant	1021	2389	16,200	22693	1618	3133	2455
Okra	613	2389	16,200	19167	4668	1062	3050
Cauliflower	631	2389	16,200	4600	4668	398	2005
Carrots	631	2389	16,200	4600	4668	398	2005
Cabbages	631	2389	16,200	4600	4668	398	2042
Paper	631	2389	16,200	2300	3268	796	2522
Lettuce	631	2389	16,200	4600	4668	398	2005
Spinach	631	2389	16,200	4600	4668	398	2005
Orange	3070	1194	8100	18860	467	1911	5014
Mandarin	3070	1194	8100	18860	467	1911	5014
Lemmon	3070	1194	8100	18860	467	1911	5014
Apple	3070	1194	8100	15793	934	3823	7248
Grapes	3070	1194	8100	12573	934	3186	4749
Banana	3070	1194	8100	44773	1805	12955	8167
Mango	3070	1194	8100	31893	747	3823	9417
Apricot	3070	1194	8100	15793	934	3823	5225
Pear	3070	1194	8100	15793	934	3823	6563
Peach	3070	1194	8100	15793	934	3823	7557
Plum	3070	1194	8100	15793	934	3823	6446
Fig	3070	1194	8100	12573	1167	2044	5057

only focuses on one sector. The proposed indicators/indices should be applied for comparing the change in the water–energy–food nexus of the agriculture production system over years. WFENI could be applied yearly to evaluate the performance of the water–food–energy nexus management. WEFNI can be applied to developed strategies for the optimal cropping pattern that minimizing the water and energy consumption and maximizing their productivity. Other indicators could be considered within the index according to the availability of the data, the use of the index, and the level of its application.

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