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A Strategic Framework for Sustainable Agriculture Development Goals Based On: Water, Energy, Food Security Nexus

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Abstract: Nexus perspective helps us to understand the wider implications for Water-Energy –Food (WEF). The paper develop a concept of water productivity (WP) and virtual water (VW) as integrating terms to go beyond a simple ratio between yield and water use or vice versa to create Productivity, Water and Energy term (PWE) which has a wide boarder including different performance indicators associated with energy as a tool in WFE nexus. Results showed that higher values of PWE $_{(\text{food energy/water//energy})}$ expressed in cal $m^{-3}kwh^{-1}$ units resulted from potatoes, raw sugar extracted from sugar beet, barley and wheat to be 54, 44, 43 and 41, respectively. While higher values of PWE $_{(\text{yield/water/energy})}$ expressed g $m^{-3}kwh^{-1}$ units were associated with vegetables crops and feed crops, however, higher values of PWE $_{(\text{water / yield /energy})}$ expressed kg $kg^{-1}kwh^{-1}$ units was associated with seeds of cotton, linen, raw cotton, lupine and chickpeas. Net virtual water import was about 27.977 km^3 which was attributable to import of cereals, vegetables oils, vegetables, fruits and meats. Water scarcity percent was high to be 81% and 75.9%, which associated with low water dependency values which were 22.4% and 30.9% in 1995 and 2015, respectively. Water self-sufficiency values dropped from 77.6 to 67.1% in 1995 and 2015 respectively. In addition to actual renewal water amounting 59.8 km^3, Egypt needs 42.1 km^3 of water to fill the food gap and water self sufficiency for different sectors to bringing the total required water 104.4 km^3. The agriculture sector only needs 90.3 km^3 of water to achieve food security, which requires an estimated energy of 5.018 million megawatts and 100.3 million US dollars to fill the food gap between the import and export. About 25% of Egypt's cultivated land is used to grow water-intensive crops such as rice and sugar and being mindful of the fact that the irrigation efficiency ranges from 40% to 65% implies that there are substantial potential savings in applying the WEF nexus. The WEF security strategy is based on stabilizing rice cultivation at 0.85 million acres, introducing new irrigation technologies, applying good agriculture practices and rehabilitation of irrigation systems in reclaimed land with an extension in wheat and maize production. Nowadays, Egypt is taking positive steps to use solar energy as a renewable energy source for water pumping in new lands as a strategic framework for food security. Status quo requires implement WEF approach which is inevitable in analysis of water and agricultural policies and strategies aim by finding effective and sustainable solutions to the problem of water scarcity and drought for maximizing utilization of natural resources in light of the coming challenges concerning the sustainable development programs of Egypt.

Key words: Water- Energy-Food security nexus (WEF) · Productivity- Water- Energy (PWE) relationship · Water productivity · Virtual water · Water scarcity · Water dependency and Water self-sufficiency

INTRODUCTION

The Water-Energy-Food nexus is framed within the broader debate on sustainable development that recognizes and tries to strike balance between the different goals, interests and needs of people as well as the environment. Furthermore, it explicitly addresses complex interactions and feedback between human and natural systems [1]. [2] revealed that water, energy and food security are closely correlated with the Arab region, perhaps more than in any other region in the world. Generally, the region is known to be water scarce, food deficient and energy intensive one of the world's most environmentally and economically vulnerable regions to climate change. Policy makers in the Arab countries need to ensure the integration of the policy cycle for the Food

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Water Energy (FWE) relation through a set of measures which including bridge the knowledge gap of the FWE approach at the national and regional levels by understanding and quantifying the inter-linkages between water, food and energy [3]. Egypt is already below the water stress level of 600 m^3/capita/year and water availability is expected to decrease by 2050, while demand will continue to grow. Egypt is the world's largest importer of wheat and recent economic instability has left its population even more vulnerable to food insecurity. Moreover, climate change, which is mostly driven by energy use, consumption patterns and land use changes, is an additional challenge that would exacerbate the critical situation of water and food resources and would intensify the use of energy resources in the region. Climatic variability adds further pressures and is likely to induce more frequent and intense extreme weather events (such as droughts or floods) and less reliable water supplies, as well as less reliable agricultural productivity [4]. Between 50% and 60% of Egypt's food requirements are met by imports. Egypt is one of the largest importers of wheat in the world [1]. The Egyptian government aims to reduce import dependency and increase domestic food production mainly because i) devaluation of local currency leads to an increase in the cost of food imports and ii) world market prices of some of the imported crops are very volatile. Agriculture is a major component of the Egyptian economy, contributing about 15% to the national GDP and accounting for 28% of all jobs (up to 55% in Upper Egypt). Agriculture is an important basis for livelihoods and employment in particular in the rural areas and especially for the rural poor.

Virtual water is defined as the water consumed in the production process of an agricultural or industrial product has been called the contained in the product [5]. If a country exports a product requiring heavy water to another country, it exports the water in a hypothetical form. In this way some countries support other countries in their water needs. For water-scarce countries it could be attractive to achieve water security by importing water-intensive products instead of producing all water demanding products domestically [6]. Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic [7]. Virtual water trade between nations and even continents could thus ideally be used as an instrument to improve global water use efficiency, to achieve water security in water-poor regions of the world and to alleviate the constraints on environment by using best suited production sites [8]. Irrigated agriculture, accounting for about 80 percent of global water consumption and 86 per cent of 1995 water consumption in developing countries, is the primary sector to be affected by water shortage. There is a major threat that the water available may be inadequate to meet growing food demands [9, 10], particularly in water short countries. For water scarce areas, it can be attractive to adopt a policy of production and export of products with relatively low water content and import of higher products in virtual water content. The virtual water volume embodied in food imports and exports remains a health concern for maximize the value of their limited water supplies [11].

Methodological Issues

Objectives: The paper develop a concept of water productivity (WP) and virtual water (VW) as integrating terms to go beyond a simple ratio between yield and water use to create Productivity, Water and Energy term (PWE) to understand the complex relationship between water, energy and food are needed to ensure the development of concerted efforts to support sustainable agriculture and to make sure that decisions on water release and allocation are taken as part of an integrated, long-term and multi-sectoral strategy.

Analysis Level:

Micro level (WEF Nexus at Field Level): The use level of analysis for water energy and food production is taken at the field level with performance indicators. In this level, crop productivity takes place the process as a result of irrigation and energy. Agricultural research at this level is often aimed at increasing productivity per unit of land and water and energy as well. It is important to understand the category of water and energy against which production is being measured, or the category of water that is being conserved.

At the field level, the magnitudes of the components of the WEF are a function of irrigation depending on energy to lift water on farm level to achieve high crop productivity. Different crops and even different varieties of crops, will transpire water at different rates. Quantities of irrigation i.e. ET, deep percolation, run off and irrigation systems are mainly based on energy for lifting water using diesel or electrical pumps. For example, drip irrigation minimizes these components, while surface application induces depletion by evaporation. Also, the amount of water delivered influences runoff and deep percolation. Other cultural practices such as intercropping, mulching and crop spacing affect the amount of water stored in the soil and the amount of runoff and deep percolation. WEF nexus procedures attempt to capture the effects of different crop and cultural practices on how water is used and depleted at the field level using the required energy [12].

At the field level, it is sometimes possible and oftentimes necessary to know the fate of inter-linkage between WEF. By overlapping for WEF interacting at the field level, then placing it in the context of irrigation, energy and agriculture services levels, it is possible to match field level interventions with requirements at the irrigation energy and agriculture services level, or national water level, or both.

Macro Level (WEF Nexus at National Level): The agricultural fields on national scale or governorate level covering all or part of national water and energy using in to achieve sustainable agriculture development goals: use level, such as an agricultural field or on farm level. The water energy and food nexus is developed in a manner such that it can be generically used for WEF nexus in areas that installed developing irrigation management projects.

The Approach:

Food and Water

Energy and Food

Water, Energy and Food Nexus

Performance Indicators: WEF performance indicators are presented in the form of water productivity, virtual water, productivity – water-energy, water- productivity energy, water scarcity, water dependency; water self sufficiency and water footprint concepts.

Water Productivity (WP) is an integrating term goes beyond a simple ratio between yield water use to include energy in calories or economic values in USD [13] as shown in Eq. [1].

$$\text{Water productivity} = \frac{\text{Yield}\left(\frac{\text{kg}}{\text{m}^2}\right) \textit{or } \text{Energy (calories) or economic value (S)}}{\text{Water use or ET}_{\text{actual}}\left(\frac{m^3}{m^2}\right) / \text{economic vlaue (S)}} \tag{1}$$

Productivity Water- Energy (PWE $_{\text{food energy}}$): Refers to the food energy producing from per unit of water per unit of energy expressed cal $m^{-3}kw^{-1}$ h^{-1} or cal m^{-3} l^{-1}

$$\text{PWF}_{\text{food energy}} = \left(\frac{\text{Food energy (calories)}}{\text{Water use or ET}_{\text{actual}}(\text{m}^3)}\right) / \left(\text{Energy}\left(\frac{\text{kw}}{\text{w}}\right) \text{or Diesel fuel in liter}\right) \tag{2}$$

Productivity- Water- Energy (PWE $_{\text{yield/water/energy}}$): Refers to the crop productivity producing from per unit of water per unit of energy expressed g $m^{-3}kw/h^{-1}$.

$$\text{PWF}_{\text{yield/water/energy}} = \left(\frac{\text{Yeild}\left(\frac{\text{kg or g}}{\text{m}^2}\right) \text{or economic value (S)}}{\text{Water use or ET}_{\text{actual}}\left(\frac{\text{m}^3}{\text{m}^2}\right)}\right) / \left(\text{energy}\left(\frac{\text{kw}}{\text{h}}\right)\right) \tag{3}$$

Water-Productivity –Energy (WPE $_{\text{water / yield /energy}}$): Refers to the water used that produce the unit of yield per unit of energy expressed $m^{-3}g$ kwh^{-1}

$$\text{WPE}_{\text{water / yield /energy}} = \left(\frac{\text{Water use or ET}_{\text{actual}}(kg)}{\text{Yeild(kg or g)}}\right) / \left(energy\left(\frac{kw}{h}\right)\right) \tag{4}$$

Virtual Water (VW): The principle of calculating water productivity is fairly simple: crop water requirements are the actual water consumption (m^3 / ha) with the coefficient of the crop per crop where programs such as CropWat programme can be used [9] for this purpose.

Water productivity is then obtained by dividing crop productivity (kg / ha) over crop water requirements. The calculation of the value of virtual water in reverse water productivity is illustrated in the following equation:

$$VW = \frac{Water\ use\ or\ ET_{actual}(kg)}{Yield(kg)} \tag{5}$$

The total use of national water and net virtual water imported can be seen as the country's water footprint, which is the total volume of water needed to produce the goods and services consumed by the country's population.

Water scarcity (WS): Water scarcity has often been defined as the ratio of actual renewal water in km^3 to the total water used in all sectors in km^3. This supply - oriented definition is useful from a production perspective, but does not express the scarcity from a demand perspective. In this study, water scarcity is defined as the ratio of the total water footprint of a country or region to the total renewable water resources [14]. The national water scarcity can be more than 100% if a nation consumes more water than domestically available.

$$WS = \frac{\text{Actual renewal water (km}^3\text{)}}{\text{Total water used in all sectors (km}^3\text{)}} x100 \tag{6}$$

Water Dependency (WD): Countries with import of virtual water depend on the water resources available in other parts of the world. The virtual water import dependency of a country or region is defined as the ratio of the net virtual water imported (NVWI(in km^3 (external water footprint of the country or region) to actual renewal water in km^3 plus NVWI in km^3 (its total water footprint) [14].

$$WD = \frac{NVWI(km^3)}{Actual\ renewal\ water\ (km^3) + NVWI(km^3)} x100 \tag{7}$$

Water Self-Sufficiency (WSS): WSS is the ratio of the internal water footprint to the total water footprint of a country. It denotes the national capability of supplying the water needed for the production of the domestic demand for goods and services. Self sufficiency is 100% if all the water needed is available and indeed taken from within the own territory. Water self-sufficiency approaches zero if the demand for goods and services in a country is largely met with virtual water imports [14].

$$WSS = \frac{Actual\ renewal\ water\ (km^3)}{Actual\ renewal\ water\ (km^3) + NVWI(km^3)} x100 \tag{8}$$

Water Footprints: The water footprint of an individual, business or nation is defined as the total volume of fresh water that is used to produce the foods and services consumed by the individual, business or nation. A water footprint is generally expressed in terms of the volume of water use per year [14].

$$Water\ footprint\ (Mm^3 per\ yr\ per\ capita) = \frac{Population\ in\ million}{Available\ water\ used\ in\ all\ \text{sectors (km}^3\text{)}} \tag{9}$$

$$Per\ capita\ water\ in\ m^3\ per\ yr = \frac{Available\ water\ used\ in\ all\ sectors(km^3)}{Population\ in\ million} \tag{9-1}$$

RESULTS AND DISCUSSION

Micro Level:

Food and Water Nexus

Water Productivity (WP): Water productivity values as kg of yield per cubic meter of used water for clover, tomatoes, alfalfa, sugar beet, onion and cabbage growing in the winter season was higher to be 13.7, 11.59, 10.42, 9.06, 7.43 and 8.17 compared to other winter crops as shown in Table 1. It might be due to higher productivity for each cubic meter of consumed water for such crops than other winter crops. As for summer crops, water productivity of summer crops such as tomatoes, sugar cane and potatoes was higher to be 5.58, 4.49 and 4.03 kg per cubic meter compared to other summer crops as shown in Table 2. This is due to each cubic meter of consumed water for such crops produced higher productivity than other summer crops. Regarding late summer crops that called Nili, tomatoes produced higher WP to be 5.83 kg per cubic meter compared to other late summer crops as shown in Table 3.

Water productivity, on base of food energy, sugar beet, wheat and potatoes produced higher calories per cubic meter to be 5836, 4739 and 4686 respectively (Table 1). As for summer crops, maize, sunflower, soybean and potatoes gave 3740, 3514, 3513 and 3308 calories per cubic meter, respectively (Table 2). In late summer season, WP of maize gave 3803 calories per cubic meter followed by potatoes which resulted in 2604 calories per cubic meter compared to other crops such as medicinal plants as shown in Table 3. Regarding food production in Egypt, more attention is given by farmers to grow rice, wheat, some cereals, vegetables and sugar production.

Table 1: Water requirements, crop production, food energy, WP, VW, P-W-E, W-P-E and energy for lifting for winter crops structure (2014/2015)

							P-W-E				Energy for lifting #			
Crops	Average water requirements m^3 acre	Average crop production kg acre	Food energy cal/100gm of production)	WP kg m^3	WP $_{\text{food energy}}$ cal/m^3 of water)	VW kg water / kg production	cal m^{-3} kwh^{-1}	cal m^{-3} l^{-1}	P-W -E g $m^{-3}kwh^{-1}$	W-P -E m^3 g^{-1} kwh^{-1}	Diesel Fuel liters	Price US$	Electricity kwh^{-1}	Price US$
Wheat	2085	2823	350	1.35	4739	740	41	206	12	6	23	4.6	116	2.3
Barely	1483	1583	332	1.07	3543	937	43	208	13	11	17	3.4	82	1.6
Fenugreek	2033	1009	345	0.50	1712	2015	15	74	4	18	23	4.6	113	2.3
Faba bean	1826	1371	345	0.75	2591	1331	26	130	7	13	20	4.0	101	2.0
Lentils	1238	861	345	0.70	2399	1438	35	171	10	21	14	2.8	69	1.4
Lupine	1135	795	345	0.70	2417	1428	38	186	11	23	13	2.6	63	1.3
Chickpeas	2245	897	345	0.40	1378	2502	11	55	3	20	25	5.0	125	2.5
Linen	1463	517	---	2.90	---	2830	---	---	4	35	16	3.2	81	1.6
Sugar beet	2399	21726	---	9.06	---	110		216	68	1	27	5.4	133	2.7
Raw Sugar		4000	350	0.60	5836	1667	44			13				
Clover	935	12844	----	13.74	----	73	---	---	264	1	10	2.0	52	1.0
Alfalfa	2889	30103	----	10.42	-----	96	---	---	65	1	32	6.4	161	3.2
Onion	1967	14613	40	7.43	2972	135	27	135	68	1	22	4.4	109	2.2
Garlic	1937	9240	27	4.77	1288	209	12	59	44	2	22	4.4	108	2.2
Tomatoes	1558	18061	27	11.59	3130	86	36	184	133	1	17	3.4	87	1.7
Zucchini	1558	8166	27	5.24	1415	191	16	83	60	2	17	3.4	87	1.7
Peas	1558	4247	27	2.73	736	367	8	43	31	4	17	3.4	87	1.7
Cabbage	1558	12732	27	8.17	2206	122	25	130	94	1	17	3.4	87	1.7
Potato	1558	8903	82	5.71	4686	175	54	276	66	2	17	3.4	87	1.7
Pepper	1658	5739	27	3.46	935	289	10	52	38	3	18	3.6	92	1.8

Source: [20, 21]

1 liter = 85-95 m^3/h; 1 kwh^{-1} = 18-20 m^3/h

Table 2: Water requirements, crop production, food energy, WP, VW, P-W-E, W-P-E and energy for lifting for summer crops structure (2015)

							P-W-E				Energy for lifting #			
Crops	Average water requirements m^3 acre	Average crop production kg acre	Food energy cal/100gm of production)	WP kg m^3	WP $_{\text{food energy}}$ cal/m^3 of water)	VW kg water/ kg production	cal m^{-3} kwh^{-1}	cal m^{-3} l^{-1}	P-W -E g m^{-3}kwh-1	W-P -E m^3 g^{-1} kwh^{-1}	Diesel Fuel liters	Price US$	Electricity kwh-1	Price US$
Rice	5300	3963	360	0.75	2692	1340	9	46	3	5	59	11.8	294	5.9
Maize	2989	3105	360	1.04	3740	962	23	113	6	6	33	6.6	166	3.3
Sorghum	3548	2015	343	0.45	1558	1760	8	40	3	9	39	7.9	197	3.9
Soybeans	3306	1371	847	0.41	3513	2411	19	95	2	13	37	7.3	184	3.7
Sesame	3137	548	574	0.17	1003	5742	6	29	1	33	35	7.0	174	3.5
Peanuts	2993	1415	546	0.47	2582	2115	16	78	3	13	33	6.7	166	3.3
Sunflowers	2444	1014	847	0.41	3514	2410	26	130	3	18	27	5.4	136	2.7
Sugar cane	10808	48481	------	4.49	----	233	---	---	7	0.4	120	24.0	600	12.0
Raw sugar		5500	295	0.51	1318	1965	8	39	3	3	34	6.7	168	3.4
Cotton (raw)	3914	663	-----	0.17	----	5903			0.7	27	43	8.6	217	4.3
Cotton (seeds)		454	884	0.12	1496	862	7	35	0.6	40	43	8.6	217	4.3
Tomatoes	3031	16918	27	5.58	1507	179	9	44	33	1	34	6.7	168	3.4
Potatoes	3031	12226	82	4.03	3308	247	20	97	24	1	34	6.7	168	3.4
Cucumber	3031	8066	27	2.66	719	385	9	44	16	2	34	6.7	168	3.4
Squash	3031	7343	27	2.42	654	413	4	21	14	2	34	6.7	168	3.4
Aubergine	3031	10179	27	3.36	907	300	4	19	20	2	34	6.7	168	3.4
Pepper	3031	6239	27	2.06	556	486	5	27	12	3	34	6.7	168	3.4
Water melon	4632	13048	27	2.82	761	355	2	11	11	1	51	10.3	257	5.1

Source: [20, 21]

1 liter = 85-95 m^3/h; 1 kwh^{-1} = 18-20 m^3/h

Table 3: Water requirements, crop production, food energy, WP, VW, P-W-E, W-P-E and energy for lifting for late summer crops structure (2015)

							P- W-E				Energy for lifting #			
Crops	Average water requirements m^3 acre	Average crop production kg acre	Food energy cal/100gm of production)	WP kg m^3	WP $_{\text{food energy}}$ cal/m^3 of water)	VW kg water/ kg production	cal m^{-3} kwh^{-1}	cal m^{-3} l^{-1}	P-W -E g $m^{-3}kwh^{-1}$	W-P -E m^3 g^{-1} kwh^{-1}	Diesel Fuel liters	Price US$	Electricity kwh^{-1}	Price US$
Maize	2557	2701	360	1.06	3803	947	27	136	7	7	28	6.0	142	2.8
Bean	2804	5164	27	1.84	497	543	3	16	12	4	31	6.2	155	3.1
Tomatoes	2804	16352	27	5.83	1575	171	10	51	38	1	31	6.2	155	3.1
Potatoes	2804	8903	82	3.18	2604	315	17	84	20	2	31	6.2	155	3.1
Cabbage	2804	8305	27	2.96	800	338	5	26	19	2	31	6.2	155	3.1
Medicinal plants	3956	6884	50	1.74	870	575	4	20	8	3	44	8.8	219	4.4

Source: [20, 21]

1 liter = 85-95 m^3/h; 1 kwh^{-1} = 18-20 m^3/h

Water and Food Nexus

Virtual Water (VW): In winter crops, it almost takes about 1667 kg of water to produce 1 kg of raw sugar resulted from sugar beet, 2502 kg of water is required to produce one kilogram of chickpea, 740 kg of water is needed to grow one kilogram of wheat, 2830 of water to produce one kg of linen and 209 kg of water to produce 1 kg of garlic and 937kg of water is required to produce one kg of barley and 1331 kg of water to produce 1 kg of faba bean and 1438 kg of water to produce 1 kg of lentils while 86 kg of water is needed to produce one kg of tomatoes, 135 kg of water is needed to produce one kg of onions, 175 kg of water is needed because production 1 kg of potatoes and 289 of water needed to produce 1 kg of pepper as shown in Table (1).

In summer crops, it takes approximately 1340 kg of water to produce one kilogram of rice, 960 kg of water to grow one kilogram of maize, 1760 to produce one kilogram of sorghum, while oil crops grown in summer are 2411 kg of water to produce 1 Kg of soybean, 5742 kg of water to produce one kg of sesame and 2115 kg of water to produce 1 kg of peanuts and 2410 kg of water to produce 1 kg of sunflower and 1965 of water to produce 1 kg raw sugar resulted from sugarcane as shown in Table (2).

In late summer that calls Nili crops, it takes about 947 kg of water to produce 1 kg of maize, 543 kg of water to grow one kilogram of beans, 171 to produce 1 kg of tomatoes, 315 to produce 1 kg of potatoes and 575 kg of water to produce 1 kg of medicinal plants as shown in Table (3). Food production is already facing water stress due to droughts and shortage of water resources, which poses significant risks for the Egyptian food security [15, 16].

Water-Energy- Food Nexus: As for the required energy, amount of the required energy for lifting water on farm level was associated with water requirements for each crop. It was higher for summer crops compared with winter crops because of frequent irrigation due to high temperature, solar radiation and (Tables 1 and 2). The required energy expressed kw h^{-1} was higher for rice, sugarcane, fruits and some medicinal plants as shown in Tables 2 and 3. Higher values of PWE $_{\text{(food energy/water//energy)}}$ indicator produced from potatoes; raw sugar resulted from sugar beet, barley and wheat and to be 54, 44, 43 and 41 cal $m^{-3}kwh^{-1}$, respectively. While higher values of PWE $_{\text{yield/water/energy}}$ indicator was associated with vegetables crops and feed crops. There are differences of quantity of crop takes the descending order clover> tomatoes> cabbage> onion > potatoes> zucchini to be 264, 133, 94, 68, 66 and 60 g m^{-3} kwh^{-1} (Table 1), however, PWE $_{\text{water / yield /energy}}$ values was arranged in the descending order seed of cotton < linen< raw cotton<lupine<chickpeas to be 40, 35, 27, 23 and 20 m^3 g-1 kwh-1 respectively as shown in Tables 1 and 2. For the time being, reliance on diesel fuel comes at a cost – related not only to climate change but also to fluctuations in diesel fuel prices, which can cause dramatic changes in food prices and it will be affected most by the cost of energy inputs into water production [17].

Importance of the various PWE performance indicators lies in its direct economic and social in agriculture, water and energy sectors, at farm and national levels, because PWE performance indicators guide the decision-maker and farmers to direct energy and water to which kind of food should be produced? Is the purpose of production to produce food that gives high calories for reducing the poverty purpose (PWE $_{\text{food energy/water//energy}}$) or to increase the productivity through cultivate crops having high productivity, short duration and less water per unit of energy for food sufficient (PWE$_{\text{yield/water/energy}}$) or to mitigate water scarcity implications via provide the required water to produce one unit of the productivity per unit of energy used in at farm level (PWE $_{\text{water / yield /energy}}$) or together according to the priority level?

Data in Tables 1, 2 and 3 revealed that the working cost of the electrical pump that used for irrigation water lifting in the agriculture production, on farm level, were about one-half of diesel pump. So, farmers can save about fifty percent of working cost using the electrical pump which reflect on their incomes. The Egyptian government encourages farmers to use electrical pump because it provides less operating cost and it environmentally friendly due to no carbon dioxide releases into the air.

Realizing the fact that about 25% of Egypt's cultivated land is used to grow water-intensive crops such as rice and sugar which use about 20% of Egypt's annual share of water amounting 55.5 km^3 [18] and being mindful of the fact that the irrigation efficiency ranges from 40% to 60% implies that there are substantial potential savings in applying the WEF nexus. Irrigation of almost 1.4 million acres of rice is located in the north delta governorates, while, irrigated cane is located in middle and Upper Egypt governorates which is critical to social stability and food security in Egypt [17]. The irrigation system in the based farming whether rice or cane use diesel and electrical pumps, to distribute water to the fields.

Maximize the Efficiency of WEF Nexus Application: Enhance the efficiency of the WEF nexus has been occurred using good agriculture practices (GAP) such as precision land-leveling which increased the grain yield of wheat by 10%, the net return by US $42 per acre and saved energy and water by 13%. Application precision land-leveling and dry planting of berseem (clover) increased the fresh yield by 13% and net return by US $32 per acre, saved energy and water by 13%. Precision land-leveling and relative long furrows increased the root yield of sugar beet by 12%, increased the net return by US $32 per acres, saved energy and water by 14%. Moreover, precision land-leveling and relative long furrows increased the grain yield of faba bean by 13%, increased the net return by US $50 per acre and saved energy and water by 17%. Precision land-leveling also increased the yield of summer crops (cotton, rice and maize) by 15% and saved water and energy by 18% as an average for different crops [19]. Tables 1, 2 and 3 showed that the electricity power increase efficiency of the WEF nexus, on farm level, because it saves about of the money and keeps the environment clean because of carbon dioxide emission reduction. Intercropping system also enhances WEF nexus efficiency on micro level because it increases the productivity per cubic meter of water per energy unit [18]. Small farmers are beneficiaries of reduced production costs due to water rationalization and lower energy costs.

The food-water security strategy is based on an increase in wheat in winter season and maize production in summer season, stabilizing rice cultivation at 0.85 million acres, introducing new irrigation technologies, applying good agriculture practices and rehabilitation of irrigation systems in reclaimed land [18]. Water and agriculture sectors are likely to benefit from the adoption of the nexus approach through linkages with energy sector. The government plans to diversify its renewable energy sources by increasing supply through solar energy because renewable energy applications are piloted in Egypt for water pumping for agricultural use in new lands.

Macro Level:

Water and Food Nexus

Virtual Water (VW): By importing agricultural commodities, Egypt "saves" the amount of water that would have required for producing those commodities locally. Egypt, is a highly water stressed country, imported 15.8 million metric tons of major grains as a total sum of 9.01 million metric tons of wheat and 6.8 million metric tons of maize in 2015 as shown in Table 4. To produce this amount of grain, Egypt would has needed about 13.21 km^3 of irrigation water which equals about one fourth of Egypt's annual supply from Lake Nasser amounting 55.5 km^3.

Most imported wheat is used to produce bread and flour that are distributed in food subsidy programme, while the imported maize is used to feed livestock. Import of agricultural products saves national water resources, while export of agricultural products loses water resources at national level. So, the importing country such as Egypt is more interested to see what volume and kind of water is being saved from its own resources by the import [14].

Egypt imported 17.243 million metric tons of cereals, sugar cane, sweeteners, legumes and oil crops [21] that required 16.305 km^3 which represent about one-third of Egypt's annual supply from Lake Nasser amounting 55.5 km^3 to produces those commodities. At the same time, Egypt exported 0.098 million metric tons that required 1.604 km^3. So, net virtual water import becomes 14.601 km^3 as a result of 16.305 km^3 coming from import minus 1.604 km^3 resulted from export. It means that Egypt saved about 14.601 km^3 of water that would be required to produce those commodities (Table 4).

Egypt produced 274 thousand metric tons and imported 633 thousand metric tons of major vegetable oils in 2015 as shown in Table 5. Production of vegetable oils in Egypt would require about 0.633 km^3 of irrigation water. Egypt exported 103 thousand metric tons of major vegetable oils which needs 0.103 km^3 of water for production. Therefore, net virtual water import becomes 0.530 km^3 as a result of 0.633 km^3 coming from the imports minus 0.103 km^3 resulted from the exports. It means that Egypt saved about 0.530 km^3 of water that would be needed to produce major oil crops (Table 5).

As for vegetables, Egypt exported 1421 thousand metric tons of major vegetable and imported 53 thousand metric tons of major vegetable. Net virtual water export was 1.368 km^3 (1.421 km^3 resulted from import minus 0.053 km^3 of water resulted from export). It means that Egypt exported about 1.368 km^3 of national water that would be used to produce major vegetable as presented in Table 6.

Table 7 showed that 1966 thousand metric tons of fruits was exported while the imported fruit was 793 thousand metric tons. Net virtual water export was 1.173 km^3 resulted from the export amounting 1.966 km^3 of virtual water minus the import amounting 0.793 km^3 of water. It means that Egypt exported 1.173 km^3 of virtual water.

Table 4: Virtual water and its relation to food imports and exports, Egypt – 2015

Food Products	Production Thousand metric tons	Imports Thousand metric tons	Total virtual water import km^3	Exports Thousand metric tons	Total virtual water export km^3
Wheat	9608	9001	6.660	261	0.193
Barely	102	29	0.027	11	0.010
Maize (white and yellow)	8060	6820	6.547	3	0.003
Raw rice	5467	46	0.061	252	0.338
Potatoes	4955	189	0.047	709	0.177
Total			13.342		0.721
Sugar crops					
Sugar cane	16055	3	0.066	*	
Sugar beet	11983	*		1	0.011
Sweeteners					
cane sugar	1025	761	1.491	302	0.592
beet sugar	1347	160	0.096	*	
Glucose	117	16	0.007	16	0.007
Total			1.660		0.610
Legumes					
Faba bean	120	293	0.381	14	0.018
Lentils	1	76	0.106	12	0.017
Other legumes	150	76	0.106	108	0.140
Total			0.593		0.175
Oil crops					
Soya bean	40	630	0.630	1	0.001
Peanut	183	8	0.008	33	0.033
Sunflowers	22	59	0.059	2	0.002
Cotton seeds	164	*		*	
Sesame	39	12	0.012	7	0.007
Olive	699	1	0.001	55	0.055
Total		17243	0.71		0.098
Gross total			16.305		1.604
Net virtual water import			16.305- 1.604 = 14.601 km^3 (Import)		

*refers to a negligible amount of water

Table 5: Virtual water and its relation to food imports and exports, Egypt – 2015

Food Products	Production Thousand metric tons	Imports Thousand metric tons	Total virtual water import km^3	Exports Thousand metric tons	Total virtual water export in km^3
Vegetable oils					
Oil of soya bean	105	229	0.229	33	0.033
Oil of cotton seeds	28	*	*	*	*
Oil of sunflowers	16	64	0.064	21	0.021
Oil of maize	9	35	0.035	4	0.004
Palm oil	*	288	0.288	7	0.007
Other oils	6	8	0.008	3	0.003
Oils frozen	274	9	0.009	35	0.035
Total		633	0.633	103	0.103
Grand total			0.633		0.103
Net virtual water import			= 0.633- 0.103 = 0.530 km^3 (Import)		

*refers to a negligible amount of water

Table 6: Virtual water and its relation to food imports and exports, Egypt – 2015

	Production	Imports	Total virtual water import	Exports	Total virtual water export
Food Products	Thousand metric tons	Thousand metric tons	km^3	Thousand metric tons	km^3
Onions and garlic					
Onions	3050	3	0.003	711	0.711
Garlic	291	11	0.011	7	0.007
Vegetables					
Tomatoes	7760	20	0.020	248	0.248
Cucumber	634	1	0.001	4	0.004
Green beans	265	*	*	41	0.041
Green pea	172	8	0.008	7	0.007
Artichoke	221	*	*	56	0.053
Green pepper	709	*	*	8	0.008
Other vegetables	3229	10	0.010	339	0.339
Total		53	0.053	1421	1.421
Grand total			1.421		0.053
Net virtual water (export)			= 1.421 – 0.053 = 1.368 km^3 (export)		

*refers to a negligible amount of water

Table 7: Virtual water and its relation to food imports and exports, Egypt – 2015

Food Products	Production	Imports	Total virtual water import	Exports	Total virtual water export
	Thousand metric tons	Thousand metric tons	km^3	Thousand metric tons	km^3
Fruits					
Orange	3351	2	0.002	1245	1.245
Mandarin	940	*	*	40	0.040
Lemon salty	351	*	*	30	0.030
Other citrus	5	34	0.034	25	0.025
Apple	696	429	0.429	1	0.001
Grape	1687	24	0.024	167	0.167
Banana	1314	34	0.034	7	0.007
Mango	881	1	0.001	27	0.027
Apricot	95	23	0.023	4	0.004
Other fruits	1558	224	0.224	364	0.364
Fresh dates	1275	*	*	*	*
Dry dates	410	20	0.020	26	0.026
Watermelon	1510	*	*	26	0.026
Melon	1029	2	0.002	4	0.004
Total	793	0.793	1966	1.966	
Gross total		0.793		1.966	
Net virtual water (export)		= 1.966 – 0.793 = 1.173 km^3 (export)			

*refers to a negligible amount of water

Table 8 showed that the import of red meat, white meat and dairy products in Egypt is contributing to national water saving of 15.301 km^3 which is about 27.6% percent of the total volume of water Egypt is entitled to according to the 1959 agreement. Egypt imported 2399 thousand metric tons of red meat, white meat and dairy products that required 17.715 km^3 which represent about 31.9% of Egypt's annual supply from Lake Nasser amounting 55.5 km^3 to produce those commodities (Table 8). At the same time, Egypt exported 470 thousand metric tons that required 2.414 km^3 of virtual water. So, net virtual water import becomes 15.301 km^3 of water resulted from total virtual water import minus total virtual water export. It means that Egypt saved about 15.301 km^3 of water that would be required to produce those commodities (Table 8). In general, livestock products have higher virtual water content than crop products because a live animal consumes a lot of feed crops, drinking water and service water in its lifetime before it produces some output. The annual volume of national virtual water flows during the period 2015 in relation to livestock products was 15.301 km^3.

Table 8: Virtual water and its relation to food imports and exports, Egypt – 2015

Food Products	Production Thousand metric tons	Imports Thousand metric tons	Total virtual water import km^3	Exports Thousand metric tons	Total virtual water export km^3
Red meat					
Big cows	225	2	0.026	*	*
Cow calves	98	599	7.787	*	*
Buffalo	330	*	*	*	*
Sheep	61	4	0.052	*	*
goats	39	*	*	*	*
Camels	10	9	0.177	*	*
Pigs	*	1		*	*
Total		615	7.995	*	*
White meat					
Chickens	1028	99	1. 287	8	0.104
Rabbits	65	*	*	*	*
Duck	83	*	*	*	*
Geese	26	*	*	*	*
Pigeon and turkey	91	1	0.013	*	*
Total		100	1.300	8	0.104
Dairy products					
Cow milk	2729	1684	8.420	462	2.310
Milk buffalo	2394	*		*	*
Goat milk	122	*		*	*
Total		1684	8.420	462	2.310
Gross total		2399	17.715	470	2.414
Net virtual water (import)			(7.995+ 1.300 + 8.420)- (0.104 +2.310)= 15.301 km^3 (import)		

*refers to a negligible amount of water

Table 9: Balance of virtual water between imports and exports in km^3

Balance of virtual water	Imports	Exports
Item	km^3	
Cereals	14.701	
Vegetables oil	0.530	
Vegetables		1.368
Fruits		1.187
Meats	15.301	
Total	30.532	2.555
Net virtual water import	= 30.532- 2.555= 27.977 km^3	

Table 10: Water footprints, WS, WSS and WD

	Egypt 1995	Egypt 2015
Population in million	62.783	95.000
Actual renewal water in km^3		
(River Nile and ground water)	55.5	55.5 + 4.3*= 59.8
Available water used in all sectors in km^3	68.5	76.400
Available water used in agricultural sector in km^3	49.7	62.350
Total virtual export in km^3	0.902	2.555
Total virtual import in km^3	16.973	29.243
Net virtual water imported in km^3	16.035	26.688
Water footprint (Mm^3/yr per capita)	1.131	1.64
Per capita water of the Nile (m^3 per year)	883	584
Water scarcity (WS in %)	81.0	75.9
Water self-sufficiency (WSS) in %	77.6	67.1
Water dependency (WD) in %	22.4	30.9
Gross value of production in millions US$	9.0	35.304
Productivity per unit of water used in agric. ($/m^3)	0.18	0.56

*Source: [24]

Table 9 showed that total net virtual water was 27.977 km^3 resulted from net virtual water import from cereals, vegetables oils, vegetables, fruits and meats which was 30.532km^3 of water and net virtual water exported from vegetables oils and vegetables which was 2.555 km^3 of water. It means that Egypt saved about 27.977km^3 of water which presents 50% of national water that would be required to produce those commodities (Table 9).

As for the food price crisis in Egypt, the key strategy is use land on long-term in the African countries for export-oriented farming. However, this strategy carries with it many risks and requires careful and continued management and making sure that benefits are shared for both sides. Common benefits could include providing funds and investing in improved agricultural productivity in these countries, aligning Egypt foreign aid spending more closely with food security aims to help the African countries to produce food surplus to be exported. Other proposed strategies are important for reducing exposure to market price volatility can be created through risk management for regional strategic food reserves and regional procurement approaches [17].

Table 10 showed that the total water use for the agricultural sector in Egypt increased dramatically from about 49.7 km^3 in the mid 1990s to about 62.350 in 2015. The majority of water resources in Egypt are being used for agriculture by 85%. It could be due to the fact that water demand in Egypt has increased dramatically as a result of increasing population, urbanization growth and improvements in the standard of living that required a comprehensive development programs to increase food self-sufficiency [22, 23].

Water footprints, WS, WSS and WD: Egypt recorded the highest water scarcity percentage to be 81% and 75.9% in years of 1995 and 2015, respectively which was reflected in the percentage values of water dependency which became low to be 22.4% and 30.9% in year of 1995 and 2015, respectively. Water dependency percent increased from year of 1995 to 2015 because there is a safe withdrawal of groundwater estimated at about 4.3 km^3.

At the same time, water self-sufficiency values dropped from 77.6% in year of 1995 to 67.1% in year of 2015 as a result of high water scarcity values and low water dependency values. These results could be attributed to increased demand for water as a result of population growth, total and net virtual import for water that has been remarkable increased started from 1995 to 2015 etc. shown in Table 10.

Egypt in 1995

$$WS = \frac{55.5}{68.5} x100 = 81.0\%$$

$$WD = \frac{16.035}{55.5 + 16.035} x\ 100 = 22.4\%$$

$$WSS = \frac{55.5}{55.5 + 16.035} x100 = 77.6\%$$

Egypt in 2015

$$WS = \frac{58.0}{76.400} x\ 100 = 75.9\%$$

$$WD = \frac{26.688}{59.8 + 26.688} x\ 100 = 30.9\%$$

$$WSS = \frac{58.0}{59.8 + 26.688} x\ 100 = 67.1\%$$

The amount of virtual water imported by Egypt through the import of agricultural crops to fill the food gap was about 27.977 km^3 per year. The gap between resources and water needs was about 16.6 km^3 resulted from available water used in all sectors amounting 76.400 km^3 which is managed through the reuse of agricultural drainage and treated wastewater minus actual renewal water amounting 59.8 km^3. So, gross water needs in Egypt amounts about 104.4 km^3 resulted from net virtual water imported (27.977 km^3) plus the gap between water resources and water needs (16.6 km^3) plus actual renewal water (59.8 km^3) to fill the food gap and water self sufficiency for different sectors (agriculture, industry - drinking and domestic uses). The agriculture sector only needs 90.3km^3 of irrigation water (Table 11) to achieve food security, which requires an estimated energy of 4.95 million megawatts and 98.9 million US dollars to fill the food gap between the import and export.

A water self-sufficiency value depends on changes associated with higher water dependency and less water scarcity. On basis of water scarcity and water dependency variables, it is possible to classify the situation to four categories as follows:

- High water scarcity (more than 50%) and high water dependency (more than 50%),
- High water scarcity and low water dependency (less than 50%),

Table 11: The required energy and it is prices for available water and total export, import and net virtual water

		Energy for lifting on farm level #			
Egypt 2015	Amount of water in km^3	Amount of diesel in thousand tons	Price in US$	Electricity in meg- watts	Price in US$
1 Available water used in agricultural sector in km^3	62.350	692.8	138.560.000	3.463.889	69.278.778
2 Total virtual export in km^3	2.555	28.4	5.681.648	141.944	2.839.930
3 Total virtual import in km^3	29.243	324.9	65.028.740	1.624.611	32.492.691
4 Net virtual water imported in km^3	27.977	310.8	62.213.489	1.554.278	31.085.004
Total (1+4)	90.3	1003.6	200.773.489	5.018.167	100.363.782

1 liter of diesel = 85-95 m^3/h

1kwh = 18-20 m^3/h

- Low water scarcity (less than 50%) and high water dependency (more than 50%)
- Low water scarcity (less than 50%) and low water dependency (less than 50%).

According to the above classification, Egypt is subjected to high water scarcity with low water dependency. In other words, countries have a water scarcity of less than 50% and water dependency more than 50% are fairly safe.

Water footprint was increased from 1.131 to 1.64 million m^{3}yr per capita in1995 and 2015 which reflected on per capita water of Nile which substantial decrease from 883 to 584 m^3 per year. Gross value of production was 0.18 UDS per m^3 in 1995 and increased to be 0.56 USD per cubic meter consumed in agriculture sector.

WEF Nexus: An annual amount of water amounting 62.350 km^3 is lifted for irrigation purposes on a national scale. This huge volume of water is currently lifted by small diesel pump sets owned by the farmers, consuming an estimated amount of about 692.8 thousand tons of diesel fuel with a total value of up to US$138.560.000, while the electricity pump consumed about 3.463.889 mega-watt with a total value of US$ 69.278.778 (Table 11). This makes food security particularly sensitive to the quality and price of energy which can cause dramatic changes in food prices. The future availability of renewable energy production in Egypt, combined with the expected reduction in diesel consumption and the escalating prices of energy, makes the use of electric power or renewable solar energy is significant to operate the irrigation pumps as the ideal choice for the current sustainability of the irrigation system [25, 26].

Egypt exported 28.4 thousand tons of diesels fuel when exported 2.555km^3 of virtual water resulted from vegetable and fruits export (Tables 9 and 11), while Egypt "saved" the amount of 324.9 thousand tons of diesels fuel or 1.624.611 megawatt when imported cereals and meat. In general, net virtual water saved 27.977km^3 of water and saved 310.8 thousand tons of diesels fuel or 1.554.278 megawatt (Table 11).

The electrical pumps option provides about 50% savings under economic prices. This can be translated into annual savings, at national level, to be US$ 69.284 million as a difference between the price using a diesel - fuel as source of energy for lifting irrigation water (US$ 138.560 million) and price the electric power (US$ 69.278 million) that used for the same purpose.

Energy consumption in Egypt continues to be dominated by diesel -fuels. However, this pattern needs to change to meet commitments of the seventh UN Sustainable Development Goals (SDG 7), which call access to reliable, affordable, sustainable and modern energy for all. So, introducing renewable energy and improving energy efficiency, modern and precision agriculture, water recycling and wastewater reuse are just few examples of such driving force between the nexus three components and technology. However, technological and innovative solutions within the FWE nexus, where two of, or the three components of the nexus are integrated as inputs to each other not only enhance resource efficiency, but also expand the available natural resource base and thus have even more contribution to the sustainability and security of the three resources [27, 28].

The key risk posed by the energy sector on food security is that the dependence on diesel fuels or the electricity increases volatility of food prices and affects access to food. So, Egypt started to take an action for a transition to clean energy using solar energy in light of the Paris COP21 commitments and to mitigate and adapt to climate change. This reliance on diesel fuels comes at a cost – related not only to climate change but also to fluctuations in diesel fuels prices, which can cause dramatic changes in food prices [17].

This approach is to support decision-makers in Egypt by supporting strategic priorities to address key challenges for water, energy and food security and identifying key trade-offs between productivity water and energy. Besides, it presents understand and manage the complex nexus between food, water and energy which are needed to ensure the development of concerted efforts to support food security and sustainable agriculture and to make sure that decisions on water release and allocation are taken as part of an integrated, long-term and multi-sectoral strategy.

As for technology and innovation, the introduction of new and appropriate technologies can improve resource efficiency in the water, energy, food sectors and contribute to their security and sustainability. Food, water and energy nexus can be increased using renewable energy such as solar energy for ground water pumping in agriculture. At the same time, increasing water efficiency in agriculture is a successful key to food security in Egypt. The food and water security strategy is based on an increase in wheat production, stabilizing rice cultivation at 0.85 million acres, introducing new irrigation technologies, applying good agriculture practices and developing irrigation systems in reclaimed land. Agriculture and water sectors are likely to benefit from the adoption of the nexus approach through linkages with energy sector. So, adopt the WFE nexus approach is imperative in Egypt.

The government started to diversify its renewable energy sources by increasing supply solar energy. Application of renewable energy is piloted in Egypt for water pumping for agricultural use in reclaimed land. For example, a 50kW off grid solar water pumping facility was implemented on Al-Tayebat farm in the Bahariya Oasis. The farm powers 30 kW submersible pumps that have an average flow rate of 120 m^3/h. The well which is supported by solar energy serves a pivot irrigation area of around 120 acres. Prominence of the project lies in its direct economic and social effect on stakeholders within agricultural sector [29].

So, the future of renewable energy generation i.e. the solar energy for groundwater pumping in agriculture proven much economically feasible in the coming years compared to diesel fuel and the electrification of irrigation pumping stations. Therefore, solar energy as a renewable energy for food security in Egypt can bring significant benefits, in terms of reduction of capital and operational costs and ease pump management in addition it is environmentally friendly energy.

CONCLUSION

- In a water-scarce region such as Egypt, policy makers should focus on the integration of the policy cycle concerning the WEF nexus through a set of measures which comprise bridge the knowledge gap of the WEF nexus at the national and regional levels through better understanding and quantifying the inter-linkages between water, energy and food;
- Boost joint management of shared river basins or aquifers and identify a sustainable formula for sharing trans-boundary waters, fairly guided by customary legal principles of ‘equitable and responsible use’ and the ‘obligation not to cause harm’;
- Under water scarcity and drought conditions, it is attractive to adopt a policy of importing products with relatively high virtual water content and exporting products having lower virtual water content. The virtual water volume depended on food imports and exports remain a valid concern for the countries suffering from water scarcity seeking to maximize the value of their limited water supplies because volume of the virtual water flow between two nations depends upon the virtual water content of the physical volume of trade and the product traded;
- Adopt economic criteria for enabling water efficiency and prioritizing the allocation of the available supply of water resources among competing sectors.

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