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Evaluation of Technology Change Effects on Quantitative Assessment of Water, Energy and Food Nexus

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Abstract

The quantitative assessment framework of the water, energy and food (WEF) nexus proposed by [1] permits the analysis of the WEF as an interconnected system of resources that directly and indirectly affect one another. The model performs simulation of policy options and scenarios that respond to quantitative variations of the use of WEF resources. One of the key outcomes of the mathematical formulation of the model is the WEF nexus intersectoral technology matrix. In order to take advantages and analyzing policy options of adopting high efficient intersectoral use technologies, WEF intersectoral use intensities and intersectoral allocation coefficients are introduced to the technology matrix of the nexus model proposed in [1]. The developed method is then applied to evaluate the WEF nexus case study of Lebanon. Lastly, the conclusions and further developments are presented.

Keywords

Water Energy Food Nexus, Technology Changes, Sustainable Development

1. Introduction

The important interactions between water energy and food are imposing new challenges to research and scientific modelling, especially that these resources are driven by many same key drivers, such as population growth, urbanization, mobility, economic development, climate change, technology modifications, governance, market, regulations and international trade [1]-[6]. Quantitative nexus approaches will certainly provide effective support for the communication between science and sustainable water energy food policies [1] [2] [7] [8]. The development of nexus tools for analyzing impacts of the above mentioned drivers on WEF resources is one of today's key challenges [9]-[16]. A practical and mathematically-based quantitative assessment framework of the WEF nexus is newly proposed by [1] (Q-Nexus Model). The methodological approach presented in [1] performs simulation of policy options and scenarios that respond to quantitative variations of the WEF resources. However, the simulation of policy options by considering the use of high efficient technologies necessitates methodological addition to the Q-Nexus Model.

This paper presents methodological supplement to the model presented in [1] to analyze policy options and scenarios of adopting efficient intersectoral use technologies. This will allow analysing scenarios of changing the technology matrix (A) by considering "Best Practice" and "High Efficient" technological alternatives.

2. Summary of the WEF Nexus Model Introduced in [1]

A quantitative assessment framework of the WEF nexus is proposed in [1]. This model is built on flexible structure to take into account variations related to local, national and regional particularities as well as being able to perform quantification, scenarios analysis and optimization, all in one integrated approach. The structure of the Q-Nexus Model is built on input-output theory and it is based on the quantitative balance of the WEF total quantities through two main conceptual elements: 1) the intersectoral use quantities (Z) and 2) the end use (or final demand) quantities (y). The sum of these two components gives the total resources quantities (x), therefore, the balance quantitative equation will be as follows:

$$Z + y = x \tag{1}$$

The end use quantities (y) are those used in the socio-economic system which cover households demands, government demands, rest of the economy demands, losses, accumulation (storage) and exports.

A set of inflows were identified to represent the WEF sectors, for example, surface water, groundwater, desalination, wastewater and drainage water reuse inflows covering the water sector, imported petroleum and all types of electricity including renewable energy, covering the energy sector, and irrigated cereals, irrigated roots and other food production items covering the area of food.

It is important to mention that these inflows are particularly identified for the Lebanese case study presented in [1], the organisation of these elements could change to take into account diversification related to local, national and regional particularities.

A set of equations are developed in [1] to mathematically shape the Q-Nexus Model. In addition to the three variable elements (Z), (y) and (x), one of the key outcomes of the mathematical formulation of the model is the expanded intersectoral intensity coefficients matrix (may be referred also as "the intersectoral technology matrix"). This matrix is one of the main variables of the model because it represents the identity of the nexus system and it is constructed as follows:

If we denote by:

n: number of water resources inflows (*i.e.* surface water, groundwater, desalination…);

m: number of energy resources inflows (*i.e.* petroleum, natural gas, electricity, renewable energy…);

h: number of food resources inflows (*i.e.* irrigated crop, animal production, fisheries…);

z_{ij}^{w-e} : the use of i^{th} water resource inflow in the j^{th} energy resource inflow;

z_{ij}^{w-f} : the use of i^{th} water resource inflow in the j^{th} food resource inflow;

z_{ij}^{e-w} : the use of i^{th} energy resource inflow in the j^{th} water resource inflow;

z_{ij}^{e-e} : the use of i^{th} energy resource inflow in the j^{th} energy resource inflow;

z_{ij}^{e-f} : the use of i^{th} energy resource inflow in the j^{th} food resource inflow;

z_{ij}^{f-e} : the use of i^{th} food resource inflow in the j^{th} energy resource inflow;

z_{ij}^{f-f} : the use of i^{th} food resource inflow in the j^{th} food resource inflow.

The expanded intersectoral intensity coefficients of the water energy food nexus system are defined as follows:

$$a_{ij}^{w-e} = \frac{z_{ij}^{w-e}}{x_j^e},\ a_{ij}^{w-f} = \frac{z_{ij}^{w-f}}{x_j^f},\ a_{ij}^{e-w} = \frac{z_{ij}^{e-w}}{x_j^w},\ a_{ij}^{e-e} = \frac{z_{ij}^{e-e}}{x_j^e}$$
$$a_{ij}^{e-f} = \frac{z_{ij}^{e-f}}{x_j^f},\ a_{ij}^{f-e} = \frac{z_{ij}^{f-e}}{x_j^e},\ a_{ij}^{f-f} = \frac{z_{ij}^{f-f}}{x_j^f} \qquad (2)\text{-}(8)$$

where x_j^w, x_j^e, x_j^f are the total use of the j^{th} water resource inflow, total use of the j^{th} energy resource inflow and total use of the j^{th} food resource inflow, respectively.

In block matrix form:

$$A = \begin{bmatrix} 0 & A^{w-e} & A^{w-f} \\ A^{e-w} & A^{e-e} & A^{e-f} \\ 0 & A^{f-e} & A^{f-f} \end{bmatrix} \qquad (9)$$

where A is the WEF nexus technology matrix.

The water for water and food for water relationships are considered quantitatively negligible, so they are set equal to zero.

In terms of nexus quantification, when the intersectoral and end use values are constructed, then we can start evaluating scenarios, for example, what if we produce more food, what if there will be droughts, what if we reduce losses and wastes, and so forth.

The total outputs (x) caused by end use quantities (y) are related by the following equations [1]:

$$x = Ly \qquad (10)$$

and

$$L = (I - A)^{-1} \qquad (11)$$

where I is the identity matrix.

The whole core of the WEF nexus is contained in the matrix L. It is easy to examine the changes in all elements in the intersectoral WEF use quantities (Z) caused by (y) [1].

The first type of simulation that could be performed using the Q-Nexus Model consists of assuming variations of the end use values represented in the model by the (y) vector. These scenarios are analyzed for any planned policy related to increasing of resources demand or reducing losses. A second type of simulation could be also performed using the model by analyzing scenarios of changing the technology matrix (A) by considering "High Efficient" and "Best Practice" technology matrix alternatives. However, this necessitates a methodological addition to the model presented in [1] to analyze policy options of adopting high efficient intersectoral use technologies. This issue will be addressed in Section 3.

3. Upgrading of the Model Presented in [1] to Analyze Technological Change Scenarios

The WEF "High Efficient" or "Best Practice" intersectoral use technologies can be defined as those for which the ratios of the intersectoral quantities used to produce one unit of resource are relatively low.

If we denote by:

$z_j^{w-e} = \sum_{i=1}^{n} z_{ij}^{w-e}$ the water use in the j^{th} energy inflow;

$z_j^{w-f} = \sum_{i=1}^{n} z_{ij}^{w-f}$ the water use in the j^{th} food inflow;

$z_j^{e-w} = \sum_{i=1}^{m} z_{ij}^{e-w}$ the energy use in the j^{th} water inflow;

$z_j^{e-e} = \sum_{i=1}^{m} z_{ij}^{e-e}$ the energy use in the j^{th} energy inflow;

$z_j^{e-f} = \sum_{i=1}^{m} z_{ij}^{e-f}$ the energy use in the j^{th} food inflow;

$z_j^{f-e} = \sum_{i=1}^{h} z_{ij}^{f-e}$ the food use in the j^{th} energy inflow;

$z_j^{f-f} = \sum_{i=1}^{h} z_{ij}^{f-f}$ the food use in the j^{th} food inflow.

The WEF intersectoral use intensities (t) and intersectoral allocation coefficients (c) are proposed to be integrated within the "technology matrix", these two policy aspects are defined as follows:

1) WEF intersectoral use intensities (t):

WEF intersectoral use intensities (t) (may be referred also as footprints) were selected because they are able to refer to the efficiency of the intersectoral use technologies. The lower the value of resources use intensities (or footprints), the better the resources usage in the production of other resources inflows.

The WEF intersectoral use intensities (t) are calculated as follows:

Intensity of water use in the j^{th} energy inflow:

$$t_j^{w-e} = \frac{z_j^{w-e}}{x_j^{e}} \tag{12}$$

Intensity of water use in the j^{th} food inflow:

$$t_j^{w-f} = \frac{z_j^{w-f}}{x_j^{f}} \tag{13}$$

Intensity of energy use in the j^{th} water inflow:

$$t_j^{e-w} = \frac{z_j^{e-w}}{x_j^{w}} \tag{14}$$

Intensity of energy use in the j^{th} energy inflow:

$$t_j^{e\_e} = \frac{z_j^{e\_e}}{x_j^e} \tag{15}$$

Intensity of energy use in the j^{th} food inflow:

$$t_j^{e\_f} = \frac{z_j^{e\_f}}{x_j^f} \tag{16}$$

Intensity of food use in the j^{th} energy inflow:

$$t_j^{f\_e} = \frac{z_j^{f\_e}}{x_j^e} \tag{17}$$

Intensity of food use in the j^{th} food inflow:

$$t_j^{f\_f} = \frac{z_j^{f\_f}}{x_j^f} \tag{18}$$

The WEF intersectoral use intensities t represent the effectiveness of the nexus system and they could be used to compare the performance of different WEF nexus systems. Moreover, the intensities t will serve to identify sustainable policy options by evaluating and analyzing the effects of technology changes on quantitative assessment of WEF nexus. For instance, the effect of the replacement of gravity irrigation with pressurized irrigation system, which achieve water savings and require more energy, could be analyzed by changing the corresponding water and energy use intensities.

The construction of the technology matrix based on the best practice WEF intersectoral use intensities will be addressed in the subsequent paragraphs.

2) WEF intersectoral allocation coefficients (c):

The WEF intersectoral allocation coefficients are defined as follows:

$$c_{ij}^{w\_e} = \frac{z_{ij}^{w\_e}}{z_j^{w\_e}},\ c_{ij}^{w\_f} = \frac{z_{ij}^{w\_f}}{z_j^{w\_f}},\ c_{ij}^{e\_w} = \frac{z_{ij}^{e\_w}}{z_j^{e\_w}},\ c_{ij}^{e\_e} = \frac{z_{ij}^{e\_e}}{z_j^{e\_e}}$$
$$c_{ij}^{e\_f} = \frac{z_{ij}^{e\_f}}{z_j^{e\_f}},\ c_{ij}^{f\_e} = \frac{z_{ij}^{f\_e}}{z_j^{f\_e}},\ c_{ij}^{f\_f} = \frac{z_{ij}^{f\_f}}{z_j^{f\_f}} \tag{19-25}$$

In block matrix form:

$$C = \begin{bmatrix} 0 & C^{w\_e} & C^{w\_f} \\ C^{e\_w} & C^{e\_e} & C^{e\_f} \\ 0 & C^{f\_e} & C^{f\_f} \end{bmatrix} \tag{26}$$

where C is the WEF intersectoral allocation matrix. WEF nexus intersectoral allocation policies vary from one system to another. Each country is characterized by specific WEF nexus system in accordance to its natural, social, economic and governance conditions.

The two coefficients t and c are introduced to Equations (2)-(8) as follows:

$$a_{ij}^{w\_e} = c_{ij}^{w\_e} * t_j^{w\_e} \tag{27}$$

$$a_{ij}^{w\_f} = c_{ij}^{w\_f} * t_j^{w\_f} \tag{28}$$

$$a_{ij}^{e\_w} = c_{ij}^{e\_w} * t_j^{e\_w} \tag{29}$$

$$a_{ij}^{e-e} = c_{ij}^{e-e} * t_j^{e-e} \quad (30)$$

$$a_{ij}^{e-f} = c_{ij}^{e-f} * t_j^{e-f} \quad (31)$$

$$a_{ij}^{f-e} = c_{ij}^{f-e} * t_j^{f-e} \quad (32)$$

$$a_{ij}^{f-f} = c_{ij}^{f-f} * t_j^{f-f} \quad (33)$$

In block matrix form:

$$A = \begin{bmatrix} 0 & A^{w-e} & A^{w-f} \\ A^{e-w} & A^{e-e} & A^{e-f} \\ 0 & A^{f-e} & A^{f-f} \end{bmatrix} = \begin{bmatrix} 0 & C^{w-e}\hat{t}^{w-e} & C^{w-f}\hat{t}^{w-f} \\ C^{e-w}\hat{t}^{e-w} & C^{e-e}\hat{t}^{e-e} & C^{e-f}\hat{t}^{e-f} \\ 0 & C^{f-e}\hat{t}^{f-e} & C^{f-f}\hat{t}^{f-f} \end{bmatrix} \quad (34)$$

where $\hat{t}$ is the diagonal matrix with the elements of the t vector along the main diagonal.

Analyzing scenarios of changing the technology matrix (A) by considering "High Efficient" and "Best Practice" technology matrix alternatives could be performed using the developed equations. Assuming that the WEF intersectoral allocation policies (as represented in C matrix) do not change, the quantitative variations of resources in any WEF nexus system due to the change of the intersectoral use intensities could be evaluated.

If the superscript "1" is used to represent the values of variables after the change in intersectoral use and the superscript "0" is used to represent the initial situation for values of variables. Assuming that WEF intersectoral allocation policies is unchanged ($C^0 = C^1 = C$), the new technology matrix A^1 caused by new WEF intersectoral use intensities (t^1) is then found as in equation 34.

$$A^1 = \begin{bmatrix} 0 & C^{w-e}\hat{t}^{1w-e} & C^{w-f}\hat{t}^{1w-f} \\ C^{e-w}\hat{t}^{1e-w} & C^{e-e}\hat{t}^{1e-e} & C^{e-f}\hat{t}^{1e-f} \\ 0 & C^{f-e}\hat{t}^{1f-e} & C^{f-f}\hat{t}^{1f-f} \end{bmatrix} \quad (35)$$

the total outputs (x^1) caused by new technology matrix A^1 are then calculated as in Equation 10.

$$x^1 = \left(I - A^1\right)^{-1} y^0 \quad (36)$$

with this result for x^1, it is easy to examine the changes in all elements in the intersectoral WEF use quantities (Z^1 matrix) caused by A^1. From the definition of intensity coefficients, we find $Z^1 = A^1 \hat{x}^1$ along with t^1, where $\hat{x}$ is the diagonal matrix with the elements of the vector along the main diagonal.

Moreover, based on the origination of (t) and (c), it became possible interpreting the A matrix to better understand the WEF nexus system and to compare different nexus systems with each other, therefore, the A matrix of the Q-Nexus Model totally befits to be a Nexus Matrix Code or fingerprinting matrix of a nexus system.

4. Application and Analysis of Results

In order to put the introduced method in practice, the data of the WEF nexus case study of Lebanon as presented in [1] will be analyzed. The considered WEF nexus inflows are as follows:

Water inflows (including extraction, treatment, conveyance & distribution) (Mm^3/year): 1) surface water ($W1$), 2) groundwater ($W2$), 3) desalination ($W3$), 4) wastewater reuse ($W4$), 5) recycled water and agricultural drainage water reuse ($W5$).

Energy inflows (evaluated in terms of primary energy equivalent in ktoe/year on a net calorific value basis): 1) imported petroleum ($E1$), 2) electricity (petroleum) ($E2$), 3) electricity (hydro) ($E3$), 4) imported electricity ($E4$), v) electricity (wind/solar) ($E5$), 5) biofuels ($E6$).

Food inflows (including agriculture, food processing & transportation) (kt/year): 1) irrigated cereals ($F1$), 2) irrigated roots and tubers ($F1$), 3) irrigated vegetables ($F2$), 4) irrigated fruits ($F3$), 5) other Irrigated agriculture ($F4$), 6) livestock-meat ($F5$), 7) livestock-milk ($F6$), 8) livestock-eggs ($F7$), 9) fishing and aquaculture production ($F8$), 10) rainfed agriculture ($F9$), 11) imported agricultural products ($F10$), 12) imported livestock products-meat, milk, eggs & fish ($F11$).

Table 1 presents the WEF inflows intersectoral use and the corresponding end use for year 2012. There was no biofuel production in 2012 in Lebanon, the use of biomass was limited to final demand for some economic activities or household use. Therefore, the food for energy indicators is not considered in this application.

Water use intensities in energy and food inflows are calculated using equations (12) and (13), the results are presented in Table 2. The results shown in Table 3 are calculated using equations (14) and (16) and account for energy use intensities in water and food inflows. Table 4 shows the results of the food use intensities in energy and food inflows calculated using Equations (17) and (18).

The WEF intersectoral allocation coefficients are calculated using Equations (19)-(25), the results are presented in Table 5.

A scenario of replacing of gravity surface irrigation with pressurized irrigation systems for some irrigated crops is analyzed. This scenario will achieve water savings (reduction of water use intensities for some food inflows) and will require more energy. The projected water and energy intersectoral use intensities are shown in Table 6 and Table 7. Using the proposed method, it becomes easy to evaluate the new intersectoral and total outputs from the water, energy and food sectors based on this new intersectoral use intensities. In this scenario we assume that the WEF intersectoral allocation matrix (as represented in the C matrix) and the end use (as represented in the y vector), are unchanged. Table 8 presents the resulted nexus technology matrix for the considered scenario calculated using Equation (35).

The resulting changes in intersectoral quantities (Δz) caused by the change of the intersectoral use intensities are then evaluated. The results could be summarized as follows:

Table 1. Intersectoral use of WEF inflows and the corresponding end use for year 2012.

	W1	W2	W3	W4	W5	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	End Use
W1	0.000	0.000	0.000	0.000	0.000	0.000	2.000	0.000	0.000	0.000	0.000	67.320	50.490	67.320	114.15	37.320	29.453	29.453	5.830	8.415	0.000	0.000	0.000	64.00
W2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	44.608	33.456	44.608	55.760	14.608	19.516	19.516	4.152	5.576	1.000	1.000	1.000	320.00
W3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	30.00
W4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.240	0.180	0.240	0.300	0.240	0.105	0.105	0.060	0.030	0.000	0.000	0.000	0.00
W5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	17.344	13.008	17.344	21.680	17.344	7.588	7.588	0.836	2.168	0.000	0.000	0.000	7.00
E1	2.500	5.100	0.033	0.210	0.520	0.000	0.000	0.000	0.000	0.000	0.000	12.127	4.537	6.948	10.769	2.651	0.571	0.559	0.347	0.095	8.500	6.500	1.200	1895.74
E2	51.244	81.892	65.373	0.064	3.308	0.000	0.000	0.000	0.000	0.000	0.000	1.923	1.923	1.923	3.923	1.923	1.923	1.923	1.423	0.323	2.600	2.500	1.200	3095.90
E3	1.176	1.661	1.554	0.002	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.883	0.008	0.008	0.008	0.008	0.008	0.000	0.001	0.000	99.74
E4	0.339	0.550	0.460	0.001	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.882	0.008	0.008	0.008	0.008	0.008	0.000	0.001	0.000	40.54
E5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.50
E6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	95.00
F1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.000	3.000	1.000	0.000	0.000	0.000	0.000	144.00
F2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	352.00
F3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	854.00
F4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	508.00
F5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	20.000	0.000	0.000	0.000	0.000	0.000	2.000	2.000	0.000	0.000	0.000	0.000	0.000	75.00
F6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	101.00
F7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	379.00
F8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	25.00
F9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.00
F10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	10.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	635.00
F11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1824.00
F12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	407.00

Table 2. Intensities of water use in energy and food inflows.

E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
(m^3/toe)						(m^3/t)											
0	1	0		0		858	276	151	378	702	561	150	435	5396	2	1	2

Table 3. Intensities of energy use in water and food inflows.

W1	W2	W3	W4	W5	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
(toe/Mm^3)					(toe/Kt)											
116	158	2247	185	35	93	18	10	32	46	25	7	71	145	17	5	6

Table 4. Intensities of food use in energy and food inflows.

E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
(t/Ktoe)						(t/Kt)											
0	0	0	0	0	316	0	0	0	0	0	69	18	80	0	0	0	0

Table 6. Projected water use intensities in food inflows (m^3/t).

F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
685	220	130	310	562	561	150	435	5396	2	1	2

Table 7. Projected energy use intensities in food inflows (toe/kt).

F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
195	40	25	65	92	25	7	71	145	17	5	6

The output of food-related water consumption will decrease by Δz^{w-f} = 96.087 Mm^3 which accounts for 8.11 % decrease in water of the total water usage. This decrease in water consumption will lead to decrease in the output of the water-related energy consumption by 11.281 ktoe. Similarly, food-related energy consumption will have to increase its output by Δz^{e-f} = 56.576 ktoe which accounts for 1.02% increase in energy of the total energy usage. This increase in energy consumption will lead to increase in the output of the energy-related water consumption by 0.0015 Mm^3. So, the evaluation of the considered scenario shows the amount of achieved water savings and the increase in energy usage, therefore, decision makers will be informed about the quantitative impacts when adopting this policy option.

5. Conclusions and Further Developments

The WEF nexus model presented in [1] performs simulation of scenarios that respond to quantitative variations of the end use of WEF resources. The simulation of policy options by considering the use of high efficient WEF intersectoral use technologies necessitates a methodological addition to the model. Therefore, a methodological approach to analyzing scenarios of adopting high efficient intersectoral use technologies is introduced. The proposed approach permits the

Table 5. WEF intersectoral allocation matrix.

	W1	W2	W3	W4	W5	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
W1	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.52	0.52	0.52	0.59	0.54	0.52	0.52	0.54	0.52	0.00	0.00	0.00
W2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.34	0.34	0.34	0.29	0.21	0.34	0.34	0.38	0.34	1.00	1.00	1.00
W3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
W5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13	0.13	0.11	0.25	0.13	0.13	0.08	0.13	0.00	0.00	0.00
E1	0.05	0.06	0.00	0.76	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.70	0.78	0.65	0.58	0.23	0.22	0.19	0.22	0.77	0.72	0.50
E2	0.93	0.92	0.97	0.23	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.30	0.22	0.24	0.42	0.77	0.77	0.80	0.74	0.23	0.28	0.50
E3	0.02	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
E4	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
E5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.43	0.50	0.00	0.00	0.00	0.00
F2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.14	0.00	0.00	0.00	0.00	0.00
F4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.29	0.29	0.00	0.00	0.00	0.00	0.00
F6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.14	0.14	0.50	0.00	0.00	0.00	0.00
F11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Resulted technology matrix for the considered scenario.

	W1	W2	W3	W4	W5	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
W1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.3561	0.1144	0.0676	0.1844	0.3017	0.3072	0.0933	0.2654	2.8570	0.0000	0.0000	0.0000
W2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.2359	0.0758	0.0448	0.0901	0.1181	0.2036	0.0618	0.1890	1.8931	0.0015	0.0005	0.0025
W3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
W4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0004	0.0002	0.0005	0.0019	0.0011	0.0003	0.0027	0.0102	0.0000	0.0000	0.0000
W5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0917	0.0295	0.0174	0.0350	0.1402	0.0791	0.0240	0.0381	0.7361	0.0000	0.0000	0.0000
E1	0.0053	0.0090	0.0011	0.1400	0.0046	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1681	0.0280	0.0195	0.0425	0.0531	0.0057	0.0015	0.0139	0.0318	0.0131	0.0036	0.0029
E2	0.1077	0.1450	2.1791	0.0427	0.0296	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0267	0.0119	0.0054	0.0155	0.0385	0.0190	0.0051	0.0569	0.1076	0.0040	0.0014	0.0029
E3	0.0025	0.0029	0.0518	0.0013	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0035	0.0002	0.0001	0.0000	0.0003	0.0028	0.0000	0.0000	0.0000
E4	0.0007	0.0010	0.0153	0.0006	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0035	0.0002	0.0001	0.0000	0.0003	0.0027	0.0000	0.0000	0.0000
E5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0297	0.0079	0.0400	0.0000	0.0000	0.0000	0.0000
F2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0099	0.0026	0.0000	0.0000	0.0000	0.0000	0.0000
F4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2105	0.0000	0.0000	0.0000	0.0000	0.0000	0.0198	0.0053	0.0000	0.0000	0.0000	0.0000	0.0000
F6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1053	0.0000	0.0000	0.0000	0.0000	0.0000	0.0099	0.0026	0.0400	0.0000	0.0000	0.0000	0.0000
F11	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

evaluation of the effects of a large number of possible WEF policy scenarios by taking advantages of best practice nexus technology matrices that are technologically most efficient. Two modeling variables are inserted into the technology matrix of the Q-Nexus Model: 1) the WEF intersectoral use intensities (t) and 2) the WEF intersectoral allocation coefficients (c).

The methodological amendment made on the Q-Nexus Model make it well suited to analyzing various technological, structural and quantitative changes scenarios:

1) It allows to analyzing scenarios of changing the technology matrix (A) by considering "High Efficient" and "Best Practice" technology matrix alternatives. It permits also to evaluate the effects of the technology shifts for future development.

2) The construction of the WEF intersectoral allocation matrix (C) allows considering "Optimized" intersectoral allocation matrix options which leads to considering "Optimized" technology matrix alternatives and calculating the resulted WEF quantities.

3) The proposed method permits interpreting the A matrix to better understand the nexus forming and to compare different nexus systems with each other. Based on the origination of (t) and (c), the A matrix of the Q-Nexus Model totally befits to be a Nexus Matrix Code or fingerprinting matrix of a nexus system.

4) It allows analyzing and comparing when effects of additional demands are offset by effects of technology change.

5) Lastly, this approach will enhance the understanding of the complex and dynamic interrelationships between water, energy and food, and support the sustainable planning and management of these finite resources to ensure WEF security and access for all.

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