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Cross-Mapping Important Interactions between Water-Energy-Food Nexus Indices and the SDGs

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Abstract: Worldwide, many developing countries are making efforts to achieve sustainability through the 17 SDGs and at the same time to contribute to environmental security. The Nexus approach enables a more integrated and sustainable use of resources that extends beyond traditional siloed thinking and is applicable at multiple scales. This is especially important in a globalized world where collaboration is becoming increasingly important for societies. In this framework, we present an analysis that will assist policymakers set priorities in investments by investigating the influence of the WEF nexus on the 17 SDGs and vice versa. Following the Nexus approach may thus enhance synergies and contribute to increased performance in connected SDGs that are positively influenced. In this article, we present an analysis that allows stakeholders to adapt it to their specific needs by entering new scores based on the characteristics of each case study; the results of this methodology should be considered in light of the specific conditions, including socio-cultural aspects and geographical, geopolitical, and governance realities, as well as the scale of the case study in question. A Fuzzy Cognitive Map analysis is also conducted on the scores to quantify SDG impact and identify the SDGs that most strongly "influence" nexus-coherent policies and the SDGs that are most strongly "influenced by" the nexus. This is achieved by analyzing the causality in this complex system of positive and negative interlinkages. Through this analysis, three SDGs, namely SDG 2 (Food), SDG 6 (Water) and SDG 7 (Energy), are indicated as the most influenced by the WEF nexus, revealing either synergies or trade-offs, while other SDGs are identified as having little interaction with the WEF nexus system.

Keywords: WEF nexus; 2030 Agenda; SDG; systems thinking; interlinkages; Fuzzy Cognitive Maps

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1. Introduction

Sustainability is commonly defined by the United Nations Brundtland Commission in 1987 as: "meeting the needs of the present without compromising the ability of the future generations to meet their own needs" [1]. Nearly 140 developing countries worldwide are trying to find out how to meet their development goals without threatening environmental security. By 2050, the world population is expected to exceed nine billion, while at the same time, a 50% increase in GHG emissions is expected, mainly due to the direct increase of CO_2 emissions by 70% related to energy production [2,3]. The economic growth experienced during the last century has been followed by an increase in the use of resources—Water, Energy and Food (WEF) [4], thus leading to irreversible impacts on aquatic and terrestrial ecosystems and to an alarming rate of natural resource depletion [5,6]. At the same time, pressures such as climate change, overpopulation and rapid urbanization are expected to lead to an evermore increasing resource use, while geopolitical instability and crises such as the COVID-19 pandemic showcase weaknesses in the implementation of the UN 2030 Agenda for Sustainable Development [7]. The 17 Sustainable Development Goals (SDGs) are divided into 169 targets and there are almost 230 indicators intending to achieve the targets. To achieve the SDGs, all relevant stakeholders should collaborate and succeed in managing the synergies and trade-offs across individual management and governance

sectors [8]. However, 'silo-thinking approaches' traditionally implemented to all countries all over the world, seem no longer to be effective enough to address these challenges and there is a need for new integrated and multi- dimensional approaches that will manage to address multiple SDGs, if not all of them [9,10].

Managing food, water and energy systems is key to achieving the UN SDGs and requires a better understanding of the interactions between the Goals, both at and across different scales, to promote social equality, human wellbeing and ecological integrity. Providing decision-makers with the multifaceted knowledge needed to seize all opportunities to enhance synergies and minimize trade-offs is, therefore, a major objective for Nexus research. In response to this, the WEF Nexus concept highlights the interactions between these systems and provides insights into the cross-sectoral implications of single-sector strategies. The Nexus approach provides a new way of thinking that is not limited to just the water, energy and food sectors, but promotes an integrated and systems thinking across all sectors. The World Economic Forum launched a report entitled "Water Security: The Water–Energy–Food–Climate Nexus", marking the emergence of the Nexus as we know it today [11]. The WEF Nexus approach focuses on the idea that WEF systems should be addressed in a collective and holistic way in order to achieve WEF security [12,13]. WEF nexus is directly linked to 3 out of 17 SDGs, namely SDG 2 (zero hunger), SDG 6 (clean water and sanitation) and SDG 7 (affordable and clean energy), but WEF nexus can indirectly affect more than these three SDGs, positively or negatively through cross-sectoral collaboration. Through the identification of positive synergies and negative trade-offs, WEF nexus approach can contribute to enhance sustainability and at the same time promote higher resource use efficiency [14], pollution reduction [15], and more coherent policy [16,17]. Nexus approach can contribute to uncovering synergies and detecting harmful trade-offs among various sectors, scales and regions, revealing unforeseen effects and thus promoting integrating planning and policymaking [18].

Several articles have been published addressing fundamental human needs using the WEF nexus approach [19–22], the Water-Energy-Food-Ecosystem Nexus approach [23], the WEF nexus approach under climate change combined with systemic resilience [24–26], and also the WEF nexus approach including Land Use and Climate [27]. Additional research focuses on how the SDGs interact with one another [28,29]. Almost 700 million people do not have access to clean and safe drinking water, lack of sanitation for 2.4 billion people [30], 795 million people are facing food insecurity [31], and 1.2 billion people still lack access to electricity [32]. The three main sectors of water, energy and food are interconnected and thus affect all the SDGs directly or indirectly, so they should not be treated in isolation. The WEF nexus approach seems to offer a holistic framework to policymakers and associated stakeholders to achieve the SDGs [18,28,33] and efforts are made on various levels to create and operationalize international Nexus Networks, such as the NexusNet COST Action network (https://www.cost.eu/actions/CA20138/, accessed on 5 May 2022) and the Nexus Community of Practice [34].

In this paper, we map the WEF nexus system on the SDGs and we explore how and in what way (positively or negatively) the three Nexus components (Water-Energy-Food), separately and in combination, interact with the 17 SDGs. Liu et al. [18] identify a gap in studies that quantify how nexus approaches may contribute to the SDGs. In a way, this article addresses this gap and explores how implementing a nexus approach and addressing resource use in a coherent way makes realizing their potential possible and contributes towards the achievement of the SDGs through synergistic and antagonistic relationships. We choose the three SDGs representing the WEF Nexus (SDG 6, SDG 7 and SDG 2, respectively) and cross-map their relationship to all other SDGs, through two indicative targets for each SDG—for a group of 34 SDG targets in total. We postulate that such an approach is highly relevant for working towards the SDGs, since the multi-sector thinking already embedded in the Nexus is a pre-condition for achieving the SDGs. By conducting a systemic analysis of the complex interactions among the WEF Nexus and the SDGs, we aim to identify trade-offs and synergies among the Goals that could help

policymakers set investment or political priorities in their agenda. Our focus on this article is not on the scoring per se, but on cross-mapping the WEF nexus on the SDGs and seeing which SDGs are underrepresented by a nexus analysis. If the scoring is modified accordingly, the analysis could be conducted for other parts of the world, leading to a different set of conclusions.

2. Materials and Methods

2.1. Cross-Mapping the WEF Nexus Indices on Selected SDG Targets

A nexus strategy, which combines management and governance across sectors and scales, can lead to improved water, energy, and food security. A nexus approach can additionally help with the shift to a Green Economy, which aspires for resource efficiency and increased coordination of policies. Given the growing interconnectedness of sectors, as well as in space and time, reducing negative economic, social, and environmental externalities can improve overall resource use efficiency, provide additional benefits, and secure human rights to water and food. Conventional policy and decision-making using "silo-thinking" must therefore give way to a nexus approach that minimizes trade-offs and promotes synergies across sectors [11].

In our analysis, we use the Nexus approach—that overcomes "silo-thinking"—to explore and quantify the interlinkages of Water-Energy-Food sectors separately and in combination with the 17 SDGs with the aim of achieving sustainability in a more integrated way. Specifically, we adapt the procedure of Weitz et al. [28], using the selected two indicative SDG targets per SDG as indicated in Table 1, to quantify how the WEF Nexus both affects and is affected by the 17 SDGs.

Table 1. The 17 SDGs and the 34 selected SDG targets.

SDGs	Selected SDG Targets
SDG1: NO POVERTY	1.3 Social protection 1.5 Economic and social resilience
SDG2: ZERO HUNGER	2.2 Malnutrition 2.4 Food production/agriculture
SDG3: GOOD HEALTH AND WELL-BEING	3.4 Non-communicable disease 3.8 Health coverage
SDG4: QUALITY EDUCATION	4.1 Primary and secondary education 4.4 Technical/vocational skills
SDG5: GENDER EQUALITY	5.4 Unpaid/domestic work 5.5 Women's participation
SDG6: CLEAN WATER AND SANITATION	6.5 Water resources management 6.6 Water-related ecosystems
SDG7: AFFORDABLE AND CLEAN ENERGY	7.2 Renewable energy 7.3 Energy efficiency
SDG8: DECENT WORK AND ECONOMIC GROWTH	8.4 Resource efficiency 8.5 Employment
SDG9: INDUSTRY, INNOVATION AND INFRASTRUCTURE	9.4 Infrastructure 9.5 Research/development
SDG10: REDUCES INEQUALITIES	10.1 Economic equality 10.7 Migration
SDG11: SUSTAINABLE CITIES AND COMMUNITIES	11.1 Affordable housing 11.2 Transport
SDG12: RESPONSIBLE CONSUMPTION AND PRODUCTION	12.1 Sustainable consumption/production 12.5 Waste
SDG13: CLIMATE ACTION	13.1 Climate change adaptation 13.2 Climate change policy/planning

Table 1. *Cont.*

SDGs	Selected SDG Targets
SDG14: LIFE BELOW WATER	14.1 Marine pollution 14.4 Fishery
SDG15: LIFE ON LAND	15.2 Forests 15.5 Biodiversity
SDG16: PEACE, JUSTICE AND STRONG INSTITUTIONS	16.4 Illicit financial/arms flow 16.6 Effective institutions
SDG17: PARTNERSHIP FOR THE GOALS	17.11 Exports from developing countries 17.13 Macroeconomic stability

To achieve a quantified cross-mapping across all SDGs, we use the scores [28] but limit the analysis on the three Nexus SDGs. All scores were on a 7-point rating scheme with the most positive scoring +3 indicating that the two targets are highly synergetic ("indivisible") and the most negative scoring −3, indicating that the two targets are highly antagonistic ("cancelling"). By focusing on the three SDGs that are relevant to the Nexus and their interlinkages, we can identify which SDGs are most influenced–either positively or negatively—by the WEF Nexus approach. An overview of the methodology in a step-by-step fashion is shown in Figure 1.

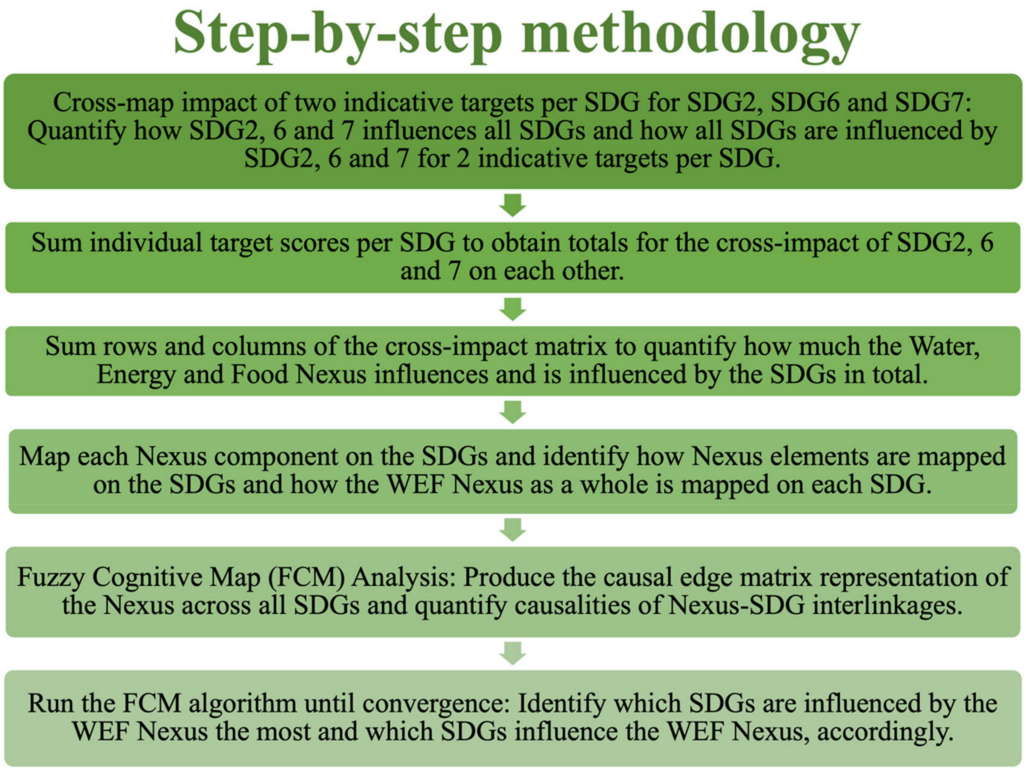

Figure 1. Flow diagram with an overview of the step-by-step methodology.

The modified matrix presented in Table 2, consists of the impact quantification of the three SDGs representing the WEF Nexus (SDG 2, SDG 6 and SDG 7) over the 17 SDGs in two ways; *influencing* targets (rows) and *influenced by* the targets (columns). In other words, the scores show how Water (SDG 6), Energy (SDG 7) and Food (SDG 2) *influences* all SDGs (presented in the 6 rows—two rows per SDG) and how the WEF Nexus *is influenced by* all SDGs (presented in the 6 columns—two columns per SDG). Influence could be positive, negative, or zero, if no influence exists. Other than the three rows and three columns that contain scores, the rest of the matrix is filled with zeros.

Table 2. Modified cross-impact matrix of 6 targets (2 for food—SDG 2, 2 for water—SDG 6 and 2 for energy—SDG 7), and their interactions, adapted from Weitz et al. [28]. The values in the matrix range from −3 (cancelling, dark red) to +3 (indivisible, dark green). Rows indicate targets influencing other targets and columns show how much each target is influenced by other targets.

NEXUS				FOOD								WATER		ENERGY																					
	SDG Targets	1.3	1.5	2.2	2.4	3.4	3.8	4.1	4.4	5.4	5.5	6.5	6.6	7.2	7.3	8.4	8.5	9.4	9.5	10.1	10.7	11.1	11.2	12.1	12.5	13.1	13.2	14.1	14.4	15.2	15.5	16.4	16.6	17.1	17.1
	1.3			1	0							0	0	0	0																				
	1.5			1	0							0	1	0	0																				
FOOD	2.2	0	2	0	0	3	0	1	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0
	2.4	0	0	0	0	1	0	0	0	0	0	2	2	1	0	1	0	2	2	0	0	0	0	1	1	2	0	2	3	3	2	0	0	0	0
	3.4			0	0							0	0	0	0																				
	3.8			1	0							0	0	0	0																				
	4.1			0	0							0	0	0	0																				
	4.4			0	1							0	0	1	1																				
	5.4			3	1							0	0	0	0																				
	5.5			2	2							1	0	0	0																				
WATER	6.5	0	2	0	2	0	0	0	0	0	0	0	3	−1	0	1	0	1	0	0	0	−1	0	1	1	2	1	3	2	1	2	0	1	0	1
	6.6	0	1	0	1	0	0	0	0	0	0	2	0	−1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	2	0	0	0	0
ENERGY	7.2	0	0	0	1	0	0	0	0	0	0	−1	−2	0	−1	2	1	3	2	2	0	1	1	0	0	1	3	0	0	−1	−1	1	0	−1	1
	7.3	0	0	0	1	0	0	0	0	0	0	0	0	−1	0	3	0	3	2	0	0	1	2	3	3	0	3	0	0	1	0	0	0	−1	0
	8.4			1	2							2	1	1	2																				
	8.5			1	0							0	0	0	0																				
	9.4			0	1							1	0	1	2																				
	9.5			0	0							1	0	1	2																				
	10.1			1	0							0	0	0	0																				
	10.7			0	0							0	0	0	0																				
	11.1			0	0							0	0	0	1																				
	11.2			0	0							0	0	1	2																				
	12.1			1	2							2	1	2	2																				
	12.5			0	1							1	1	1	2																				
	13.1			1	3							2	3	−2	−1																				
	13.2			−2	1							0	−1	2	3																				
	14.1			0	2							2	3	0	0																				
	14.4			1	3							1	2	0	0																				
	15.2			0	2							1	3	−1	0																				
	15.5			1	2							1	2	0	0																				
	16.4			1	1							0	0	0	0																				
	16.6			2	2							2	1	0	0																				
	17.11			0	−1							0	0	−1	−1																				
	17.13			0	2							0	0	2	1																				

To see the effects of the WEF Nexus to SDG interaction at the SDG level, we proceed with summing the scores of the 2 targets both in rows and columns. The result is a single value per SDG considering the two targets in an integrated form. In Figure 2, we show an example of how we get from 4 values per SDG to a single value. Given that the maximum and minimum value per original cell was +3 and −3 respectively, we obtain a table (Table 3) with scores ranging from −12 to +12, since it combines four individual cells in one. We continue by summing the rows and columns for the three Nexus SDGs, to compare the influence among the three Nexus components: row sums indicate the strength of the influence of each component on all SDGs, while column sums indicate which Nexus component is most influenced by the SDGs.

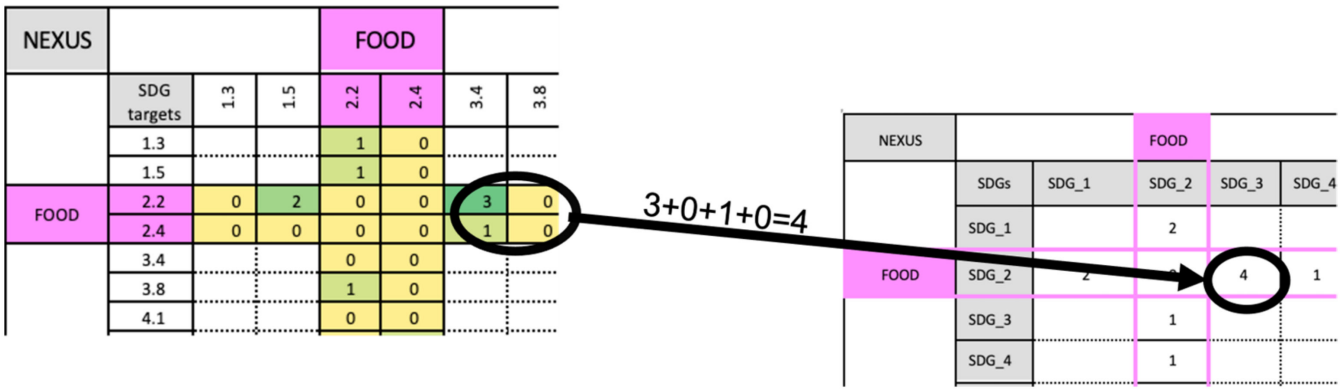

Figure 2. An example of how 4 scores between the targets of SDG 2 (rows) and SDG 3 (columns) from matrix in Table 2 are summed to constitute the score of how the SDG 2 influences the SDG 3 in total.

The presented analysis borrows scores presented by Weitz et al. [28] performed at the national level for Sweden but are found to be relevant for a large part of European countries; obviously, the scores are not applicable universally, but rather reflect the peculiarities of specific region.

2.2. Fuzzy Cognitive Maps

Fuzzy Cognitive Maps (FCMs) are widely used to analyze causal complex systems, which have originated from the combination of fuzzy logic and neural networks [35]. FCMs usually involve feedbacks, consisting of nodes and directed edges between them. Along these lines, the cross-impact matrix that cross-maps the 17 SDGs with scores on how the targets influence one another and how they are, in turn, influenced by the others has causality and feedback loops making it a good candidate for an FCM of this complex system. In our case, the nodes represent the SDGs, and the edges represent cause-effect relations (influencing/being influenced by) among the SDGs (our scores), creating a causal diagram with closed loops and paths in them. Closed loops show feedback among the SDGs, and they are fuzzy because the scores assigned [28], represented by causal arrows in the diagrams, inherently include fuzziness, or "shades of gray" [36].

Feedback loops in our Nexus to SDG system imply that the system is dynamical and evolves from an initial state, which is defined by the activation vector, which is initially set at 1 for all nodes. The weights of the links (fuzzy causal edges) in the FCM include the fuzzy value of the relative influence which is transformed via a normalization technique from the [−12, 12] range (Table 3) to the [−1, 1] range (Table 4). Table 4 now becomes the causal edge matrix representation **E** for the Nexus-SDG FCM. Each cell shows the fuzzy causal edge value e_{ij}, which signifies how much the i_{th} SDG influences or is influenced by the j_{th} SDG. Once the edge matrix is input, the causal activation iterates in the FCM until the node values reach equilibrium—most FCMs reach it quickly and the equilibrium serves as the system's forward inference from the input.

Table 3. 17 × 17 cross-mapping matrix with the sums of the target scores and their respective total sums per row and per column. Numbers in red indicate negative values.

NEXUS			FOOD				WATER	ENERGY											
	SDGs	**SDG_1**	**SDG_2**	**SDG_3**	**SDG_4**	**SDG_5**	**SDG_6**	**SDG_7**	**SDG_8**	**SDG_9**	**SDG_10**	**SDG_11**	**SDG_12**	**SDG_13**	**SDG_14**	**SDG_15**	**SDG_16**	**SDG_17**	**SUMS**
	SDG_1		2				1	0											
FOOD	SDG_2	2	0	4	1	0	4	−1	4	4	0	0	4	4	5	5	0	0	36
	SDG_3		1				0	0											
	SDG_4		1				0	2											
	SDG_5		8				1	0											
WATER	SDG_6	3	3	0	0	0	5	−2	1	1	0	−1	2	5	5	7	1	1	31
ENERGY	SDG_7	0	2	0	0	0	−3	−2	6	10	2	5	6	7	0	−1	1	−1	32
	SDG_8		4				3	3											
	SDG_9		1				2	6											
	SDG_10		1				0	0											
	SDG_11		0				0	4											
	SDG_12		4				5	7											
	SDG_13		3				4	2											
	SDG_14		6				8	0											
	SDG_15		5				7	−1											
	SDG_16		6				3	0											
	SDG_17		1				0	1											
	SUMS		48				40	19											

Table 4. Causal edge matrix representation **E** for the Nexus-SDG FCM. All e_{ij} entries in this FCM are fuzzy values in the $[-1, 1]$ interval. Red values are negative, while zero values denote the absence of causal inference.

NEXUS			FOOD				WATER	ENERGY										
	SDGs	**SDG_1**	**SDG_2**	**SDG_3**	**SDG_4**	**SDG_5**	**SDG_6**	**SDG_7**	**SDG_8**	**SDG_9**	**SDG_10**	**SDG_11**	**SDG_12**	**SDG_13**	**SDG_14**	**SDG_15**	**SDG_16**	**SDG_17**
	SDG_1		0.1667				0.0833	0										
FOOD	SDG_2	0.1667	0	0.3333	0.0833	0	0.3333	−0.0833	0.3333	0.3333	0	0	0.3333	0.3333	0.4167	0.4167	0	0
	SDG_3		0.0833				0	0										
	SDG_4		0.0833				0	0.1667										
	SDG_5		0.6667				0.0833	0										
WATER	SDG_6	0.25	0.25	0	0	0	0.4167	−0.1667	0.0833	0.0833	0	−0.0833	0.1667	0.4167	0.4167	0.5833	0.0833	0.0833
ENERGY	SDG_7	0	0.1667	0	0	0	−0.25	−0.1667	0.5	0.0833	0.1667	0.4167	0.5	0.5833	0	−0.0833	0.0833	−0.0833
	SDG_8		0.3333				0.25	0.25										
	SDG_9		0.0833				0.1667	0.5										
	SDG_10		0.0833				0	0										
	SDG_11		0				0	0.3333										
	SDG_12		0.3333				0.4167	0.5833										
	SDG_13		0.25				0.3333	0.1667										
	SDG_14		0.5				0.6667	0										
	SDG_15		0.4167				0.5833	−0.0833										
	SDG_16		0.5				0.25	0										
	SDG_17		0.0833				0	0.0833										

The algorithm we used for convergence [37,38] was based on Equation (1) (Kosko's inference) and function f is described in (2):

$$A_i(k+1) = f\left(\sum_{j=1,\ j\neq i}^{N} e_{ji} \times A_j(k)\right) \quad (1)$$

$$f(x) = \frac{1}{1+e^{-x}} \quad (2)$$

In Equation (1), A_i is the value of each node (SDG), e_{ji} is the strength of the influence between the SDGs and k is the iteration number. Because the algorithm includes e_{ji} (as opposed to e_{ij}), it takes into account columns, not rows. The results are a list of values obtained after convergence for each SDG and denote how the SDGs are influenced by the Nexus (Case A), with 0.5 being the lowest value (indicating no influence) and 1 being the maximum value (indicating the highest possible effect on the SDGs). To assess how the SDGs influence the Nexus, we ran the transpose matrix (Case B) with the same algorithm and produced different results for the SDGs (A_i values). These results are shown in Table 5 and Section 3.

Table 5. Fuzzy Cognitive Mapping analysis results after convergence: Node values for all SDGs quantifying their influence in an ascending order; (**a**) Case A: how the SDGs are influenced by the Nexus and (**b**) Case B: how the SDGs influence the Nexus.

SDGs Case A	Final Values Case A	SDGs Case B	Final Values Case B
SDG_5	0.5	SDG_3	0.5184
SDG_17	0.5040	SDG_10	0.5184
SDG_4	0.5193	SDG_17	0.5360
SDG_10	0.5301	SDG_4	0.5535
SDG_16	0.5342	SDG_1	0.5546
SDG_11	0.5561	SDG_11	0.5701
SDG_3	0.5767	SDG_9	0.6550
SDG_1	0.5949	SDG_13	0.6571
SDG_8	0.6789	SDG_16	0.6588
SDG_14	0.6835	SDG_5	0.6596
SDG_12	0.6953	SDG_8	0.6732
SDG_15	0.7032	SDG_15	0.6904
SDG_7	0.7249	SDG_14	0.7346
SDG_9	0.7291	SDG_12	0.7593
SDG_13	0.7531	SDG_7	0.8471
SDG_6	0.9194	SDG_6	0.8642
SDG_2	0.9288	SDG_2	0.8846

3. Results and Discussion

3.1. Analysis and Visualization of the Results

To facilitate understanding of the scores shown in Table 3, we present them through a Sankey diagram (Figure 3), also available in an interactive form through this link: https://rpubs.com/alexioan/931954 (accessed date on 15 May 2022). We calculate how Water, Energy and Food influences each SDG separately and we post absolute values of influence scores. In total, Energy has the highest influence on the SDGs (if we only take the absolute values), with Water coming second and Food following last. The size of the SDG boxes

corresponds to the total influence of the Nexus on them. The third WEF Nexus column sums up the Water, Energy and Food columns, showing the total mapping of the Nexus on the SDGs. SDG 13 (Climate Change) has the highest value, with SDG 9 (Industry Innovation and Infrastructure) and SDG 15 (Life on Land) coming second. SDG 6 (Water) and SDG 12 (Responsible Consumption and Production) come third and the other SDGs follow.

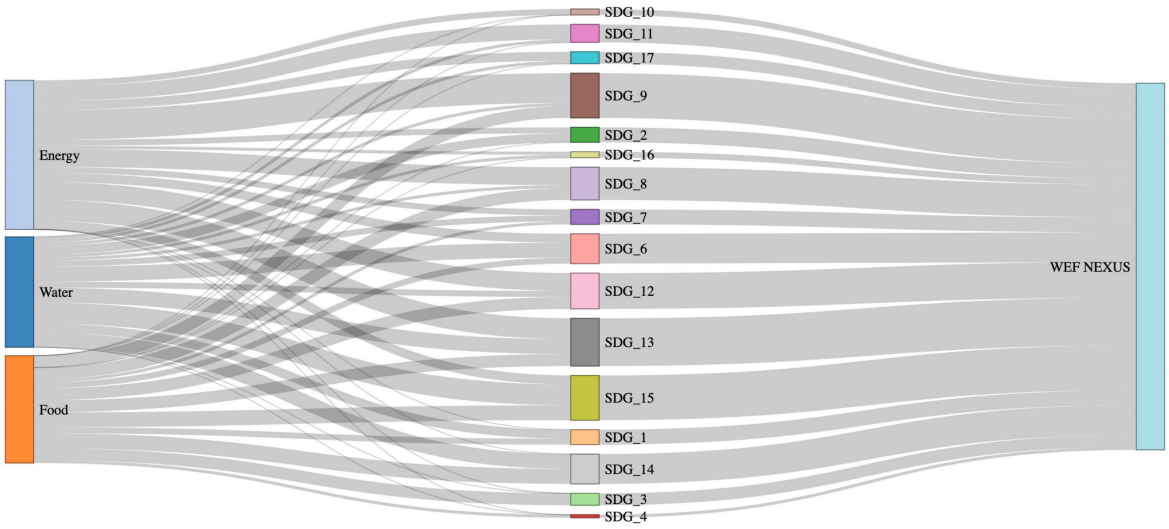

Figure 3. The Sankey diagram showing how the three Nexus components Water, Energy and Food both separately and in total (WEF Nexus) affect the 17 SDGs for a European-level analysis.

In Table 3, we also see that Food provides the highest sum both in rows and columns out of the three Nexus components, showing its high net positive influence, due to its strong interlinkages with water and energy. Surely ensuring sustainable Food production will act in synergy with Water and Energy, making the realization of these targets easier. In terms of the column sum, it makes sense that Food is the highest since it is greatly positively influenced by Water and Energy. Energy is quite a bit lower than the other two, due to negative scores between its own two targets and negative relationship with the other two Nexus components (a discussion on the negative energy scores is presented below). This lower score of Energy indicates that progress in the other SDG targets makes it more difficult to reach the Energy target.

It is important to see that the Nexus is mapped on SDG 13, suggesting that the Nexus offers a sustainable way of addressing the effects of Climate Change and increase resilience. The WEF Nexus includes the main drivers of climate change (water, energy, and food security) and the main sectors affected (water and the environment). Decisions around policy, infrastructure, etc. developed on the basis of WEF Nexus assessments will be suitable as elements of climate change mitigation and adaptation. In fact, it is difficult to imagine solutions to the climate change issue that are not built on a form of Nexus approach. The same is true with the other SDGs that score high, which are all relevant to biodiversity (SDG 15), innovation, infrastructures, sustainable industry (SDG 9), etc. A Nexus approach will clearly benefit all these SDGs that score in the top 3 positions, after our analysis. On the other hand, the lowest score corresponds to SDG 4 (Quality Education), while SDG 5 (Gender Equality) is completely absent. This shows a weakness in the link between WEF Nexus and these two SDGs. Needless to say, that these results are relevant in the European setting, and should not be simply extended or generalized. For instance, the use of traditional biomass for heating and cooking in sub-Saharan Africa will likely influence gender equality (SDG5) and education quality (SDG4) [39], especially because of the necessity to harvest the resource. However, this dependence is not evident in a European setting, which translates in the initial absence of influence in the cross-impact matrix shown in this article. The same occurs for Energy (SDG6) and Water (SDG7). The

initial negative influence of Renewable Energy (target 7.2) on Water related ecosystems (target 6.6) comes from the importance of hydropower in Europe, which negatively affects water quantity and quality through its impact on ecological flows. Clearly, in many other contexts that hydropower is not an important part of the energy mix, this influence is likely to be very different.

Additionally, we plot the same results with a radar chart (Figure 4). While in the Sankey diagram we plot influence as an absolute value, thus not being able to distinguish between positive and negative influence, in this plot, we provide this extra information of the sign (plus or minus) of the scores for each SDG. Negative scores correspond to trade-offs, while positive scores correspond to synergies, with some being more intense than others. The most interesting element of this graph is with the link of Energy and SDG 6 and 7. The negative score in SDG 7 stems from the fact that the two targets that were selected were targets 7.2 Renewable Energy and 7.3 Energy Efficiency. These two targets are considered either constraining or counter-active: An increase of renewables in the energy mix will not automatically lead to an increase in energy efficiency (at least compared to conventional systems), thus we observe the negative score. In terms of the interaction of SDG 6 and 7, we see that hydropower, even though a renewable energy, affects water quality and ecosystem health (Target 6.6).

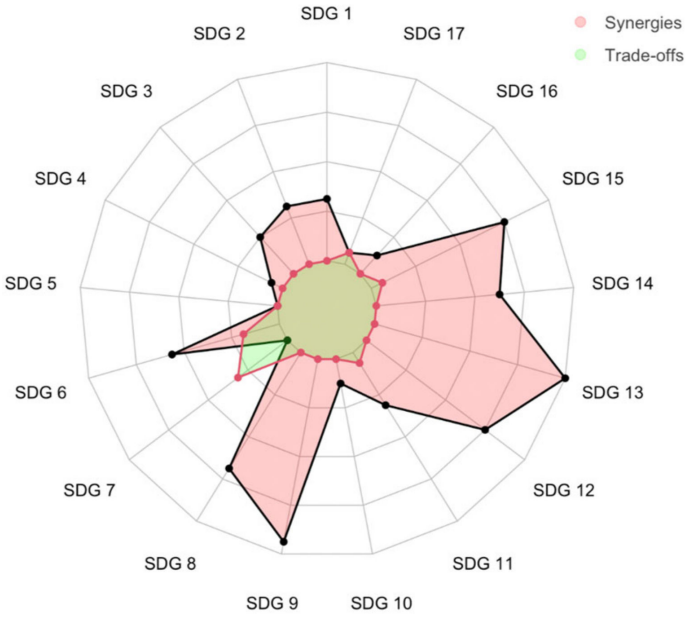

Figure 4. The radar chart indicates how the 17 SDGs are affected either in a synergistic (positive) or antagonistic (negative) way by the Nexus.

3.2. Fuzzy Cognitive Maps Results

Figure 5 shows the results of the FCM analysis. The arrows indicate the edge values e_{ij} as shown in Table 4, with the line width being associated with the magnitude of the value. Red lines indicate negative values. As expected, we see most of the arrows connecting SDGs 2, 6 and 7, but other SDGs show interlinkages as well. Negative interlinkages are shown mostly around SDG 7, as observed also in Figure 4, while strong interlinkages are also shown between SDG7 and 9 which are obviously strongly interlinked as energy is at the core of achieving innovative infrastructures and sustainable industries (SDG 9). The sizes of the circles denoting the nodes (SDGs) correspond to the values of A_i, as they converge after a few iterations of the algorithm (k = 20 for both cases). Figure 5 shows the FCM results in a graphical format for only the first case (how the SDGs are influenced by the Nexus—Case A), while Table 5 shows the actual values of the nodes for both Case A and Case B—how the SDGs influence the Nexus.

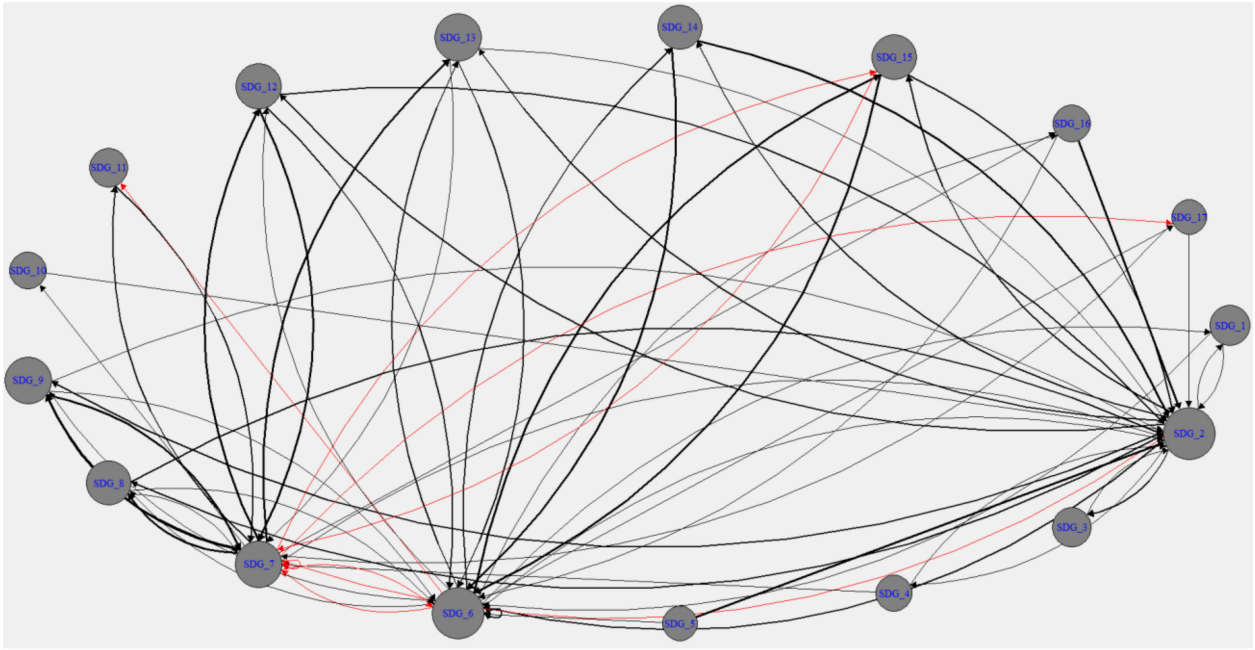

Figure 5. Fuzzy Cognitive Map analysis—graphical representation for Case A (how the SDGs are influenced by the Nexus). Black lines indicate positive values, while red lines indicate negative values.

Since the analysis focuses on SDGs 2, 6 and 7, we expect to have the largest values for these SDGs in the final FCM results, since these nodes would naturally have most of the interlinkages and influence. However, in Case A we see that SDG13 (Climate Change) takes the 3rd highest value, following SDG 2 (Food) and SDG 6 (Water) and SDG 7 (Energy) comes 5th in place after SDG 13 and SDG 9 (Industry, Innovation and Infrastructure). This is indicative of the strong links already evident with Climate Change, Industry/Innovation and the Nexus. We see that SDG2 (Food) is the most influential of all SDGs for both cases, with SDG 6 coming 2nd. Through a different analysis that quantified the interlinkages between the Nexus components performed by Laspidou et al. [27], Food was showcased as the one component that was the most influential and Water as the one mostly influenced by the others. So, the strength of the influence of Food has been established elsewhere, since it has strong links mainly with Water, but also with Energy mainly through the water-energy nexus (via pumping). As mentioned before, SDG 5 has the lowest value in Case A showing zero influence by the Nexus (0.5 is the lowest possible value), but has influence on the Nexus, as shown in Case B. It is interesting to see that SDG 3 (Good Health and Wellbeing) has the lowest value in Case B, while it lies in about the middle of the ranking in Case A, indicating that even though SDG 3 is influenced by the Nexus (an obvious link with water quality, energy pollution and food for example), its influence on the Nexus is minimum. Finally, SDG 10 (Reduced Inequalities) ranks at the bottom in Case B and relatively low in Case A, while SDGs 14 and 15 ("Life Below Water" and "Life on Land", respectively) with obvious strong links with the Nexus appear with relatively high values, as expected.

The Nexus approach leads to more integrated and sustainable resource use that goes beyond traditional silos and is applicable at multiple scales. This approach needs to be governed by a coordination mechanism, allowing for the creation of a Community of Practice [34], where key stakeholders can work towards identifying and prioritising solutions, benefitting from an overall Nexus perspective. Under Nexus-coherent governance and its linkage with the SDGs, priorities are integrated, compromises are promoted by sometimes adopting decisions that may not be optimal from a single sector policy perspective, but which result in an overall better solution for all sectors involved. This article promotes such thinking and facilitates evidence-based policy making [40].

FCM analysis reveals a wide range of implications (synergies and tradeoffs) between the WEF Nexus and the SDGs, and it also highlights the need for additional research into key interconnections such as the WEF Nexus to Gender Equality (SDG 5) and Quality Education (SDG 4). Specifically, the presented analysis supports policymakers in responding to the ensuing demands for sustainability by proposing solutions and minimizing problems.

4. Conclusions

The Nexus approach ensures a more integrated and sustainable use of resources that goes beyond traditional silos and is applicable at different scales. This is particularly relevant in an increasingly globalised world where collaboration becomes essential for societies. By exploring the impact of the WEF nexus over the 17 SDGs and vice versa, and by quantifying that impact, we provide an assessment framework that will help policymakers set priorities in investments. This way, investing in the Nexus might promote synergies and help achieve greater success in associated SDGs that are influenced positively. Since not all SDG targets were considered, but only two targets per SDG, it is important to understand the limitations of the approach, which is dependent on the selected targets and the Case Study under consideration. In this article, we provide the framework that allows the users to adjust it to their needs by entering new scores, depending on the peculiarities of each case study; the results of this methodology should be taken into account considering the specific conditions, including socio-cultural aspects and geographical, geopolitical and governance realities, as well as the scale of the case study in question.

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