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Review

Water Energy Food Nexus Analysis and Management Tools: A Review

David Borge-Diez [1], Francisco José García-Moya [1] and Enrique Rosales-Asensio [2,*]

[1] Department of Electrical Engineering, Systems and Automation, University of León, 24008 León, Spain; david.borge@unileon.es (D.B.-D.); fgarcia701@gmail.com (F.J.G.-M.)
[2] Department of Electrical Engineering, University of Las Palmas de Gran Canaria, Campus de Tafira S/n, 35017 Las Palmas de Gran Canaria, Spain
* Correspondence: enrique.rosales@ulpgc.es

Abstract: In order to eradicate water–energy–food poverty, Sustainable Development Goals (SDG) proposed milestones to overcome the feeding problem. The development of water–energy–food (WEF) nexus management tools, and approaches has increased during last years. The aim of this research is to review WEF nexus management methods, tools, and examples to identify gaps, goals, or future development that arise when modelling goods management issues for designing a sustainable development framework. It is also presented the food–biofuel competition for resources problem focusing in threatened systems. In addition to the resource trade-off quantification issue, it proposed an analysis for WEF systems management from economic, environmental, and practical points of view with the aim of identifying results, challenges, gaps, or assumptions for nexus. The renewable energy highlights as an enabler for sustainable development.

Keywords: sustainable management; Water Energy Food Nexus; WEF; synergies improvement; analysis of strategies; Millennium Development Goals

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1. Introduction

It is a fact that human activity induces negative effects on the environment. From transport, energy generation, and others that generate GHG (Green House Gas) emissions [1], joint to increasing needs on developing countries, provokes increasing climate change impacts. In parallel, over recent decades, increasing world population has led to an increase in requirement of global food production [2]. According to Ortiz-Bobea et al. [3] anthropogenic climate change provokes among others impacts that precipitation events become more intense and frequent. In addition, precipitation variability on regional scales will likely intensify. From an environmental and economic point of view, increasing food production has repercussions in other sectors, mainly with the energy and water sectors, and either agriculture and livestock farming. Even if human-related GHG emissions stop, climate change impacts will continue. Rising warming rates and magnitudes accompanied by ocean acidification, increase the risk of severe, pervasive, and in some cases, irreversible detrimental impacts.

In order to boost human development, the international community proposed the MDG (Millennium Development Goals) [4]. Among these goals were to eradicate poverty and hunger by 2030. Efforts for feeding a growing population provoked sustainable development concerns. In the light of this growing interest, UN released the 2030 Agenda for Sustainable Development [5]. One of the outstanding objectives is to achieve food security. According to Alexandratos et al. [6] to maintain the current nutrition levels, an increase of 70–100% in the food supply chain is needed. From an environmental and economic point of view, food production has repercussions in other sectors, mainly with the energy and water sector and either agriculture and livestock farming. This leads to a substantial correlated impact in the water resource consumption, as well in the CO_2

associated emissions. It is especially important to consider the food industry water impact because it is the largest world's freshwater user. Accounting for 70% of total global water withdrawals [7], this sector is also responsible of 30% of the global energy consumption along food supply chains [8], as well as of its correlated GHG emissions [9]. Food security is potentially affected by climate change from food production, to access, use, and price stability.

Agriculture is among the most climate-vulnerable sectors, impacted by further drying water-scarce regions, and region-specific changes in crop productivity. Despite its critical consideration, water perspectives globally show a 40% gap in fresh water demand in 2030 [10]. As fresh water is needed for citizens' consumption, irrigation, processing, and packaging in the agri-food industry, its supply is basic to achieve the aforementioned sustainable development goals. Climate change conditions have derived difficulty in accessing drinkable water. In the 21st century global population, suffering from water scarcity is projected to increase with the level of warming. In addition, it is also projected that renewable surface water and groundwater resources reduce in most dry subtropical regions. Changes in precipitation in a warming world will not be uniform: extreme precipitation events become more intense and more frequent as global mean surface temperature increases, and precipitation variability on regional scales will likely intensify. In most developing countries, population is highly dependent on agriculture. Despite the high percentage of total labor force involved in agriculture [11] only six percent of the 2.9 million smallholder farmers in Kenya is irrigated showing decoupled WEF systems. In order to assess the performance of previous actions taken either at local, regional, national, or international level case studies are necessary, for evaluating in the medium and long term.

Adaptation, mitigation, and sustainability development highlight the most outstanding strategies for managing climate change risk concerns. When sustainable—synergized with the water and food system—renewable energy becomes an enabler to lower the anthropogenic climate change impacts. In the complex and uncertain climate change environment, effective decision-making tools and risk management is mandatory for resource-use maximization.

In order to face the objectives to globally increase environment sustainability, the UN proposed 17 SDGs (sustainable development goals) for a sustainable global growth [12]. In this sense, the water–energy–food (WEF) nexus management tools and approach explore synergies for designing a sustainable environment. These are intrinsically connected at different levels. Either at resource management, infrastructure development, or political measures needed level; either at regional, or national level these three subsystem goals are linked. Defining and accounting tradeoffs between systems is basic for a better understanding of interconnections. According to Dyllick et al. [13] a central meaning for sustainability is the triple bottom line approach for increasing the performance of the network through the economic, environmental, and social dimensions where the minimum performance of a network can be achieved. Bigs et al. [14] analyzed the importance of a sustainable approach for the water–energy–food nexus at a small scale. The synergies between water, energy, and food systems provokes that the deterioration of one factor will cause a series of chain reactions among them. Gulati et al. noted that food production needs groundwater and energy consumption, a fact that leads to changes in regional climate, which affect food production [15,16]. Stylianopoulou et al. [17] reviewed Water–Energy–Food indicators and ratios for addressing security and sustainability in water, energy and food challenges, highlighting land use, GHG emissions, crop water productivity, energy consumption for crops, among others.

Where feeding the world population is concerned, it is highlighted by WEF management tools. Because of its importance, WEF Nexus have their specific SDGs. Three out of the 17 objectives refer specifically to food, SDG 2 (food); 6 (water), and 7 (energy). According to Fader et al. [18] the greatest synergies are likely to occur where conflicting resource needs appear. Depending on the synergies between systems and their integration degree, the consequences of a not synergized systems management threat SDG fulfillment.

A joint resource management would be essential not only for SDG's fulfillment, but also for sustainable growth. Some discussed interlinkages between water, energy, or food SDG's objectives, with others SDG's. Nilsson et al. [19] developed a systematic path to map out target interactions for policy makers. Coopman et al. [20] developed a methodology to analyze the implications of policy measures needed for achieving SDGs although did not consider inputs needed for achieving certain targets, and infrastructure costs and labor needed were not considered. Table 1 shows the most outstanding sustainable objectives for water, and energy, as well for food security nexus approach. Across these objectives, it is assessed how tools deals with systems trade-offs and linkages, for boosting SDG success.

Table 1. Objectives for a Sustainable Nexus Approach [19].

Sustainable Water	Sustainable Energy	Food Security
Access to water resources	Access to modern energy services	Food Availability
Sustainable use and management of water resources	Increase efficiency of energy use	Food Access and Supply
Resilient societies and ecosystems to water-related disasters	Energy is clean/renewable and reliable	Utilization & Nutrition
		Stability of Prices

In order to increase environmental sustainability, WEF tools will benefit from synergies between systems, through the development of solutions that boost multiple objectives. For assessing trade-offs and interconnections, it highlights boundaries and scenario definition. This fact will lead to the development of tools, and approach for enabling identification of possible interventions, or new policies on the natural environment. Endo et al. [21] reviewed the identification of water, energy, and food nexus multiple trade-offs at different levels. Flamini et al. [22] assessed the WEF nexus, and focused on sustainable energy as the main enabler for nexus improvement, noting that the impacts will be observed on economic, social, and environmental goals. When evaluating the anthropogenic climate change contribution, quantifying trade-offs between systems is basic for a proper impact assessment. It is a well-known fact that globally renewable energy deployment has increased over the last years, becoming an enabler for lowering climate change impacts of WEF systems. It is forecast that renewable electricity capacity will reach more than 4800 GW by 2026, increasing by over 60% between 2020 and 2026 [23]. On the other hand, since biofuels and crops production are competing for the same resource either water or land are becoming a great concern for food security. Table 2 presents different types of biofuels regarding to the production process [24].

Table 2. Types of biofuels.

Biofuel Generation	Production Process
First	Fermentation (starch + sugar) and oil transesterification
Second	Thermo/Bio chemical
Third	Microbiological
Fourth	Thermochemical and hydro-processing

By reviewing tools, as well as examples of WEF nexus systems assessment and management, this research analyses how WEF nexus systems research deal with resource allocation problem, and proposes a methodology for evaluating scenarios with WEF nexus systems analysis tools. First, it is defined by the overarching methodology adopted in this review paper, outlining the food security problem, and presenting the most outstanding tools employed for WEF systems—tradeoffs accounting. Secondly, examples and actions taken for increasing WEF nexus system management perspectives are presented. These are analyzed to figure out how they account trade-offs, what are the actors involved in nexus management, and identify gaps, errors, and future development. This is followed by a brief discussion to identify the performance of reviewed tools, as well goals, and fails of actions taken. It is proposed as a methodology for increasing the sustainable performance of WEF systems according to a technological, practical, economic, and environmental point of view actions taken in the short, medium, and long term.

2. Analysis of Actions and Examples

This section reviews the most outstanding WEF systems analysis tools, and approaches since they fulfil the following criteria: include all three nexus resources, have been recently used, and are among top cited articles. It also presents examples, and actions taken for boosting sustainable WEF management of threatened systems focusing in renewable energy deployment as a synergies' facilitator. Through a methodologic analysis of how tools define the problem, and what the aim of the approach is, this research proposed an innovative approach for a sustainable management of systems. As can be seen in Figures 1–3, the area used for crops production with an extension higher than 100,000 Ha in Asia, Africa, and America has exponentially grown since 1980. It is worth mentioning that the Asia-Pacific area takes up two-thirds of the global food supply and uses about 60% of the world's fresh water.

WEF management tools' final goal is to define synergies, and trade-offs' quantification between systems for a complete understanding of how these systems are linked. Through definition and quantification, these tools intend to boost a system's sustainable management. While some tools use quantitative approach for accounting these tradeoffs, qualitative approach include social assessment, opinions through surveys for evaluating deployed, or proposed policies within the nexus. A feasibility assessment of proposed actions was unbundled for analyzing technological, economical, sustainability, and practical feasibility of proposed actions within the nexus. In addition, it is to identify gaps, future development, or new research approach.

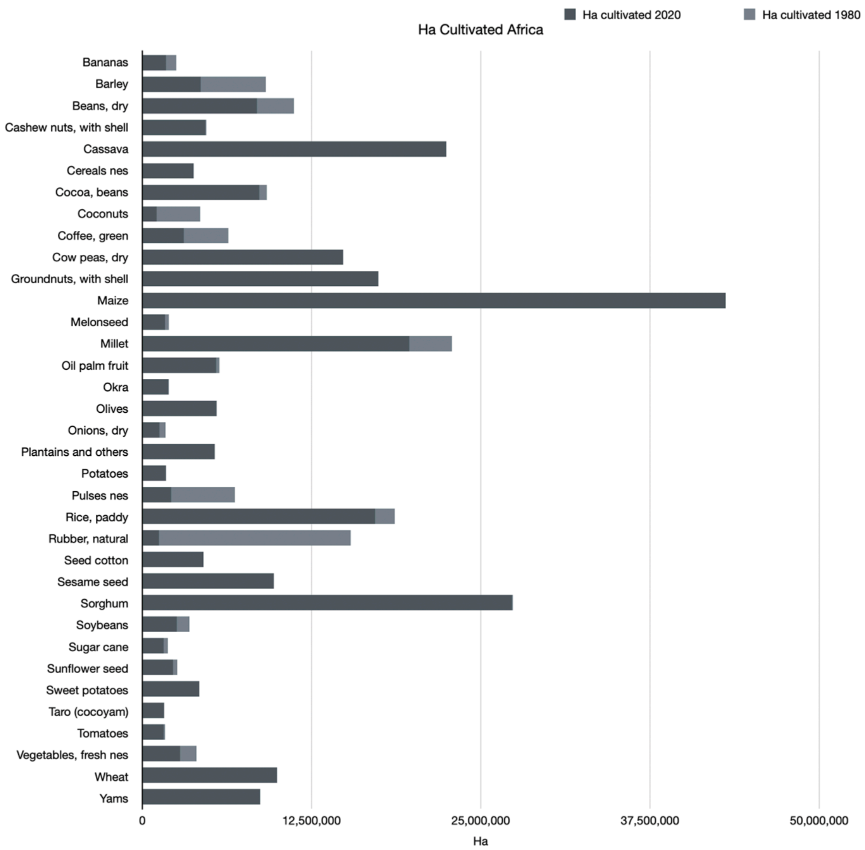

Figure 1. Crops production with an extension higher than 100,000 Ha in Africa, adapted from [25].

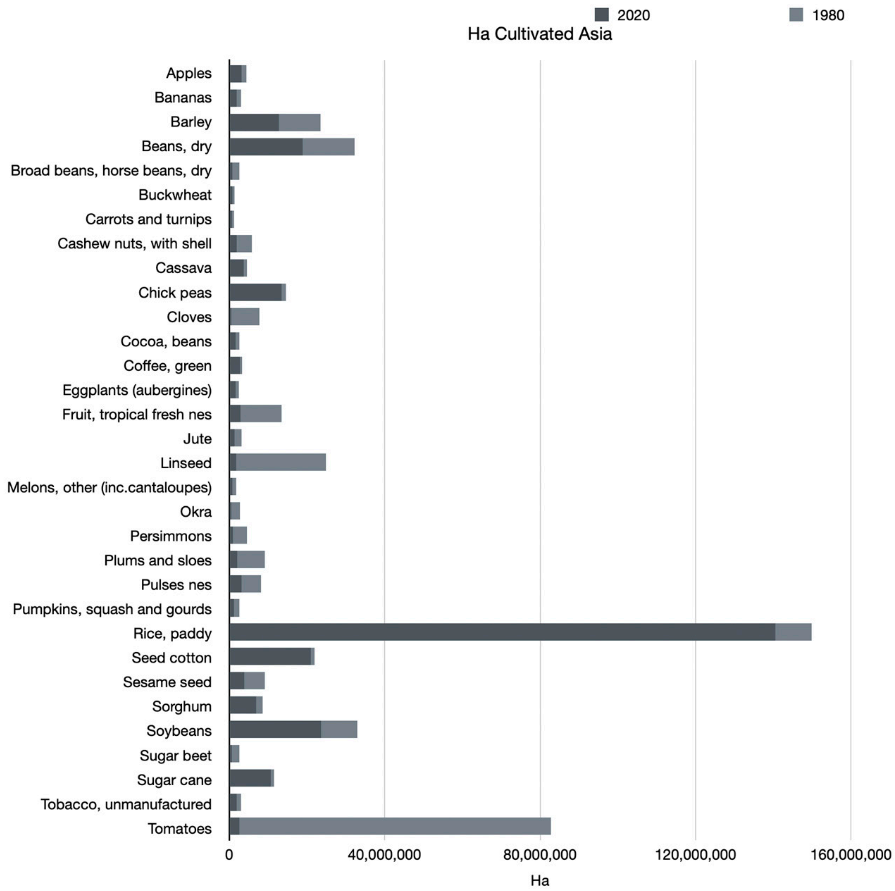

Figure 2. Crops production with an extension higher than 100,000 Ha in Asia, adapted from [25].

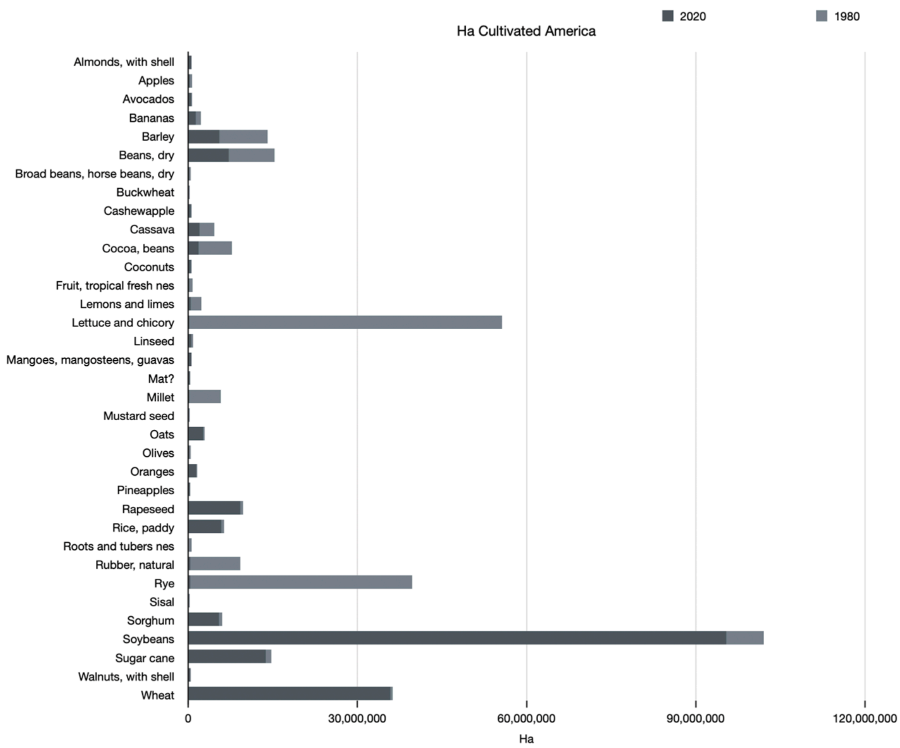

Figure 3. Crops production with an extension higher than 100,000 Ha in America, adapted from [25].

2.1. WEF Analysis Tools

Concerns about SDG's achievement have promoted the development of tools for synergies analysis, and trade-offs' quantification. When the analysis relies on realistic models and accurate data it is easier to achieve their goals. Research on WEF systems initially focused on correlations between two systems, and how do they account system externalities such as changes in climate through GHG related emissions or population increases, although challenges increased for studying the interconnection of the three elements of the nexus.

Table 3 shows WEF nexus assessment tools considered in this research. Among these, it highlights WEF Nexus Tool 2.0 [26]. In this tool, the user identifies data inputs from the systems' food, water, and energy portfolios, agricultural conditions, and food import–export data for assessing requirements of the systems among other indicators. Developed for Howels et al. [27] CLEWs (Climate, Land-use, Energy–Water strategies) this open-source tool investigates how a changing sector influence other. This is done by indices development, scenario making, and forecasting. Focusing in small islands, the KTH Royal Institute of Technology investigates these interconnections [28]. It is also to mention the Nexus Assessment framework [29] that looks at power irrigation, bioenergy, hydro-power, or water desalination interventions to evaluate water, energy, food, labor, and cost components. They proposed the Nexus Rapid Appraisal tool for indices development. Among quantitative tools, it highlights MuSIASEM that focuses in water, energy, and food systems, in relation to socio-economic and ecological variables. Giampietro et al. [30] analyzed the 'metabolic pattern of energy, food, and water' for land-use changes evaluation, population dynamics, or GHG emissions. According to this approach MuSIASEM [31] provides quantitative information for discussing constraints such as feasibility to refer to the availability of natural resources, or environmental services in relation to the required supply and sink capacity. The viability concerns in this tool consist of internal constraints imposed through the metabolic pattern by the human socioeconomic system. Allwood et al. [32] designed the Foreseer Tool. By using Sankey diagrams, this tool allows users to track water, energy, and land resources through the production chain. Developed by Stockholm Environment Institute, two software models [33] for supporting and analyzing the water–energy nexus: WEAP (Water Evaluation and Planning System) and LEAP (Long Range Alternatives Planning System). It is also to highlight the integrated Sustainable Development Goals Planning Model (iSDG Planning Model) consisting of a tool for evaluating trends towards achieving SDGs according to defined scenarios [34]. Only by focusing on quantitative data, Rosales et al. [35] built a sustainability index for quantitative analysis of water consumption, and CO_2 evaluation of different energy electricity generation programs. Among the quantitative–qualitative approach is to highlight the European project: "Moving Towards Adaptive Governance". It proposed the Quantitative Story-Telling (QST) approach [36] that uses narratives to elucidate different points of view about the analyzed system highlighting implicit assumptions and uncertainties. This analysis also relies on multi-scale resource quantifications for evaluating nexus interconnections. In addition, it includes the opinions of involved actors for of building narratives. First it maps actors for narratives identification. It quantifies nexus relations through quantitative tools. Other tools included in this approach are: socio-institutional analysis, media analysis, interviews, coding, and surveys to farms and food industries to be included. In the next step, an analysis is developed for quantitative and quantitative data to build feedback on narratives. From the mixed analysis of narratives, it presents different storylines. In a next step, they are assessed under different scenarios. Finally, a longitudinal analysis and synthesis of results infers lessons and policy impacts that can be assessed. QST draws upon qualitative issues only when the analysis includes constraints to the system and trade-offs between systems [37]. Cabello et al. [38] used the narratives of involved actors for identifying convergences. SDG's also used qualitative and quantitative considerations. First: a pair of (water, energy, or food) SDG targets are selected, assigning a number for identifying when the objectives compete for the same resource.

Table 3. WEF Tools performance reviewed in this research [31–38].

Objective	Calculation Tool	Model Capacity	
Forecasting and analysis of scenarios	WEF Nexus Tool 2.0	Quantitative	
Forecasting and analysis of scenarios, index calculation	CLEWs	Quantitative/	Qualitative
Calculation of performance assessment considering five different parameters	Nexus Rapid appraisal	Quantitative	
Scenario analysis and forecast scenarios model	MuSIASEM	Quantitative	
Water, energy and land trade-offs prediction	Foreseer Tool	Quantitative	
Forecasting and analysis of scenarios	WEAP-LEAP	Quantitative/	Qualitative
Forecasting and analysis of scenarios	iSDG Planning Model	Quantitative/	Qualitative
Energy and climate mitigation models	Sustainability tool	Quantitative	
Multi indicator analysis	WEF nexus indicator	Quantitative	
Analysis of policies and narratives on governance.	QST	Quantitative/	Qualitative

2.2. WEF Analysis Examples

The complexity of systems involved include among others, different grades of economic development, climatic regions, development of energetic systems that makes it more difficult to model the systems. Analysis of WEF systems analysis examples lets one find gaps, future development, as well as goals. Wang et al. [39] analyzed WEF nexus synergies in a water scarce region of China, from 2005 to 2017. They focused in population, arable land, energy consumption for analysing the problem. On the other hand, qualitative study such as the one developed by Yuan et al. [40] discussed urban priority development strategies in Amsterdam, Eindhoven, Taipei, and Tainan. They highlighted the importance of renewable energy for WEF nexus systems' sustainable management.

Some are the actions that aim to lower environmental threat. The problem of the lack of effective and efficient water pumping technology for smallholder farmers. The problem of sugar beet can be included for synergies analysis. Some like Silversands Ethanol company [41] produces ethanol from sugar beets in South Africa. These crops need 530 mm of water for crop maturing, which is equal to the annual rainfall in the region. The problem appears under lack of water scenarios, when irrigation is needed under droughts scenarios. Sugar beet's water efficiency is around 60 m^3/GJ compared to sugar cane's water efficiency of 110 m^3/GJ for ethanol production. From a quasi-qualitative manner, this example created 31 jobs in 2009. The incentives for a nexus approach include economic efficiency, resource efficiency, and improved livelihood options [42,43]. Cheng-Ting et al. [44] analysed the economic performance of different crops deployment joint to the operation of a wind turbines, and proposed small-scale and renewable based irrigation systems could provide a viable alternative to polluting fossil-fuel powered generators. Brazil's biofuel industry is based on sugar molasses for bioethanol while crops for food production increase. In addition, in India's incorporate non-edible oil for biodiesel production. These processes are not competing with land and water resources. Since it is a residue of the sugar industry, bioethanol from molasses does not add further stress on land and water resources [45]. Water conflicts for agricultural activity and energy generation exist in Ethiopia, as they do throughout Asia and Africa [46–48]. By exploring WEF nexus synergies within the Shenzhen region, Li et al. [49] proposed stabilizing water supplies, coordinating energy exports and reducing crop sowing areas for improving synergies. Bian et al. [50] built a methodology and frameworks to find study linkages between water, energy, food, and other components, in Asia, Europe, America, and Africa. They also classified the studies according to water–energy, water–food, water–energy–food, water–energy–land–climate nexus approach. Zhang et al. [51] analyzed the complex WEF relationships in the Manas River Basin which is located in the inland arid area of northwest China. Through an analysis of main productions and consumptions of agricultural, animal husbandry, and industry statistics he highlighted that water footprints of agriculture and livestock products is much higher than the water footprints of energy consumption.

A renewable-powered desalination plant involves interconnected systems that synergies between WEF systems increase as long as they make use of more energy than in standard water supplying techniques, and renewable energy intends to reduce this energy environmental impact. As long as the system provides water for crop production, the synergies between systems increase as well. Provided that the facility shares the surpluses of generated energy, synergies will increase as well. According to this scheme, Rosales et al. [52] found a standard water cost of 0.5 to 0.6 EUR/m^3. As desalinated water demand increases costs and emissions as well, leading to a higher climate change risk itself. This fact threatens the achievement of sustainable development goals in these regions. The scheme combining renewable energies with the amount of water resource provided by desalination plants can be used to compensate for the intermittent nature of primary renewable energy sources. improve the manageability of this "combined resource" water–energy in a region that its managed. In isolated systems like islands, they suffer more than any other WEF system although these are well-defined systems, where inputs/outputs enter only by plane or ship that WEF systems trade-off analysis becomes easier. They cannot receive water transfers provoking harder conditions for agriculture, or livestock, becoming even more difficult in those at high water scarcity risk. In addition, the more synergies between water and energy systems, the more joint development that can be achieved. In systems where the desalination industry is essential provokes higher prices in agriculture, livestock, among others. Independent of the desalination technology, it accounts for 60–75% of total costs increasing water and energy WE synergies. As previously mentioned, synergies between the water and energy systems let one reduce water costs only by implementing renewable energy generation means in the pumping, and/or in the desalination process. Borge et al. [53] proposed a strategy for locating facilities that increase a sustainable operation of desalination plants. They also analyzed the economic performance of a hybrid renewable powered desalination plant for testing market profitability as well as the economic and environmental consequences [54].

3. Analysis

This section discusses what the challenges are when facing WEF sustainable management of the systems. The final goal is to investigate the feasibility of solutions for increasing the synergies between resources for lowering climate change associated impacts. Institutions such as UNECE (United Nations Economic Commission for Europe), International Renewable Energy Agency (IRENA), or Food and Agriculture Organization of the United Nations (FAO) [55–57] analyzed ecosystems nexus synergies from a sustainable approach. Some proposed tools comparison charts to compare different tools and identify relationships and synergies between sectors [29]. Dargin et al. [58] classified tools according to a complexity index that intended to model their complexity and suitability. Due to the amount of population, and warming rates MENA (Mediterranean and north Africa) region is among the most threatened areas that also increase water restrictions. In order to develop a complete assessment of proposed actions, these tools must assess the technological, economic, or environmental development in the short, medium, and long-term.

3.1. Feasibility Assessment

Through proper synergies' definition, these tools intend to find a solution for joint management of these three resources [24]. Innovation highlight as a facilitator for taking advantage of synergies between systems although their implementation will face risks also related to the grade of synergies development. The feasibility of actions taken, or scenarios tested with WEF nexus evaluation tools should be assessed, in the short as well in the medium and long term. In order to analyse the deployment of WEF nexus innovations, it is important to investigate the technologic, economic, practical, and environmental performance in the short, medium, and long term. Figure 4 show how to evaluate strategies that hypothetically increase synergies. The multiple point of view approach must include a technological, environmental, and economic evaluation of the proposed actions, or the actions to take. Risks, opportunities, as well other issues for citizens, firms, and governments must be investigated for identifying gaps, errors, that decrease sustainable management. Through case study analysis, it is possible to inform not only the quantitative results of actions taken, but also of qualitative aspects at policy and social level.

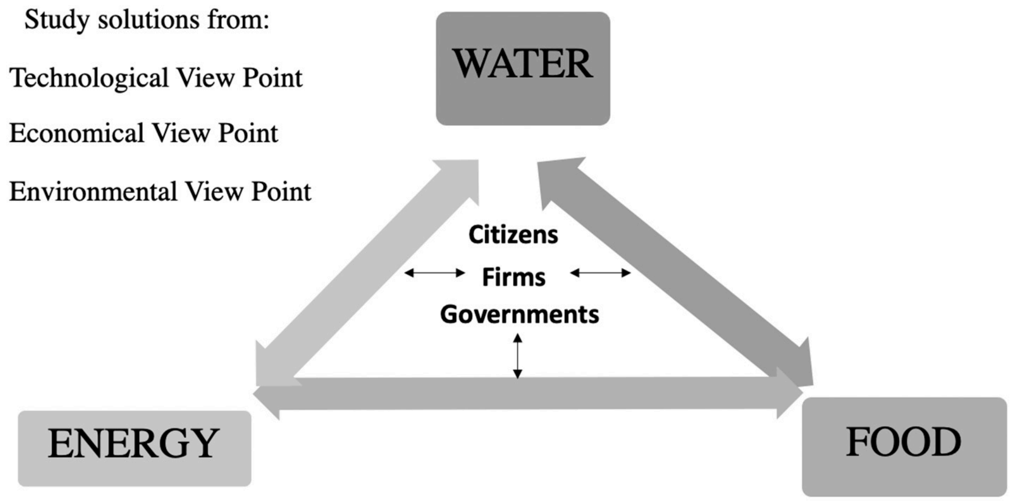

Figure 4. Environmental approach for WEF systems management.

3.1.1. Technological Evaluation

At the technological level it is mandatory to assess the performance of the innovations that increase the sustainable operation of WEF systems. The system analysis with WEF tools depicts the interactions to be further developed for increasing synergies. These must be technologically assessed for detecting innovations that increase synergies.

3.1.2. Economic Analysis

As long as sustainable approach in synergized systems include investment, among the objectives for the evaluation of innovations that boost synergies it is mandatory to evaluate its economic behavior. Target fulfilment in one subsystem would ultimately require share investment with other systems, and if properly developed, it must be properly evaluated. An economic feasibility assessment should be developed in order to verify their economic performance, and to identify shortage of customers for the generated products by the type of business.

3.1.3. Practical Application

It is a well-known fact that adaptation can reduce climate change impacts risks. The potential for adaptation, as well as constraints and limits to adaptation, varies among sectors, regions, communities, and ecosystems. Actions taken, or that to be taken also must be analyzed from a practical point of view. The sustainable narratives that explore synergies are analyzed including risks management issues at a short, medium, or long-term, or because of the deficient development of the various information systems associated with the innovation.

3.2. Involved Actors

Different actors are involved in WEF nexus synergies. Citizens not only strongly impact in environment sustainability, but also suffer from water scarcity, water resource access problems, longer droughts periods, food, and energy security problems, but they do not have influence in the food production system. Involved actors can direct, or indirectly affect the actions that tools suggest. Table 4 defines the influence they have in nexus management issues.

Table 4. Relationships between involved actors.

	Governments	Firms	Citizens
Technological	Directly	Indirectly	Indirectly
Practical	Indirectly	Directly	Directly
Economic	Directly	Directly	Indirectly
Environmental	Indirectly	Directly	Directly
Water System	Directly	Directly	Directly
Energy System	Directly	Indirectly	Directly
Food Production System	Indirectly	Directly	No Influence

Among these relationship highlights:

- Governments are the actors who own the power to influence in management issues through politics, plans, programs, taxes, bills. Governments "own" the power to define, and regulate relationships between firms and environment: mainly water, land, or emissions. Additionally, they promote innovation investment programs to boost technology knowledge in different areas, although often did not focus on the interlinkages.
- Firms mainly impact the environment through the productive system, the supply chain, and their relationship with costumers. In addition, they indirectly have influence in politics, as long as they participate in a free-market scenario. In addition, transport companies strongly impact environment. As firms are expected to improve their economic performance, they are affected by sub-systems trade-offs quantification either at the local, national, or international level. The interconnection between these levels also provokes consequences in the systems that they are trading with. In addition, investors are not attracted to using integrated methods like the WEF nexus because existing subsidizations do not focus on the nexus as one system.
- Citizens are those who consume goods and resources, and decide what governments may promote, and might be influenced with. Small systems, such as neighborhoods, small towns, or islands among others own high-qualitative knowledge about regional concerns.

4. Discussion

Methods for nexus assessment depends on the scales, goals, and data availability. As can be seen, tools intend to model system or creating narratives for the management of the systems. It is clear that quantitative tools offer further insight into the nexus, simplifies policy evaluation, and a guidance to stakeholders. Although food industry GHG emissions is often focused in food transport, these are also due to agriculture, and livestock farming in related processes. Saladini et al. [59] evaluated freshwater withdrawals in agriculture production, although GHG emissions of the agri-food sector should be further evaluated for a better understanding of the problem [60]. Similarly, methodologies for estimating biomass and biofuel emissions from combustion [61] should be further investigated for increasing trade-offs knowledge. Joined to estimating emissions from transport, energy generation, others complete GHG emissions estimations, and future development can be used to completely assess the sustainable performance of actions proposed. The SDG (Sustainable Development Goals Index) [62–64] must rely on real and accurate information. Despite most OMC's countries develop sustainable programs for decades; governments as well in different economic conditions may provoke change of proposed actions. Regions are not equally prepared for adopting different solutions. Botai et al. [65] reviewed the overall change in WEF management approach in Africa for analysing how they varied.

It is worth mentioning that greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits. It is especially important to quantify trade-offs between water–energy–food systems for a proper modelling system [66,67] that increases the understanding of the problem. It is especially important to provide urgent solutions for threatened systems like those presented here. Specifically, Gulati et al. [15] identified challenges and opportunities for food security in South Africa. As QST [37] combines quantitative as well qualitative indicators for nexus assessment leads to a better definition of trade-offs between systems this tool stands out as a solution for sustainable management. Similarly, software development with agile tools that mixes quantitative indicators fulfilment with qualitative opinions of developers, QST permits an increasing flexibility when actions and politics are revised. On the other hand, QST do not assess the interlinkage level between sub-systems. As renewable energy electricity deployment is increasing globally, it opens a medium- and long-term synergy development scenarios at either technological, economical, and environmental points of view. Figures 5–7 propose an approach for actions that can be taken for WEF systems sustainable management.

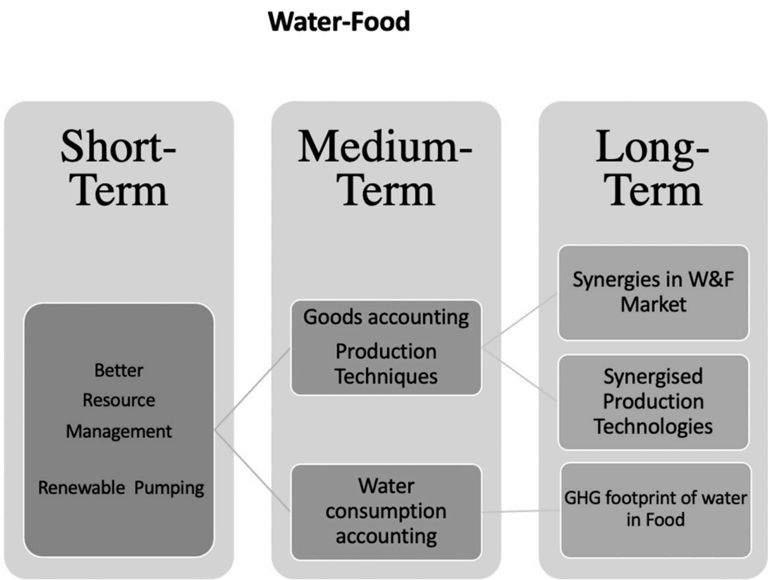

Figure 5. Sustainable environment approach for WEF systems management.

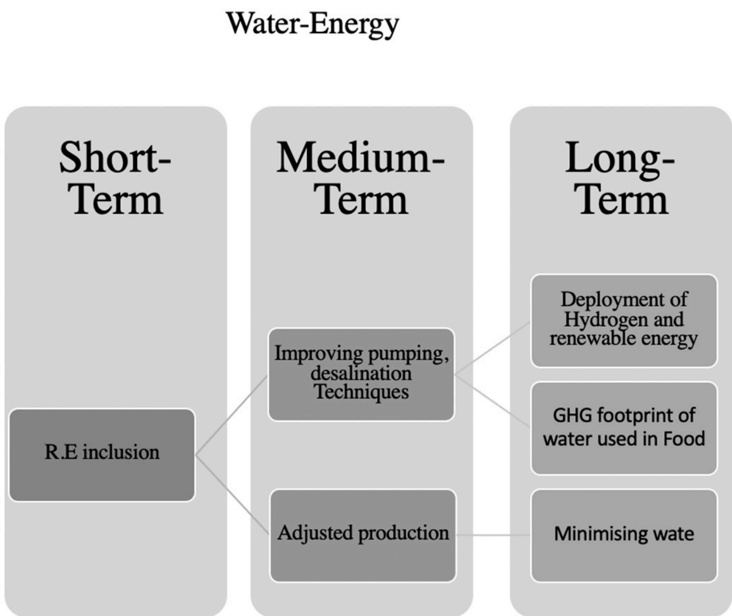

Figure 6. Sustainable environment approach for WEF systems management.

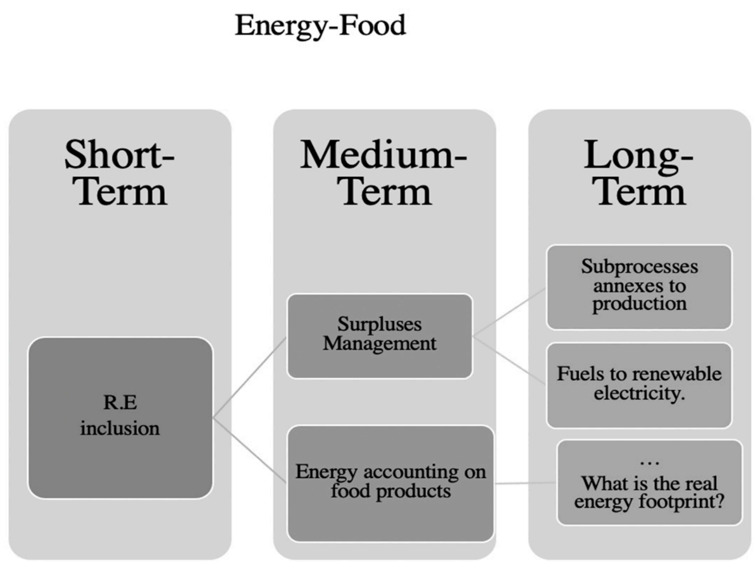

Figure 7. Sustainable environment approach for WEF systems management.

Synergies sometimes becomes risks when different SDG's are competing for the same scarce resource. Actions taken in one subsystem might lead to higher risks in other sectors. For example, environmental costs of water pumping between facilities with a high-share resource degree is reduced when they are closely located. Biofuel crops have certainly environmental advantages including improved sequestration of carbon in the soil, reduced soil erosion. On the other hand, dedicated energy crops are competing for the same resource, land, and water. First generation biofuels' production leads to water depletion and scarcity for agriculture, leading to an increased competition for water, affecting negatively their food security [60,61]. Among the additional environmental impacts associated with feedstock cultivation include biodiversity loss, water consumption, and reduced water flows, water quality and effluent run-off problems, and land degradation. As can be seen in Figures 1–3, the exponential growth of cultivated surface in these regions may lead to systems overexploitation. Increasing demand for biofuels impact these systems as well. On the one hand, as competition for water and land resources increase, price is expected to increase as well. This fact may lead to food security problems. Only two countries, USA and Brazil took up 460 million tons of maize and sugarcane, respectively, for producing biofuel [24]. On the other hand, when processed from agricultural residue crops outstands as a solution to produce biofuels because there are no requirements for additional water and land. Generally, perennial trees do not need dedicated inputs and can even promote land restoration, although harvesting these crops is generally harder than dedicated crops. In a short–medium term energy management is supposed to play an important role for increasing renewable energy use. It is basic accounting in ways for managing or storing electricity surpluses from renewable energy generation. The excess of energy to power chemical batteries, produce hydrogen are examples for the medium- or long-term deployment to be analysed from the aforementioned perspectives. It is mandatory to investigate how to take advantage of the water, energy, and food system joint operation. Rosales et al. [68] investigated how to reduce water stress in regions at high water scarcity risk with desalinated water, leading to increase synergies between subsystems.

On the other hand, the strategy proposed does not account for the positive effects of synergies with sectors such as capital goods, steel, etc. that also interfere with WEF management, but others at an early stage of development such as big data, information technologies, artificial intelligence, and real time information development. Despite most tools including a quantitative approach for assessing tradeoffs, real data of resource generation and consumption still remains uncounted. Among other impacts, it would allow regions forecasted of water scarcity to develop sustainable businesses models, in addition to the positive effects on the income effect, the push and pull effect on related sectors, upstream or downstream. Synergies between electricity and water markets can be analysed from different perspectives in the long term. The evaluation relies on the implementation of a decision-making system that control the "combined resource", acting in markets under different rules, where the water resource provision surrounding orchards and population. Only by exhaustive water accounting would it be able to assess the amount of water comprised in the food system, in the energy industry, and in the food processing industry. It could be mandatory to include in food labels the accounted amount of energy for processing the product. This issue let to classify products according their energy, and eventually GHG related emissions. Through interlinkages matrices nexus tools can evaluate synergies and trade-offs. For setting sustainability indicators either at local, national, or international level it is mandatory to account for data from different organizations or initiatives, such as from FAO. These indicators are basic for assessing the sustainability of the ecosystem.

Among others examples of opportunities in related-systems to be analyzed include lowering food wastage, as well as municipal water leakage. These actions engage citizens, firms as well as governments. A complete understanding of the environmental consequences of increasing yields on large-scale versus crop production in smallholder farms must be assessed for governments, researchers, and firms. Similarly, increasing transport fuel efficiency, or increasing penetration of electric and hybrid vehicles draws directly on the same actors, although highly dependent on citizens decisions. Improving irrigation techniques, or water use in power plants also relate directly or indirectly to different actors. Only by analyzing the economic, technological, practical, and environmental performance of these and other opportunities could the sustainability of actions taken or to take be assessed. The more synergized the system, the more the reduction in GHG gas emissions can be achieved through combined operation of the systems. Only by locating facilities near each other lets reducing energy consumption of the sustainable-synergized system. Sustainability performance of renewable powered desalination plants that provide water for crops can be improved reducing the distance between facilities. On the other hand, WEF Nexus sustainable management faces problems when competing with world trade agreements. When synergizing WEF systems it is important to figure out total costs of food products because this offers governments extra information for eventually taxing products according to their sustainable performance. How to evaluate environment threat concerns versus social advantages of job creation must be further investigated. Depending on the initial conditions of the systems it may be desirable to boost one action, or another. Citizens do not have influence on crops production techniques, although they decide the products they consume. This results in a complex decision structure that selling techniques or environmental concerns of citizens must be considered despite different objectives to meet.

5. Conclusions

In light of the developed analysis, difficulties and gaps for sustainable management of WEF systems are identified. Assumptions made in these were analyzed for a better understanding of sustainable WEF problem. Scarce resource use optimization concerns cause the appearance of WEF systems analysis tools. By identifying and defining the interlinkages and relationships between these systems, tools intend to improve resource allocation management strategies. Either at the system design stage, or to analyze the performance of actions taken, the presented scheme intends to take advantage of synergies between water, energy, and food systems for increasing the sustainable performance of the system.

Because the complexity of interconnections, synergies, and actors in multiple levels, and scales, different WEF-nexus tools and approach define the synergies between systems under multiple points of view. Mainly focused on quantitative and qualitative concerns, as lessons from its implementation are drawn, and relationships between systems further defined, these tools must be constantly improved. Only by increasing the knowledge of synergies and through the development of resources, and trade-offs accounting systems, tools and frameworks might lead to a complete understanding of WEF systems that allow corporations, whether public, or private to compare between alternatives when evaluating the water–energy–food problem. Depending on the scale of a WEF analysis, involve different actors such as key decision-makers, companies, and inhabitants in a participatory environment over a short, medium, and long term. Although, tools lack a sustainable actions definition and performance evaluation tools for improving WEF sustainable management. Through WEF indexes, evaluation could be assessed for the WEF sustainability performance of food products that may lead to political proposals for markets based not only in monetary decisions. Specially this is important in poorer, and water scarce regions, such as developing countries in Africa and Asia that also have less laws for environmental protection. Not only analyzing proposed actions from a technological, economic, or environmental point of view across actors involved in the nexus management issues, but also from lessons learned, can proposed strategies for increasing positive synergies impact that constantly improve scarce resource utilization. Tracking energy costs of food products is mandatory for offering costumers the total costs of the products they are consuming.

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Nomenclature

BAU	Business-as-usual scenarios
CLEWs	Climate, Land-use, Energy-Water
FAO	Food and Agriculture Organization of the United Nations
GHG	Green House Gas
Ha	Hectare
IRENA	International Renewable Energy Agency
iSDG	Integrated Sustainable Development Goals
LEAP	Long Range Alternatives Planning System
MDG	Millennium Development Goals
MENA	Mediterranean and north Africa
QST	Quantitative Story-Telling
SDGs	Sustainable development Goals
UN	United Nations
UNECE	United Nations Economic Commission for Europe
WEAP-LEAP	Water Evaluation and Planning System
WEF	Water, Energy, and Food

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