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Water-Energy-Environment Nexus Analysis Tools: Case Study for Canary Islands

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Abstract: Despite that previous research exists, there is a need for further research on the quantitative aspects of this Nexus. Existing Water-Energy-Environment Nexus management tools and frameworks are based on indicators aiming to model the whole system, analyze the involved resources, and test potential management strategies. The environmental, social, and economic consequences of actions already taken and ongoing projects require important focus because of the strong relationship between water and energy supply, and that both are key issues for society's development and sustainability. The present research focuses on the indicators that the Water-Energy-Environment Nexus tools and frameworks use to analyze the whole problem. Existing tools often require large amounts of data, becoming a time-consuming process that lowers the capacity to evaluate the political problems of high pollutants. With the aim of accelerating time evaluation, this research builds an indicator to rapidly evaluate the Water-Energy-Environment Nexus implications of replacing fossil-based power generation systems with wind and photovoltaic renewable energy systems in the water-scarce region of the Canary Islands. This indicator allowed the rapid evaluation of storylines in a small system with well-defined boundaries. Results show that the water sustainability index improved by 6.2% in comparison to fossil-based plants, while reducing 2750 tons of CO_2. Although this methodology can be easily applied in different scenarios and locations, it further development to evaluate system boundaries and to provide extensive results.

Keywords: Water-Energy-Environment nexus; analysis tool; renewable energy; greenhouse gases; sustainable development goals

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1. Introduction

From product manufacturing to transport or energy generation, among others, all human activities heavily impact the environment. Rapid population growth reduces the earth's ability to provide basic resources [1]. For example, with regard to food needs, Crosson et al. [2] predicted a substantial increase in the food production required to satisfy future requirements. As far as basic resources are concerned, this highlights the increase in energy and water needs. The water and energy (WE) systems are strongly connected and are directly responsible for an important share of Greenhouse Gas (GHG) emissions. Among other needs, energy is required for pumping, moving, distributing, and treating water, as well as in the construction of large-scale supply infrastructure projects. In addition, water is needed for irrigation, but also in industry or in energy production. Due to this fact, it appears that there is potential for improving water use efficiency through the indirect improvement of the whole energy system. Folke et al. [3] discussed the challenges facing humanity in reducing environmental impact and identified the potential and necessity for interdisciplinary collaboration to address these challenges. The nexus approach aims to enhance water, energy, and food security by increasing efficiency as a whole. Estoque et al. [4] reviewed the origin of nexus thinking in societies (addressing sustainability challenges) and highlighted how this increased in complexity and diversity. Nexus thinking discusses, among other aspects, how trade-offs can be reduced, how to build synergies, and how to improve governance across sectors. In order to enhance governance, it is crucial to adopt an integrated approach to policy-making and decision-making that considers external costs across sectors, space, or time. This is vital for addressing the needs of the most vulnerable and impoverished populations. These poorest populations often lack access to clean water, sanitation, or modern sources of energy. Oxford's Lexicon [5] defines nexus as "a connection or series of connections linking two or more things". In this context, this term refers to a study of dependencies and interdependencies among two or more elements [6].

According to De Laurentiis et al. [7], it is important to distinguish between nexus thinking and silo thinking. The nexus analysis addresses the joint management of systems. This definition focuses not only on the definition of synergies and trade-offs among systems, but also on social–ecological issues, in order to boost positive interactions. In this sense, trade-off consists of actions or strategies that cause a beneficial impact on a system, but a detrimental impact on the related system [8]. For example, generating energy electricity in coal-based thermal power stations generates GHG-related emissions. Synergies are known to be an interaction between two or more components, including social–ecological systems. On the other hand, management strategies sometimes provoke co-benefits, consisting of positive impacts both in the system where the action takes place and in the other considered system. Unexpected impacts on the systems should also be taken into account.

Firstly, researchers focused on the definition of trade-off. Secondly, the definition of systems became an important consideration for accounting trade-offs in tools. The greater the specificity of the trade-off definition, and the more aspects included, the greater the level of effort required to model comprehensive tools that assess the entire system. In order to deeply investigate these interactions, it is common to focus on dual systems: water and energy, food and energy, or food and water.

The complexity and diversity of tradeoffs and interactions between systems have led to the emergence of indicators that are used for trade-off and co-benefit evaluation. The Water-Energy-Environment (WEE) nexus approach focuses on WEE systems to analyze the problems directly related to WE nexus management. Approaches and tools have increased lately. In this process, the analysis of evaluation tools and the indicators that they consider, as well as how they model the consequences of already taken actions, help identify gaps, goals, and future development needs.

The modeling of WEE system interactions requires more effort, resulting in increased processing requirements for the tool. Authors such as Zhao et al. [9] focused on the WEE urban environment. In this growing water and energy needs scenario [10], decision-makers need effective decision tools for assessing the WEE resource allocation problem. They are also needed to strengthen adaptation and mitigation strategies to cope with the effects of climate change. In order to enhance the efficiency of water and energy use, WEE analysis tools are mandatory to test and evaluate the sustainability and the performance of the adopted strategies. Sustainable performance can be assessed by means of indicators for quantifying exchanges between systems, and analyzing how they take place is vital for reducing the use of resources and related emissions.

Another important term to consider when analyzing the sustainability of actions taken is the development pathway. This term relates to the direction in which the systems flow over time. Whether the expected scenario concurs with the results can be analyzed, considering all the actions taken. On the other hand, the cascading effect refers to the consequences that actions in a system have on others. Hoffman et al. [11] suggested that, by identifying key indicators, the outcomes of various development pathways could be predicted. However, the timeframe for delivering results was not taken into account. Especially in threatened systems, such as islands, where it is harder to provide water and energy, sustainable projects have often been launched to optimize the use of resources [6,7].

Efforts centered on analyzing and evaluating the sustainable performance of previously implemented actions [7,8,12,13]. This was crucial for quantifying the trade-offs between systems and, henceforth, determining objectives, shortcomings, and measures, although its applicability to the decision-making process lacks rapid evaluation tools for quantitative results.

The Quantitative Story-Telling (QST) [12,14] approach uses narratives to follow different paths in relation to the analyzed system. QST is a technique used for proposing narratives. Hypothetically, these narratives drive the story according to a defined path, for example, managing electricity surpluses from RE generation. Narratives often do not rely on quantitative accounting and, due to this fact, forecasting tools are mandatory for assessing the tradeoffs between the nexus subsystems. For instance, evaluating the social advantages of job creation is an example of a qualitative narrative that cannot be easily analyzed from a quantitative point of view. From satellite images to data bases, many data sources can be used for indicator development. Lodge et al. [15] reviewed the available data sources for modeling the WEF nexus. For assessment of the quality of the ecological environment, image processing is commonly used. Hanqiu [16] developed the Remote Sensing Ecological Index (RSEI) to monitor the changes in the ecological environment. An et al. [17] studied the influencing factors on the ecological environment quality in the Three Gorges Ecologic Economic Corridor. They noted that anthropogenic factors, such as population density, urbanization rate, or agriculture, among others, impact environmental quality negatively, and verified that some of these varied throughout the 18 years of data research.

There are many models and tools to assess the Water-Energy-Environment nexus [18,19], although it is not clear how they include factors such as rainfall and its consequences on the environment. It is common that models and tools consider quantitative and/or qualitative indicators among the nodes. During the last few years, many tools have been released for modeling and accounting trade-offs between systems, to evaluate scenarios, or to forecast the consequences of each decision. Dai et al. [20] reviewed the scopes of different WE nexus methods and classified them according to the nexus challenge (understanding, governing, and implementing) and the method employed (quantitative, simulation, or integrated method). Berger et al. [21] analyzed the sustainability indicators contained in sustainability frameworks. In the WE nexus management approach, qualitative indicators often appear when storylines and narratives are deployed. In order to perform a social assessment, it is common that non-accountable indicators rely on the opinions of experts in the matter [22]. Among the most outstanding tools, we can highlight:

- WEAP and LEAP [23,24]. WEAP is a model designed to forecast water inflows and outflows. This tool also considers water quality or the preservation of ecosystems, although it is complex and needs especially high data. WEAP can also be integrated with LEAP to conduct WE analysis. Authors such as Siddiqi, Kajenthira, Anadón [25] and Chiu and Wu [26] analyzed different regions and highlighted that, due to data extensiveness, the complexity of the study increased.
- Climate, Land-use, Energy, and Water (CLEW) [27] is used to forecast and analyze scenarios. It integrates the energy models LEAP, WEAP [23,24], and the Global Agro-Ecological Zoning Model (GAEZ) [27,28]. This tool uses the Open-Source Energy Modelling System (OSeMOSYS) [29] that has been also applied to policy making.
- MARKet Allocation (MARKAL) [30] is a mathematical model generator that creates an energy model based on real and accurate data with a time horizon from 20 to 100 years. This tool evolved into the embedded MARKAL-EFOM (Energy Flow Optimization Model) system known as TIMES [31]. MARKAL is used for energy modeling, capturing energy complexities, showing time projections, and evaluating long-term sustainability goals, although it needs extensive data inputs, being inappropriate for planning in the short term [32]. In addition, FAO developed MuSIASEM—The Flow-Fund Model [33] that studies the socio-ecological behavior of societies, assuming that they interact in a system. As an analysis tool, it offers a quick overview of a current

metabolic process in a society [34]. MuSIASEM offers quantitative information to discuss limitations provoked by humans, and others that are not under human control, on viability, in order to describe the existence of natural resources [35]. Serrano-Tovar et al. [36] highlighted the capacity of MuSIASEM to investigate the sustainability of nexus systems. From periods of economic downturn [37] to the study of oil extraction [38], this tool has been used to forecast the energy metabolism of systems. These tools rely on indicators as well as extensive data to forecast the consequences these actions have on the system.

The primary aim of this article is to evaluate the methodology for measuring the sustainable performance of actions within the nexus of water, energy, and environment. The index this research proposes specifically focuses on the quantitative consequences of deploying several energy plans. Additionally, we propose an index to quickly analyze a case study in the water-scarce Gran Canaria Island system, located in Spain. In order to do this, this research reviews the most commonly used tools in the Water-Energy-Environment nexus analysis. Secondly, this text examines the indicators utilized within these frameworks before presenting an index that enables the rapid evaluation of the interlinkages between energy, water, and environmental systems. Finally, this index is used for measuring the sustainable performance of energy strategies. It will be possible to analyze the effects of various power generation scenarios. This paper discusses the isolated, water-scarce, and energy-pollutant system of Gran Canaria. With the proposed index, it will be possible to quickly forecast the consequences that deploying RE plans might have on the water and emissions systems, and, therefore, the nexus between the involved systems.

2. Water-Energy-Environment Management Concepts

Organizations such as the United Nations Economic Commission for Europe (UNECE), International Renewable Energy Agency (IRENA), or Food and Agriculture Organization (FAO) of the United Nations [39], among others, reviewed the synergies of the ecosystems for analyzing sustainable operation, and they proposed the use of indicators for nexus assessment. Among the tools for reviewing and studying the nexus, comparison charts are used to identify relationships between the analyzed systems. In order to assess trade-offs and interconnections, it is important to define boundaries between systems and different scenarios. Endo et al. [40] focused on the trade-off of evaluation analysis. There are many indicators for measuring WE trade-offs and they can be determined through different methods. The methods to determine the validity of proposed indicators include trade-offs assessment. Haghjoo et al. [41] proposed indicators to validate the links between water and energy security. Xu Hanqiu [16] proposed four indicators of greenness, humidity, dryness and heat. The indicators also depend on the methodologies used; for example, Material Flow Analysis (MFA), Life Cycle Assessment (LCA), and Data Envelopment Analysis (DEA). An et al. [17] noted that air quality is of great importance in measuring ecologic environment quality (EEQ) and used night light data to dynamically monitor carbon emissions (CE).

2.1. Use of Indicators

Different methods have been employed for assessing the indicators that highlight WE for food production and irrigation nexus management. It is common for tools and approaches to group measures related to the energy and water supply security nexus around specific categories: affordability, availability, ease of use, and consistency. Different authors have reviewed the tradeoffs between water and energy systems. Sun et al. [42] highlighted the complex coupling between water, energy, and environmental pollutant subsystems, and developed an integrated analysis at three levels. In order to fully understand the complexity, they proposed three indicators that were assessed at three levels, including WEEN correlation intensity. Yin et al. [43] proposed a nexus system model where relationships were quantified by optimizing the water resources system under different scenarios that were weighted in multi-objective programming. In addition, different indicators can be used for sustainability assessment. Berger et al. [12] analyzed the frameworks containing these indicators and highlighted the limitations of the trend indicators. One of the most important is the clear distinction between analytical sustainability factors, which can be used for the quantitative analysis of trade-offs between energy and water systems. Different indexes can be developed from the indicators for representing tradeoffs between systems. Figures 1–3 show indicators sorted according to water, energy, and food. It highlights water prices as a key indicator of accessibility. Gonzalez-Garcia et al. [44] investigated sustainability in cities considering environmental, social, and economic parameters. Among the environmental indicators, their research highlights emissions, electrical consumption, waste generation, packaging recovery, and others. Da Silva et al. [45] analyzed 18 methodologies and selected 396 indicators to analyze municipal waste management. They weighted them according to sustainability criteria importance, highlighting measurable, viable, dynamic, or simple qualities, among others. They also highlighted some key aspects, such as water usage, energy generation, disposal of wastewater or total installed capacity of renewable energy generation, or costs of energy recovery.

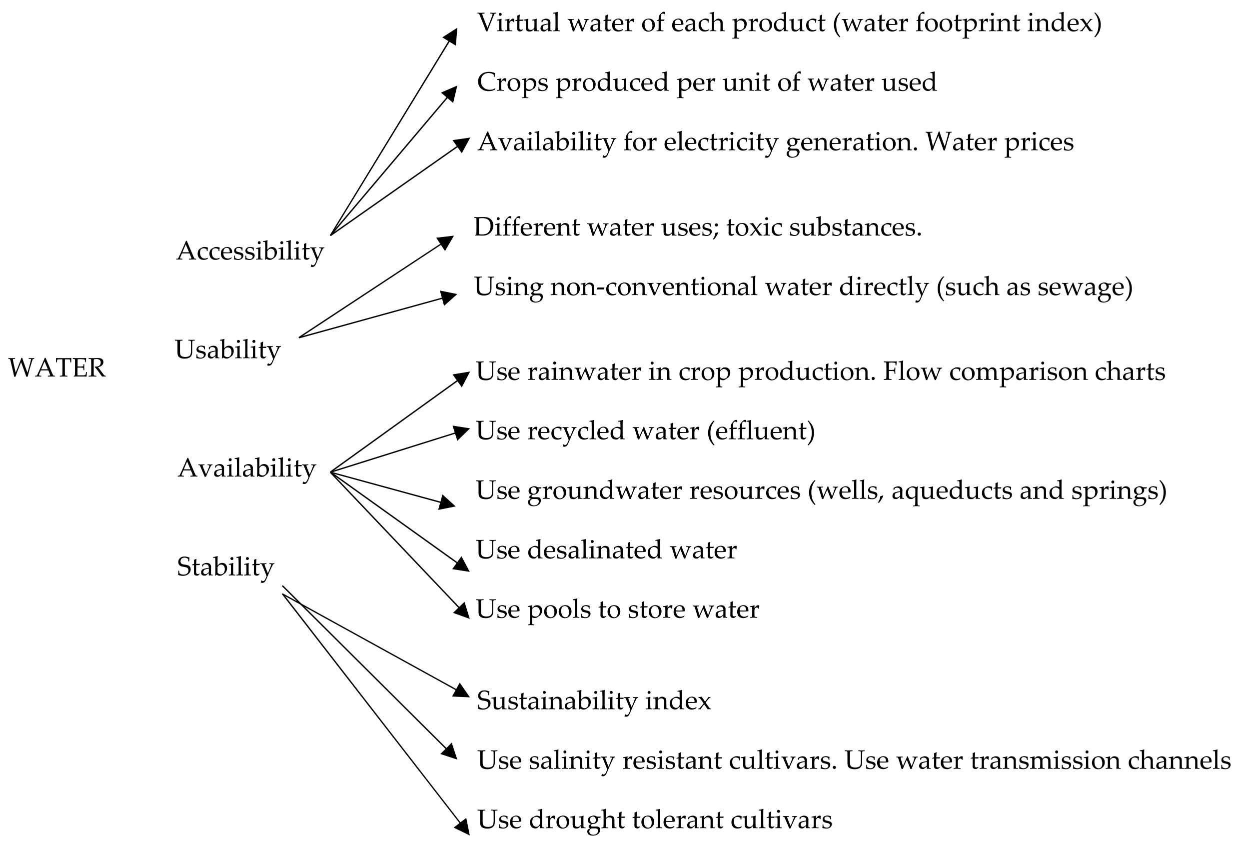

Figure 1. Indicator for water management strategies.

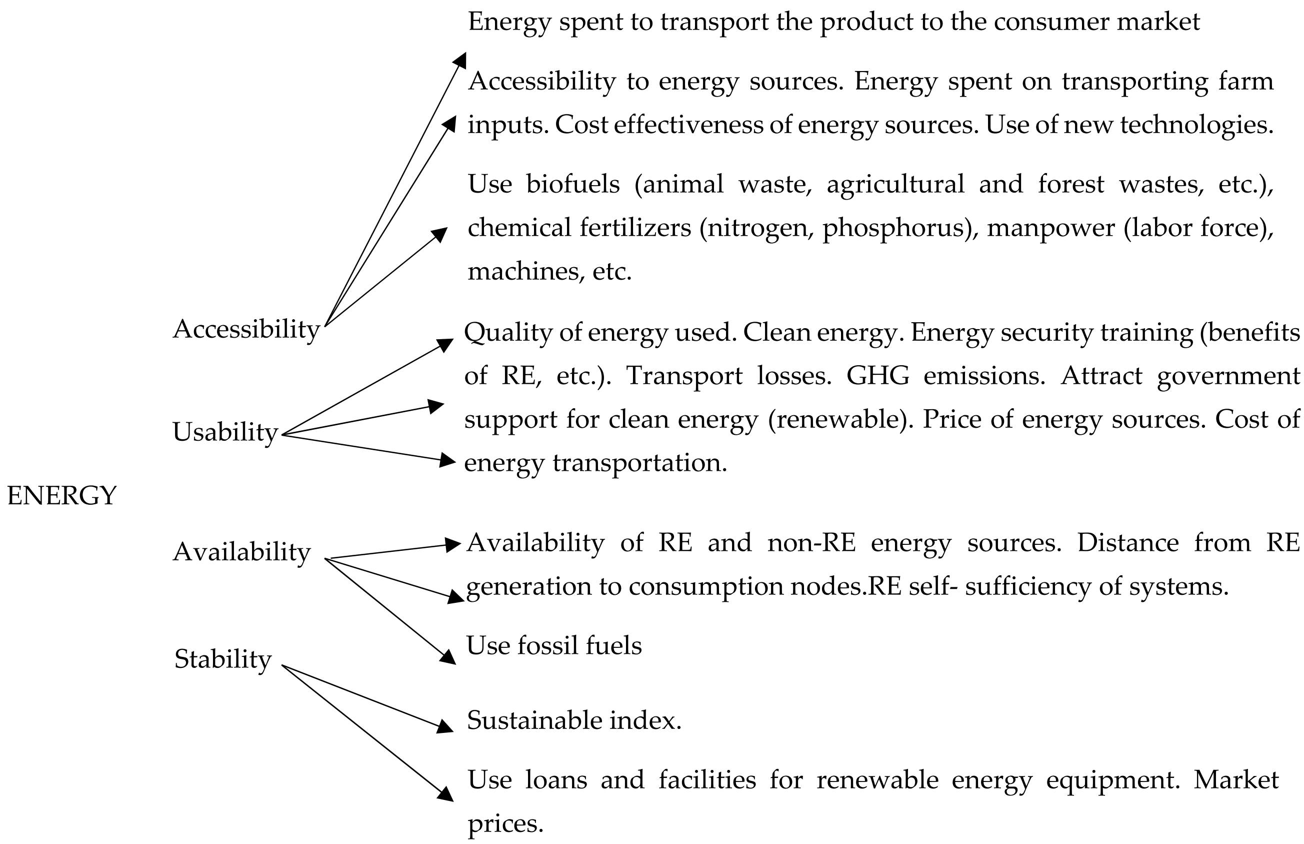

Figure 2. Indicator for energy management strategies.

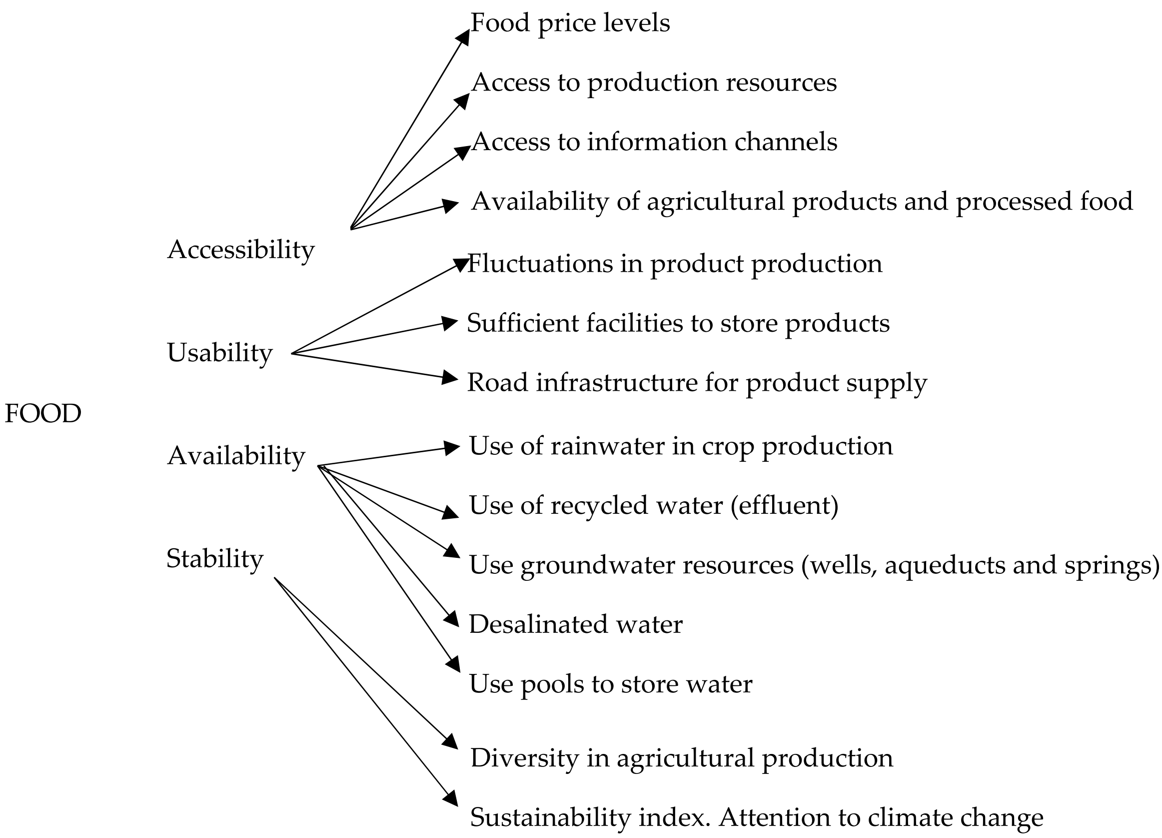

Figure 3. Indicators for food management strategies.

In order to tackle the nexus analysis, various frameworks and approaches have been designed. Many authors have analyzed the WE nexus, focusing on the design and performance of the system [46–48]. The diversity of approaches and frameworks, including various inputs, outputs, and points of view, is rooted in the intricacy of the nexus [49]. Alternatives like that proposed by UNECE have embraced water resources as a starting point [50]. Dargin et al. [51] ranked the tools using a complexity index aiming to model their complexity and suitability. The complex and high number of interrelationships have led to the development of different points of view to solve the problem and specific tools for all these different approaches. These frameworks have been developed to assess sustainability using a variety of indicators.

2.2. Water-Energy-Environment Nexus Analysis Tool

To depict a specific measure of a storyline, tools have used indicators in the analysis. These indicators were used for analyzing the consequences of deploying various storylines. This section focuses on designing a tool to assess the WEE nexus analysis related to the deployment of renewable energy plans in a power system. This section presents the tool that is used to perform the analysis of the role of RE in the WEE nexus. In order to develop the storyline, it is mandatory to assess the energy needed. Equation (1) evaluates the amount of power needed in the system. The forecasted power needs (*FPN*) take into account the power capacity of the system and the already installed renewable power (solar and wind) in the system is evaluated in the storyline, as well the energy storage needs, to forecast the reduction of thermal power stations (TPS) in the system.

$$FPN = Installed\ Power - Solar - Wind - Energy\ Storage \tag{1}$$

The Water-Energy-Environment nexus analysis is carried out by reviewing the influence of the integration of renewable-based energy plans for energy electricity generation. The study of WE nexus management strategies is performed using an index that analyzes the consequences of deploying RE plans. Rosales Asensio et al. [52] reviewed different frameworks for the nexus assessment and proposed an index for the rapid evaluation of various strategies. The sustainability index in Equation (2) is used for the quantitative analysis of trade-offs between energy and water systems. This equation comprises different terms, including Baseline Stress (*BS*), Acceptable Stress (*AS*), and Incremental Stress (*IS*). *BS* depicts the current consumption scenario of a specific resource in the system. *AS* relates to the resource consumption objective in the system. *IS* measures the changes in resource management strategies.

$$\frac{BS + IS}{AS} = Sustainability\ Index\ (p.u.) \tag{2}$$

The sustainability index clearly distinguishes between two different sustainability factors: water consumption and GHG emissions reduction. The whole calculation process can be shown in the proposed methodology flowchart, Figure 4.

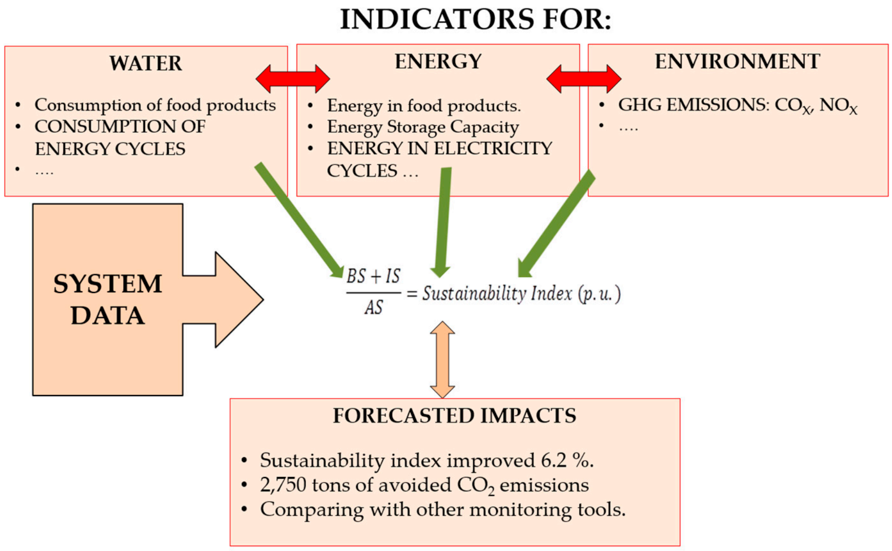

Figure 4. Proposed methodology flowchart.

3. Case Study

The Water-Energy-Environment nexus analyzes a storyline that consists of installing RE generation systems and pumping hydro storage (PHS) for renewable energy surpluses on the Island of Gran Canaria. The development pathway related to this storyline reports a reduction of water consumption in the system, as well as GHG emissions.

Trade-off analysis is especially important in isolated systems because they suffer high stress due to their remoteness from the main water and energy resources. Their isolation also prevents them from accessing water and energy transfers from other systems. In arid regions, where desalination systems are necessary, it is common to have higher water costs that are directly linked to higher energy costs. As more trade-offs and synergies occur among subsystems, more actions can be adopted to increase sustainable performance within the nexus. Independently of the desalination technology employed, the water and energy synergies increase because energy is needed in the process. Liu et al. [53] assessed the WE nexus through the exhaustive evaluation of the inputs and outputs of a desalination project. Borge-Diez et al. [54] proposed a strategy for boosting economic performance and improving the sustainable operation of desalination plants. The energy storage support reduces the consequences of the intermittency of RE and the adopted strategy was that of hydraulic storage.

3.1. Water-Energy-Environment Nexus Sustainability Index for the Case Study

This case study evaluates the impacts on the water system of deploying various RE electricity generation plans and also evaluates the emissions changes from these strategies. It is performed by means of the designed indicator, BS, which includes an exhaustive analysis of the water demand of the system. In order to propose an objective for the system, AS must be used to assess the availability of the resource. This required information includes rainfall forecasts, historical data, wells, and desalination plants. In addition, to compare strategies and to measure the sustainability of the proposed strategy, the tool needs the IS indicator to measure the changes according to the tested strategy. Among the terms used for evaluating AS, it highlights rain-gauges values, the capacity of reservoirs, and the desalinated water that can be included in the system. BS includes all terms related to the baseline consumption of the system, including human consumption, industries, crop watering, etc. On the other hand, IS refers to alternative plans for resource allocation of the water and energy system.

The analysis developed with the water index tool was used to compare different energy strategies that, as previously mentioned, include the PHS strategy for increasing the manageability of the WE system. The sustainability index assessed and analyzed the implementation of sustainable energy solutions in the system of Gran Canaria. Similarly, this index can also be used for the evaluation of indicators such as CO_2 emissions, among others. The index analyzes how changes in a sector influence other parameters and this is done by quantifying the virtual deployment of different alternative power generation plants in the system of Gran Canaria. In this case study, the objective of the index was to verify that solar PV or wind energy can reduce the water consumption and the GHGs emissions of the whole system.

3.2. System Analysis

In this section, the most important results are presented and analyzed. Table 1 shows the water impacts caused by electricity generation technologies, as well as the impacts on the studied system. It also presents the CO_2 equivalent emissions in the analyzed system; both terms are part of the BS indicator to be included in the sustainability analysis.

Table 1. Life-cycle water withdrawal of energy sources on the island of Gran Canaria [52–58].

Technology	Water Impact (m^3/MWh)	Emissions Impacts (gCO_2/kWh_e)
Biomass Wet cooling	1.89–2.271	650
Biomass for dedicated energy crops	151.4–378.5	
Natural gas Simple circuit	15.918	499
Natural gas Combined cycle	8.34	250
Solar Photovoltaic	3.79	300
Wind	-	-
Wind powered power plant (Onshore)	0.985	123.7
TOTAL		1826

The BS term is the overall water footprint of each of the foods produced in the analyzed system, as well as the amount of water consumed by the inhabitants of the island. Gerbens-Leenes et al. [59] studied the water footprint of the food production subsystem and proposed water footprints for grown food products. In addition, Fry et al. [55] and Heinonen et al. [60] estimated the emissions footprint of these production subsystems. Among the agricultural products grown on the island, the production of vegetables is remarkable, accounting for 170,000 t [61] in the BS indicator of water consumption [62]. Table 2 shows the water consumption according to the type of food product grown in the system of Gran Canaria and also evaluates the CO_2 footprint of each of the elements in the analyzed system [61]. In order to assess the mean human intake of water in the analyzed system, a consumption ratio of 140 L per day is adopted per inhabitant, implying a total water consumption of 49.34 Hm^3/year. After evaluating the BS, results show a consumption of 280.22 Hm^3 and total emissions of 664.83 t CO_2. Trubetskaya et al. [63] estimated direct emissions and, for the indirect emissions, they proposed the use of energy intensity values of CO_2 per 1 kWh and concluded that the carbon footprint is about to increase due to water supply reduction. Vanham et al. [64] investigated whether the water footprint is relevant in addressing the WEF nexus and concluded that some relevant components are missing.

Table 2. Global BS of water footprint [59].

Product	Baseline Scenario (Hm^3)	Baseline Scenario (t CO_2)
Tomatoes	30.6	238
Potatoes	7	14
Pork	23.3	33.98
Chicken	9.98	15.35
Apple/pear	70	40
Banana	68	59.5
Milk	22	264
Human Consumption	49.34	
Total consumption	280.22	664.83

Due to water scarcity on the island, the system needs desalinated water as a main source. The desalination capacity in the analyzed system reaches 138,000 m^3/day. The water storage subsystem comprises a storage capacity of 78 Hm^3, which accounted for a total of 321.6 Hm^3 for the AS indicator. Table 3 shows an acceptable scenario for the system and proposes an amount of water that can be certainly ready in the system without compromising the ability of the island to regenerate the water resource. The sustainability index informs the change derived from the alternative scenarios.

Table 3. Acceptable Water Scenario (AS) [61].

	Assumption	Initial Ww (Hm^3)
Capacity of reservoirs	100% of capacity	78
100% Rainfall	In 37% of cultivable land	173.16
Desalination plants	Capacity factor of the plant: 30%	14.49
Total		270.54

Table 4 reviews the electric power generation of the system, the generated energy, and the associated water withdrawals that will be added to BS. In addition, it presents the GHG emissions in this system. The power stations in the system include a vapor turbine (VT) and a gas combined cycle power station (CC) and, additionally, it includes solar and wind-powered power plants.

Table 4. Electric power generation in Gran Canaria. Source: [62].

Energy Generation Technology	Installed Power (MW)	Energy Generated (GWh)	Ww (Hm^3)	Baseline Scenario (t CO_2)
Vapor Turbine	438.27	1409.83	21.37	1,491,840
Combined Cycle	481.28	1464.89	12.21	423,000
Wind Power	154.3	248.97	0.245	2415.6
Solar Power	41.5	57.53	0.22	20,700
Total	1024	3181.2	34.04	1,937,955.6

3.3. Alternative Electric Power Generation Schemes

This section outlines the alternative scenarios to be analyzed and the water and CO_2 costs associated with power generation in these plans. According to Table 4, 195.8 MW out of the 1024 MW of installed power in the system corresponds to that from solar and wind energy power plants. In addition, the storyline draws an energy storage strategy of 350 MW [43]. As can be seen in Equation (3), to virtually meet the proposed full RE generation scenario, 478.2 MW of solar and wind energy must be added to the system.

$$Wind/Solar\ Energy = 1024 - 41.5 - 154.3 - 350 = 478.2\ (MW) \quad (3)$$

In order to achieve this scenario, the storyline proposes to replace combined cycle gas power stations with renewable power plants: the analyzed scenarios are 100% solar PV, 50% solar PV 50% wind power, and 100% wind power. Based on data from Table 1, Table 5 evaluates the water costs associated with these changes. It also shows the consequences of replacing steam turbines with 100% wind power systems.

Table 5. Energy electricity generation structure, generated energy and water withdrawal in the different scenarios.

Technology	100% Wind to CC Ww (Hm^3)	50-50 Wind/Solar to CC Ww (Hm^3)	100% Solar to CC Ww (Hm^3)	100% Wind to ST Ww (Hm^3)
Vapor turbine	21.37	21.37	21.37	0
Combined cycle	0	0	0	10.81
Wind power	1.44	0.69	0.245	1.38
Solar power	0.22	2.67	5.55	0.0002
Total	23.03	24.73	27.16	12.19

3.4. Sustainability Index Analysis Results

This section shows the results of the performed analysis. Based on the BS, AS, and IS, the sustainability index assessed the consequences of deploying solar and wind power plants in the island. Table 6 shows the data needed to perform the analysis and the incremental entry corresponds to the virtually deployed energy plans.

Table 6. Indexes associated with a renewable-based energy deployment strategy.

Index	IS	BS	AS
Water index units	Hm^3	Hm^3	Hm^3
	Alternative EP	314.26	270.54
Emissions index	t of CO_2	(t of CO_2)	t of CO_2
	Alternative EP	1,616,253.23	Legislator's entry

Applying the sustainable index presented in Equation (2) to the proposed energy plans, the sustainability of the water system. Table 7 shows that water consumption in the system lowers from 8.11 to 10.71 Hm^3. In addition, higher GHG emissions reduction was achieved when the steam turbine power plants were virtually replaced with wind turbines.

Table 7. Water and emissions index results.

Energy Strategy	Incremental Water Use (Mill m^3)	WI Change (%)	GHG Emission Reduction (t of CO_2)
100% Wind to CC	10.71	3.4	1120.89
50-50 Wind/Solar to CC	8.81	2.8	960
100% Solar to CC	8.11	2.6	686.8
100% Wind to VT	10.71	6.2	2750.35

It must be highlighted that it is more beneficial to reduce generation from coal-fired power plants. Likewise, monetary costs related to the taxes imposed on GHG emissions can also be analyzed. It must also be highlighted that the deployment of generation technologies based on RE sources, mainly solar or wind, has encountered problems in the different markets in which they operate. Rosales-Asensio et al. [65,66] analyzed both these and the different wind power technologies for the system under study. The index quantifies the adopted storyline in this case study, supporting that RE lowers GHG emissions and reduces water consumption.

4. Discussion

Innovation is a key enabler to improve the Water-Energy Nexus and take advantage of the synergies between the energy and water systems. For the development of different storylines, technological, practical, and environmental assessments are important in the short, medium, and long term. Some tools allow analysis of the impacts of actions taken and perform scenario forecasting to analyze both the quantitative and the qualitative results of these actions and also evaluate policy aspects and social impacts. In these tools, data availability and design are key factors for the success of the analyses and evaluation scales and goals. Another factor affecting the WE management approach is the capability of regions to adopt the proposed solutions. On the other hand, policies and programs affecting the water–energy nexus do not fully take into account side effects in other sectors. This important disadvantage is directly related to the fact that they are developed individually and, therefore, lack information on the whole system relationships [12]. The most important risks and challenges occur when trade-offs and interconnections are not fully investigated; this might provoke a reduction in positive side effects leading to a reduction in the performance of the evaluation and all the analyzed systems. This situation has not been ignored and studies and research efforts have been carried out to propose different actions and tools to evaluate the actions, in order to support the entire decision-making system in the development of different policies in terms of resource strategies. Resource management tools improve the long-term decision-making process affecting the nexus systems, but a full comprehension of the processes within the indicators affecting the WE nexus is mandatory. An important aspect is the need to completely review the consumed energy in the water sector for each involved process, with special focus on energy production and power plants [67]. The analysis also highlighted that it is equally important to quantitatively assess the economic feasibility of storylines.

The storyline in the presented case study proposed an electricity generation scenario for lowering the consumption of some WEE nexus indicators. The index used quantitatively forecasted the consequences of the storyline. Additionally, it established a methodology that can be applied in other scenarios.

Specifically, this case study foresees an energy generation of 80 MWh for a 100% wind system deployment. This represents up to 75% of the energy generated in the system's thermal power plants. Likewise, the half wind/half solar deployment represents an energy contribution of 40 MWh. A fully 100% solar deployment is expected to generate 90 MWh. Furthermore, the energy storage strategy through hydraulic pumped storage (PHS) allowed the addition of 89 MWh/0.1 Hm^3. Zhang et al. [68] stated that is mandatory to enable informed decision-making considering electricity supply reliability. Iteratively applying the index allows the refining of the information systems that are part of the indicators. According to this storyline, it is important to highlight the positive impacts of the energy storage strategy. Consequently, this indicator, as well as others that could eventually be used to inform the consequences of deploying RE plans in the studied system [69], are key to evaluating the tradeoffs between systems. PHS storage becomes a sustainable form of energy storage only if energy surpluses from RE sources are used. Among the methods and tools used for the rapid evaluation of ecological variables, non-accountable resource monitoring tools through image analysis highlight a rapid manner for the evaluation of results. The methodology here depicted makes it possible to compare results with these tools. Explicitly, it will allow enhancement of the methodologies such as the RSEI [17] because they did not take into account that rainfall (litter account) might change over the years. Comparing these quantitative indexes with images would help improve these tools. Only by including a rainfall index would it allow verification of the greenness indicator used in that approach. In addition, the results of applying this storyline might lead to a reduction of 2750 tons of CO_2.

With the proposed Storyline, electricity generation systems can be used to pump fluid to a higher reservoir to be used as needed. Increasing synergies between water and energy are achieved by providing an extra amount of water to the system. In addition, the WE resource would have a double use; after pumping, water is stored to generate electricity, and after the water passes through the turbine, it can be used to irrigate crops, feed animals, etc. For the studied location, more water for crop production can only be available if the capacity factor of desalination plants is increased. In this sense, it would be necessary to optimize the size of the renewable-powered desalination plants (both their desalination capacity and the optimal size) for joint operation in a real market [70,71]. Additional measures can be taken to improve the energy resources availability while simultaneously improving energy production. Using floating PV plants seems to be a new tendency for reducing evaporation in both water reservoirs and water troughs [72].

Whether electricity power plants use fossil fuels as primary energy sources or are RE plants, they impact other nexus systems throughout the entire life cycle of the process. The most significant impacts include those on the water and associated emissions. The indirect and non-operational emissions include fuel extraction, processing, transportation, and burning, among others, and also power plant construction, manufacturing of all the equipment, power plant decommissioning, etc. Likewise, renewable-based energy electricity generation technologies impact other sectors in the nexus. Unlike the generation of electricity from fossil fuels, technologies such as solar PV and wind power do not generate emissions during operation and, although they do not consume much water, water is consumed during the manufacturing, as well as on-site construction and decommissioning. Other factors include mounting type, location of facilities, shadow efficiency of the PV modules, maintenance protocols, among others. In the case of biomass-fired plants, estimating the biomass and biofuel total $CO_{2\text{-eq}}$ emissions is mandatory for a full evaluation of sustainability and performance. As the lifecycle of products becomes better informed in terms of water, energy, and emissions costs, monitoring tools such as the one used here might become more useful for the quantitative evaluation of storylines [73]. On the other hand, the problem appears of evaluating the GHG emissions of products through system boundaries.

As shown in this research, changes in the energy subsystem provoke changes in water consumption and GHG-related emissions. In order to give a realistic measure of the sustainable performance of actions, the analysis must rely on accurate data results. Synergies sometimes become risks because the strategies in a subsystem might threaten other nexus systems. For example, dedicated crops for biofuel manufacturing include certain advantages, such as the reduction of GHG emissions, but they need resources like land or water that will not be available for other uses. This, as well as other development pathways, can be assessed by developing indexes adapted to each scenario.

In order to further develop the baseline scenario (BS), it is possible to include terms such as aquifers management. According to Chen et al. [74], aquifer recharge management is a promising adaptation measure to reduce water vulnerability and maintain its sustainability. On the other hand, the more the development, the higher the computational cost and the need for large amounts of data to be parameterized. Non-dedicated crops, such as molasses, can be used in bioethanol production since this is a factor of production waste and does not compete for water resources. Saltelly and Giampietro [75] highlighted the importance of quantifying strategies to study the feasibility and viability of the storyline. Quantitative storytelling would be mandatory for a proper forecast of the consequences of storylines. Rosales-Asensio et al. [66] proposed a methodology for lowering water stress in water-scarce systems by means of desalinated water and RE and they found that, despite the increasing synergies among subsystems, drawbacks such as the amount of energy that can be injected into the system limited the deployment of the methodology. Despite the fact that the analysis assessed water consumption change in each scenario, the indicator should truly account for the system boundaries. The indicator must represent reality and use similar boundaries for assessing water footprints. Independently of the simplicity of the analyzed index, the number of terms that can be included and the weighting indicator for each of them will increase the analysis level of detail. The use of these tools has become mandatory in order to analyze the potential that renewable energy has to improve the sustainable performance of societies in relation to WE use.

5. Conclusions

Resource management and infrastructure development, both at the local and regional scale, converge to provide water and energy supply in an economic and sustainable way. As an indispensable part of the development of tools for the analysis of the energy–water nexus, indicators are essential to quickly study different strategies for the management of these resources. The indicators developed quickly assessed the reduction of water consumption and emissions related to a specific energy strategy but, due to the complexity of indicator development, special care must be taken in the designing process for real measurement of the analyzed process.

Despite the fact that much of the quantitative information can be processed, deep investigation is still needed of the quantitative consequences of the WEE nexus, including tradeoffs and drawbacks of both renewable and fossil fuel-based storylines. This study analyzed the indicators that Water-Energy-Environment Nexus tools and frameworks used to model the problem. Particularly, it focuses on the used indicators and their implications and proposes a new indicator to rapidly evaluate the Water-Energy-Environment Nexus implications of replacing fossil-based power generation systems with a wind and photovoltaic renewable energy system for the Canary Islands, a water-scarce region where these tools can be of great interest in mitigating potential risks. Results show that the water sustainability index is improved in comparison to that of fossil-based plants and this methodology can be applied in different scenarios and locations. The proposed methodology can be used to adapt or develop new tools that can be used to study all the important implications of each strategy and to compare the trade-offs and drawbacks of these strategies.

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Nomenclature

AS	Acceptable Stress
BS	Baseline Stress
CC	Gas combined cycle power station
CLEWs	Climate, Land-use, Energy-Water
DEA	Data Envelopment Analysis
EFOM	Energy Flow Optimization Model
FAO	Food and Agriculture Organization of the United Nations
FEN	Forecasted Energy Needs
GAEZ	Global Agro-Ecological Zoning Model
GHG	Green House Gas
IAEA	International Atomic Energy Agency
IRENA	International Renewable Energy Agency
IS	Incremental Stress
LEAP	Long Range Alternatives Planning System
LCA	Life Cycle Assessment
MARKAL	Market Allocation
MENA	Mediterranean and north Africa
MFA	Material Flow Analysis
MuSIASEM	Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism
OSeMOSYS	Open-Source Energy Modelling System
QST	Quantitative Story-Telling
PHS	Pumping Hydro Storage
PV	Photovoltaic
RE	Renewable Energy
RSEI	Remote Sensing Ecological Index
SDGs	Sustainable Development Goals
UN	United Nations
UNECE	United Nations Economic Commission for Europe
VT	Vapor Turbine
WEAP-LEAP	Water Evaluation and Planning System
WE	Water, Energy
WEF	Water, Energy, and Food
WW	Water Withdrawals

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