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Review

The Water–Energy–Food Nexus in European Countries: A Review and Future Perspectives

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Abstract: The interaction between water, energy, and food as the water–energy–food (WEF) nexus has drawn much attention recently to solve upcoming uncertainty in food security. The aim of this study is to investigate the status of the WEF nexus in European countries. It is indicated that the largest nexus studies (among 27 European countries) have been conducted in Spain and Italy. It is confirmed that there is a large number of nexus studies in water-stressed countries while there are few studies on water-abundant countries (Slovakia and Luxembourg). Based on existing research, the majority of nexus studies focused on energy production. It is highlighted that most of the nexus studies were focused on water quantity aspects (rarely related to quality aspects) and energy; however, other resources including land, climate, ecosystem, soil, and environment received little attention. The migration of people as a result of climate change in the WEF nexus is not considered. Moreover, there is a lack of common and standard frameworks for nexus assessment. Therefore, we suggest a standard approach for nexus studies and produce a cross-sectoral and holistic approach for the evaluation of a water (quantity and quality)–energy–food–land–climate (WqEFLC) nexus that takes into consideration the circular economy.

Keywords: sustainable development goals; water–energy–food nexus; water security; energy security; food security; climate change adaptation

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1. Introduction

Water, energy, and food are essential resources for improving sustainable development goals (access to food, water, and energy for all people) and human well-being. These resources are inseparable and interrelated resources [1]. Interaction and interlinkage between these resources are of utmost importance, and they are evaluated by the water–energy–food (WEF) nexus [2]. This nexus shows that the interaction between these resources is essential and the same resources should be managed altogether [3]. The nexus was initially introduced at the Bonn conference in 2011 as a crucial element to achieve sustainable development goals. After the Bonn conference, the number of nexus studies increased and so many approaches were created, such as [4–10]. In spite of the sharp increase in nexus publication after the Bonn conference, to date, there is not any review on the WEF nexus focusing on European countries. This study fills this gap for the first time. In particular, this study points out those aspects that should be integrated into the actual approaches through the following items: (i) methodology and protocol for conducting this review, (ii) an overview of the evolution of the nexus, (iii) an overview of the number of nexus studies in different European countries, (iv) the percentages of different types of nexus studies (including the water–energy [WE] nexus, water–energy–food [WEF] nexus, water–energy–food–land–climate [WEFLC] nexus, water–energy-land [WEL] nexus, WEL–carbon nexus, water–energy–food–environmental [WEFE] nexus, land–water [LW] nexus, and water–energy–soil [WES] nexus) in 27 European countries, (v) integration among circular economy and nexus approach, (vi) nexus gaps in European countries, and (vii) a summary of the main finding of this paper and future perspectives.

On the whole, the following research questions will be answered during this study. (i) What is the evolution of nexus worldwide? (ii) Which European countries have the largest number of nexus studies, and why? (iii) Which types of nexus studies have drawn much attention in European countries? (iv) What are the research gaps related to the nexus in European countries? Then, what future perspectives are emerging and what previously unanswered questions must be answered soon?

2. Materials and Methods

This study used a narrative review based on papers published before 2023 because this kind of review is comprehensive and can cover a variety of issues within a specific topic [11]. The following steps have been conducted:

1. Conducting a search: it is crucial to use different databases to ensure that most of the relevant databases have been covered [12]. In this study Scopus, ISI Web of Science, PubMed, Google Scholar, and Science Direct were used.
2. Finding appropriate keywords: using appropriate keywords helps to answer the research questions.
3. Reviewing relevant articles: after completing the search, all duplicated articles are removed. In this step, the abstract section from the remaining papers is reviewed to find the relevant papers that can answer the research questions; less relevant papers based on a review of abstracts and their titles are omitted; then, the relevant papers based on research questions were reviewed. In the narrative review, it is not necessary to include all of the existing relevant papers on the topics because we need the papers that address our research questions. Therefore, taking into consideration the main goal of the present work, this research reviews the 109 papers focused on studies that were carried out within Europe.
4. Writing results: in this step, all of the results are summarized and integrated appropriately [12].

The search string used to classify the papers consisted of all types of nexus discussed until now in the scientific literature, including (i) the water–energy–food (WEF) nexus, (ii) water–energy–food–land nexus (WEFL), (iii) water–energy–food–climate nexus (WEFC), (iv) water–energy–food–security (WEFS), (v) the impact of climate change on the WEF nexus, (vi) the WEF nexus in seafood, in livestock, and in crop production, (vii) net primary production in the WEF nexus, (viii) the WEF nexus and ecological footprint, (ix) the WEF nexus and land use, (x) the resource nexus, (xi) ecosystems and the WEF nexus, (xii) soil and the WEF nexus, (xiii) forests and the WEF nexus, (xiv) water quality and the WEF nexus, (xv) sustainable development, and (xvi) food security.

3. Results

3.1. The Evolution of Nexus Study

Numerous nexus studies, conferences, and projects have been performed around the world. The interaction between water and energy became obvious in the 1970s. The food–energy nexus was created by United Nations University (UNU) in 1983 to solve water and energy insecurity [13]. In the next year, a water–energy–ecosystem conference was conducted in Brazil by UNU. The second water–energy ecosystem nexus symposium was held in India by UNU in 1986. In the 1990s, the World Bank used the terminology of nexus for interlinkage between water, energy, and trade [14]. The concept was like virtual water and water footprint [15]. Scientists around the world acknowledged the need for considering energy as one of the pillars of the nexus [16]. Finally, the WEF nexus was officially introduced for the green economy at the Bonn conference in November 2011. Considerable attention has been paid to the interlinkage between water, energy, and food after the Bonn conference. In the following year, the food–water–energy (FWE) nexus was created (ICIMOD, 2012) for the Himalayan ecosystem [4]. The ecosystem was identified as a key factor in this framework, which contributes to resource security. Andrews-Speed et al. (2012) created a new framework, called the resource nexus, by considering five resources in the nexus approach, including water, energy, mineral, food, and land. Physical, economic, political, environmental, and equity dimensions were added to the framework [5]. Howells et al. (2013) provided a framework which was called climate, land-use, energy, and water strategies (CLEWs), combining climate change, land, water, and energy [6]. The United Nations Food and Agriculture Organization provided a conceptual framework for the WEF nexus in 2014 [10]. The water–energy–food–ecosystem nexus framework was created by considering political and physical dimensions and taking into consideration transboundary rivers [7]. Melo et al. (2021) [17] produced a novel nexus approach by adding forests to the usual WEF nexus.

3.2. Analysis of Different Types of Nexus in European Countries

Figure 1 shows the number of nexus studies in European countries. Spain had the largest nexus publications (26). Italy and Portugal are the second (eleven) and the third (nine) largest cases of nexus studies, respectively. It can be indicated that the largest nexus studies were carried out in water scarcity countries, because the WEF nexus is identified as a solution to manage water supply and water demand spanning water, energy, and agricultural sectors, especially in water scarcity areas [18]. Conversely, only one study was conducted in water-abundant countries, such as Slovakia and Luxembourg.

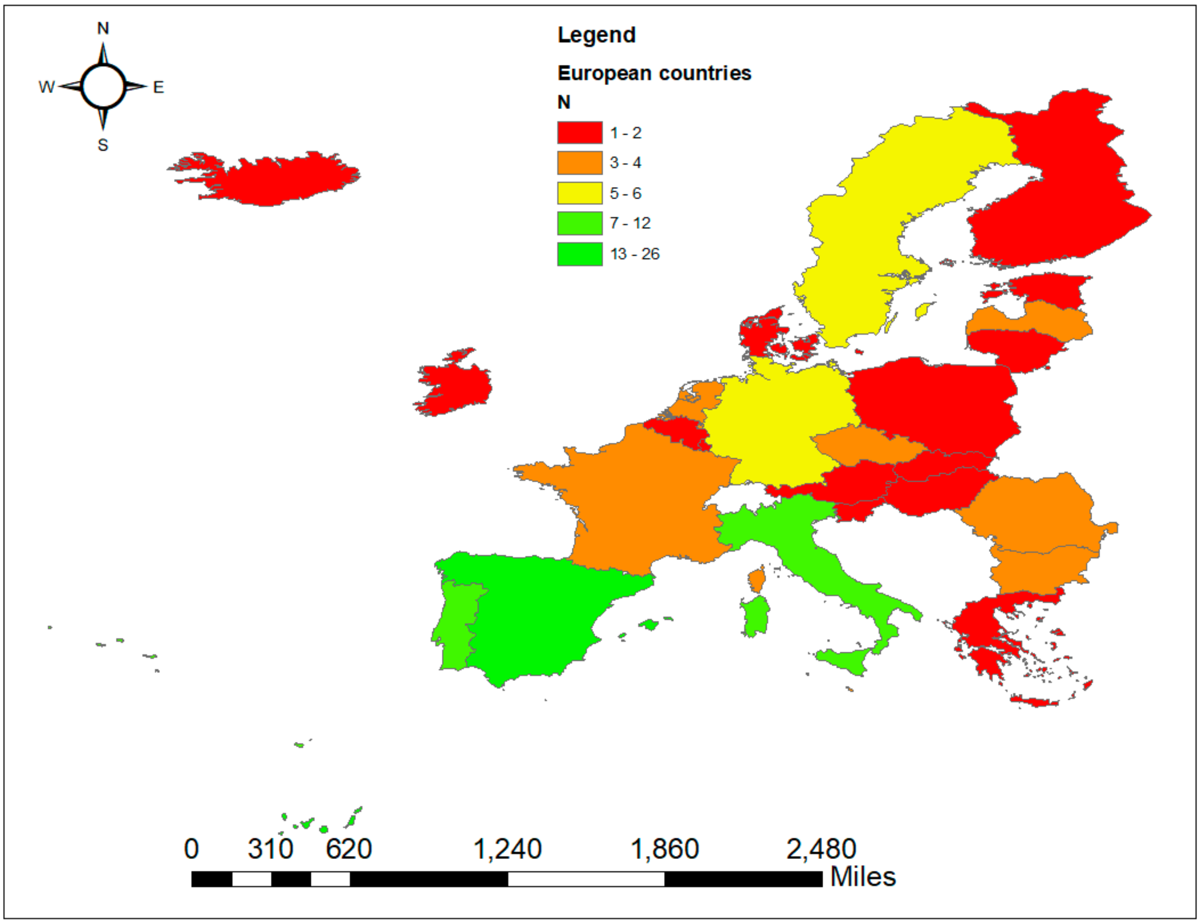

Figure 1. The number of nexus studies in European countries before 2023.

Figure 2 shows the percentages of different types of nexus studies in 27 European countries. Most of the nexus studies focused on the WE and WEF nexus, accounting for 39% each and, therefore, suggesting that in different countries nexus studies are mainly focused on the interlinkage between water and energy sectors. For example, in Italy and Spain, the majority of nexus research were focused on energy production, and the nexus was applied with two pillars as the WE nexus, such as in [19–28]. The WE nexus is important since electricity fuel production relies on non-sustainable water resources [29]. Recently, the WE nexus has received numerous attention from scholars and policymakers [30]. However, in some geographical areas, such as Sweden, Finland, Romania, Malta, and Latvia, more focus has been paid on the interconnection and interaction between the water, energy, and food sectors. Only 4% of nexus studies focused on the WEFLC nexus because the application of a complex nexus is not successful, due to a lack of data availability [31]. A few studies were focused on other types of nexus, such as the WEL nexus, WEL–carbon nexus, WEF nexus, LW nexus, and WE–soil (WES) nexus, accounting for only 1% each.

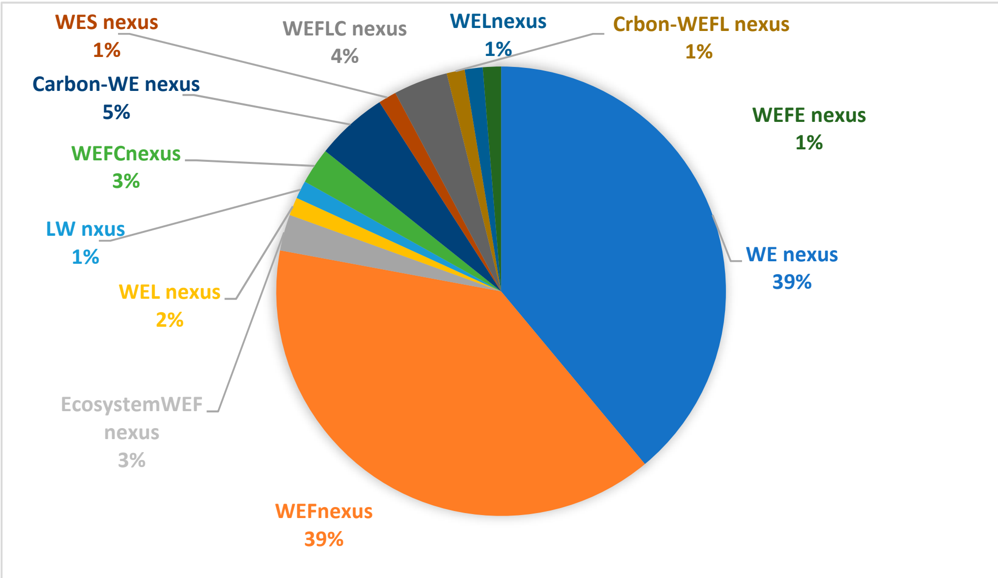

Figure 2. The percentage of different types of nexus in studies that were carried out before 2023.

Figure 3 shows the number of studies for each resource/sector in European countries. The largest number of nexus studies was focused on the water sector (87 papers). The energy sector is the second one (77 papers). Only 38 studies considered the food sector. On the whole, in European countries, the water and energy sectors are more considered than the food and other sectors. There are very limited studies on land use and land change (eight papers). Carbon and climate were considered rarely in nexus evaluations, with only eight and five studies, respectively. Other resources such as the ecosystem, soil, and environment have received little attention, with only three, one, and one papers, respectively.

3.3. Overview of Different Nexus Approaches in the European Countries

Table 1 shows the existing nexus studies in the 27 European countries in terms of approach, sector, and results. Nexus studies can be carried out at different scales, from the farm level, urban, tourism, industry, forest, river basin, hotel, household, to country scale. In the agricultural sector, the nexus approach can be applied with different aims, such as for irrigation management [32,33], for comparing different fertilization systems in terms of economic and environmental sustainability [34,35], for climate change adaptation by comparing different climate change scenarios [36], and for providing a new guideline for drought management [37–40]. At the urban scale, it was applied with the aim of obtaining sustainable aquaponic production [41,42] by comparing different wastewater treatment scenarios in terms of resource use efficiency [27,43–46], increasing a sustainable smart environment for cities [47]. In Portugal, a new framework, the Water–Energy–Greenhouse gas emission nexus, was created for wastewater treatment in urban drainage systems. Only CO_2 emissions were considered for greenhouse emissions as a result of wastewater treatment [48]. Another study by Santos et al. (2021) also accounted for WE–CO_2 emissions of wastewater treatment at the urban scale in Portugal [46].

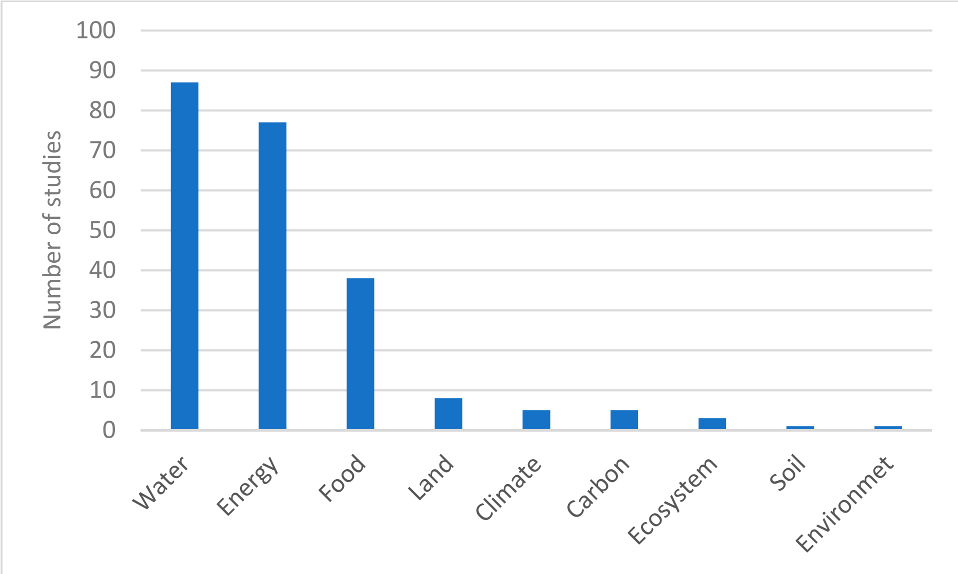

Figure 3. The number of studies for each resource/sector before 2023.

From the methodological point of view, there is no universally accepted approach for nexus analysis. Each scholar used a different approach for his/her analysis. In some cases, the life cycle assessment (LCA) was integrated with the nexus because this combination was identified as a powerful tool for evaluating environmental impacts in the life cycle of products [49,50] and can provide sustainable alternatives for global food insecurity by developing sustainable production and consumption [50]. Numerous nexus studies used the LCA in order to analyze some environmental impacts, with the aim of finding effective solutions for coping with climate change and increasing resource security (e.g., [27,28,36,41,43,51–54]). Some of the scholars used the LCA for the evaluation of carbon footprints [53,55–57]. The system dynamic model was used to accelerate the analysis of the complex system between different variables [58], which can contribute to increasing synergic strategies and sustainability solutions [59]. In Latvia, the WEFLC nexus was applied to different policies in cereal crop production using the integrated system dynamics model [60]. Based on the existing literature, most of the studies evaluated land use in terms of land suitability, land use change, [21,27,43,61,62], economic land productivity [32], and land productivity [33]. However, indirect land use in terms of the ecological footprint was not considered. The ecological footprint enables one to account for both direct and indirect land use (land use associated with carbon dioxide emission as a result of fossil fuel for machines) for crop production [63].

In the Netherlands, a nexus was performed with the aim of producing new frameworks. For example, the NexSESF was created by considering the social–ecological system in the FEW nexus [64]. Additionally, the CLEW nexus framework was produced [65] to increase land security. A new framework for water security assessment in Finland was established by using the WEF nexus and considering human well-being, human health, and sustainability of livelihood [66].

Data availability is one of the challenges of creating a nexus. The lack of data availability was claimed in some studies, such as [48,67].

Table 1. The nexus studies in 27 European countries.

Country	Approach	Sector	Result
Italy (central Italy)	WEF nexus + energy inputs-outputs analysis	Farm (wheat)	The economic and environmental impacts of chemical and organic fertilizers were compared. The result indicated that organic fertilizer has a lower environmental impact in terms of low nitrate leaching in groundwater and low energy use, while chemical fertilizer contributes to increasing crop yield [34].
Italy	WE nexus + economic water productivity + WF	Electricity production	A novel nexus framework as economic WE nexus was created [19].
Italy	WE nexus	Hydropower plant	The WE nexus under different climate scenarios was analyzed [20].
Turin, Toronto, Oslo, Nantes	WE–carbon nexus + LCA	Water treatment (city)	Water treatment in terms of the WE–carbon nexus was evaluated in Italy, France, and Canada [43].
Italy (northern, central, and southern)	WE nexus Water footprint + LCA	Biogas production (maize, sorghum, and wheat)	The result shows that bioenergy crop production in southern Italy is unsustainable in terms of water consumption. The crop cultivation stage is identified as the main source of environmental impact because of fertilization [51].
Italy	WEF nexus	Wine production	[68]
Italy (Milan)	WEFC nexus water footprint + carbon footprint +Energy footprint	Wastewater treatment (reuse)	The nexus approach was used with the aim of understanding the interlinkage between the WEFC and assessing the impacts of different scenarios of wastewater reuse. The nexus can increase sustainable water resource management [55].
Italy (Sardinia)	WEFLC nexus (SIM4NEXUS method) (RCP 8.5 and RCP 4.5)	Agriculture, tourism, and domestic	Provide a novel approach for different climate change scenarios, such as the SIM4NEXUS approach [36].
Italy (Turin)	Urban WE L nexus	Mini-hydro power plants	[21]
Italy (Emilia Romagna)	WE nexus + LCA	Drinking water supply	The environmental impacts of different drinking water production systems were compared [52].
Italy (south)	LWEF nexus multi-criteria decision analysis +GIS	(Rapeseed and cardoon) Biofuel crops	The nexus was applied to find suitable areas for crop production in terms of more efficiency in water, energy, and land resources. The nexus approach provides a sustainable solution for resource management. Economic land productivity is an important factor for assessing irrigation sustainability [32].
Italy (Puglia)	WEF nexus	Crops at catchment scale	The WEF nexus was used to evaluate irrigation sustainability and land productivity [33].
Germany (Munich)	WEF nexus and urban nexus (use QGIS and ArcGIS)	City	The result indicated that urban agriculture can provide around 60% and 240% of fruit and vegetable demand. Wastewater treatment and rainwater harvesting can save water supply. Biogas can contribute to saving electricity supply [69].
Germany (Berlin)	WEF nexus + LCA	Urban Aquaponics (Circular city)	It is indicated that aquaponics contributes to saving 2 Mm^3 of water. It contributes to providing sustainability resources. Aquaponics increased food production and reduce environmental impacts [41].
Germany	FEW nexus	Framework	[70]
Germany	Climate change impact on the WEF nexus energy system model TIMES PanEU + integrated assessment approach	Cooling technologies	There will be a risk of water scarcity in Germany that can be reduced by using recycled water [71].
Germany	FEW nexus	Water supply and livestock bioenergy	A novel analytical framework was introduced by adding ecosystem service and network to the nexus framework. The WEF nexus contributes to increasing sustainable development goals [72].
Germany	WF–technology nexus + interview + survey	Sewage treatment plant for hydroponic	A new framework was produced and the results show that new technology can accelerate sustainable developments goals [73].
Germany	Evaluate the SDG of the WEF nexus sector	New framework	The green economy innovation index for the evaluation of sustainability was produced [74].
France	WES nexus + statistical model + GIS	City	[75] New framework.
Netherland	FWE nexus + social–ecological systems (SES)	Framework called NexSESF	A novel framework was produced [64].
Netherland	WEF nexus	Different scenarios and the SIM4NEXUS game was tested in terms of policies	[76]
Belgium, Denmark, Germany, Latvia, and Sweden	CLEWF nexus	Framework	A new framework was created [65].

Table 1. *Cont.*

Country	Approach	Sector	Result
Spain	WE nexus	Irrigation	The long-term WE nexus for drip and sprinkler irrigation was analyzed. The result shows that water conservation technology can increase water use efficiency [23].
Spain	WE nexus + environmental Kuznets curve (EKC) + ARDL model	Thermoelectric	The result shows that there is a direct relationship between water withdrawal and per capita income [24].
Spain	WEF nexus	Duero river basin	The result indicated the important role of the nexus for synergy between resources and policies [77].
Spain	WE nexus	Water user associations (WUAs)	There is an interlinkage between the WUA, energy, and other water use and the environment [25].
Spain (Andalusia)	WEF nexus + fuzzy cognitive maps (FCMs) to analyze different scenarios + interview	Agriculture	Produce a system dynamic model [78].
Spain	WE nexus	Irrigation	[26]
Spain	WE nexus + LCA	Urban water system (wastewater treatment)	The region that used tertiary treatment for wastewater treatment shows a higher environmental impact related to energy consumption and GHG emissions [27].
Spain	WEL nexus + LCA	Decarburization on the WEL nexus (electricity)	The results show that decarburization contributes to reducing all environmental impacts except aquatic ecotoxicity [28].
Spain (Almeria)	WEF nexus + process systems analysis + LCA	Tomato	The result indicated that carbon footprint, water footprint, and chemical footprint are good indicators for the evaluation of environmental performances in terms of sustainability in the nexus approach and suitable tools for decision-makers [53].
Spain	WEFC nexus and carbon footprint	Agriculture	[56]
Spain	WE nexus + virtual water + water footprint	Biofuel crop	The nexus between water and energy in Spain was evaluated [79].
Spain	WEC nexus of gin linear programming (LP) + LCA	Spirit drinks	Created a novel integrated index, the IWECN, by integrating the LP, LCA, and WEC nexus. The result shows that using solar energy and plastic material for bottles is the best alternative in terms of reduction in the IWECN [54].
Spain	WEF nexus + SDM	Agriculture	The system dynamic model can contribute to increasing synergic strategies and increasing sustainability solutions [59].
Spain	WEF nexus	Crop	[80]
Spain (Benidorm)	WE nexus + interview + questionnaire	Tourism	The result shows a strong relationship between water and nonrenewable energy. An unsustainable tradeoff between water and energy was found for salty groundwater withdrawal [81].
Spain (Benidorm)	WE nexus	Urban water cycle	The results show that energy consumption will be increased six times more in dry years than in normal years when desalination is applied. Wastewater treatment and transfer show better performances [45].
Spain	WEF nexus Water footprint + carbon footprint + energy footprint	Crops	Modernization in irrigation contributes to increase water use efficiency by around 8% [57].
Spain (Barcelona)	WEF nexus surveys	Households	Creating WE vulnerability [67].
Spain	WE nexus	Wastewater treatment plant	Different scenarios were analyzed with the aim of reducing GHG emission [44].
Spain	WE nexus	EU27 for electricity production	Provide yearly water consumption for energy consumption in the EU [82].
Spain	WEF nexus + multi-scale integrated analysis	Desalination for crop production	A new integrated approach and quantitative analysis for nexus was introduced [83] which was called the MUSISEM approach. The approach provides a holistic view of the different components of the system.
EU	WE–carbon nexus + input–output model	Different countries in the EU	France, Germany, and Austria are identified as eco-friendly in European countries. Sweden, France, Portugal, and Lithuania used more energy and low CO2 emissions due to using renewable energy [84].
EU	WE nexus Water and energy efficiency, energy saving, water saving	Industry (metal, chemical, food, paper, and pulp)	Improvement in the water efficiency trend can contribute to a similar trend in water efficiency [85].
Austria	Water assessment tool (SWAT) Ecosystem–WEF nexus	Danube river basin	A new approach for the nexus was produced by considering the environmental flow requirement for the lotic ecosystem [86].

Table 1. *Cont.*

Country	Approach	Sector	Result
Portugal (southern)	CWEF nexus	Hydropower production	Variability in climate and water; energy was evaluated [87].
Portugal	Economic impact on the WE nexus	Transboundary river basins	The economic impact in 2050 relies on the interaction between other sectors. The impact is high when water consumption in a neighboring country is considered [88].
Portugal	WE nexus + co_2 emission	Wastewater treatment municipal scale	Different scenarios were compared and the best scenario in terms of energy saving was introduced [46].
Portugal (Lisbon)	WE nexus	Urban irrigation system	Helps to increase a sustainable smart environment at the urban scale [47].
Portugal	WE nexus and emission	Urban drainage	A different scenario with the aim of increasing energy saving was compared. Data availability is the main challenge [48].
Portugal	WE nexus	University building	Water efficiency at the building level shows the water efficiency at the urban scale. There is small nexus between water and energy since the demand for hot water is small and the pump was not used [89].
Portugal (Algarve)	WE nexus		[90]
Portugal	WE nexus and emission	University building and hotel building	The cascade effect of water efficiency on the reduction of water energy and GHG emissions [91].
Italy	Dynamic simulation model WE nexus	Energy production from different sources	The nexus between different sources of energy. Renewable energy is a good option in terms of efficiency and a reduction in GHG emissions [92].
Cyprus	WE nexus		The WEF nexus helps to achieve sustainable development goals [93].
Czech Republic and Greece	WEF nexus	Wheat	Compare different fertilization technologies by taking into account the economic and environmental aspects. The result shows that variable rate technology (VRT) can increase environmental impacts and reduce groundwater pollution while resulting in economic (low cost) benefits [35].
Belgium	Ecosystem–WEF nexus	River basin	[86]
Belgium	WEF nexus Water efficiency, energy efficiency, and food efficiency	Biofuels	A new nexus index was designed by efficiency indexes [94].
Estonia	LW nexus	Kemi River hydropower and tourism	In the nexus, wet and dry rhythms should be considered [61].
Greece	WE nexus	Electricity generation	The WE nexus in the electricity sector, the energy used for sewerage, conventional and thermal power plants, and biodiesel [95].
Latvia	WEFLC + system dynamics mode + SIM4NEXUS		Investigate how policy in one sector can impact other nexus sectors [60].
Latvia	WEFLC	Forest (biofuel)	Land use changed as a result of converting forest land to the biofuel crop and new policies were provided for current and future changes [62].
Malta	WEF nexus	Aquaponics	The nexus of water and energy for aquaponics was evaluated [42].
Romania Tulcea, Roman	WEF nexus ISO50001 (standard framework for energy management) + ISO14046 (water footprint assessment)		The value system is identified as one of the requirements for appropriate water management [96].
Romania	WEF nexus	Country	Synergic and trades of the nexus between w–e–f and waste regarding economic dimensions [97].
Sweden	WEF nexus + mesoscale model	Crop irrigation	Evaluation of the impact of drought on agricultural water consumption, water stress, yield, and energy. Provide a new model and guideline for drought management [37].
Sweden	WEF nexus	Drought impacts on irrigation and agriculture	Irrigation water saving and water productivity based on the new model were compared in drought and normal years. In a normal year, water saving and high yield were obtained. In drought years, there was no water saving. However, crop yield increased by 10% [39].
Sweden	WEFLC nexus	Country sector	Integrating the ecosystem with the nexus can contribute to an increasing tradeoff between resources and figuring out the impacts [98].
Sweden	Impact of drought WEFE nexus	Catchments	Standardized drought indices were produced [40].
Sweden	WEF nexus + mesoscale MESAN and STRÅNG models	Effects of drought on the agriculture	Provide an irrigation guideline and water management [38].

Table 1. *Cont.*

Country	Approach	Sector	Result
Finland	WEF nexus	Produce a new framework	Considering stakeholders in the framework can help to accelerate water security [66].
Finland	WEF nexus+ hydrological model	Hydropower and water supply	Local drought management can reduce drought [99].

3.4. Importance of the Circular Economy in the Nexus Study

The circular economy contributes to enhancing the world's green economy, reducing greenhouse gas emissions, and increasing global resource security [100]. The circular economy is the key to increasing nexus thinking in European countries by analyzing the whole life cycle of products [101]. The Netherlands uses circular economy technologies to reduce stress on the WE and WF nexus [100] by increasing recycling infrastructure. Another example is in southern Spain, where approximately 90% of wastewater is reused in the agricultural sector [102]. Moving toward the circular economy involves activities such as reducing wastage (zero waste), enhancing recycling, and reducing greenhouse gas emissions while increasing job opportunities (European Commission, 2014). The European Commission provided a new circular economy action in March 2020 with the aim of increasing sustainable growth and climate neutrality (European Commission, 2020). Integrating the nexus approach with the life cycle thinking approach provides a good opportunity for a circular economy [103].

In the existing WEF nexus studies, a lack of attention has been paid to considering the circular economy. Furthermore, a circular economy needs to be integrated with the WEFL nexus to increase resource use efficiency. Based on the existing nexus literature, it is obvious that there is an essential need to provide a systematic approach to analyze interactions between the use of water, energy, food, and land, for instance, in multiuser systems, waste, and byproducts, which can be reused for other product and services. Mitigating waste can contribute to maintaining products and materials at the biggest benefit at any time and reducing resource use and CO_2 emissions and mitigating the WEFL nexus. This approach can be made by conducting a circular economy integrated with the WEFL nexus. The circular economy helps to increase resource protection and economic development. The circular use of products (for example, biomass) helps resource use efficiency and enhances production with high value in terms of reducing wastage. Considering the circular economy in the WEF nexus approach contributes to mitigating stress on natural resources and providing sustainable growth, it also helps to achieve climate neutrality and reduce biodiversity loss. The strategy helps the European green deal and clean energy strategy [104].

3.5. Research Gaps in European Countries

The review of scientific papers published before 2023 on the WEF nexus in European countries revealed several gaps. The most important issues are listed:

1. To date, most of the studies look at the WE and WEF nexus by considering historical data. There are very limited studies that considered future changes in water and energy demand due to climate change, although climate change is an important factor that impacts water availability, snowpack, and precipitation [105]. There is a lack of research that evaluates the impact of climate change on other pillars of the nexus framework in European countries. Climate change leads to some disasters, such as floods and drought, in some geographical areas [106,107]. It is expected that climate change puts pressure on water and energy resources; therefore, these dimensions need to be addressed in European countries appropriately. It is recommended to analyze the different climate change scenarios related to various pillars of the nexus on both the supply and demand side at a regional scale. There is no study that evaluates the interlinkage between food security, water stress, land security, and the migration of people as a result of climate change.

2. The majority of the papers focused on the energy sector and the interaction between water and energy. However, there is a lack of research on land use, land productivity, and land suitability. Moreover, there is a lack of attention on soil and the environment nexus, despite the fact that food security can only be achieved by having access to healthy soil for cultivating crops. Food and soil are interlinked and considering soil in the nexus could contribute to increasing sustainability in water quality and food by enhancing soil care development. Soil is a finite resource that can endanger food security by soil erosion in some geographical areas due to mismanagement [108].
3. Most of the nexus frameworks and approaches have only considered water consumption, and water quality is rarely taken into consideration. To date, there are no studies that consider both water quantity and quality as one of the nexus dimensions in the nexus framework in European countries, while just one work was conducted outside Europe [109]. Water quality in the nexus can contribute to identifying an appropriate solution for achieving sustainable development goals since environmental issues associated with low water quality leads to other social and economic problems. For example, low water quality can lead to other social and economic problems, such as a lack of equality and human well-being [110]. In more detail, water quality is identified as the chemical, substantial, and biological dimensions of water including water treatment. Only two studies by Fabiani, Vanino, Napoli, and Nino, 2020 [34] and Fabiani et al. (2020) [35] considered water quality in nexus evaluation in European countries. Another study in Thailand considered the water quality–energy–food nexus in aquaculture [109]. Water quality was evaluated in terms of pH, nitrite, suspended solids, total phosphorus, ortho-phosphate phosphorus, fecal coliform bacteria, dissolved oxygen, electrical conductivity, and ammonia. One study by Fabiani, et al. (2020) only considered water quality, while water quantity was not considered in wheat production since wheat production was cultivated as a rainfed crop in their study area. Water quality was evaluated in terms of nitrate loss in green water during different fertilization applications. Another study conducted similar research in two regions (in Greece and the Czech Republic) to evaluate the water quality–energy–food nexus with a focus on sustainability (the economic and environmental dimensions) of variable rate technology (VRT) for wheat production in different fertilization methods [35]. Food and energy production need water in appropriate quality and efficient quantity. In return, energy production and crop cultivation can reduce water quality. The water quality in terms of well-being, health, and the environment is rarely considered by the WEF nexus approach [111]. One reported impact is the impact of biomass cultivation on soil and water pollution. For instance, one study in the USA on biofuel crop production shows that soybean and corn can help to reduce nitrate; however, water consumption increased [112].
4. Most of the nexus researchers in European countries focus on two pillars of the nexus rather than using a holistic nexus. There is a lack of studies on a comprehensive nexus that takes into account the possible interactions between the different resources, including water, energy, food, and land use. There is an essential need to provide a comprehensive approach in which all the resources are evaluated equally.
5. In the existing WEF nexus studies, a lack of attention has been paid to considering the circular economy. It is essential to consider circular economy needs to be integrated with the WEFL nexus to increase resource use efficiency, reduce greenhouse gas emissions, and mitigate wastage.

4. Conclusions

This paper provides valuable and useful information about research papers related to nexus studies in European countries published before 2023. It provides important information for researchers to deeply understand the WEF nexus approach in different sectors. It also contributes to researchers and scholars knowing the existing nexus gaps in

European countries, therefore suggesting the unanswered questions to be addressed in the near future.

It is indicated that resource security, optimal resource management, climate change adaptation, and policymaking are the main topics in nexus research. Based on existing literature, in European countries, more focus has been paid to the energy sector, the WE nexus, and bioenergy crop production. There is a lack of studies on the impact of climate change on the WEF nexus. Additionally, water quality is not considered in the nexus evaluation in European countries. This study confirms that the largest nexus studies were conducted in water scarcity countries to solve water stress, while the lowest studies were allocated to water-abundant countries.

Therefore, how does one face the interlinkage between food security, water security, land security, and the migration of people as a result of climate change? Firstly, the expected effects of climate change in a specific region must be identified based on an area-specific study. For example, within the so-called "Food Valley" in the Emilia Romagna Region (northern Italy), D'Oria et al. (2018) showed a substantial invariance of precipitation in the period 1986–2005, with changes that were comparable with the natural variability of the climate. Differently, the warming of the study area is unequivocal [113]. A progressive rise of atmospheric temperatures is expected with increments (i) up to +0.75 °C in the short term (until 2035), +1.5 °C in the medium term (2046–2065), and +2 °C in the long term (2081–2100) under RCP 4.5 assumed by the ICCP in the 5th Assessment Report (AR5, ICCP, 2014) and (ii) up to +4 °C in the long term with RCP 8.5 [114]. Similar results were obtained in the wider Mediterranean area by Todaro et al. (2022), who did not find any significant tendencies in precipitation but found upward trends in temperature, which were statistically significant for some sites over a historical period [115]. Therefore, what type of influence is expected as a consequence of this kind of climate change and, then, which specific problems must be solved (and how) in that region (or in similar ones)? Undoubtedly, there will be an increase in evapotranspiration and then a decrease in water availability. Nevertheless, recent studies also demonstrated that an upward trend in atmospheric temperature can also negatively influence the microbial groundwater quality [116–118], combining land desertification with the increase in human diseases. In some low-income countries, the combination of water scarcity and water pollution can force people to migrate, and the related problems can (must) be solved by designing problem- and site-specific approaches and solutions.

From a methodological perspective, the present review revealed that there is not a common and universal approach for nexus evaluations, suggesting the need to provide a standard and holistic approach. A new holistic framework is needed with the aim of enhancing the effectiveness of future nexus approaches by considering all of the resources/sectors, including water (quantity and quality), energy, food, land, and climate (the WqEFLC nexus).

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Abbreviation

LCA	Life Cycle Assessment
LW nexus	Land–Water nexus
LWEF nexus	Land–Water–Energy–Food nexus
WE nexus	Water–Energy nexus
WEF nexus	Water–Energy–Food nexus
WEFC nexus	Water–Energy–Food–Climate nexus
WEFE nexus	Water–Energy–Food–Environmental nexus
WEFLC nexus	Water–Energy–Food–Land–Climate nexus
WEL nexus	Water–Energy–Land nexus
WES nexus	Water–Energy–Soil nexus
WqEFLC nexus	Water (quantity–quality), Energy, Food, Land, and Climate nexus

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