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Water Energy Food Nexus in Urbanizing Wetlands: Challenges and Solutions Explored through Choremes and Focus Maps

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Abstract: Addressing complex interactions within water, energy, and food (WEF) resources, innovative tools for in-depth analysis and decision-making are imperative. This study introduces choromatic focus maps (CFMs) as a groundbreaking method to visualize and tackle the WEF nexus's complexities, focusing specifically on the Danube Delta Biosphere Reserve (DDBR). By merging geospatial analysis with on-site validation, this research reveals intricate interdependencies within the nexus and positions CFMs as an effective tool for stakeholders. This study adopts a methodological approach that focuses on identifying human activities and evaluating their impacts on the WEF nexus, with the goal of developing practical and grounded strategies for managing these essential resources. By testing this approach within the DDBR, the potential for wider application is demonstrated, offering a promising framework for addressing similar socio-environmental challenges across various regions. Future research directions include refining CFMs' precision and practicality through extended fieldwork and stakeholder engagement, testing the framework's adaptability across various locations and nexus dynamics. Additionally, incorporating cutting-edge technologies such as machine learning could provide deeper insights and reinforce CFMs' role in decision support for the WEF nexus. Conclusively, this investigation into the WEF nexus through CFMs emphasizes the critical need for strategies that navigate the complexities of environmental management and resource optimization, marking CFMs as a significant tool for both decision-makers and researchers.

Keywords: decision makers visualization tools; WEF nexus visualization; choremes; focus maps

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1. Introduction

The water–energy–food (WEF) nexus represents a concept to describe and address, to better understand and systematically analyze the interactions between the natural environment and human activities [1]. This concept, which underscores the intricate connections between water, energy, and food systems, is crucial for sustainable development and requires a comprehensive and integrated management approach [2,3].

Harwood (2018) called for a ''systems thinking'' approach that can help effectively evaluate and implement actions in regard to the area pertaining to the WEF nexus [4]. Adopting this kind of ''systems thinking'' approach in the Danube Delta is essential due to its fast development and increasing urban pressure in recent decades. These facts

challenge the delicate balance within the WEF nexus, making it crucial to consider the interconnectedness of water, energy, and food systems holistically.

According to a literature review by Torres et al. (2019), which covers the years from 2011 to 2019, the nexus approach primarily focuses on the interconnectedness of water, energy, and food systems. These three elements emerged as the central focus of "Nexus thinking" [5]. Alternative perspectives, such as reducing the nexus to just two elements (Shang et al., 2018), or expanding it to include additional factors such as ecosystem health and climate dynamics, were less frequently explored. These findings underscore that this WEF study is of coherent interest with other studies in this field [6].

The increasing interest in the WEF nexus over the last 20 years has been accompanied by an increasing awareness that we are currently living in a period of rapid environmental degradation due to human activities, the Anthropocene. Haidvogl (2018) described the increasing human pressure on freshwater lakes and rivers in the twentieth century, in particular mentioning pollution, changes in water hydrology, the invasion of alien species, the decrease in fish yields, and the loss of biodiversity, among others [7]. Despina et al. (2020) provided an overview of the anthropogenic pressures within the Danube Delta Biosphere Reserve, focusing particularly on the degradation observed in floodplains and Danube River ecosystems spanning a period of 25 years [8]. In the historical context, the "growing awareness of the limits to growth" (Du Pisani, 2006) strengthened the thinking about the sustainable use of nature, which was also a key concept for the WEF nexus later [9]. With this globally growing awareness about the sustainable use of resources, concepts about the WEF nexus were applied worldwide (e.g., [10–13]), including for the Danube River. A more detailed picture towards an integrative perspective of Danube River systems in the 21st century linked to the WEF nexus concept and the degradation of the Danube River over 70 years was elaborated in various studies in the context of ecosystem services, agriculture, and urban life [14–19].

The Tulcea WEF nexus, a case study of a mid-sized city in the Danube Delta (Tulcea, population size: 65.624; population density: 571 inhabitants per km^2; census, 2021), was explored in two prior studies [20,21]. The key finding pertinent to this study was that the WEF nexus showed less awareness among local residents in Tulcea than could be expected from rural development, as analyzed by scientists (for degradation of environment see, e.g., [22]). Through the survey on the WEF nexus (interviews and workshops) concerning the vegetable supply in Tulcea, which encompassed various commodity flows including a local vegetable market in the city, at least a larger number of respondents was interested in appreciating nexus knowledge, to learn more about the interconnection of the three elements: water, energy, and food [20]. Accordingly, these residents utilized "the Tulcea tool", developed as a user-friendly interactive data collection tool within the framework of the WEF nexus. When asked about the appeal of the information offered by this tool, 46% of respondents expressed a preference for the interactive map to be the primary feature. This led to two conclusions drawn from Balaican et al. (2023): (A) that the interest in the WEF nexus context was expanding beyond scientists and local authorities and included a growing interest from the general population; and (B) that there is a demand for a graphical representation of the complex relationships within the WEF nexus. This outcome resonated with the contemporary concerns of other studies including citizen science activities in the DDBR [23], i.e., indicating a growing public awareness of sustainability of resources, all aimed at enhancing human well-being. Thus, the communication of complex relationships, such as those of the WEF nexus, is demanded, and needs to be visually presented [24].

In the exploration of the WEF nexus, this article introduces choromatic focus maps (CFMs) as a tool for intensifying the understanding and management within this complex framework. These maps serve not only as educational instruments but also as crucial catalysts in comprehending the intricate interdependencies within the nexus. By visually representing these relationships, they provide stakeholders with a holistic perspective on how individual actions impact the entire system, thereby advocating for sustainable resource management practices. This approach is essential for fostering an integrated

environmental management strategy [25,26]. Moreover, the role of CFMs extends beyond simple data representation; they are instrumental in offering clear, visual insights into dynamic environmental systems. Their application is critical in informing policy decisions, promoting sustainable practices, and upgrading the overall understanding of key environmental interactions, thus playing a vital role in effectively navigating and managing the complexities of the WEF nexus [27–29].

CFMs' development started from the concept of the "choreme", introduced by Brunet in 1986, which was primarily used by geographers to manually represent the basic characteristics of a territory. The knowledge they depict essentially comes from their familiarity with the territory, its history, the climatic constraints, and the main sociological and economic issues [30]. Features such as cities, the population, and trends of specific phenomena represent the most common concepts that can be outlined through choremes. Since then, the growing popularity of choremes as a metaphor for representing elements of interest has involved new research areas, where the use of choremes can represent an effective tool both to obtain an immediate idea of data in terms of visual summary, and to derive new information from basic visual models [31–33].

KLIPPEL changed the conceptual approach related to the choreme given by Brunet from the structural perspective that presents the spatial distribution of elements to a functional perspective oriented towards the actions that take place in certain areas and their consequences for the entire system. An important aspect of this theory is that it is represented by a combination of theory and collected real data [34]. The main goal is not considered to be the exact visual representation of geographic data, but rather to show the most relevant aspects of the phenomena, as Bouattou et al. (2017) also found when presenting animated choreme-based summaries of geographic data streams [35].

Focus maps are designed so that the user's attention is drawn to the part of the map that is of interest. The user's interpretation process is directed to the region of interest, which facilitates the process of reading the map as the amount of information that needs to be processed is reduced. The focusing effect is achieved by using two techniques: varying degrees of generalization and color fading. Cartographic elements in the area of interest are displayed with precision; the generalization of these elements is kept to a minimum. As the distance from this area increases, so does the degree of generalization of cartographic elements, meaning the cartographic elements that are away from the area of interest are simplified to a high degree [36].

Combining the two approaches mentioned above (choreme maps and focus maps) results in CFMs that merge structural focus with functional focus, resulting in a map where attention is directed towards relevant information and areas [37]. Richter et al. (2008) emphasized the significance of CFMs in guiding attention to relevant spatial information tailored to specific tasks. He highlighted the critical role of context in designing focus maps, underscoring their ability to emphasize various elements such as features, areas, or actions based on the intended use [38].

Drawing on Richter's findings, this article establishes the groundwork for utilizing CFMs as a potent tool for local decision-makers to visualize anthropogenic impacts within the WEF nexus, particularly in complex regions such as urbanizing wetlands. These maps are not only simple geographical representations; they are dynamic illustrations of the relationships and interdependencies within the WEF nexus, making them invaluable for decision-makers. By converting complex data into an accessible format, these maps enable informed decision-making and facilitate a deeper understanding of the nexus [39,40]. Wetlands play critical roles in water purification, flood control, and as sources of food and energy, yet they are vulnerable to anthropogenic impacts, requiring a comprehensive and integrated management approach [2,3]. Through these maps, the multifaceted impacts on wetlands, and by extension on the WEF nexus, are vividly portrayed, highlighting areas that require urgent attention and sustainable management [17,41].

2. Materials and Methods

Danube Delta represents a complex study case where environment, economic activities, traditions, and culture form the identity of the place. Economic activities are determined by seasonal dynamics, directly influencing the daily life of the inhabitants in the area. Demographic decline of local communities, disparities between the administrative territorial units, acute isolation, and harsh conditions of living represent pressing issues for local decision-makers [42]. In 1991 the Danube Delta was assigned as Biosphere Reserve and several restoration measures were implemented [17].

Assessing the impact of anthropogenic activities on natural habitats and the environment in the Danube Delta is an essential component for the sustainable management of this delicate ecosystem. The use of satellite imagery and spatial analysis technologies provides an effective approach to monitoring and evaluating changes that may affect this region. The proposed methodology represents an integrated approach, using satellite images and space analysis technologies to assess the impact of anthropogenic activities in the Danube Delta. This approach was validated by the work of several researchers, such as Medinets et al. (2023), Oteman et al. (2021), Kuenzer et al. (2019), and Tziavos et al. (2016), who utilized satellite imagery to monitor changes in coastal ecosystems, demonstrating its effectiveness in environmental monitoring and management, particularly in sensitive areas such as the Danube Delta [43–46].

Careful selection of images, analysis of changes in vegetation, and use of advanced techniques allow identification and quantification of specific changes caused by deforestation, intensive agriculture, and other human activities. Drawing upon the methodologies presented by Schlemm et al. (2023), this research integrated considerations of water, air, and soil quality into the WEF nexus visualization, recognizing the interlinked effects of human activities on water, energy, and food systems [47]. Field validation ensured the accuracy of resulting CFMs, highlighting high-risk areas, providing essential information for the sustainable management of this unique ecosystem.

In order to maximize the potential effectiveness of CFMs as a valuable visualization tool for decision-makers within the WEF nexus framework, a multi-criteria methodology involving the following aspects was proposed.

1. Identification of anthropogenic activities

In the initial phase of conceptualizing CFMs, the identification of anthropogenic activities is crucial. Concerning the Danube Delta, this was accomplished by evaluating long-term trends of diverse indicators of human pressure. Based on these indicators, the methodology was refined to emphasize shifts in land use, infrastructure expansion, and time-series analysis. This adaptation allowed us to further underscore the influence of human activities linked to tourism, industry, transportation, and agriculture within the water–energy–food (WEF) nexus [48].

2. Distribution of anthropogenic activities using focus maps

By using satellite images, the spatial distribution of anthropogenic activities in the Danube Delta was identified and focus maps on the distribution of activities that highlight the impact of tourism, industry, transport, and agriculture were created. The detailed imaging analysis aimed to create a comprehensive spatial understanding of human influences in the Delta. This procedure was crucial for creating connections between both existing and new data, laying the foundation for deeper understanding of the complex dynamics formed by human activities and the WEF nexus. The focus maps generated through this research significantly improve understanding and identification of regions at risk of substantial anthropogenic impact. Their utility is particularly notable in assessing WEF nexus interconnections in expansive areas, such as the Danube Delta (the site of community importance, Danube Delta ROSCI0065, covers an area of 453,645.5 ha), highlighting their value in large-scale environmental analysis.

3. Field validation

In this phase, the identified trends and correlations between generated focus maps were validated by integrating field-based water, air, and soil measurements. Furthermore, a citizen science component was involved, local knowledge being assessed through informative interviews. For effective data assessment, measurements were taken in different areas and in different periods of the year, to highlight the most damaged areas based on anthropogenic impact and following the touristic peaks to observe the WEF nexus's capability to return to parameters identified in periods with low anthropogenic impact. The proposed measurements will further ensure the accuracy of CFMs and also link the WEF nexus as follows.

Water quality analysis is a focal point in developing CFMs, aligning information presented in maps with the WEF nexus's pivotal principle of sustainable resource management. Hydrological and physicochemical indices were utilized to provide information about ecosystem conditions at the time of sampling. Such data are critical for assessing water quality and pinpointing areas undergoing significant environmental changes. Such analysis is key to understanding the element "water" of the WEF nexus, providing vital information that could be further integrated to ensure a comprehensive representation of the interdependencies within the Danube Delta's ecological system.

Air quality monitoring using an online anthropogenic impact assessment system on inland lakes and canals was developed and the data obtained were subsequently correlated with information related to the distribution of anthropogenic activities. Air quality represents an important factor when taking into consideration WEF nexus in a fragile ecosystem such as the Danube Delta.

Existing data related to soil quality and organic carbon were used to assess changes in soil according to different anthropogenic activities [49].

To identify the areas affected by erosion or degradation, mapping was carried out following drone flights in pilot areas designated for testing and optimizing the system based on multiparameter sensors for real-time monitoring of anthropogenic impact on indoor channels. These data were further integrated into CFMs, resulting in a powerful visualization tool.

4. Creating choromatic focus maps as local decision-making tool

Choromatic focus maps were generated to highlight areas at high risk of habitat degradation and soil, air, and water contamination based on data-driven extraction and presentation of focus maps shown later in this article. Similar to focus maps, color coding was used in CFMs to represent different levels of anthropogenic impact. These maps aimed to highlight areas with maximum vulnerability to anthropogenic impact. Doing this, the integration of CFMs as local decision-making tools for WEF nexus assessment was showcased.

CFMs stand as the primary visualization tool for local decision-makers to synthesize and showcase the nuanced interactions within the WEF nexus. Based on focus maps enriched using extensive field-verified data, they visually articulate the intricate dynamics of the nexus, offering a powerful means for presenting comprehensive insights. Such approach underlines the importance of integrated resource management in the Danube Delta, ensuring that policy and community discussions are informed by an integrative understanding of environmental, social, and economic interdependencies.

This article further presents the current stage of creating Danube Delta CFMs as a local decision-making tool to show the distribution of anthropogenic activities using focus maps. These focus maps are further discussed as valuable resource for anyone interested in the interaction between human activities and the environment in the Danube Delta, contributing to informed decision-making and sustainable development.

In the process of generating focus maps, diverse methodologies and data sources were identified. The main sources included satellite images for detailed insight into the delta's territory and identification of the spatial distribution of human activities. Corine

Land Cover (CLC) data also provided key information about land use, and public data on population density, infrastructure, and accessibility complemented the analysis [50]. The Google Earth Engine platform was used for efficient analysis and processing of satellite data, facilitating the extraction of relevant information [51]. Data available at the National Institute of Statistics (INSSE) were also integrated to obtain information on population and economic activities in the area [52]. The following specific sources were further used to present/create seven themes utilized for visualization in focus maps in this study:

1. Focus landscape Map, Figure 1.

Applying mapping of the Danube Delta Biosphere Reserve (DDBR) data using Corine Land Cover 2018 (CLC) [50].

Figure 1. Focus map of land use in protected natural areas of Danube Delta Biosphere Reserve (ROSCI0065); data source https://land.copernicus.eu/en/products/corine-land-cover (accessed on 20 November 2023).

2. Focus Map of the human footprint source, Figure 2.

Extracting human footprint data available through Wildlife Conservation Society platform [53].

3. Focus map of tourist attractions per Administrative Territorial Unit (ATU), Figure 3.

Applying data related to tourist attractions in localities; original data available at www.obiective-turistice.ro (accessed on 28 November 2023) [54].

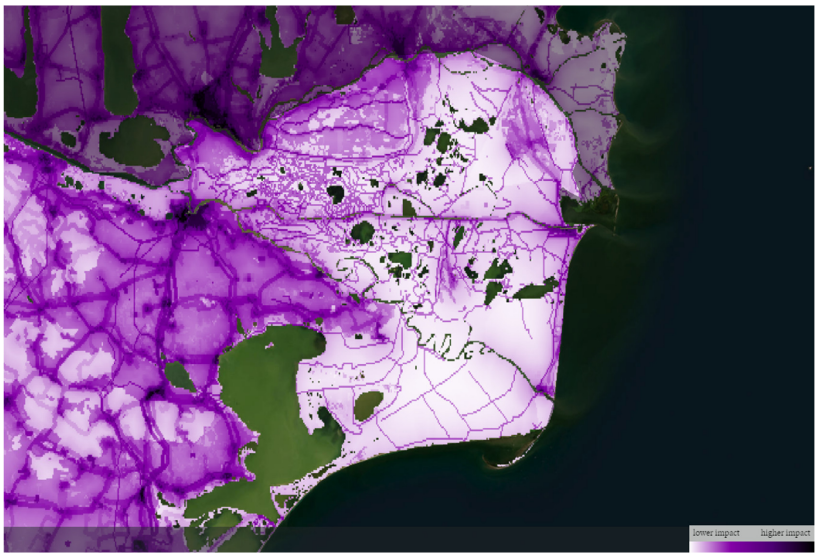

Figure 2. Focus map of the human footprint; source: https://wcshumanfootprint.org/map/ (accessed on 25 November 2023).

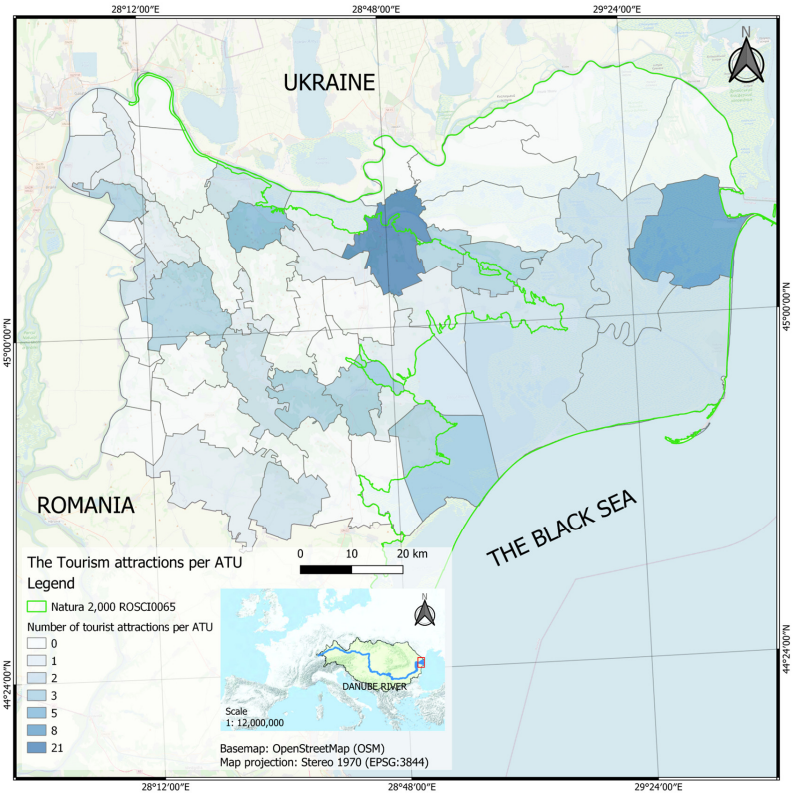

Figure 3. Focus map of tourist attractions per ATU.

4. Focus Map of touristic and leisure routes, Figure 4.

Creating this aspect of touristic and commonly used leisure, integrating public data available from Danube Delta Biosphere official site [55].

5. Focus maps of the total number of tourism overnight stays in 2020, 2021, and 2022 (Figures 5–7).

Maps of the total number of overnight stays in tourist accommodation structures within the administrative limits of Tulcea County developed using statistical data available on INSSE portal [52].

Figure 4. Focus map of touristic and leisure routes.

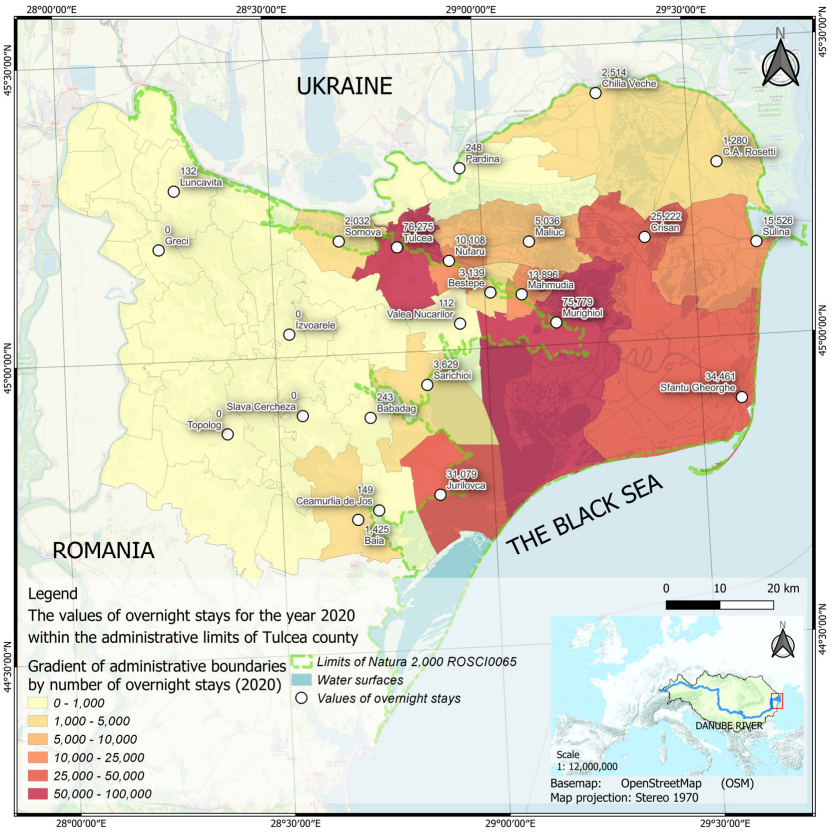

Figure 5. Focus map of the total number of overnight stays in tourist accommodation structures within the administrative limits of Tulcea County for 2020.

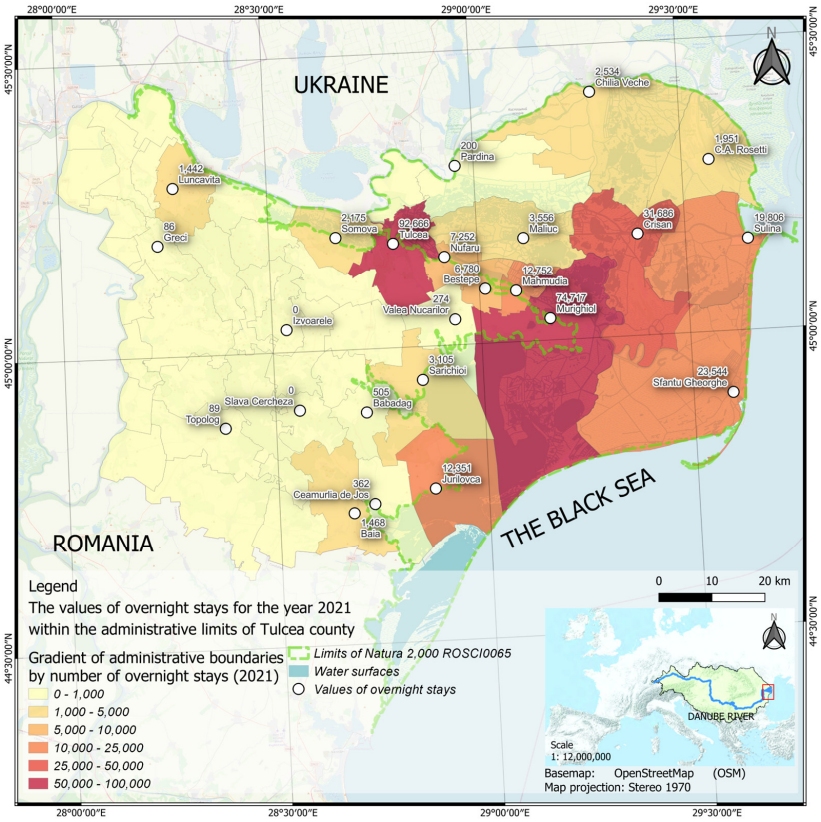

Figure 6. As Figure 5 but for year 2021.

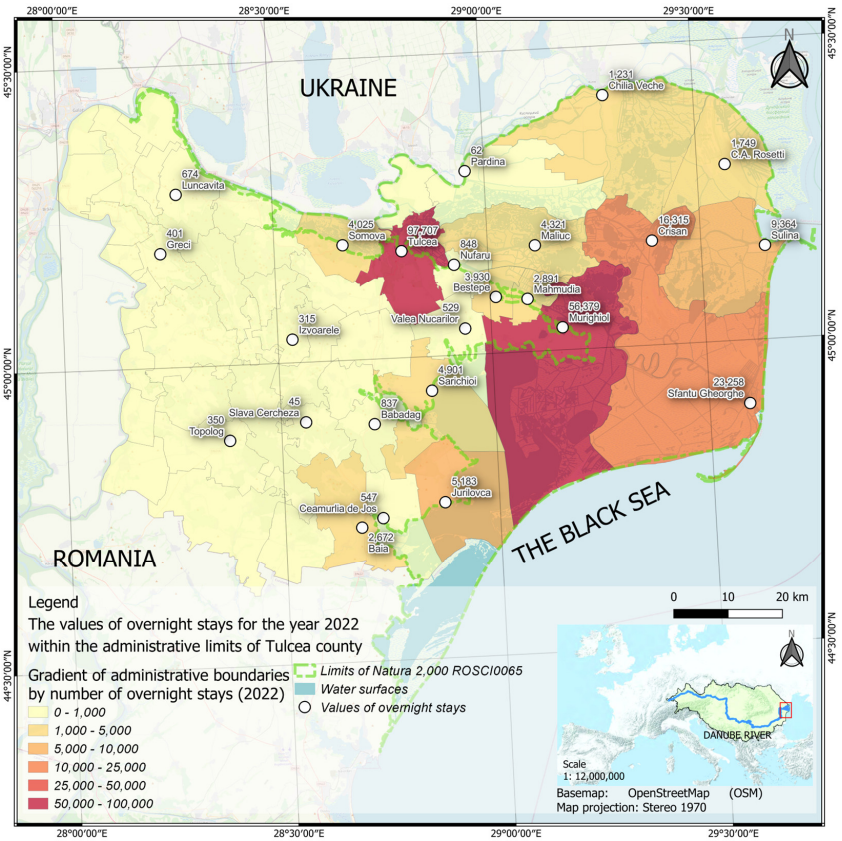

Figure 7. As Figure 5 but for year 2022.

6. Focus Map of water management in Danube Delta Biosphere Reserve (DDBR) (Figure 8).

Public data related to water consumption available at National Agency for Land Improvements were used [56].

7. Focus Map of navigation (Figure 9).

Data available on Delta Danube Biosphere Reserve official website regarding touristic routes were combined with authors' data regarding water bodies in Danube Delta to focus on areas where touristic routes will have impact on transport [55].

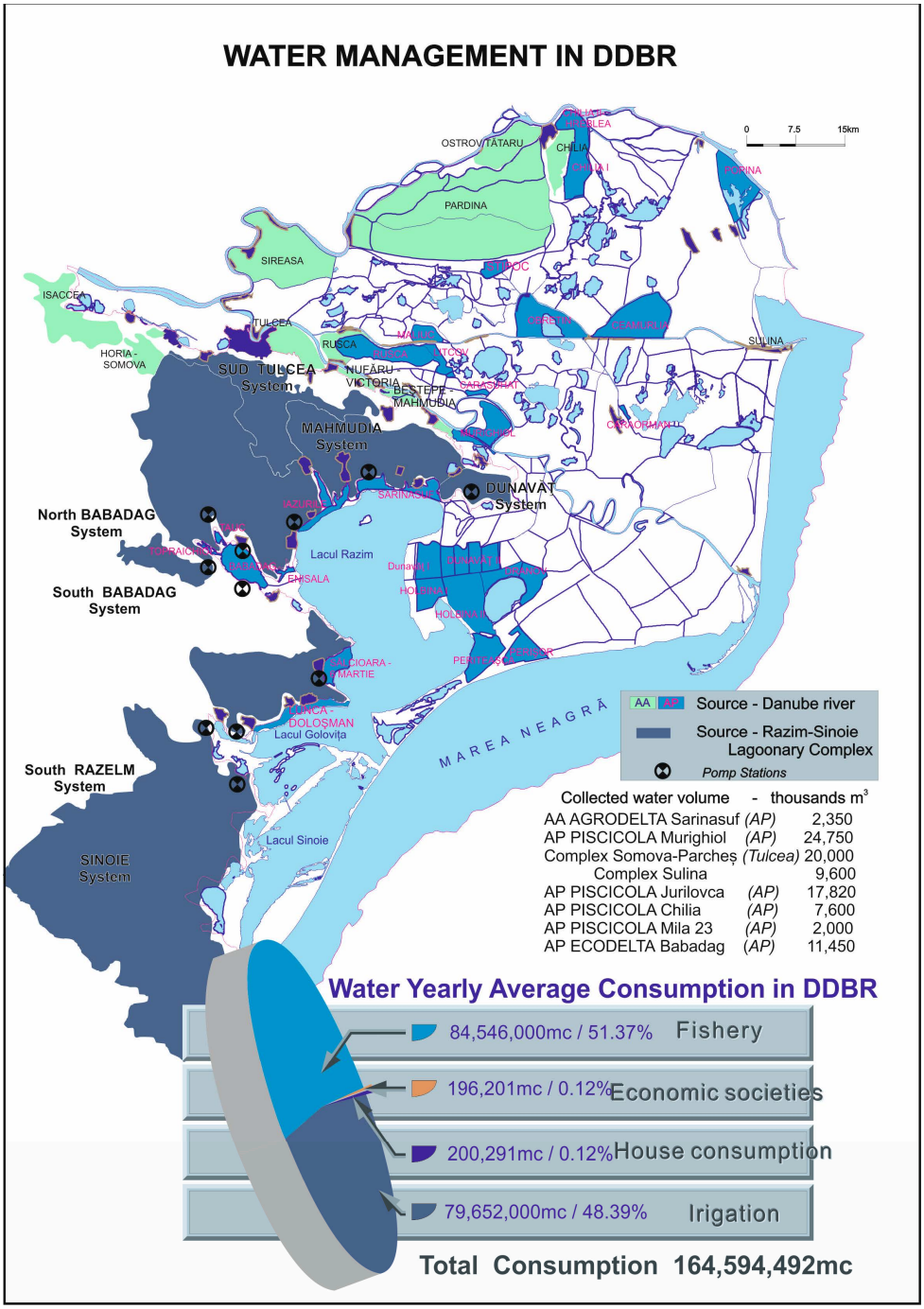

Figure 8. Focus map of water management in Danube Delta Biosphere Reserve (DDBR).

Figure 9. Focus map of navigation in the DDBR area.

3. Results

In this section, the results of a suite of focus maps are provided which indicate a comprehensive exploration of the dynamic interplay between human activities and the delicate ecosystems within the Danube Delta Biosphere Reserve (DDBR). Each focus map served as a unique lens, offering distinct insights into various facets of the region's landscape and anthropogenic impact. From understanding land utilization patterns to assessing the human footprint, mapping recreational areas, and overnight stays in tourist accommodation, these visual representations show a nuanced picture of the challenges and opportunities within the WEF nexus present in this biosphere reserve.

3.1. Land Use Focus Map

The focus map about land use, as an anthropogenic activity, has a significant impact on the morphology and biodiversity of the territory. This complex interaction is reflected in the evolution of the local landscape, where variations in land use are influenced by a number of factors such as natural conditions, property rights, and the activities of local communities.

The detailed representation of land use within the DDBR serves as an important analytical tool for the WEF nexus, supporting the sustainable management of these interconnected resources. By mapping areas dedicated to agriculture, forests, and water bodies, the map offers insights into water usage, energy demands, and food production. For water, it highlights regions of potential stress or abundance, guiding effective water resource management. In terms of energy, it identifies energy needs across different land uses and opportunities for harnessing renewable sources. The maps depiction of agricultural land

directly informs strategies for food production, stressing the importance of maintaining ecological balance to ensure food security.

This focus map facilitates an integrated analysis of the WEF nexus, revealing the synergies and trade-offs between water use, energy consumption, and food production. Additionally, the map serves as a valuable tool for community engagement, enabling stakeholders to visualize land use impacts on the WEF nexus. It promotes a collective understanding and fosters collaborative efforts towards the sustainable management of natural resources, balancing the needs of the local communities with environmental conservation. (Figure 1).

3.2. Focus Map of the Human Footprint

The human footprint is the total sum of the ecological footprints of the human population. It expresses this sum not as a single number, but as a continuous form of human influence spread across the Earth's surface, revealing, through its variation, the main patterns of human influence on nature [57].

The Focus map of the human footprint is the most common measure of how human activities affect the planet, but the concept applied here is quite simple. The human footprint is a weighted combination of where people live (population density), build infrastructure (roads, railways, factories and others), can circulate (accessibility), and use electricity (an indicator of access to industrial energy sources measured by night lights). These impacts are illustrated on maps at a resolution of about 300 m. The human footprint focus map for the Danube Delta thus provides a detailed look at the anthropogenic impact in the different regions, highlighting urban, agricultural, forestry, open water, tourist route areas, and access routes (Figure 2).

The focus map of the human footprint presents the extent and variety of human activity across the Danube Delta, serving as a valuable tool for exploring the connections of the WEF nexus within this region. By mapping the ecological impact of human presence, including population density, infrastructure, accessibility, and signs of industrial energy use such as night-time lighting, this map helps to clarify the spatial patterns of human influence across the delta.

This visualization tool plays an important role in WEF nexus analysis, highlighting how human settlements, development projects, and energy consumption intersect with natural resources. It signals areas under stress from anthropogenic pressures, informing targeted strategies for mitigating environmental impacts. Pinpointing zones with intensive development or significant energy use, for instance, helps identify potential risks to water resources and agricultural land, which are critical for food production. This analysis facilitates the identification of sustainable practices that can mitigate adverse effects on the ecosystem while supporting the community's needs.

Moreover, the map offers a detailed perspective of the dynamic interplay between human activity and the natural environment, enabling a deeper understanding of potential pressure points within the ecosystem. By identifying specific regions of high human activity, it becomes possible to forecast the implications for water quality, energy sustainability, and food security. This anticipation is valuable for planning integrated resource management that aligns with the ecological and social goals of the Danube Delta, fostering a balance between human advancement and environmental preservation.

3.3. Focus Map of Tourist Attractions and Viewpoints

The focus map of tourist attractions and viewpoints, as discussed in the context of the WEF nexus within the DDBR, provides a detailed visual representation of the distribution of natural and anthropogenic tourist attractions across this territory. These attractions include monasteries, natural monuments, wooden churches, fortresses, archaeological sites, museums, reservations, viewpoints, etc., which are distributed per Administrative Territorial Unit (ATU). This methodological approach helps identifying 'hot-spots' of tourism within the Danube Delta, linking these directly to the element "water" due to the

region's significant reliance on aquatic tourist activities such as visits to the seaside and deltaic areas [58].

Tourism, by its nature, can lead to an increased consumption of water and energy, and can affect local food production systems either directly through the demand for food resources or indirectly through the impact on water and energy resources essential for agriculture. Therefore, the focus map of tourist attractions and viewpoints becomes an instrumental tool for local decision-makers, providing a visual summary that represents the intricate dynamics of tourism within the WEF nexus. This facilitates the understanding of the interactions and dependencies within the nexus, promoting a sustainable approach to managing natural resources and planning for tourism development that respects the delicate ecosystem balance.

This focus map is of high importance within the WEF nexus framework as it enables the visualization of tourism's impact on water resources, an essential component of the nexus. The map not only aids in identifying areas with significant tourist attractions, but also assists in understanding the potential pressures these attractions may exert on the local environment and resources, specifically water. In the broader context of the WEF nexus, where sustainable management of interconnected water, energy, and food resources is vital, such visual tools facilitate informed decision-making by highlighting areas where sustainable tourism practices could mitigate negative environmental impacts (Figure 3).

3.4. Focus Map of Touristic and Leisure Routes within DDBR

The focus map of touristic and leisure routes within the DDBR is a visualization tool that outlines the interactions between tourism, recreation, and the ecosystem's sustainability within the WEF nexus framework. By highlighting areas of significant anthropogenic activities related to tourism and leisure, this map serves as an important instrument for decision-makers and stakeholders. It provides a visual summary that not only presents the distribution of tourism and recreational potentials, but also underlines the impact of these activities on the region's ecological balance. This dual function emphasizes the map's importance in promoting sustainable tourism practices that harmonize socio-economic development with environmental conservation efforts (Figure 4).

The data presented through this focus map reveal the spatial dynamics of touristic and leisure activities, offering insights into areas that are potentially at risk due to overexploitation. The visual representation aids in identifying regions where tourism activities concentrate, which can be critical for allocating resources, implementing conservation measures, and planning sustainable tourism development strategies. The map's focus on touristic routes implies a need for continuous monitoring and management to ensure that water resources, energy demands, and food security considerations are integrated into the sustainable tourism development plans, reflecting a comprehensive view of resource interdependencies and environmental conservation.

Despite its utility, this focus map faces challenges in terms of data accuracy, representativeness, and scalability. One primary concern is the dynamic nature of tourism and leisure activities, which may not be fully captured through static maps. Seasonal variations, emerging trends in tourism, and the introduction of new leisure activities necessitate frequent updates to ensure the map remains relevant and accurate. Additionally, the map's ability to influence policy and planning decisions is dependent on local stakeholders' understanding and interpretation of the visualized data, highlighting the need for in-depth outreach and education efforts to maximize its impact.

Using field-based data measurements for the focus map of touristic and leisure routes within the DDBR could substantially refine its utility, paving the way for the realization of CFMs. By using GIS and remote sensing technologies for the dynamic integration of datasets, these maps can offer up-to-date insights into touristic and leisure activities within the DDBR. This approach not only ensures responsive management and planning, but also enriches the maps with environmental indicators such as water quality and habitat conditions.

3.5. Focus Maps of the Total Number of Overnight Stays in Tourist Accommodation Structures within the Administrative Limits of Tulcea County

The focus map of the total number of overnight stays in tourist accommodation structures in Tulcea County is an essential resource for understanding the WEF nexus in the context of tourism. By identifying areas with high tourist activity, this map contributes to a holistic view of how tourism intersects with local resource utilization. It provides insights into water and energy consumption trends in areas with dense tourist concentrations, which is crucial for sustainable WEF management. The delimitation of areas with intense tourist activity provides a clear perspective on the places with the largest flow of tourists and related activities. The map is also a tool for monitoring tourism trends over time. Changes in overnight stays offer crucial insights into the dynamics of tourism activities, enabling the continuous refinement of development strategies in response to these fluctuations. Using statistical data from the INSSE database, maps depicting the total number of overnight stays in tourist accommodation facilities within Tulcea County's administrative boundaries were generated for the years 2020, 2021, and 2022 (Figures 5–7). They show that the number of overstays in these three years was almost the same, even though these maps aimed to represent a dynamic view from year to year. These maps serve as an input for CFMs, complementing the basic static information provided in the focus map of tourist attractions per ATU (Figure 3) and the focus map of touristic and leisure routes (Figure 4).

3.6. Focus Map of Water Management in Danube Delta Biosphere Reserve (DDBR)

The focus map of water management in the DDBR holds a critical position within the WEF nexus analysis, offering a thorough view of how water resources are distributed, utilized, and managed across this unique ecological landscape. The significance of this map extends beyond water management; it acts as a key to understanding the interdependent relationships between water usage, energy production, and food security within the DDBR. The data displayed on this map present the important role of water as both a resource and a connector within the nexus, highlighting areas of intensive agricultural use, zones of significant energy usage, and critical habitats for fishery-based food sources (Figure 8).

By visualizing water management practices and identifying potential stress points and areas of efficient use, the map provides a solid foundation for developing integrated strategies that address the sustainability goals of the WEF nexus. It enables decision-makers and stakeholders to locate where improvements in water efficiency can lead to gains in energy conservation and food production, ensuring a balanced approach to managing the delta's resources.

Furthermore, the development of CFMs after field-based data collection and interviews with local stakeholders will be significantly improved using the insights gained from the water management focus map. The real-world data and local perspectives gathered will enrich the initial map, adding layers of socio-economic and environmental considerations. This iterative process of mapping, data collection, and stakeholder engagement ensures that the CFMs are not only grounded in empirical evidence, but also reflect the nuanced realities and priorities of the local communities.

3.7. Focus Map of Navigation in DDBR

Integrating the focus map of navigation routes into the study impacts the understanding of the energy and water dynamics within the WEF nexus. This map, compared to the one used for water management, does more than just trace paths; it brings to light the often-overlooked interplay between transportation networks and resource utilization (Figure 9).

By mapping navigation routes, areas are visualized where waterways are heavily used and are thus subject to potential environmental stress. This is essential for understanding the element "energy" of the WEF nexus, considering that shipping and transportation are significant energy consumers. The map can serve in assessing the balance between transportation efficiency and its ecological footprint, particularly in water resource management.

In the context of creating CFMs, these navigation data improve the ability to visualize the WEF nexus. They offer nuanced insights, especially in how transport networks interface with water and energy use, potentially impacting food distribution channels.

For decision-makers, this map can be an essential asset. It aims at interpreting the complexities of energy and water management in relation to transportation. The visual clarity can drive more informed, sustainable policy-making, particularly in areas where waterway navigation is a key economic and environmental factor.

Furthermore, this map can act as a predictive model for future scenarios, such as shifts in trade routes or the introduction of new, more sustainable transportation technologies. This foresight is crucial for proactive planning within the WEF nexus, ensuring that future developments are in harmony with sustainable resource use.

These focus maps, developed from a blend of satellite insights, Corine Land Cover data, and comprehensive demographic and infrastructural information, serve as a premise for the development of CFMs. Each map presents the complex relationship between human activities and the environment, intensifying our understanding and helping in sculpting informed, sustainable strategies for the Danube Delta's future.

The seven thematic focus maps not only showcase the spatial distribution of human activities, but also underline the potential of such detailed visual tools in fostering sustainable development. Here, the element water of the nexus is omnipotent (Table 1). By highlighting specific areas of interest associated with "water"—ranging from the landscape and human footprint to tourism, agriculture, and navigation—these maps offer important insights into the dynamics of land use, resource exploitation, and environmental conservation. This approach not only facilitates informed decision-making, but also paves the way for applying these methods in similar ecological contexts, thereby broadening the scope of their impact (Table 1).

Table 1. Overview of focus map type relevance within WEF nexus, local/regional stakeholders, and potential similar application areas.

Focus Map	Valid for	Focus Stakeholder Interest Group	WEF Nexus Elements	Similar Areas for Application
Focus Landscape Map	Danube Delta Biosphere Reserve (DDBR)	Environmental planners, conservationists	Water, food	Wetlands, other Biosphere Reserves
Focus Map of the Human Footprint	Danube Delta Region	Policy makers, environmental agencies	Water, energy, food	Urban and rural regions globally
Focus Map of tourist attractions per Administrative Territorial Unit (ATU)	Recreational areas within DDBR	Tourism sector, local communities	Water (tourism's impact)	Coastal regions, national parks
Focus Map of touristic and leisure routes	Cultural and Natural Tourist Sites within DDBR	Tourism businesses, cultural heritage organizations	Water, energy (indirect)	Heritage sites, areas of natural beauty
Focus Maps of the Total Number of Overnight Stays	Tourist accommodations within Tulcea County	Tourism sector, hoteliers	Water, food (tourism impact)	Popular tourist destinations worldwide
Focus Map of water management in Danube Delta Biosphere Reserve (DDBR)	Intensively farmed areas within DDBR	Agricultural sector, environmental agencies	Water (agriculture impact), food	Agricultural regions, farmlands
Focus Map of Navigation	Waterways within DDBR	Business, tourism businesses	Water, energy (navigation impact)	River basins, canal systems

4. Discussion

Although the number of elements integrated in the WEF nexus approach varied, the element "water" was always present according to Torres et al. (2019) [5]. The element "water" was also omnipresent in this WEF nexus study aimed at creating chorematic focus maps, as identified in the table providing an overview about these maps. The many aspects of the element "water" were incorporated in the view of land use and agriculture (areas of irrigation and permanent land under water), of the human footprint (water surface areas are indicated by low footprint scores), of tourist attractions, recreational areas, and tourist accommodation locations (seaside and Danube Delta tourisms hotspots; e.g., [59]), and of

navigation (the use of water ways in the Danube Delta). From this perspective, "water" is central in this WEF nexus approach.

The prominent role of "water", however, goes far beyond even what is seen at first glance in these focus maps. Within the WEF nexus, the sustainable use of water resources involves managing water in a way that meets the present needs without compromising the ability of future generations to meet their own needs. Sustainable water management practices include understanding water as a habitat, reducing water pollution inputs, managing land use to minimize water runoff, or preventing flooding with open wetland areas, and thus also implementing effective watershed management strategies. The key understanding of water within the WEF nexus refers to the interconnection between water quality and ecosystem health, which is critical for sustaining water, energy, and food systems. Maintaining high water quality in lakes and tributaries in the DDBR is known to support aquatic biodiversity, favoring fish species important for food production. Water quality is also of importance when using water for drinking and agricultural irrigation, and builds up the scenery for sustainable ecotourism. This multifaceted importance of water is deeply embedded as foundational knowledge within the presented WEF nexus focus maps, even if it is not explicitly depicted. By integrating water into the map visualization, the study ensures a comprehensive understanding of the intricate relationships and dependencies of water within this complex WEF framework.

An effective mapping of the complex WEF nexus meets two needs: (1) the data-driven selection of the most important aspects of elements which are (2) introduced in the specific geographical references through map representations. CFMs are, thus, a hybridization of scientific metrics or indicator parameters and cartographic design.

Concerning the parameter-driven impact on the elements within the WEF nexus, a suite of ecological and social background parameters were empirically captured. Extracting key parameters is utilized to reflect complex circumstances effectively. Key parameters thus essentially serve as indicators, designated to trace climate and other environmental changes in sentinel environments, such as lakes and rivers, in the long-term. Consequently, the biocenosis structure is often evaluated today, as it is assumed that organisms integrate well over long periods of time with their occurrences during their life span, unlike current measurements of environmental conditions. The well-known application of biocenotic metric measures, as also utilized for the DDRB, or being in general the basic assessment tool for the European Water Framework Directive, is mentioned here (metric measures derived from the proportions of the many species living together in an aquatic community are compared with those biocenotic descriptions from natural reference habitats; see, e.g., [22]). Even more aggregation of information is possible when using single key indicators. Such an aggregation of information is given by the parameter "water clarity". This socio-ecological indicator goes far beyond its original meaning used for determining the depth in ocean water for safe navigation or monitoring water quality in aquatic sciences [59]. Water clarity is nowadays seen bridging the gap of information flow from sustainable ecosystem health to ecosystem service supply, and from scientific assessment documenting an overall success of sustained urban-lake restoration or urban-ecosystem health in the lab to human perception enhancing human well-being in urban life [60]. These two examples, the application of metric parameters and of key indicators, demonstrate that the simplification of an issue that is scientifically grounded (empirically data-driven outcome) and targeted can help to better understand complex relationships applicable for a broader audience, including local residents. Such a simplification of the complexity concerning the WEF nexus in the DDRB was also achieved using correlation analysis to identify the largest anthropogenic pressures for the WEF nexus in the DDBR prior to creating focus maps. The main human impacts on the WEF nexus extracted were tourism, population density, industry, transport, and agriculture [48]. Utilizing the human footprint (Sanderson et al., 2002) for creating a focus map in the WEF context, this parameter again is a reliable and robust key parameter, as it amplifies the overall human impact, encompassing not only population density but integrating various human activities such as traffic, indus-

try, tourism, and other components weighted in an index [57]. From this perspective, the simplification, i.e., reducing parameters to a few extracted key indicators on geographical reference maps, can be seen as highly focused information processing in a visualization that still meets the complexity of the WEF nexus. Thus, it can be helpful for decision makers and can enhance the attractiveness of becoming informed for local people demanding greater awareness in their understanding of the WEF nexus from a future perspective [61]. The simplification, to present a lower number of reliable indicators but to maintain the information level depicted, also goes along with limits of human perception when utilizing maps. It is known that the spontaneous and fast recognition of items by adults is limited to up to five items [62–64]. From this perspective, simplification is demanded on both sides when creating effective focus maps: the reduction to few reliable and robust key descriptors as discussed before and a well-structured simple cartographic design, e.g., as in the abstraction to a lower number of color codes and icons used as an overlay on a simplified geographic reference map [65,66]. This way, focus maps can be seen as powerful tools assessing the WEF Nexus.

The next level of abstraction displaying the complex interdependencies between natural and human systems of the WEF nexus can be seen in CFMs [31,67,68]. Discussing CFMs, collaboration and constructive criticism about essential features for advancing CFMs as a decision-support tool are seen to become important in the next perspective. In this view, this study aimed to stimulate further visual representation and innovation in this field, acknowledging the current approach's limitations while recognizing its vast potential for future research. An iterative method for creating CFMs will ensure that each phase deepens the understanding of the WEF nexus and, in turn, also redefines CFMs as a tool. Future studies, including more diverse case studies, expanded datasets, and various geographical applications, are expected to provide an even more comprehensive toolkit for local decision-makers, making information accessible and understandable for policy makers and the local community.

This study introduced choremes and focus maps as a powerful tool to visualize the WEF nexus, covering large areas with diverse anthropogenic stressors. The final proposed result (CFMs of the DDBR) will be validated using field-collected data covering an over one-year assessment period to ensure data quality, the precise identification of impacted areas, and the WEF nexus's recovery capability based on different stressor levels. This methodology will be presented, discussed, and improved during the SRI2024 Congress session Co-producing the Nexus: Stakeholder-Driven Exploration of the Water–Energy–Food–Ecosystems Interconnections.

5. Conclusions

The exploration of the water–energy–food nexus using chorematic focus maps in this study represents an interdisciplinary approach aimed at addressing the challenges within socio-environmental systems, particularly highlighted through the Danube Delta Biosphere Reserve. Through the innovative integration of geospatial analysis with field validation, this research not only elucidates the complex interdependencies characterizing the WEF nexus but also introduces a novel tool for stakeholders to visualize and manage these interactions more effectively.

One of the significant contributions of this study is the methodological framework it proposes, which includes the identification of anthropogenic activities, their distribution, and the impact they have on the WEF nexus. By doing so, it offers a comprehensive perspective on managing water, energy, and food resources in a manner that is sustainable and grounded in the reality of local ecosystems. This approach, demonstrated within the context of the DDBR, has the potential to be applied in other regions facing similar challenges, providing a scalable solution for sustainable development and policy formulation.

Looking forward, the study outlines several directions for further research. Perfecting the accuracy and applicability of CFMs through additional fieldwork and stakeholder consultations represents a crucial next step. Expanding the application of CFMs to vari-

ous geographic regions and nexus configurations will test the framework's adaptability and scalability. Furthermore, the integration of advanced technologies, such as machine learning and big data analytics, into the CFM framework could unveil deeper insights and predictive capabilities, thus enriching the decision-support utility of CFMs for managing the WEF nexus.

In conclusion, this study exploration of the WEF nexus through the perspective of CFMs highlights the indispensable need for integrated management strategies that are responsive to the complexities of environmental management and resource utilization.

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