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Constructed Wetlands as Nature-Based Solutions in the Post-COVID Agri-Food Supply Chain: Challenges and Opportunities

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Abstract: The COVID-19 crisis has highlighted the interchangeable link between human and nature. The health and socioeconomic impacts of COVID-19 are directly or indirectly linked to the natural environment and to the way that agri-food systems interact with nature. Although the pandemic continues to evolve and there are still many uncertainties, important issues about the future of the agri-food sector and the need for a sustainable and environmentally friendly reformation are beginning to arise in society. Nature-based Solutions (NbSs) encompass a broad range of practices that can be introduced in the agri-food supply chain and address multiple environmental challenges of the COVID-19 and post-COVID-19 era while providing economic and societal benefits. In this perspective, the design and establishment of multifunctional constructed wetlands as NbSs opens a portfolio of eco-innovative options throughout the agri-food supply chain, offering a realistic and promising way towards the green regeneration of the post-COVID-19 economy and the welfare of society. The aim of this work is to explore the potential role of constructed wetlands as Nature-based Solutions in the agri-food supply chain of the forthcoming post-COVID-19 era. More specifically, this work aims to reveal application opportunities of constructed wetlands in the different segments of the agri-food supply chain, identify linkages with societal challenges and EU policies, and discuss their potential limitations, future challenges, and perspectives.

Keywords: agri-food supply chain; environment; NbSs; eco-innovation; constructed wetlands; post-COVID-19

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1. Introduction

The agri-food sector entails a wide and complex network of feedbacks and tradeoffs between environment, economic activities, transport, trade, livelihoods, and human health. Since its first wave in 2019, the outbreak of COVID-19 is still having an unparalleled effect on the agri-food sector. The health and socioeconomic impacts of the pandemic have been linked to the natural environment and to the way that agri-food systems are organized and operate [1]. The crisis that the agri-food sector is facing today requires adapting transformative changes in technological, economical, and socio-ecological activities to address human needs while preserving Earth's systems in the post-COVID-19 era [2,3]. Nature-based Solutions (NbSs) are gaining importance as solutions that integrate societal challenges and nature conservation across scales and landscapes. In this perspective, they have the potential to offer long-term transformative pathways to agri-food supply chains towards sustainability [4]. Constructed and natural wetlands are at the epicenter of NbSs [5,6]. Unfortunately, constructed wetlands attract attention mainly as natural wastewater treatment systems, while other important ecosystem services that they provide are usually overlooked or are simply considered ancillary [7]. Thus, the multifunctional role of constructed wetlands in the different segments of the food supply chain is often underestimated and their contribution as NbSs to the post-COVID-19 resilience and sustainability of the agri-food sector is not fully assessed.

The aim of this work is to explore the potential role of constructed wetlands as Nature-based Solutions in the agri-food supply chain of the forthcoming post-COVID-19 era. More specifically, this work aims to reveal application opportunities of constructed wetlands in the different segments of the agri-food supply chain, identify the linkages with societal challenges and EU policies, and discuss their potential limitations and future challenges.

For this purpose, a literature review was conducted based on emergent qualitative analysis (deductive and inductive) [8]. This dual approach combines critical elements without relying completely either on existing literature or on the data themselves [9]. The analysis follows a stepwise approach, in which first the environmental aspects of agri-food sector in the post-COVID-19 era are discussed to set the framework for the analysis. Focus is given on the environmental challenges of the agri-food supply chain, as these have been affected by the pandemic and evolved according to the changes in public perceptions and attitudes after the outbreak. In answer to the identified challenges, the authors present the concept of NbSs in the agri-food sector followed by a chapter that presents the relevance and classification of constructed wetlands as NbSs. The next chapter analyzes in detail the present and perspectives of constructed wetlands in the agri-food supply chain by demonstrating existing applications and potential opportunities, analyzing linkages with policies, and discussing limitations and future challenges.

2. Environmental Aspects of the Agri-Food Supply Chain in the Post-COVID-19 Era: A Consumers' Driven Approach

The COVID-19 pandemic has led the agri-food systems into a novel reality with multiple challenges that need to be addressed. In this perspective, issues related to sustainability and environment are of primary importance for the agri-food supply chain [10,11]. Although the pandemic continues to evolve and there are still many uncertainties, important issues about the future of the agri-food sector and the need for a sustainable and environmentally friendly reformation are beginning to arise in society. In this perspective, Kotler (2020) [12] pointed out the emergence and growing importance of five consumer types in the post-COVID-19 era, which are interestingly all related directly or indirectly to environmental issues. These types include:

- Degrowth activists, who worry about the carrying capacity of the earth in relation to the consumption of goods and natural resources and call for nature conservation and the reduction of human material needs;
- Climate activists, who are concerned about climate change and the future of our planet while aiming to reduce the human carbon footprint and the degradation of natural resources;
- Sane food choosers, who are persons who have turned into vegans or vegetarians, are abstaining from the use of meat or animal products, and are opposed to industrial farming of animals for ethical and environmental reasons, including high methane emissions and the increased water footprint of raising livestock;
- Conservation activists, mainly environmentalists with social concerns, who promote the philosophy of repair–reuse–recycle;
- Life simplifiers, who are less interested in owning goods, and in order to cover temporal needs they prefer renting instead of owning.

Considering that consumers may regulate market growth, competitiveness, and economic integration, the assessment of consumers' preferences and behavior is of primary importance in planning post-COVID-19 strategies and measures towards green and sustainable agri-food supply chains [13]. The shifting of consumer preferences can unlock a multitude of both health and environmental benefits such as combating biodiversity and climate threats and crises, relieving environmental stresses, and contributing to sustainable socioeconomic schemes and healthier lifestyles with tangible long-term impacts on the livelihood of human society.

Following the evolution of public perceptions, needs, attitudes, and intentions [14], the environmental aspects of the agri-food supply chain are becoming of primary importance in the agenda of the food industry, decision-makers, and scientists, as these are related to human and environmental health and safety issues. As identified in several recent studies [15–19], challenges related to the environment in the COVID-19 and post-COVID-19 era of the agri-food sector are mainly related to (1) emerging greener consumer behavior, (2) climate change, (3) environmental pollution, (4) resource efficiency, (5) health and hygiene concerns, (6) green energy transition, (7) conservation of biodiversity, and (8) systems resilience and sustainability (Figure 1).

Figure 1. Environment-related challenges of the agri-food supply chain in the COVID-19 and post-COVID-19 era.

Although these challenges are not new in principle, the pandemic resulted in a reorientation of priorities and the urgent need for integrated solutions in respect to multiple societal needs and the changes of citizens' behavioral patterns. Key issues of environmental interest as well as associated challenges affected by pandemic are the following:

- Climate-related issues have improved during COVID-19. Nitrogen and carbon emissions decreased significantly because of the restrictions in transportation and mobility, the decreased usage of electricity, and the ceased industrial production. However, based on projected changes in climate and upcoming socioeconomic developments, most climate change impacts are expected to rebound and maybe increase even more in the coming decades across Europe [20]. Based on these projections and given the sharp rising of fossil fuel prices, as was recently recorded, the gradual transition to green energy is necessary in order to safeguard both the viability of the agri-food sector and climate health in the post-COVID-19 era [21]. Investment in renewable energy sources (e.g., wind, solar, and bioenergy) along with interventions for energy efficiency (e.g., insulation retrofits, green buildings, and infrastructure) are indispensable parts of the armory against the global energy crisis in the years to come. This is of primary importance for the agri-food sector in which the cost of energy and the reliability of supply is critical (e.g., greenhouses, storage, and processing facilities). Green energy solutions may contribute to autonomous and safe operations even in case of emergencies and unexpected events (e.g., COVID-19 outbreak). In a win–win scenario, countries and business in the agri-food sector may benefit from a robust green energy economy and the cutting down of spending over more expensive and less reliable fossil-based sources of energy [22].

- In terms of pollution, water-quality issues related to emerging pollutants and microplastics are of growing importance. The extensive use of personal protective equipment (e.g., masks and gloves) that become waste and the inappropriate use of chemical substances to control pests and/or prevent the transmission of diseases may raise important environmental problems [23]. Soil degradation issues became more intense during COVID-19 lockdown because of the increased quantities of municipal food wastes, the suspension of recycling programs, and restrictions on sustainable waste management practices [17].
- The lockdown measures were found to drive an important shift towards the "circular economy" approach, which aims to maintain the value of products and resources through time while minimizing the generation of waste [23]. According to FAO (2021) [18], the main opportunities and challenges are related to the treatment and reuse of wastewater as well as the recycling of irrigation water, the precision agriculture, and the optimization of agricultural inputs, biofertilizers, and bioenergy. In this direction, the G20 encourages eco-design that permits products and resources to be repaired–recycled–reused and the uptake of relevant business models for economic recovery [24].
- According to the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the emergence of zoonotic diseases, as well as changes in land use, the expansion of agriculture, and urbanization, could be associated with more than 30% of emerging diseases. Furthermore, it was emphasized that birds, mammals (primates, bats, and rodents), and livestock (e.g., poultry, pigs) could act as reservoirs of pathogens that may have pandemic potential [25]. Thus, multiple biodiversity-related issues arise in the COVID-19 and post-COVID-19 era, including the interconnections between agriculture, biodiversity, and infectious diseases; the trade and consumption of wildlife; the importance of climate change on biodiversity and eventually on the emergence of diseases through the spatiotemporal distribution of potential reservoirs and vectors; the degradation of ecosystem functions and the loss of habitats; and the impact of land-use change on biodiversity from deforestation for agricultural purposes to landscape fragmentation due to transport networks and other human infrastructure development [26,27].

3. The Growing Importance of Nature-Based Solutions

Environmental sustainability may contribute to the prevention as well as coping of potential future pandemics and their impacts [28]. The concept of Nature-based Solutions (NbSs) introduces an alternative pathway towards sustainability through balanced socioecological adaptation and resilience [29]. The European Commission defined NbSs as solutions that are inspired and supported by nature, are designed to address societal challenges, are cost-effective, provide environmental and socioeconomic benefits, and help build resilience [30,31]. In this perspective, the concept of "innovating with nature" may effectively contribute to more sustainable and resilient societies through green growth and job creation [32]. NbSs as an umbrella concept may range from the wise management of natural ecosystems to the establishment of new ecosystem functions and processes [33]. From the perspective of degrees of intervention, NbSs can be divided into three broad categories, as presented in Table 1 [34,35].

NbSs are acknowledged among policy/decision-makers and major European Policy frameworks and strategies, such as the European Green Deal, the EU Health Strategy, and the EU Biodiversity Strategy, all considering their potential to increase health and well-being. They are considered credible means able to address key societal issues (e.g., impact of climate change, natural disasters, and loss of biodiversity) [35], and this was acknowledged at the high-level ministerial panel on NbSs in green recovery held by the IUNC in March 2021. A prominent outcome of the panel was the commitment of involved parties to increase efforts and investment to allocate NbSs a larger role in COVID-19 stimulus plans, acknowledging the great cost–benefit ratio of NbSs, their potential for speedy and streamlined implementation, and their contribution to sustainability and citizens' well-being [29].

Table 1. Types of Nature-based Solutions.

NbSs Typology	
Type I	Minimal (or no) intervention in ecosystems. Aim to sustain protected/natural ecosystems, improve the conservation status and increase environmental awareness, and enhance or restore their functional role and ecosystem health (e.g., ecosystem conservation and restoration strategies).
Type II	Partial interventions in ecosystems. Aim to improve selected ecosystem functions and services by contributing to sustainable, multi-functional ecosystems (e.g., sustainable forestry and agriculture, multifunctional rural landscapes, application of agroecological practices, or strengthening of forest resilience to extreme events through biodiversity enhancement).
Type III	Interventive management of ecosystems (extensive/intrusive) or establishment of new ecosystems. Aim to draw benefits from newly established assemblages of organisms and natural processes while also linked to the concepts of green and blue infrastructure (e.g., green roofs or walls to mitigate city warming or air pollution; natural systems such as constructed wetlands for water pollution control and non-conventional water supply, bio/phyto remediation of heavily polluted or degraded areas).

In agri-food supply chains, NbSs encompass a wide range of promising practices and potential solutions that can be introduced, addressing multiple environmental challenges of the COVID-19 and post-COVID-19 era.

In agricultural production, NbSs can be deployed directly in the context of food and fiber production on agricultural lands, in rural landscapes, or regarding water resources that are used for production [36]. At the farm level, examples of NbSs include agroforestry; intercropping; cultivar mixtures; biological pest control; rehabilitation of soil functions and improvement of soil quality; erosion control measures; biological nitrogen fixation; multifunctional field margins; precision agriculture and smart irrigation techniques for the reduction of inputs; natural systems of water management and recycling of nutrients, waste, and energy; and avoiding contaminants to ensure food safety [37].

In terms of urban sustainability transformation, the concept of edible cities (urban food production and local distribution) can be seen as a multifunctional NbSs [38]. Simultaneously, circular economy-related initiatives can stretch to connect urban with rural areas, as in the case of Kitakyushu city in Japan, where the adoption of a food-recycling loop allows compost from urban areas to be used as fertilizer or an energy source in rural areas [24].

From the consumers' point of view, the COVID-19 outbreak introduced multiple changes in the daily life of people by affecting the foundations of our societies and economies. This is characteristically reflected in the behavior and attitude of consumers [39]. According to Durante and Laran (2016) [40], in stressful situations such as the pandemic, consumers tend to save money and spend strategically on necessary products in order to restore their sense of control. In this perspective, NbSs that reduce the stress of citizens may contribute to more rational consumer behavior and the gradual rebound of the economy in the post-COVID-19 era and potentially lead to greener consumption patterns with considerable environmental benefits. A gradual shift to plant-based diets, for example, may contribute to sequestration from 332 Gt to 574 Gt CO_2 [41].

Furthermore, the use of NbSs for improving townscapes and favoring social cohesion [42] may contribute to the mitigation of climate change impacts (e.g., urban heat shocks) and associated heart and respiratory diseases [43], which is of critical importance under the threat of COVID-19.

In addition to the above, NbSs may also provide employment opportunities, which is critical in the post-COVID-19 era, especially in disadvantaged and climate-vulnerable areas [44]. It is highlighted that approximately 1.2 billion jobs globally are dependent on ecosystem health (e.g., agriculture, forestry, fisheries, tourism), with considerable societal and economic importance [45,46]. NbSs can be used to sustain or enhance the jobs and productivity of those working in the agri-food sector and thus contribute to social justice goals of reduced inequalities, decent employment, equal opportunities, social safety, and cohesion.

A common element in the NbSs approach is that based on nature's paradigm, the establishment of healthy and resilient ecosystems may deliver valuable services that contribute to human well-being while simultaneously addressing environmental and socioeconomic goals [35].

4. Constructed Wetlands as Nature-Based Solutions

Constructed or artificial wetlands are engineered ecosystems that combine the core structural components of natural wetland ecosystems (e.g., water, vegetation, and soil/substrate) in such a way as to mimic and perform selected functions of natural wetlands and thus deliver a range of monetary and non-monetary services. In this perspective, wetland systems are an important tool in the armory of NbSs. The services of constructed wetlands, as in case of natural wetland ecosystems, may include [47]:

- Supporting services (e.g., nutrient cycling, food-web support);
- Regulating services (e.g., water-quality improvement, water-flow regulation, groundwater recharge, and climate regulation);
- Provisioning services (e.g., food, fiber, and water supply, including non-conventional water);
- Cultural services (e.g., education, recreation, aesthetic, spiritual).

The design of constructed wetlands is adjusted according to the targeted services and the purpose of their establishment [48]. Depending on their main functions and the targeted wetland ecosystem services, constructed wetlands may be established as:

a. Natural wastewater (black or grey) treatment systems focused on water-quality improvement;
b. Blue–green areas focused on cultural services;
c. Food and fiber production systems focusing on provisioning services;
d. Building interventions such as wet roofs and green walls with a focus on climate regulation services;
e. Landscape interventions for water-flow regulation and flood control in urban, rural, and mountainous areas;
f. Biodiversity enhancement areas focused on food-web support.

Based on their structural and functional characteristics, constructed wetlands are referred to as green infrastructure, classified under Type III of NbSs. Green infrastructure, as part of NbSs' armory, is defined by the European Commission [49] as a network of areas that are strategically planned, designed, and managed in order to deliver a range of ecosystem services, such as, for example, the improvement of water and/or air quality, mitigation of/adaptation to climate change, recreational areas, and natural risk or disaster attenuation.

Although historically, constructed wetland technology was mainly focused on pollution control and wastewater treatment, a broader approach has recently evolved. According to this, constructed wetlands are part of a wider picture that involves multiple integrative technologies to address sustainability issues in water, energy, and food [50]. Nowadays, and within the concept of circular economy and the water–food–energy nexus, the designers of constructed wetlands are aiming to build multifunctional systems that are able to deliver multiple services with associated benefits for society. A characteristic example in urban areas is the establishment of wet roofs for grey-water treatment, climate regulation, the improvement of energy efficiency, and the reuse of wastewater for primary production and/or landscape amelioration. In parallel, the introduction of constructed wetlands in rural areas as multifunctional wet field margins may contribute to non-point source pollution control and floodwater management, while at the same time creating wildlife habitats and enhancing the biodiversity of the rural landscape [6]. In this perspective, it is underlined that the typologies of NbSs, as presented in Table 1, are dynamic benchmarks and not static classifications of possible NbSs interventions, since many hybrid NbSs may exist along the gradients. For example, constructed wetlands established initially as green infrastructure of Type III will be subsequently managed as Type I systems [34,36].

5. Constructed Wetlands in Agri-Food Supply Chains: Challenges and Opportunities

5.1. Applications and Opportunities

Constructed wetlands, given their nature and multidimensional role, are at the center of NbSs since they constitute cost-effective solutions based on and supported by nature, able to provide multiple environmental and socioeconomic benefits [5]. Considering the increased priority given by the international community to NbSs, constructed wetlands are gaining attention as potential promising solutions to important challenges of the agri-food supply chain that are related to the environment.

The considerable progress of constructed wetland eco-technology in deploying selected ecosystem functions and services opens a portfolio of options throughout the agri-food supply chain. These offer a realistic and promising way forward for addressing conservation, climate, and economic as well as social challenges, while maintaining healthy and resilient agri-food systems in the post-COVID-19 era. Constructed wetlands and NbSs in general can often operate as standalone solutions. However, there is also a recent tendency to integrate them with gray infrastructure, creating hybrid solutions that are able to address complex challenges and meet increasing demands from different sectors of the broader water–food–energy nexus [50]. The applications of constructed wetlands cover the entire range from farm to fork by addressing multiple challenges, from pollution control, green energy transition, biodiversity conservation, and resource efficiency, to social welfare and post-COVID-19 economic regeneration. The potential role and applications of constructed wetlands in the agri-food supply chain in relevance with key societal challenges are presented in Table 2. These societal challenges were selected based on a review of the SDGs of NbSs frameworks [51], the EEA report on NbSs [20], and the outline of the societal challenges of the Horizon 2020 research programme [52].

Table 2. The potential role and applications of constructed wetlands in the agri-food supply chain in relevance with key societal challenges.

Agri-Food Supply Chain	Potential Role and Applications of Constructed Wetlands	Linked Societal Challenges
Production	• Non-point source pollution control in agricultural areas [53] • Non-conventional water supply for irrigation through the reuse of reclaimed wastewater [54] • Green energy production (e.g., from wetland vegetation biomass or through microbial fuel cells) [55,56] • Raw materials for the production of agri-food products (e.g., biomass as substrate for mushroom production) [57] • Food production, including fish farming [58] • Promoting circular economy within the water–soil–waste nexus [59] • Creation of habitats and increase in rural biodiversity [60,61] • Mitigating climate change impacts, including erosion, desertification, depletion of groundwater aquifers, wildfires, floods, etc. [62] • Multifunctional landscapes, including wet field margins for pollution control, water flow regulation, and biodiversity enhancement [63,64] • Remediation of polluted soils and sensitivity to degradation areas [65]	SC 1. SC 2. SC 3. SC 5. SC 6. SC 7. SC 8. SC 10.
Storage and Processing	• Wastewater treatment in food-processing industries [66] • Wetland roofs and green walls to improve buildings' energy efficiency [67] • Non-conventional water supply for industrial use (cooling, landscape amelioration, firefighting, etc.) [68] • Green energy production (e.g., from wetland vegetation biomass or through microbial fuel cells) [69,70]	SC 1. SC 2. SC 3. SC 5. SC 7. SC 10.

Table 2. *Cont.*

Agri-Food Supply Chain	Potential Role and Applications of Constructed Wetlands	Linked Societal Challenges
Transport and Distribution	• Treatment of runoff waters from road and transport networks [71] • Carbon sequestration and CO_2 sinks [72–74] • Providing ecological niches and mitigating ecological impacts of habitat loss or fragmentation [75,76] • Seawater pollution control, including petroleum hydrocarbons in the marine environment, using floating wetlands [77]	SC 4. SC 5. SC 8. SC 10.
Retail and Markets	• Wetland roofs and green walls to improve the energy efficiency of commercial and market buildings [64] • Decentralized water treatment in public and central markets [78] • Food-waste pollution control through landfill leachate treatment [79] • Social cohesion and environmental responsibility strengthening, as in the case of Dumaguete city's public market, where the funds collected from the public restrooms cover the operational and maintenance expenses of a wetland system for wastewater treatment [80]	SC 1. SC 3. SC 5. SC 6. SC 9. SC 10.
Customers and Consumption	• Greywater treatment and reuse for urban landscape amelioration [81] • Enhancement of urban biodiversity and mitigating climate change impacts in urban areas, including heat stress, stormwater management, etc. [82,83] • Urban agriculture and support of short local food supply chains (e.g., floating wetlands for vegetable cultivation in urban areas) [84] • Establishment of educational and environmental awareness areas [85] • Blue–green spaces for people to feel connected with nature and enhance psychological well-being in line with emerging consumer behaviors in the post-COVID-19 era [86]	SC 1. SC 2. SC 3. SC 5. SC 6. SC 7. SC 8. SC 9. SC 10.

(SC 1: Public health and well-being; SC 2: Food security, sustainable agriculture, and forestry; SC 3: Secure, clean, and efficient energy; SC 4: Smart, green, and integrated transport; SC 5: Climate action and resilience to extreme weather- and climate-related events; SC 6: Inclusive, innovative, reflective, and resilient societies; SC 7: Sustainable economic development and decent employment (including green jobs); SC 8: Preserving habitat, reducing biodiversity loss, and increasing green and blue spaces; SC 9: Making cities and human settlements inclusive, safe, resilient, and sustainable; SC 10: Environmental quality (including air quality, water, and waste management), resource efficiency, and raw materials).

The complexity of tackling the environmental challenges in the agri-food sector in the post-COVID-19 era requires an effective transformative change across a wide range of political, technological, and socioeconomic factors [87]. Working with nature is considered today a promising path to this transformative change [88]. In this context, innovative tools for the design, implementation, and assessment of multifunctional constructed wetlands and NbSs in general are required, along with effective processes that are able to effectively support stakeholders' participation [69].

Critical steps in this process are both the deployment of relevant research initiatives as well as the realization of large-scale demonstrative actions and the active mobilization of stakeholders and local champions as lighthouses for the transfer of knowledge and innovation at an operational level across borders. In this direction, the EU already supports several flagship projects, such as WaterLANDS and HYDROUSA through H2020, AQUACYCLE through ENI CBC Med, and MARA-MEDITERRA through the PRIMA Foundation, which not only promote the research and innovation in natural and constructed wetlands as NbSs, but also demonstrate their operational applications and capitalization potential to address environmental, economic, and societal challenges towards a sustainable future.

The new EU Framework Programme pays special attention to transferring the developed knowledge and innovations at an operational level, where they can generate tangible results and serve citizens. Thus, according to EU political priorities and the COVID-19 recovery plan, four key strategic orientations for EU research have been established [89]:

A. To promote open strategic autonomy through the development of key digital, enabling, and emerging technologies, sectors, and value chains;
B. To restore biodiversity and ecosystems as well as to sustainably manage natural resources in order to ensure food security and environmental health;
C. To set Europe as a protagonist in a digitally enabled sustainable, climate-neutral, and circular economy;
D. To establish a resilient, inclusive, and democratic society with high-quality health care, EU citizens empowered to act in green and digital transitions, and an increased level of readiness against disasters and threats.

In this perspective, the introduction of constructed wetland ecotechnology in multiple segments of the agri-food supply chain may have a significant contribution to the achievement of the expected impacts outlined in the Horizon Europe Strategic Plan 2021–2024 [89]. Based on a literature review of constructed wetlands' applications and services, a preliminary assessment of their potential contribution to the abovementioned impacts was performed (Table 3). These ecosystems may provide solutions in the agricultural production phase in respect to climate change adaptation/mitigation, pollution control, biodiversity enhancement, sustainable management of natural resources, and alternative primary and green energy production. Constructed wetlands may also play an important role at the consumer level, especially in urban areas, by addressing environmental challenges for a healthier environment and by promoting social transition towards responsible resource management, consumption of safer products, and eventually the flourishment of green economy and the well-being of society.

Table 3. Potential contribution of constructed wetlands to the expected impacts of Horizon Europe 2021–2024 key strategic orientations, per stage of the agri-food supply chain.

Agri-Food Supply Chain	**Expected Impacts of the Key Strategic Orientations**														
	A1	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**	**C4**	**D1**	**D2**	**D3**	**D4**
Production															
Storage and Processing															
Transport and Distribution															
Retail and Markets															
Customers and Consumption															

(A1: Competitive and secure data economy; A2: Industrial leadership in key and emerging technologies that work for people; A3: Secure and cybersecure digital technology; A4: High-quality digital services for all; B1: Enhancing ecosystems and biodiversity on land and in water; B2: Clean and healthy air, water, and soil; B3: Sustainable food systems from farm to fork on land and sea; C1: Climate change mitigation and adaptation; C2: Affordable and clean energy; C3: Smart and sustainable transport; C4: Circular and clean economy; D1: A resilient EU prepared for emerging threats; D2: A secure, open, and democratic EU society; D3: Good health and high-quality accessible healthcare; D4: Inclusive growth and new job opportunities. Colors: Green-High, Yellow-Moderate; Pink-Low; Grey-N/A).

Overall, constructed wetlands appear to be a promising ecotechnology with a potential significant contribution to EU policy objectives and strategies and especially the EU Green Deal (2019), the EU's Biodiversity Strategy for 2030 (2020), the new EU Strategy on Adaptation to Climate Change (2021), and the Bioeconomy Strategy and its recent update [29]. Especially concerning the agri-food sector, constructed wetlands are expected to play a key role in the Farm to Fork Strategy (2020) and the new Common Agricultural Policy 2023–2027 as potential measures supported by Eco-Schemes (e.g., measures to reduce and prevent water and soil pollution from excess nutrients, creation of nutrient traps and buffer strips, semi-natural habitat creation, rewetting wetlands/peatlands), aiming to provide stronger incentives for climate- and environmentally friendly farming practices [90].

5.2. Shortcomings and Challenges

Although constructed wetlands and NbSs in general appear to have a promising future, there are still several limitations and challenges to be addressed in order to fulfil their potential. In terms of technological maturity, some of the potential applications presented in Table 2 are already applied at an operational level (e.g., wastewater treatment), whereas for others (e.g., microbial fuel cells), further research and testing is needed to reach the necessary Technology Readiness Level (TRL) for commercial exploitation. Furthermore, performance models need to be developed in the case of conventional solutions. These should consider the potential long-term climate implications and scenarios, as well as the eco-evolutionary mechanisms that underpin the capacity of the ecosystems under study to perform and recover or adapt to major perturbations [88]. Another important issue is the documentation of their socio-economic and environmental contribution/benefits. This is directly related not only to decision-making in terms of planning, but also to their effectiveness and impact as part of policy measures and strategies. The social and cultural implications should be studied and analyzed before designing such systems. However, the problem with current evidence for the cost-effectiveness of constructed wetlands as NbSs is that appraisals underestimate the economic benefits of working with nature, especially over the long term. In this perspective, non-monetary benefits (e.g., carbon sequestration, education) are difficult to monetize, or there is high uncertainty about their non-market value. Furthermore, appraisals rarely factor in trade-offs among different interventions and ecosystem services or between stakeholder groups, which may experience the costs and benefits of NbSs differently. For example, the importance of wet field margins is different for farmers, local civil society, visitors, etc., reflecting differences in the extent of dependency on natural resources [77]. Additional challenges appear also in terms of governance. NbSs often involve multiple actions taking place over broad landscapes and seascapes, crossing jurisdictional boundaries. For example, constructed wetlands as buffer zones for non-point source pollution control in rural landscapes require collective action across different levels of decision-making (e.g., local and regional) and among multiple ministries (e.g., agriculture, environment, finance). Therefore, such efforts require cooperation and coordination between stakeholders whose priorities, interests, or values may not align [91].

6. Conclusions

The COVID-19 pandemic reminded people that the pressures of humankind on the planet has disrupted the balance and resilience of natural systems [92]. The interconnections of the pandemic to human and environmental health, including food systems, indicate the need to increase the levels of resilience and the preparedness against disturbances [93]. The pandemic revealed several structural shortcomings regarding the production and access to healthy products, the resilience of agri-food systems, and their relation to environmental health and sustainability [11]. On the other hand, the COVID-19 pandemic opened an opportunity window for the reformation of economies and the transition towards a greener model of development. As massive programs and mitigation measures are launched for the recovery of economies after the pandemic [94], it is important to ensure that sustainability plays a central role in the post-COVID-19 era [95,96]. This represents a critical intervention point in which NbSs could be effectively embedded within strategies and policies regarding sustainable land-use planning and development, resource efficiency, and environmental management, as well as social interventions in support of a green economy. In light of the transformation process towards a green and sustainable post-COVID-19 economy, there are several potential applications for constructed wetlands in the agri-food supply chains as Nature-based Solutions, with multiple environmental and socioeconomic benefits. In this perspective, relevant research activities should be further strengthened to address post-COVID-19 environmental challenges within a broader water–food–energy nexus framework, and social and economic aspects of their operational application as multifunctional systems should be further explored.

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