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Chapter 14

Enhancing sustainability of constructed wetlands for agricultural water and nutrient management practices through social innovations

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ABSTRACT

Constructed wetlands (CWs) have a long history of pollution control in urban but also in rural and agricultural settings. As one of the solutions to water and nutrient management issues in European agriculture, CWs were assessed in the European H2020 project WATERAGRI not just for their effectiveness but also for their role towards sustainability. In this chapter, we show different methods used to assess the effectiveness and sustainability of CWs by applying a rapid assessment, driver–pressure–state–impact–response analyses, and life-cycle thinking. We also demonstrate the need for an advanced inter- and transdisciplinary understanding of how sustainability, both as a concept and in its implications, is perceived by applying a Delphi analysis and an online questionnaire. The results show that CWs can be considered a sustainable measure for water and nutrient management in agricultural sites for their environmental benefits, which are the most highlighted by the scientific community and practitioners. However, findings also show that social benefits may indeed be the tipping point for these systems to be sustainable and that more research and insights are needed to highlight the role of social innovation.

Keywords: Nature-based solutions, Delphi approach, Life Cycle Thinking, Social sustainability, Policy recommendations.

14.1 INTRODUCTION

Intense agricultural practices are the leading cause of Europe's water, soil, and biodiversity degradation. Since the implementation of the Water Framework Directive 15 years ago, farm fertilizer and pesticide applications have been identified consistently as the leading cause of excess pollution loads both of surface waters and groundwater and for aquatic species loss (Bieroza *et al.*, 2021; Schäfer *et al.*, 2007). As per Dudley (2022), the massive loss of insects, both in species diversity as well as in absolute

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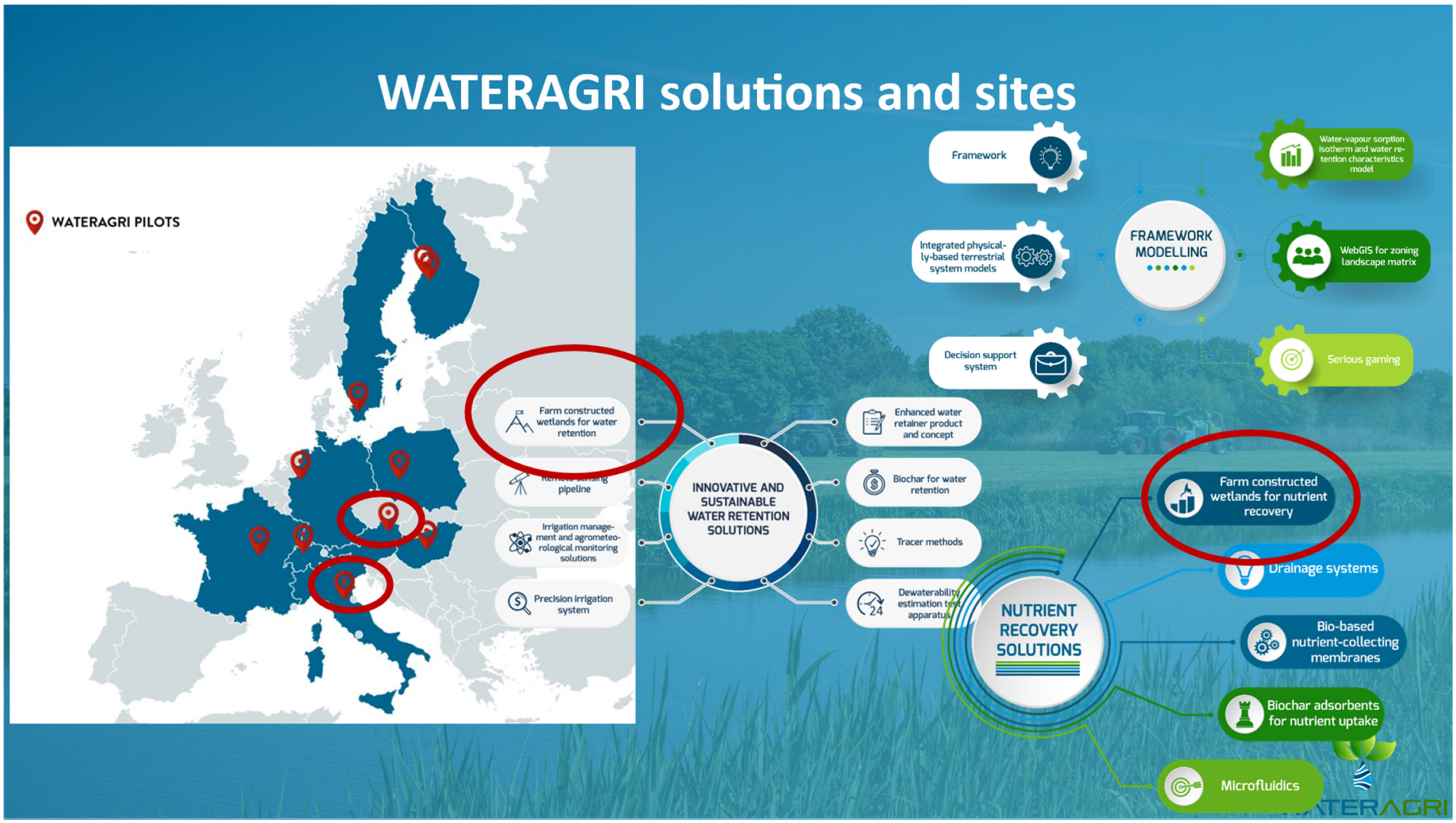

Figure 14.1 Overview of WATERAGRI sites and solutions with farm constructed wetlands for nutrient recovery and/or water retention being implemented in the cases in Austria and Italy. In the context of WATERAGRI, the term farm constructed wetlands was used to refer to FWS wetlands, also known as surface flow constructed wetlands.

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numbers, can be traced back directly to the use of agrochemicals. Accordingly, soil biodiversity has suffered a significant toll as well, and soil structure has been altered leading to poor water absorption, retention, and release for plant uptake. Overall, there is thus a clear need to rethink agricultural practices not only to rescue the remaining healthy ecosystems, but also to restore the degraded ones for the sake of agricultural production itself and our own human livelihoods (Boix-Fayos & de Vente, 2023; Giannakis *et al*., 2019).

There is thus a need for a holistic picture to the implications of constructed wetland (CW) implementation in agricultural and landscape contexts. This chapter collates the findings from the EU H2020 project WATERAGRI (https://wateragri.eu/), that intended to solve agricultural water management and soil fertilization challenges in a sustainable manner to secure affordable food production in Europe for the 21st century. This project was implemented through the development of a new framework for the use of small water retention approaches for managing excess and shortage of water as well as better recovery of nutrients from agricultural catchments applying a multiactor approach. In the context of European river basins, where diffuse pollution from agriculture poses a significant challenge, efficient water management becomes pivotal. Solutions include infrastructural changes such as the implementation of CWs towards better water or nutrient retention, modelling approaches towards better soil moisture forecasts, and more generic knowledge tools such as the development of a serious game (see all solutions in Figure 14.1). Integrating WATERAGRI's approaches also aligns with the European bio-economy strategy, aiming to reduce pollution, enhance resilience, and promote sustainable agricultural food production. The project's commitment to developing integrated water management approaches underscores its dedication to achieving sustainable agricultural production and food security. Operating in diverse climatic and socio-economic contexts, ranging from large farms to regions with numerous small farms, the project encompasses 10 distinct cases. Its implementation spans 10 case study sites strategically distributed across the Boreal, Continental, and Pannonian climatic zones.

Although WATERAGRI offered a number of different solutions for water and nutrient management in European agriculture, not all solutions are suitable nor sustainable in all contexts. This chapter delves into the complexities of identifying sustainable water and nutrient management practices for European agriculture, acknowledging that not all solutions offered by WATERAGRI are universally applicable or sustainable. The chapter begins by outlining methods to determine the suitability and sustainability of various solutions under different conditions. The chapter then provides a detailed sustainability assessment of a specific practice – a CW system in Italy – using life-cycle thinking. This assessment includes an exploration of how WATERAGRI stakeholders perceive sustainability in the context of CW systems. Concluding the chapter, policy recommendations aimed at promoting sustainable practices in agricultural nutrient and water management are presented, with a particular emphasis on the role of CWs.

14.2 MODALITIES TO FIND SUSTAINABLE SOLUTIONS IN AGRICULTURAL WATER AND NUTRIENT MANAGEMENT

14.2.1 Understanding which solutions addresses best the causes: driving forces, pressures, states, impacts, and responses

The driving force, pressure, state, impact, and response (DPSIR) framework (European Environmental Agency, 1999) is a simple systematic, rapid, and holistic method recommended by the European Commission as a causal framework for describing the interactions between society and the environment. This tool helps to outline the environmental problems at hand including the assessment of solutions and how they interact with the environmental problem. The framework divides a given environmental concern/problem into five compartments, namely: driving forces, pressures, states, impacts, and responses. The driving forces 'D' represent broader trends and changes in social, economic, and human activities such as agriculture. It can also consider changing climate conditions.

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The drivers generate pressures 'P' that can be understood as processes that affect biological, chemical, and physical cycles in water systems. Pressures influence the state 'S' of water systems. State changes lead to impacts 'I', which is a multidimensional concept involving economic, social, health, and environmental aspects, but often with a focus on environmental impacts if environmental problems are to be solved. Responses 'R' represent actions by water managers, society, or policy makers to respond to solve the environmental issue under consideration. These actions consist in elaborating and implementing regulations, planning documents, or economic instruments. Actions also include the emergence of technological innovations and changes in behaviour.

Within WATERAGRI, the primary objective revolved around devising strategies for 'water retention and nutrient recovery'. The project thoroughly evaluated the DPSIR model, leveraging a comprehensive understanding of water resources and their interlinkage with the agriculture sector. To facilitate this assessment, the project relied on its case studies and factsheets that were developed for the different solutions (https://wateragri.eu/factsheets/). These resources offer a detailed perspective on the identified issues, serving as a foundation for the DPSIR evaluation. Figure 14.2 illustrates the overarching assessment, intricately connecting DPSIR compartments with the research efforts dedicated to developing and evaluating solutions. The devised solutions within WATERAGRI play a pivotal role by providing responses denoted as 'R' to one or multiple compartments within the DPSIR model. This integrative approach ensures a holistic understanding of the challenges related to water resources in agriculture, ultimately contributing to outlining effective and targeted solutions.

The WATERAGRI solutions affect the DPSI compartments in different ways. An assessment of where the effects can be seen is outlined in Table 14.1. Depending on where the solutions respond to the DPSI compartments, the solutions can have wide, synergetic, cross-benefit, and win–win effects. For example, water retention will decrease leaching as less water is required for irrigation, reducing the pressure on irrigation demand (P), which, in theory, can lead to more yields and less leaching. All solutions have the potential to influence compartments S and I. The serious game, AgriLemma, can lead to changes in agriculture and agricultural management itself, which influence all compartments.

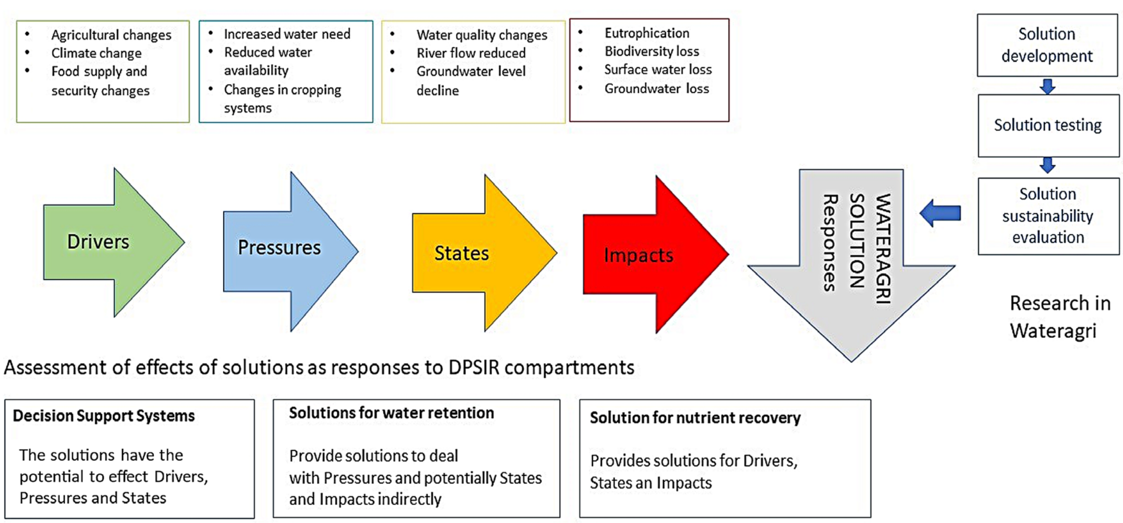

Figure 14.2 Overview of the DPSIR process showing the responses and their development in WATERAGRI. The DPSIR compartments are evaluated for the case of water use and pollution from agriculture. The effect and potential effect of the solutions on DPSIR compartments is drafted.

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Table 14.1 Solution classified into the DPSI framework.

Solution Name	DPSI Compartments	More Information and Reasoning
AgriLemma serious game	DPSI	Potentially all DPSI compartments as the method is a game where different stakeholders participate
Water retainer	PSI	An organic liquid that can be sprayed on soil to increase water retention. This can reduce irrigation needs, thus limiting the leaching of nutrients and pesticides. Also, plants can take up more nutrients, which might limit leaching
Biomembranes	(P)SI	It works as an end-of-pipe solution that allows for nutrient recycling. Biomembranes tested, but solutions not ready for application yet
Filters at end of drain pipes	(P)SI	It works as an end-of-pipe solution that allows for nutrient recycling. Tested in field operation, but frequent replacement might limit usage
Multilayered filter system	(SI)	Can retain nutrients. Developed and tested in meso-scale field operation
Microfluidics	(SI)	Tested in lab scale set-up
Wetland for Water Retention	PSI	Water stored for irrigation which limits nutrient runoff losses
Wetland for Nutrient Retention	PSI	Nutrients recycled, which limits nutrient runoff losses

Solution names relate here to the ones used in the factsheets.

The DPSIR analysis allowed WATERAGRI to better understand which solutions might address best the underlying drivers and pressures to influence the state and cause beneficial impacts. However, it did not fully address sustainability.

14.2.2 What is ‘sustainability’ in agricultural water management

As a first step the vague concept of sustainability needed to be defined. In the past, sustainability has been defined in slightly different ways, reflecting institutional values. The Brundtland Commission first defined sustainable development in 1987 as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED, 1987). This definition laid the foundation for sustainability’s three-dimensional concept: social, environmental, and economical.

WATERAGRI is an inter- and transdisciplinary project and encompasses project partners from different scientific and professional backgrounds. These different backgrounds may lead to different understandings of key concepts, which in turn may lead to misunderstandings across the project members. To overcome this, Dahal *et al.* (2023) conducted a consensus-building approach through a Delphi survey. A Delphi survey is ‘a method of structuring a group communication process so that the process effectively allows a group of individuals as a whole to deal with a complex problem’ (Hugé *et al.*, 2010). Experts from the WATERAGRI consortium members (9 WATERAGRI case study owners, 11 WATERAGRI solution providers), local WATERAGRI case study stakeholders (10), and persons not related to the project in any way (9) were invited to participate in this survey. A two-round survey was conducted: the former focused on prioritizing keywords in the three dimensions of sustainability, whereas the latter intended to clarify remaining conflicts among the responses of the experts.

The findings showed that environmental sustainability emerges as a prime focus, with most experts emphasizing climate change, water quality, and quantity concerns. Additionally, they expressed worries about the impact of agricultural practices on environmental degradation. Notably, experts from the Global North emphasize water quality due to concerns about pollution from agricultural

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activities, whereas those from the Global South stressed water quantity due to water-scarcity issues. Agricultural sustainability remains a central concern, with experts advocating for efficient water use in farming practices. Social sustainability considerations encompassed stakeholder participation and capacity building, with differences observed between expert groups based on geographic regions. Economic sustainability priorities varied, with consortium members emphasizing economic growth, stakeholders focusing on affordability, and external experts prioritizing income and profit generation. Gender differences in perceptions highlighted varying concerns, suggesting the need for nuanced policy formulations tailored to diverse expert perspectives. A recent policy brief on gendered agricultural practices in Europe also evidenced gendered differences in perceptions, with female experts prioritizing water availability, and underscored the importance of inclusive decision-making and targeted interventions tailored to regional challenges and the voices of marginalized groups (UNU-CRIS, 2024).

Based on the most prominently featuring keywords the following definition was coined for 'sustainable management of water in agriculture' for the WATERAGRI project:

> Managing water in a way that ensures its quality and has minimal negative effects on the natural environment. It involves stakeholder satisfaction and wellbeing, ensuring equal participation, and improving competency by entailing effective governance and equitable laws. It promotes long-term economic growth and provisions of incentives and subsidies. In summary, it exemplifies the ideal level of water management incorporating climate change concerns.

Establishing a common definition within the WATERAGRI consortium facilitated a more cohesive understanding and communication among its members. This process not only helped in harmonizing perspectives but also uncovered the consortium's predisposition towards prioritizing the environmental aspects of sustainability. Additionally, it highlighted a male-centric viewpoint from the Global North, which tended to focus more on water quality rather than water quantity concerns.

14.2.3 Understanding which solutions work where: rapid assessment of sustainability

Before diving deeply into various sustainability assessments of solutions and sites, a rapid assessment of which solutions might be considered sustainably 'suitable' for which site was performed. For this purpose, several criteria for the three dimensions of sustainability, namely environmental, economic, and social, were identified by the research team at the University of Oulu and vetted by the solution and case study owners for general soundness (Figure 14.3). From the literature and the project

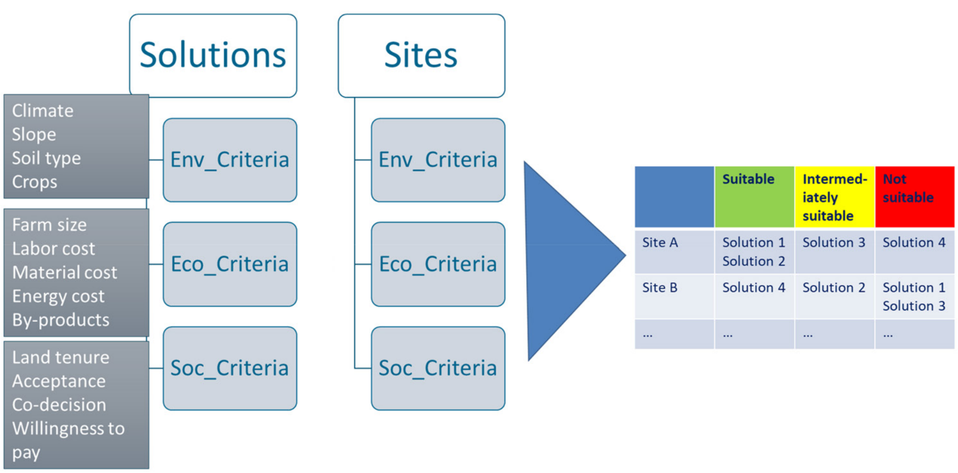

Figure 14.3 Overall schematic of the rapid assessment and criteria in each of the dimensions of sustainability used to determine the potential suitability of WATERAGRI solutions for WATERAGRI sites.

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documentation for the respective solution and case study information data for each criterion was sought and solution providers and case study owners were asked to double-check and correct the data if needed. In this process, several solutions were removed as the evidence base was not considered to be strong enough for a sufficiently sound judgement/. The assessments were therefore only conducted for four WATERAGRI solutions that had seen implementation on sites, namely: farm constructed wetlands, precision irrigation systems, biochar application, and Drainage systems.

Finally, the 'fit' of the solutions for the respective sites was carried out by matching the information of the criteria through a traffic light system (highly matching, medium, not at all) for each of the dimensions of sustainability. Not matching at all meant that the solution was considered to be 'Not Suitable' in any of the three dimensions, whereas for a solution to be fully suitable for a site it had to be suitable in all dimensions. All other (mixed) scenarios were considered as moderately suitable. As such, across all sustainability dimensions, farm constructed wetlands and precision irrigation systems were deemed suitable solutions for all cases except for Finland. Biochar application and drainage systems were considered moderately to highly suitable solutions in some cases (see Table 14.2). It must be noted that in particular biochar is still being tested and that the data used for the rapid assessment

Table 14.2 Overview of the suitability of WATERAGRI solutions for WATERAGRI sites.

WATERAGRI Sites	Suitable WATERAGRI Solution	Potentially Suitable WATERAGRI Solution	Non-suitable WATERAGRI Solution (Hindrance)
Finland I	–	Farm constructed wetlands (climate, costs) Biochar (climate, costs) Drainage systems (costs)	Precision irrigation systems (farm size)
Finland II	–	Farm constructed wetlands (climate, costs) Biochar (climate, costs) Drainage systems (costs)	Precision irrigation systems (farm size)
Sweden	Farm constructed wetlands Precision irrigation systems	Biochar (costs) Drainage systems (costs)	–
France	Farm constructed wetlands Precision irrigation systems	Biochar (costs) Drainage (costs)	–
Germany	Farm constructed wetlands Precision irrigation systems	Biochar (costs) Drainage (costs)	–
Poland	Farm constructed wetlands Precision irrigation systems Biochar Drainage systems	–	–
Switzerland	Farm constructed wetlands Precision irrigation systems	Biochar (costs) Drainage (costs)	–
Austria	Farm constructed wetlands Precision irrigation systems	Biochar (costs) Drainage (costs)	–
Italy	Farm constructed wetlands Precision irrigation systems	Biochar (costs) Drainage (costs)	–
Hungary	Farm constructed wetlands Precision irrigation systems Biochar Drainage systems	–	–

Element in parenthesis marks the criteria that limit the suitability of the respective solution.

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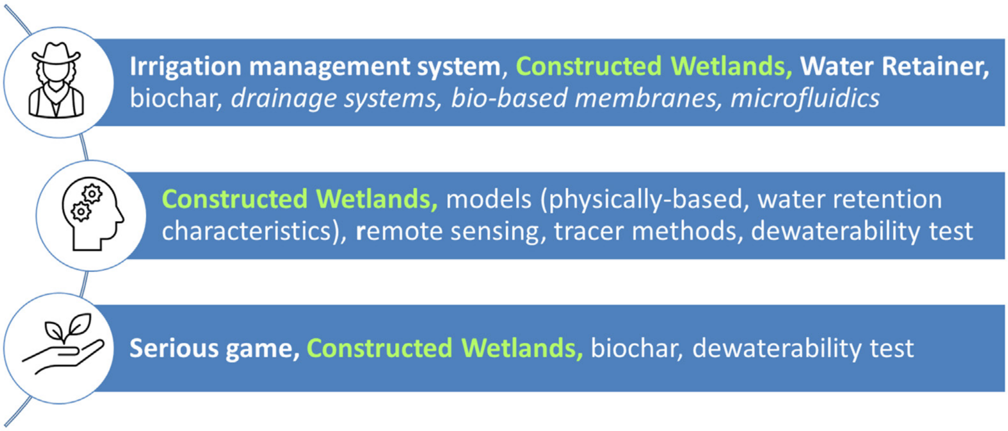

Figure 14.4 Overview of the maturity (bold) and usefulness of the WATERAGRI solutions by user groups (top to bottom: farmers, researchers, advisory services); solutions in italics were considered useful for 'future farmers'.

are mostly based on experimental information and not so much on field testing. Suitability here is therefore to be taken with caution.

The swift evaluation indicated that categorizing WATERAGRI solutions based on sustainability criteria present challenges. Primarily, this is due to the fact that numerous WATERAGRI solutions have not been applied at the farm level, exhibiting low technology readiness levels, and the scarcity of definitive data pertaining to economic and social criteria. Caution is essential when utilizing these findings, and expert consultation is vital for ensuring secure on-site application. For those interested in self-guided exploration and application of the rapid assessment, resources are available through the WATERAGRI website and its framework.

14.2.4 Sustainable solutions for water and nutrient management: preliminary considerations

The preliminary considerations showed that sustainability in the field of agricultural water (and nutrient) management is a challenging one. Being able to determine which solutions to assess in more detail was strongly limited by several factors, such as (1) the maturity of the solution to be used by end-users, (2) the intent of the solution to be used by end-users or not, and (3) the availability and access to data in all three dimensions of sustainability. Of the 19 solutions, some can be lumped as they represent one product package, and others are similar. Only four (groups of) solutions were actually destined for end-users, that is farmers, and of those, the maturity level of deployment in the field was only given for three, namely the family of precision irrigation through GIS, those of CWs, and the water retainer product and concept (Figure 14.4).

14.3 UNDERSTANDING THE SUSTAINABILITY OF FARM CONSTRUCTED WETLANDS

CWs for pollution control are nature-based solutions for wastewater purification, with a long-standing history of reducing organic and inorganic pollution loads from a variety of liquid and semi-liquid effluents, for example, domestic wastewater, acid mine drainage, stormwater runoff, animal manure, and human faecal sludge (Dotro *et al.*, 2017; Kadlec & Wallace, 2008; Vymazal, 2011). They not only reduce nutrients and organic matter concentrations in effluents, but are also known to support the reduction of medication-derived substances such as hormones, antibiotic resistance, and painkillers (e.g., Cavalheri *et al.*, 2022). The removal of contaminants is achieved by

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physical, chemical, and biological processes (Garcia *et al.*, 2010). In addition to pollution reduction, these systems offer various co-benefits such as enhanced biodiversity, aesthetics, water retention, and thus potential flood protection, the possibility to reuse the treated effluent, and the use of the biomass for multiple purposes, including bioenergy production, construction material, or artwork (Turcios *et al.*, 2021). CWs can, therefore, be used to reduce and compensate for the losses caused by intense agricultural purposes and have been used effectively in agricultural and landscape settings (Carty *et al.*, 2008).

CWs, particularly in agricultural settings, represent a significant investment. They require land that might otherwise be allocated for more immediately productive purposes. Moreover, the design, construction, and maintenance mandate the involvement of trained professionals, rendering them a lower priority for farmers and farm managers (Soldo *et al.*, 2022). Notably, the need for incentives, both in terms of subsidies and enforcement, deters their adoption and scaling potential. Therefore, although the return on investment may not be immediately attractive for farm owners or managers, it is important to consider the broader societal benefits and perspectives associated with these systems in short, medium, and long time frames.

14.3.1 Assessing sustainability of a farm constructed wetland

To better understand what drives sustainability of farm constructed wetlands, the CW of WATERAGRI's Italian case study located in the Emilia-Romagna region, specifically in Budrio, was chosen. The wetland treats the agricultural drainage water of an experimental farm of 12.4 hectares cultivated with cereals, vegetables, and orchards. The CW has a surface of 5557.5 m^2 with a water course length of 470 m composed of four meanders that are 8–10 m wide. The outlet is set at 0.4 m above the bed surface level, setting the overall CW capacity at 1500 m^3. However, the volume of drainage water treated and present in the system depends on the frequency and volume of the seasonal precipitation. Furthermore, the water outflow is discharged into a network of ditches from which farmers in the areas withdraw the water for irrigation purposes. The case study area is equipped with a hydraulic system and sensors which measure the water level inside the CW as well as a weather station. The vegetation is mainly composed of *Phragmites australis*, *Typha latifolia*, and *Carex* spp.

The experimental data for the sustainability assessments were collected in 2020 and 2021 in the context of the WATERAGRI project and complemented with other existing data collected in 2018 and 2019. During the project years the research team monitored and analysed the system functioning through operations for hydraulic system maintenance, sampling for water quality monitoring, and processes for meteorological data collection (Nan *et al.*, 2023). These operations were carried out by work and training activities of PhD students, master students, and researchers of the University of Bologna (Italy).

For this CW, a full sustainability analysis based on life-cycle thinking was carried out. Life-cycle thinking provides a comprehensive framework for assessing the impacts of processes or products throughout their entire life cycle, incorporating environmental, social, and economic dimensions of sustainability (Hunkeler *et al.*, 2008; ISO, 2006a, 2006b; UNEP *et al.*, 2020). Life-cycle assessment (LCA) specifically focuses on environmental impacts and is a standardized procedure for evaluating sustainability, aiding decision-making by identifying environmental hotspots and trade-offs (Corominas *et al.*, 2020). Life-cycle costing assesses the economic dimension of sustainability, considering costs over the entire life cycle of a product or service and aligning with LCA techniques. Social life-cycle assessment (sLCA) is a newer methodology focusing on social aspects, offering guidelines for studying the social performance of products or services. The integration of these analyses enables a more holistic understanding of sustainability across all dimensions.

By combining the results of each assessment, an integrated score was computed, offering an overarching perspective on the overall sustainability of the WATERAGRI case study. This score averages positive (environmental and social) and negative (economic) impacts of the WATERAGRI

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scenario compared to the business-as-usual scenario. In this instance, the integrated score indicated that implementing the WATERAGRI scenario results in a 32% increase in sustainability. Although standalone, this metric lacks external comparison, it serves as a starting point for understanding the role of CWs in sustainable land and water management strategies. Despite its limitations, an integrated score can aid advocacy and policy-making due to its communicative simplicity. Further research is necessary to refine scoring strategies, develop reference cases, and test scoring designs across multiple case studies.

14.3.2 Understanding the criteria that drive decision-making: asking the community

Although our findings indicated that the implementation of farm CW is sustainable for the one WATERAGRI case, the research team wanted to further understand the perceptions of WATERAGRI stakeholders about the sustainability of CW implementation. The research team pondered: What criteria drive actors towards implementing CWs?

CWs have been shown to serve as a cost-effective solution for the removal of pollutants from wastewater (García-Herrero *et al*., 2022). Moreover, they contribute to the enhancement of biodiversity and play a significant role in ameliorating habitat and ecosystem conditions. They therefore foster environmental sustainability, an aspect that was already seen as prominent in the WATERAGRI community. Although CWs offer co-benefits, they also entail trade-offs, particularly concerning the allocation of costs for implementation and maintenance. Farmers operate with narrow margins and thus need to invest into new technology conservatively.

Various sustainability aspects were identified as pertinent for the implementation of CWs through a comprehensive review of the literature, supplemented by expert consultations. Subsequently, these identified aspects were subjected to a Delphi-like exercise to solicit expert opinions and achieve consensus. A survey, conducted from 7th July to 26th September 2023, was utilized to gather responses from relevant stakeholders. To ensure broad stakeholder participation, the survey was disseminated through multiple channels, including WATERAGRI project platforms and professional networking interfaces such as LinkedIn.

A total of 48 respondents were engaged in the survey, among which only 22 completed the survey and agreed to the treatment of personal data: the results presented in this study are henceforth referred to this subsample. As far as gender distribution is concerned, 59% of the respondents identified as men and 41% as women. The respondents' geographical distribution was mainly focused on the Mediterranean (38%) and Continental (27%) zones, followed by the Boreal zone (14%). The Pannonian zone (3%) was the least covered. In total, 18% of the respondents selected another country outside the European continent. Due to the sampling strategy and self-selection bias, stakeholder coverage was unbalanced towards researchers, accounting for 68% of the total respondents. The remaining 32% of non-researchers included advisory services (17%), decision-makers (5%), farmers (5%), and others (5%). This distribution represents a limit of the study that could be addressed with more refined stakeholder engagement strategies.

14.3.2.1 Ranking sustainability dimensions

Initially, participants were tasked with prioritizing the triple bottom-line sustainability dimensions (i.e., environmental, social, and economic sustainability) in the ascending order of relevance. As anticipated, a significant majority of respondents (72%) identified environmental sustainability as the most pertinent dimension in CW implementation, trailed by economic (22%) and social (6%) considerations (Figure 14.5). Notably, none of the researcher identified social sustainability as the foremost dimension of importance. Moreover, social sustainability received primary ranking only once, from a respondent affiliated with advisory services. Interestingly, one-fourth of the researchers identified economic sustainability as the primary dimension of importance.

In the second phase, stakeholders were asked to assign a score the relevance of selected sustainability aspects for the implementation of CW in the rural context. Respondents could choose to rank each

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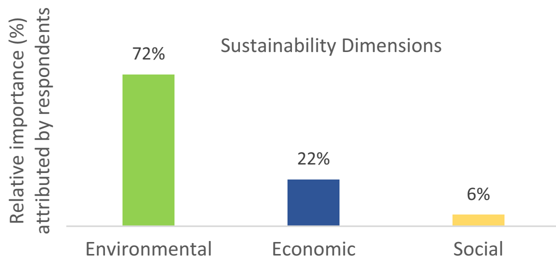

Figure 14.5 Relative importance (% of respondents ranked the dimension first) of sustainability dimensions.

sustainability aspect as having low (0–1), medium (1–2), or high relevance (2–3). Coherently with the literature evidence and the control question on the sustainability dimensions (see above), the respondents agreed on ranking the sustainability aspects related to environmental sustainability as the most relevant, while social aspects were overarchingly disregarded. However, as a general trend the sample showed a high degree of heterogeneity in the ranking (Figure 14.6).

14.3.2.1.1 Environmental aspects

The capacity to treat effluents is the only aspect that none of the stakeholder perceived as having a low relevance. More than 60% of the respondents agree on the high relevance of this aspect, and this percentage increases to 82% among researchers while dropping to 48% among non-researchers. Another important environmental aspect that was considered of high relevance is the water reuse potential. Although none of the researcher ranked water reuse relevance as low, around one-third of non-researchers attributed low relevance to this aspect. There are no significant differences among the two stakeholder groups regarding the perception of the relevance of the role of CW in ameliorating the ecosystem conditions, which is considered to be of low relevance by 28% of the respondents.

14.3.2.1.2 Economic aspects

As far as economic sustainability is concerned, more than 50% of the respondents agreed on ranking investment cost as a highly relevant aspect of CW sustainability. This aspect is considered highly relevant for researchers, while on average it was ranked as of low relevance by the rest of the respondents. This perspective is mirrored by the high relevance ranking of the need for a subsidy to implement a CW by non-researchers (48%), whereas only 18% of the researchers ranked this aspect's relevance as high. The lowest-ranked economic sustainability aspects are those related to the production of biomass from CW. In particular, the production of biomass itself is considered of low relevance by 67% of the respondents: this perspective is consistent with the low level of knowledge on CW biomass valorization opportunities evidenced by Avellán and Gremillion (2019).

14.3.2.1.3 Social aspects

Social aspects can be found at the lower end of the spectrum of relevance. As already hinted by the sustainability dimensions' control question, it was confirmed that these aspects are among the least known and considered. For instance, the improvement of the landscape quality is considered of low relevance by 57% of the non-researcher respondents, even if only 9% of researchers ranked this aspect low and most expressed a more balanced opinion. Similarly, potential social benefits are also perceived generally as of low relevance especially by non-researchers. All the non-researchers ranked the possibility to provide training to disadvantaged people as of low relevance, whereas 45% of researchers ranked this aspect as a highly or medium relevant aspect.

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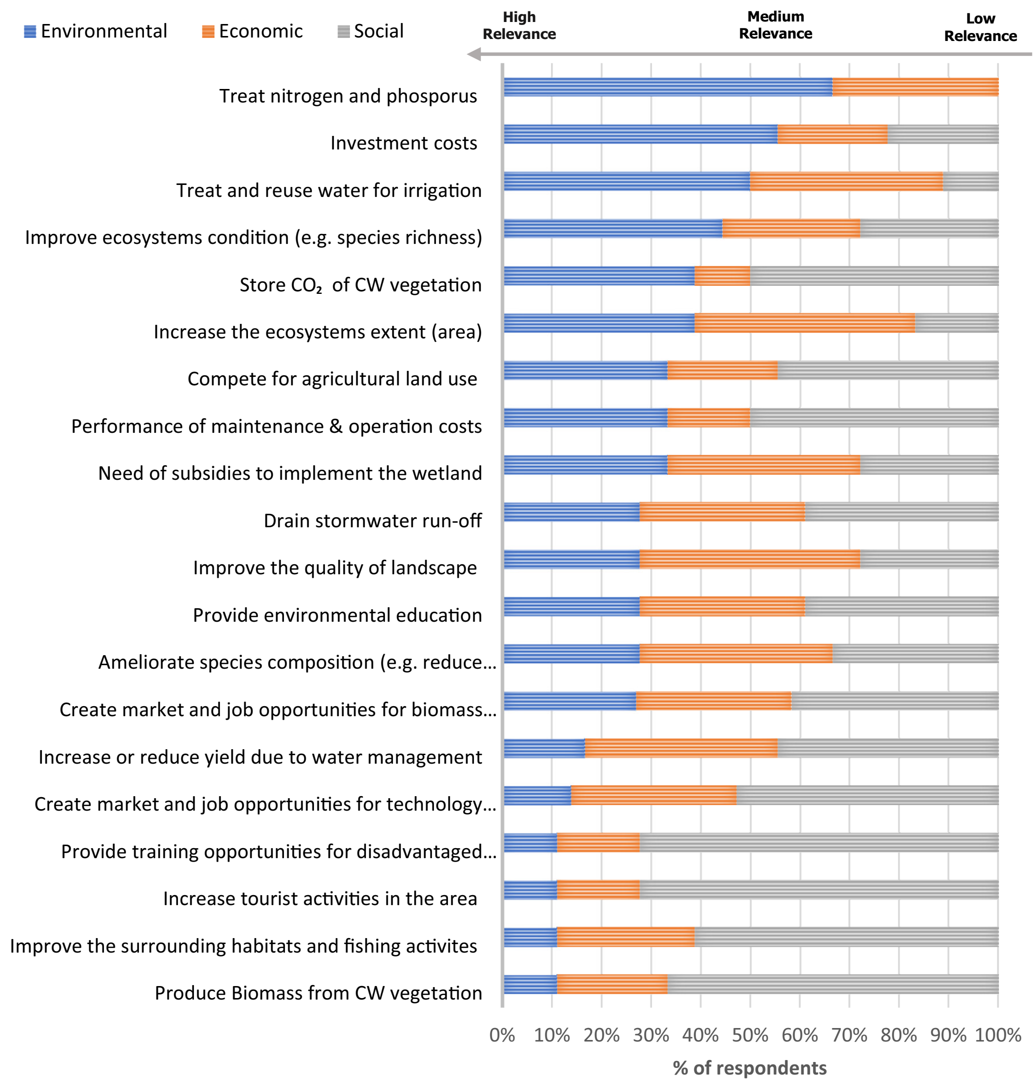

Figure 14.6 Gradient of the relevance of the perception of sustainability aspects according to respondents.

Testing the validity of these assumptions would require a more statistically significant sample, but this consultation offered a first overview of the possible trends, and some overarching conclusions can be drawn. Apart from the consensus on the nutrient retention capacity, there is a wide variability in responses, hinting that sustainability aspects might be perceived differently according to stakeholders' groups and context. Moreover, environmental aspects seem to be largely perceived as more relevant.

14.3.2.2 Impact of different sustainability aspects on different types of wetlands

In the last phase of the questionnaire, respondents were asked to rate their potential willingness to implement free water surface (FWS), horizontal flow (HF), and vertical flow (VF) CWs on a likelihood scale (ranging from very unlikely to very likely) considering the different sustainability aspects

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presented above. The top three sustainability aspects were then analysed and compared among the three different systems, as shown in Figure 14.7.

More than 60% of respondents responded that they would implement all three types of wetlands due to their nutrient retention capacity even though differences in the treatment capacity for different pollutants were not investigated in the survey. This perspective is mirrored by the likelihood of implementing the three systems for their water reuse potential: about 60% of the respondents would implement FWS and HF CWs for this function.

In the case of HF CWs, more than 50% of the respondents would implement this system considering maintenance and operation costs, which are generally lower than those of the other types of wetlands. Similarly, the investment costs would be an important theme in VF CWs, as more than 50% of the respondents would implement this infrastructure considering this aspect. Flood management scored among the lowest for HF CWs, consistently because these systems are feeble to drain stormwater runoff (Langergraber *et al.*, 2020).

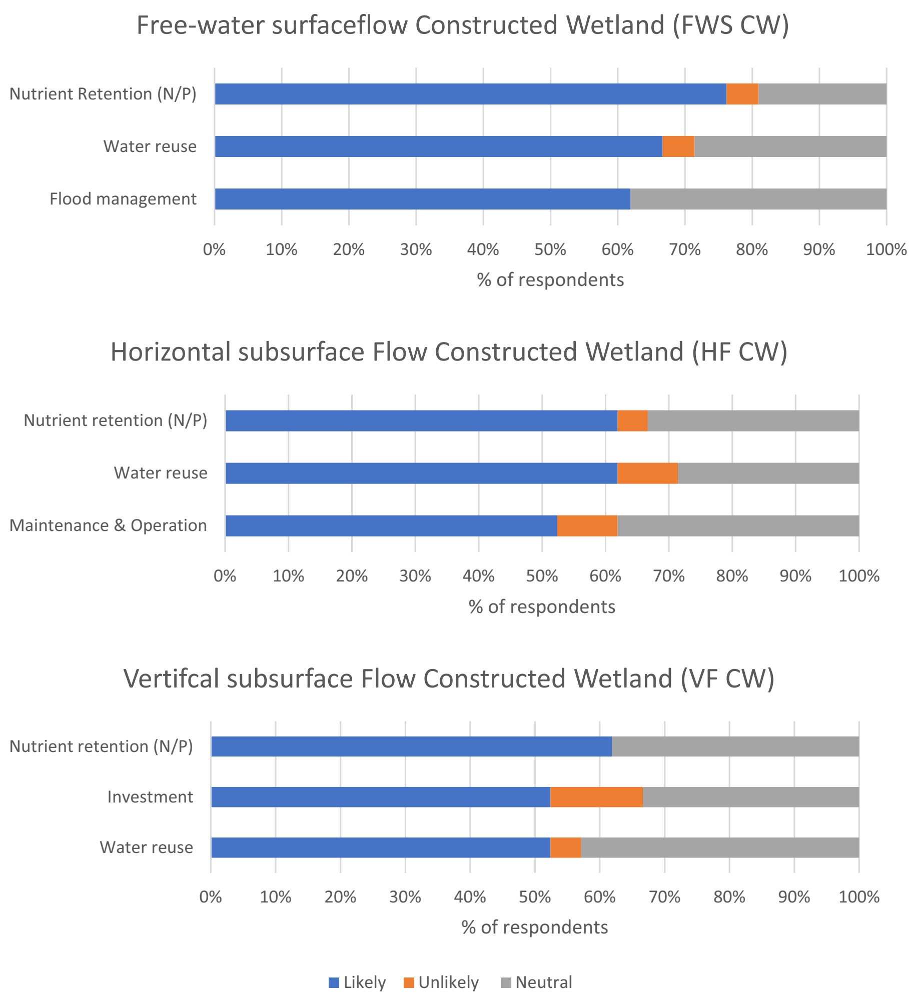

Figure 14.7 Three most relevant aspects to implement different type of wetlands (FWS, HF, VF).

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Table 14.3 Comparison of requirements and performance of different types of CWs.

	FWS Wetlands	HF Wetlands	VF Wetlands
Required treatment area/land use	+++	++	+
O&M costs (OPEX)/maintenance & operation	+	++	++
Investment costs (CAPEX)	++	+	+
Removal of ammonia	++	+	+++
Removal of total nitrogen	++	++	+
Removal of phosphorus (long term)	+	+	+
Removal of dissolved organic matter	+	+	++
Removal of suspended solids	+	+	++
Removal of coliforms	+	++	++
Biomass production	+	++	++
Water retention/flood management	++	+	O
Water reuse	++	++	++
Environmental education	+++	+	+
Association with tourist activities	+++	+	+
Landscape quality	+++	++	++
CO_2 storage	++		
Ecosystem condition	+++	+	+
Ecosystem extent	+++	+	+
Enhance biodiversity/species composition	++	+	+

Source: From Dotro *et al.* (2017) and Langergraber *et al.* (2020).
+: low performance, ++: medium performance, +++: high performance.
O: not used for this aspect; blanks: unknown performance.

Despite the high degree of variability in responses, half of the respondents agree that an increase in the fishery activities that could be associated with a wetland is not an aspect they would consider when confronted with the opportunity to implement an FWS CW, whereas those percentages are around 40% for HF and VF CWs. As a general trend, one-third of the respondents would not implement these infrastructures considering socio-economic aspects such as the association with tourist activities, yield increase, and training opportunities.

As noted in Table 14.3, these aspects are also less investigated in the academic literature, except for biomass production. Furthermore, the results show a high percentage of neutral responses, hinting that these results could stem from a lack of knowledge in these sustainability aspects more than from an opposition.

14.4 SUMMARY AND CONCLUDING REMARKS

The WATERAGRI project set out to provide affordable and equitable solutions to the growing need to keep more water and nutrients in agricultural soils for better yields and lower environmental impacts. The sustainability assessments are one method to determine the sustainability of the WATERAGRI solutions to make sure that future sustainability is not impacted by their recommendations. Our analysis shows that many of the WATERAGRI solutions are not at a level of maturity to provide meaningful recommendations about their sustainability. Information about their environmental effects, their costs, and the perception of actors about their usefulness is largely missing.

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Overall, solutions were found to be mostly sustainable in their environmental dimension, contributing either directly to increased yields, or indirectly to improved environmental conditions by reducing eutrophication and/or contributions to climate change. The solutions are also not sustainable in their economic dimension. They are currently too costly or do not exhibit a large enough return on investment either through additional benefits such as biomass or irrigation use from CWs. The social dimension is the weakest link in full sustainability assessments. The sLCA for CWs looked at an atypical CW which is not really used for farming conditions, but represents an experimental site.

It is interesting to note that the discourse in sustainability has been dominated by the environmental dimension of sustainability, and this consortium is no exception to this as we saw from the Delphi study by Dahal *et al.* (2023) and the stakeholder assessment on CWs. Our analyses show positive environmental effects for the solutions. Under traditional settings, this consortium may have gone ahead in recommending the use of these solutions. A more holistic picture that also includes the other dimensions of sustainability paints a different picture. Any of the solutions may be more sustainably suitable in other contexts and with more information and maturity.

Despite challenges for farmers due to high construction and operation costs, the analysis suggests that with initial subsidies and ongoing support, CW implementation could be financially viable. Additionally, integrating CWs into established value chains for bioenergy and bio-based products could enhance profitability. Upscaling CWs requires engagement strategies such as water-oriented living labs and water citizen science approaches to foster knowledge transfer and community involvement. Overall, although technical improvements do not enhance perceptions of elements for social innovation, economic support can enhance the economic sustainability of CW implementation, enabling effective utilization of the system's environmental and social benefits (Figure 14.8).

CWs, hence, represent nature-based solutions with significant potential, offering both challenges and opportunities within European agrarian systems. Challenges arise in integrating wetlands' functions into policies effectively, particularly within the agricultural sector, where a cohesive policy on water management is lacking. However, as classified under nature-based solutions, CWs provide green infrastructure that can be strategically integrated into regional policy frameworks, supporting environmental sustainability goals. Recognizing their role in improving water quality and offering diverse functions, CWs hold promise for providing sustainable solutions for wastewater treatment. By addressing challenges and embracing opportunities, policymakers can facilitate the integration of CWs into European agrarian systems, thereby enhancing environmental sustainability and agricultural landscape resilience.

Environmental Benefits and Social Innovation: Fostering social innovation is the key to their successful use in farming.

Diverse CW Technologies for Specific Contexts: It is crucial to assess 'Long-Term Gains' over immediate 'Farm-Level Return of Investment (RoI)' as immediate returns on investment may be challenging to achieve at the farm level, the actual benefits are more likely to be realized at the landscape or catchment levels.

Promoting CW Adoption with Subsidies: Providing financial subsidies to farmers or groups could help establish CW as a promising strategy.

Sustainability-focused approach: A holistic perspective considering environmental, social, and economic dimensions of sustainability remains critical for making well-informed decisions that benefit society (farming community) and not just individuals.

Figure 14.8 Main findings from the WATERAGRI studies on sustainable water and nutrient management practices in particular for CWs.

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REFERENCES

Avellán T. and Gremillion P. (2019). Constructed wetlands for resource recovery in developing countries. *Renewable and Sustainable Energy Reviews*, **99**, 42–57, https://doi.org/10.1016/j.rser.2018.09.024

Bieroza M. Z., Bol R. and Glendell M. (2021). What is the deal with the green deal: will the new strategy help to improve European freshwater quality beyond the water framework directive? *Science of The Total Environment*, **791**, 148080, https://doi.org/10.1016/j.scitotenv.2021.148080

Boix-Fayos C. and de Vente J. (2023). Challenges and potential pathways towards sustainable agriculture within the European green deal. *Agricultural Systems*, **207**, 103634, https://doi.org/10.1016/j.agsy.2023.103634

Carty A., Scholz M., Heal K., Gouriveau F. and Mustafa A. (2008). The universal design, operation and maintenance guidelines for farm constructed wetlands (FCW) in temperate climates. *Bioresource Technology*, **99**(15), 6780–6792, https://doi.org/10.1016/j.biortech.2008.01.045

Cavalheri P. S., Mello M. A., Pereira A. L., Marques T. R., Moraes T. N., Cavazzana G. H. and Magalhães Filho F. J. C. (2022). Chapter 16 – Ecotoxicity evaluation of diclofenac potassium in vertical flow constructed wetlands as posttreatment of septic tank effluent. In: Circular Economy and Sustainability, A. Stefanakis and I. Nikolaou (eds), Elsevier, pp. 271–282, https://doi.org/10.1016/B978-0-12-821664-4.00028-5

Corominas L., Byrne D. M., Guest J. S., Hospido A., Roux P., Shaw A. and Short M. D. (2020). The application of life cycle assessment (LCA) to wastewater treatment: a best practice guide and critical review. *Water Research*, **184**, 116058, https://doi.org/10.1016/j.watres.2020.116058

Dahal B., Avellán T., Haghighi A. T. and Kløve B. (2023). Defining sustainability in agricultural water management using a Delphi survey technique. *Water Policy*, **25**(6), 597–621, https://doi.org/10.2166/wp.2023.057

Dotro G., Langergraber G., Molle P., Nivala J., Puigagut J., Stein O. and von Sperling M. (2017). Treatment Wetlands. Biological Wastewater Treatment Series. IWA Publishing, London, UK, Vol. **7**, p. 172. eISBN: 9781780408774, https://doi.org/10.2166/9781780408774

Dudley N. (2022). Impact of agriculture on insect species decline. In: Imperiled: The Encyclopedia of Conservation, A. Dominick, Sala D. and M. I. Goldstein (eds), Elsevier, Oxford, pp. 500–506, https://doi.org/10.1016/B978-0-12-821139-7.00238-5

European Environmental Agency (1999). The DPSIR Framework – European Environment Agency. https://www.eea.europa.eu/publications/92-9167-059-6-sum/page002.html (accessed 16 April 2024)

Garcia J., Rousseau D. P. L., Morato J., Lesage E. L. S., Matamoros V. and Bayona J. M. (2010). Contaminant removal processes in subsurface-flow constructed wetlands: a review. *Critical Reviews in Environmental Science and Technology*, **40**(7), 561–661, doi: 10.1080/10643380802471076

García-Herrero L., Lavrnić S., Guerrieri V., Toscano A., Milani M., Cirelli G. L. and Vittuari M. (2022). Cost–benefit of green infrastructures for water management: a sustainability assessment of full-scale constructed wetlands in northern and southern Italy. *Ecological Engineering*, **185**, 106797, https://doi.org/10.1016/j.ecoleng.2022.106797

Giannakis E., Kushta J., Giannadaki D., Georgiou G. K., Bruggeman A. and Lelieveld J. (2019). Exploring the economy-wide effects of agriculture on air quality and health: evidence from Europe. *Science of The Total Environment*, **663**, 889–900, https://doi.org/10.1016/j.scitotenv.2019.01.410

Hugé J., Trinh H. L., Hai P. H., Kuilman J. and Hens L. (2010). Sustainability indicators for clean development mechanism projects in Vietnam. *Environment, Development and Sustainability*, **12**(4), 561–571, https://doi.org/10.1007/s10668-009-9211-6

Hunkeler D., Lichtenvort K. and Rebitzer G. (2008). Environmental life cycle costing. Boca Raton: CRC Press, https://doi.org/10.1201/9781420054736

ISO (2006a). ISO 14040:2006, Environmental Management – Life Cycle Assessment – Principles and Framework. International Standards Organization. Geneva, Switzerland, https://www.iso.org/obp/ui/en/#iso:std:iso:14040:ed-2:v1:en

ISO (2006b). ISO 14044:2006b, Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Standard Organization. Geneva, Switzerland, https://www.iso.org/obp/ui/en/#iso:std:38498:en

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by Wageningen University & Research – Library user

Kadlec R. H. and Wallace S. (2008). Treatment Wetlands, 2nd edn, CRC Press, Boca Raton, USA.
Langergraber G., Dotro G., Nivala J., Rizzo A. and Stein O. (2020). Wetland Technology: Practical Information on the Design and Application of Treatment Wetlands. IWA Publishing, London, UK, https://doi.org/10.2166/9781789060171
Nan X., Lavrnić S., Mancuso G. and Toscano A. (2023). Effects of design and operational conditions on the performance of constructed wetlands for agricultural pollution control – critical review. *Water, Air, & Soil Pollution*, **234**(7), 434, https://doi.org/10.1007/s11270-023-06380-y
Schäfer R. B., Caquet T., Siimes K., Mueller R., Lagadic L. and Liess M. (2007). Effects of pesticides on community structure and ecosystem functions in agricultural streams of three biogeographical regions in Europe. *Science of The Total Environment*, **382**(2), 272–285, https://doi.org/10.1016/j.scitotenv.2007.04.040
Soldo C., Wilson R. S., Walpole H. and Shaffer-Morrison C. D. (2022). Farmer willingness to implement constructed wetlands in the Western Lake Erie Basin. *Journal of Environmental Management*, **321**, 115928, https://doi.org/10.1016/j.jenvman.2022.115928
Turcios A. E., Miglio R., Vela R., Sánchez G., Bergier T., Włodyka-Bergier A., Cifuentes J. I., Pignataro G., Avellan T. and Papenbrock J. (2021). From natural habitats to successful application – role of halophytes in the treatment of saline wastewater in constructed wetlands with a focus on Latin America. *Environmental and Experimental Botany*, **190**, 104583, https://doi.org/10.1016/j.envexpbot.2021.104583
UNEP, Benoît Norris C., Traverso M., Neugebauer S., Ekener E., Schaubroeck T., Russo Garrido S., Berger M., Valdivia S., Lehmann A., Finkbeiner M. and Arcese G. (2020). Guidelines for social life cycle assessment of products and organizations 2020. *United Nations Environment Programme (UNEP)*, p. 140, http://www.unep.fr/shared/publications/pdf/DTIx1164xPA-guidelines_sLCA.pdf
UNU-CRIS (2024). A Regional Overview of Gender Sensitive Dimensions in the European Agricultural Sector. https://cris.unu.edu/regional-overview-gender-sensitive-dimensions-european-agricultural-sector (accessed 16 April 2024)
Vymazal J. (2011). Constructed wetlands for wastewater treatment: five decades of experience. *Environmental Science & Technology*, **45**(1), 61–69, https://doi.org/10.1021/es101403q
WATERAGRI (2023). Deliverable 6.3: Assessment of Sustainability.
WCED (1987). Our Common Future. Report of the World Commission on Environment and Development (WCED). United Nations, New York, https://sustainabledevelopment.un.org/milestones/wced

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