United Nations University
Institute on Comparative Regional Integration Studies

POLICYBRIEF
No. 01, 2024

Understanding Multifunctionality of Constructed Wetlands in Agricultural Settings in the European Region

Tamara Avellan[1,6], Alba Canet-Martí[2], Eriona Canga[3], Valentina Guerrieri[4], Simone Amadori[4], Aashna Mittal[5], Stevo Lavrnić[4], Marco Hartl[3], Nidhi Nagabhatla[6]

Highlights

1. **Environmental Benefits and Social Innovation**: Environmental factors play a crucial role in the advantages of implementing Constructed Wetlands (CWs) in agriculture. Yet, fostering social innovation is the key to their successful use in farming.

2. **Constructed Wetlands as Nature-Based Solutions**: CWs are natural solutions that could offer a wide range of benefits, but they also come with trade-offs that must be considered carefully and cautiously.

3. **Diverse CW Technologies for Specific Contexts**: Various CW technologies exist, each tailored to specific purposes and more advantageous in particular settings and agricultural contexts. Also, it is crucial to assess 'Long-Term Gains' over immediate 'Farm-Level Return of Investment (RoI)' as quick returns on investment may be challenging to achieve at the farm level, the actual benefits are more likely to be realised at the landscape or catchment levels.

4. **Promoting CW Adoption with Subsidies**: Implementing CWs' social and environmental advantages can far outweigh the associated economic costs. Therefore, providing financial subsidies to farmers or groups could help establish CW as a promising strategy.

5. **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. To facilitate sustainability, understanding is enabled through 'serious gaming', an effective tool designed by the Water Retention and Nutrient Recycling in Soils and Streams for Improved Agricultural Production (WATERAGRI) project to better comprehend challenges and opportunities associated with implementing technologies like CW toward sustainable farm management.

Background

Intense agricultural practices are the leading cause of water, soil, and biodiversity degradation in Europe. Since the implementation of the Water Framework Directive 15 years ago, agricultural fertiliser and pesticides applications have been identified consistently as the leading cause of excess pollution loads both in surface waters and groundwater, and for aquatic species loss (Schäfer et al. 2007; Bieroza, Bol, and Glendell 2021). Similarly, the massive loss of insects, both in species diversity as well as in absolute numbers, can be traced back directly to the use of agrochemicals (Dudley 2022). Accordingly, soil biodiversity has suffered a significant toll and soil structure has been altered to a state where water absorption, retention and release for plant uptake has become difficult. 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 (Giannakis et al. 2019; Boix-Fayos and de Vente 2023).

Constructed wetlands (CWs) for pollution control have a long-standing history of reducing organic and inorganic pollution loads of a variety of liquid and semi-liquid effluents (e.g. domestic wastewater, acid mine drainage, stormwater runoff, animal manure, human faecal sludge, etc.) (Kadlec and Wallace 2008; Vymazal 2010; Dotro et al. 2017). They not only reduce nutrients and organic matter in the outflow 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 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 (Lavrnić et al. 2020). Constructed wetlands, particularly in agricultural settings, represent a significant investment. They require land that might otherwise be allocated for more immediately productive purposes. Moreover, their 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, while the return on investment may not be immediately attractive for farm owners or managers, it's essential to consider the broader societal benefits and perspectives associated with these systems.

Therefore, a more holistic picture of the implications of constructed wetlands implementation in agricultural and landscape contexts may need to be applied. Sustainability assessments look at situations through an economic, environmental, and social lenses (Pope et al. 2017). In these assessments, the selection of criteria is critical and may differ by stakeholder group. This policy brief is based on findings from the EU H2020 project Water Retention and Nutrient Recycling in Soils and Streams for Improved Agricultural Production (WATERAGRI), which intended to solve agricultural water management and soil fertilisation challenges in a sustainable manner to secure affordable food production in Europe for the 21st century. This 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 multi-actor approach. This policy brief therefore outlines different constructed wetland systems used in agricultural settings, sustainability assessments of constructed wetlands and points out the needs of different communities to achieve a sustainable implementation of constructed wetlands as well as innovative capacity development opportunities through serious games.

Different types of constructed wetlands and their use in agricultural settings

The treatment beds consist of (usually) shallow lined basins filled with filter media (generally gravel or sand) and are commonly planted with aquatic plant species. The systems are characterized by their low external energy demand, comparatively low cost, easy operation and maintenance as well as the possibility to use local materials and manpower. A disadvantage of CWs is their relatively high area requirement per person equivalent (of 3.5 m2/PE) compared to conventional treatment systems (0.6 m2/PE) depending on the design and type of inflow wastewater (Kadlec & Wallace, 2008; Garfi et al, 2017). While new designs and intensification strategies such as recirculation or artificial aeration can increase the treatment efficiency and reduce the area requirement, these strategies increase the energy demand significantly and complicate the design and operation of the originally low-tech systems (Austin & Nivala, 2009).

While there are many different kinds of systems and also combinations of systems (i.e., hybrid systems), the basic widespread types of CWs can be categorized into two major groups (Figure 1):

1. **Free Water Surface (FWS) constructed wetlands, also known as surface flow constructed wetlands.**

2. **Subsurface flow constructed wetlands:**
    a. Horizontal flow (HF) wetlands.
    b. Vertical flow (VF) wetlands.

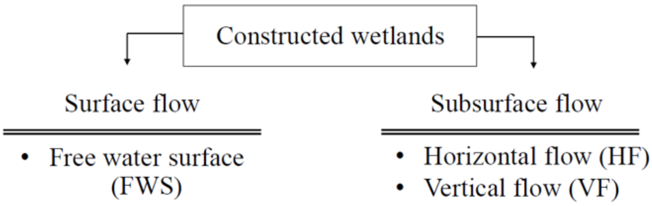


Figure 1. Classification of Constructed wetlands for wastewater treatment (based on Vymazal & Kröpfelová, 2008)

In addition to the commonly used systems, **hybrid** systems, combine different systems and designs in series or parallel, for example a VF followed by HF for initial nitrification (aerobic) of ammonia in VF and subsequent denitrification (anaerobic) of nitrate to dinitrogen in HF. Moreover, **intensified** systems allow for a smaller land footprint while achieving the same removal rates. An example of this is the widely used artificially aerated systems which use a small amount of energy for small compressors to aerate the filter bed and intensify aerobic treatment process. This way smaller surface area requirements are achieved (around 1m² per person equivalent (PE)). Other options include the recirculation of effluent water to the influent or the use of special substrates, such as porous materials (biochar, zeolite, volcanic stones etc.) or electroactive substrates to foster bio-electrochemical processes.

Free water surface (FWS) wetlands

A typical FWS wetland is a shallow basin, similar to natural wetlands, with a water depth of 20-50 cm. They can have floating or rooted plants (Figure 2). The most common vegetation used to treat agricultural wastewater is emergent vegetation, e.g., Scirpus spp. (bulrushes), Thypha spp. (cattails) or Phragmites australis (common reed), but also floating vegetation such as Lemna spp. (duckweed), or Eichhornia spp. (water hyacinth) are used. Low flow velocity and different biochemical processes make it a land-intensive biological treatment system. The most common application of FWS wetlands is the advanced treatment of effluents from secondary/tertiary treatment processes. They are nearly an exclusive choice for the treatment of agricultural runoff and urban stormwaters, because of their ability to deal with pulse flows and changing water levels.

Horizontal flow (HF) wetland

The HF wetlands are engineered systems where water flows horizontally through a gravel or coarse sand-based filter beneath the surface, creating a water-saturated environment (Figure 3). The filter media is placed on an impermeable layer to prevent infiltration to the surrounding land and is planted with wetland vegetation, often native macrophytes, e.g., common reed or cattail in Europe. Pollutant removal occurs within the filter media and root system through microbial and physico-chemical processes, including filtration, anaerobic organic matter degradation and denitrification. HF wetlands are typically used for secondary and tertiary treatment. The first full-scale HF wetland was put into operation in 1974 in Germany, and the treatment process was called the “Root Zone Method”. Nowadays, HF wetlands are also used for agricultural wastewater treatment from food and agricultural product processing that contains high concentrations of organic matter and sufficient nutrients. This includes applications like treating wastewater from wine production or by-products from milk and cheese making.

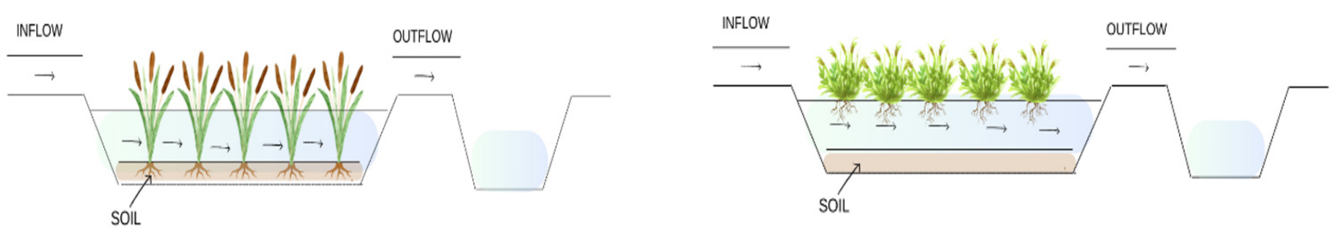


Figure 2. Free water surface wetland: free floating (top), emergent rooted plants (bottom) (based on Vymazal, 2007)

Vertical flow (VF) wetlands

In VF wetlands, wastewater is evenly distributed over a bed of porous media like sand or gravel, which is planted with macrophytes. Classical VF wetlands are operated with intermittent loading. Water flows downwards in the VF bed and in between two loadings air re-enters the pores and ensures aerobic conditions, ensuring efficient ammonium removal (Figure 3). This contact with the filter media and aerobic microbes effectively degrades organic matter and nitrifies ammonium. VF wetlands require less surface area compared to HF wetlands and can use finer filter materials. They are also employed for treating wastewater from food and agricultural processing. VF wetlands with saturated water flow can be fed from the bottom or top, water thus flows upwards or downwards, respectively. In these systems aerobic conditions prevail and thus processes similar to those in HF wetlands occur. To enhance the degradation of organic matter and nitrification processes, a forced aeration system can be integrated.

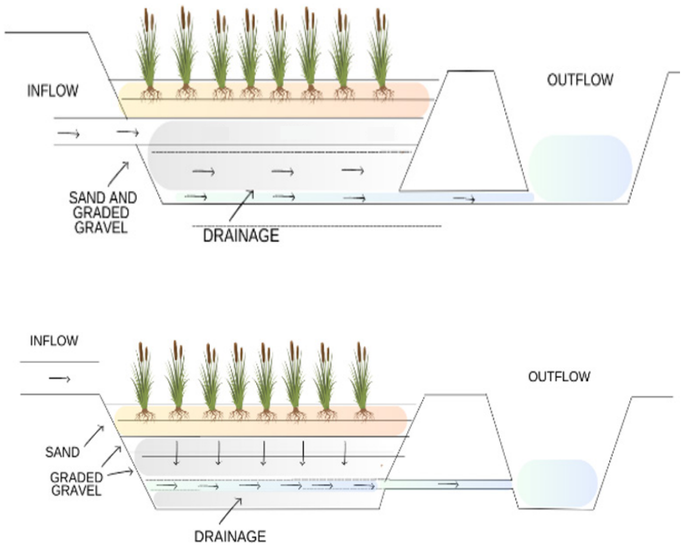


Figure 3. Horizontal flow (HF) wetlands (left) and vertical flow (VF) wetlands (right) (after Vymazal, 2007).

Cabragh Wetlands, at the site of the old Irish Sugar Company factory in Co Tipperary, Ireland. Photo: Eamon Brennan

Examples of constructed wetland application in agricultural settings

1. Case Example of 'El tancat de pipa' - A CW System Between Rice Fields (Albufera Natural Park. Valencia, Spain)

Source: www.tancatdelapipa.net

El Tancat de la Pipa (hereafter El Tancat) is a nature reserve within the Albufera de Valencia Natural Park, a Ramsar and Natura 2000 site, located on the northern shore of the Albufera lake. In 2007, 40 hectares of rice fields were transformed into a freshwater wetland habitat, with 9 hectares specifically allocated to a FWS wetland system. This system was designed to address the issue of eutrophication in the lake by treating both the lake's waters and the wastewater conveyed by a canal and a gully before reaching the lake (Vallés et al. 2016). The wastewater was a mixture of runoff (urban and agricultural) and treated and untreated wastewater from urban areas and industries in the Júcar River catchment. The site is owned by the Júcar River Authority and managed by two non-governmental organizations (NGOs): Acció Ecologista-Agró and SEO/BirdLife. In the Tancat area there is also an environmental education centre with all the necessary educational material to learn about the habitats and their species as well as the FWS wetlands.

Pros:

- Improvement of the water quality of Albufera lake.
- Restoration of natural wetland ecosystems and biodiversity enhancement in the Albufera Natural Park.
- Involvement of diverse stakeholders for a comprehensive monitoring process, including biologists, local authorities, tourism companies, and local fishermen and farmers in the vicinity of the lake.
- Emphasis on fostering information exchange and decision-making through participatory governance models and co-management agreements.
- Engagement of the local community and citizens through citizen science and volunteering activities.
- Accessibility to the area via a 1.2 km path adapted for wheelchairs.
- Implementation of educational and public awareness initiatives, e.g. information along the accessibility path to explain habitats and species, as well as the role of FWS wetlands in El Tancat.

Cons:

- Possible conflicts of interest between stakeholders, e.g. the increase of nesting birds in La Pipa might affect nearby crop productivity as the birds could seek food in the fields.

Figure 4. Aerial view of the wetland system showing fully naturalised wetlands including different habitats. (Source: Confederación Hidrográfica del Júcar)

2. Case Example of Farm Constructed Wetland in Northern Italy

In Northen Italy (Emilia-Romagna region), researchers of University of Bologna studied a CW that is treating agricultural drainage water of an experimental farm of 12.4 hectares cultivated with cereals, vegetables and orchards. The CW has a surface of 5.557,5 m2 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 around 1500 m3. However, the volume of drainage water treated and present in the system depends on the frequency and volume of the seasonal precipitation. Furthermore, the system effluent is discharged into a network of ditches from which farmers in the areas withdraw the water used 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. This CW was one of the solutions assessed in WATERAGRI for its sustainability.

Pros:

- Water treatment, removal of different contaminants and therefore a positive effect on the environment
- Biodiversity enhancement of an agricultural area since the system is home to different animal and plant species
- Improvement of water availability of the area – infiltration from the system can positively affect groundwater level and soil water content
- CW created opportunities for work and training activities for PhD and master students and researchers involved in the system management, water quality and quantity monitoring
- The system can serve as a show-case area for the governmental and other institutions that want to apply or support application of such a solution

Cons:

- Application of such a solution requires a certain surface area that means a lower land availability for agricultural production

Figure 5. Aerial photos of the CW. (Source: University of Bologna)

3. Case Example of CWs and Drainage Well Filters Treating Drainage Water in Denmark

In Denmark, CWs have been adopted as a new targeted measure since 2012 to mitigate agricultural nutrient losses from drainage. Several CWs and drainage well filters were constructed and monitored under the Supreme-Tech project during 2010-2015 in agricultural farmlands as end-of-pipe solutions on former farmland to mitigate drainage losses of nitrogen and phosphorous (P) from agricultural fields. For example, six parallel subsurface flow constructed wetlands (SSF-CWs) consisting of woodchip and seashells filling media, were constructed in Skannerup, Denmark (N 56.214132 – E 9.742723) in 2012, to mitigate nitrate removal in agricultural drainage water (Brunn et al., 2016). The SSF-CWs received drainage discharge from an 85 hectares catchment and had individual inlet – outlet wells. Each SSF-CW was 10 m wide, 10 m long and 1 m deep. Three different hydraulic designs (horizontal flow, vertical upward and vertical down flow) and two flow rates were investigated (0.49 and 1.83 L/s) (Figure 6). The substrate used in the SSF CW consisted of willow woodchips and Seashells mixed in different ratios (Bruun et al., 2016). Three of the SSF-CWs (1, 3 and 5) were initially planted with common reed (Phragmites australis), while the remaining SSF-CWs (2, 4 and 6) were left unvegetated.

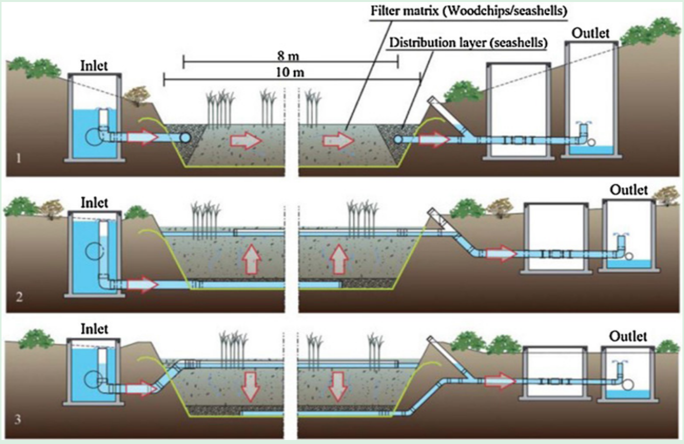


Figure 6. Visual representation of subsurface flow constructed wetlands (SSF-CWs) with horizontal flow (1), vertical upwards flow (2) and vertical downwards flow (3). SSF-CW (Source: Bruun et al. 2016)

Pros:

- Subsurface drainage water treatment in a limited area using SSF CW as an end of pipe solution to mitigate nitrate and phosphate discharge in surface waters.
- Nitrate reduction via denitrification in reactive granular woodchips-based filter media, is generally recognized as the dominant mechanism controlling NO3-N removal
- Combination of woodchips and seashells can mitigate both nitrate and phosphate removal from agricultural waters. The woodchips have a large intra-granular porosity and serve as a carbon source for denitrification processes, while seashells as a Ca-based material help to retain ortho-phosphate (Canga et al., 2016).

Figure 7. Orthophoto of the constructed wetland, June 2015 (Source: Google Earth)

Cons:

- Application of constructed wetlands requires a certain surface area that means a lower land availability for agricultural production, therefore subsidies for farmers would encourage their implementation.

Decision Making Towards Sustainable Solutions in Complex Settings

Decision-making can be described as a 3-step process that leads to a final decision or choice (output): (i) identification of the interest, goal, or aim; (ii) framing and decomposing, and (iii) an evaluation . Sustainability intends to simultaneously take into account and provide for the need of "*striving for the maintenance of economic well-being, protection of the environment and prudent use of natural resources, and equitable social progress which recognises the just needs of all individuals, communities, and the environment*" (Waas et al. 2011). Achieving sustainability is often referred to as accomplishing the 'triple bottom line' or serving 'People, Prosperity, and Planet'.

Using Serious Games to Facilitate Decision-Making

Decision-makers are often faced with the difficulty of choosing between options whose outcomes are uncertain and often, this process requires making trade-offs on social, environmental and financial objectives. Serious games have the potential to capture this decision complexity and present it through a fun and engaging medium. Serious games are those whose objectives go beyond entertainment and focus on increasing awareness of complex problems and supporting decision-making by allowing players to make decisions and learn from them in a safe environment. Many examples of serious games exist where they have been used for exploring the division of common water resources (Seibert and Vis, 2022), increasing awareness for water scarcity in farming (Barreteau et al., 2001), and allowing farmers to experiment with the operational management of their farms (Appel et al., 2018).

The serious game AgriLemma was developed in WATERAGRI to increase awareness of sustainable technologies such as constructed wetlands and allows players to experiment with their decisions and gain a better understanding of the performance of the technologies, including farm constructed wetlands, and the trade-offs involved in selecting them. The technologies considered in the game are primarily targeted at farmers to enable them to gain a better understanding of the technologies being developed as part of the WATERAGRI project and can be played by other stakeholders such as management organizations, researchers, students, and policymakers who want to step into the shoes of a farmer and experience the dilemmas and decisions involved in farming. In the game, players are challenged to make their farms profitable and socially and environmentally sustainable. Players compete to maximize the farm's total sustainability score, which is calculated as the sum of environmental, financial and social scores. The board game and its instructions can be downloaded and used under the creative commons license from the WATERAGRI homepage https://wateragri.eu/serious-gaming-2/, and corresponding deliverables (Mittal, 2023 a,b).

An example of how a technology – constructed wetlands is represented in the game is shown in Figure 8. The key aspects highlighted on the card focus on the costs and benefits/ impact of using a technology. Both one-off /capital investment costs (top-left of the card) and recurrent/maintenance costs (top-right of the card) are presented to highlight the initial and recurrent costs in using and maintaining a technology. Similarly, one-off and recurrent benefits of using the technology and presented on the bottom part of the card. In addition, a short description of the technology along with a simplified image is presented on the card to provide a short layman description of the technology. For more information on

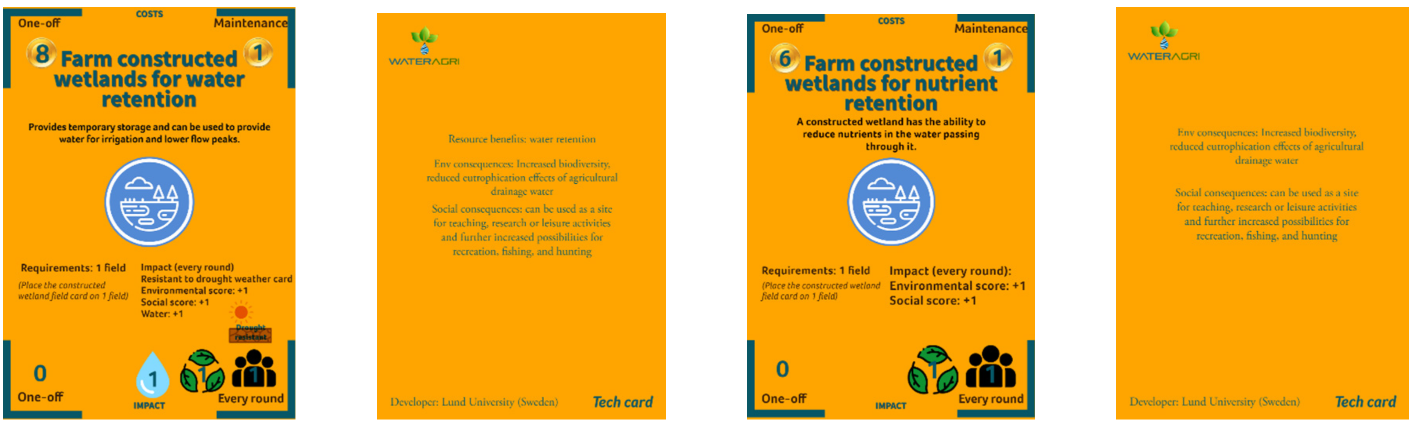


Figure 8. AgriLemma cards describing the CWs used in WATERAGRI

the impact of the technology, players can refer to the backside of the card where the name of the solution developer is also presented in case the player is interested in establishing contact with them for further queries.

From a review of 41 serious games Mittal et al. (2022) found that current serious games rarely support and include early phases of decision-making that are focused on understanding the "real-world" decision problem that must be supported. More detailed analysis of the problem is recommended by involving stakeholders from an early stage either by interviewing them or using a companion modelling approach to collectively develop a better understanding of the real-world problem. Moreover, the impact of current games is not systematically evaluated by using explicit evaluation indicators and controlled experiments. Systematic evaluation using before-after testing is recommended to build rigor and better understand the causal effect and added value of serious games.

Agrilemma was therefore designed and developed over a period of 3 years from May 2020 to January 2023. The game went through multiple iterations to refine and adapt aspects of play, meaning, and reality. Preparatory work to understand and conceptualize the real-world problem to be presented in the game was done through desk research of farming in Europe and interviews with representatives of WATERAGRI case studies to understand local problems with respect to agricultural water and nutrient management. The first prototype of the game was tested with 15 MSc students at TU Delft. With the feedback received from students, the game rules were simplified, and the technology cards were made more intriguing and informative – for instance, by providing more information about the solution on the backside of the cards. The game was further tested with WATERAGRI consortium members at various project meetings where feedback was collected through post-game debriefing discussions and written questionnaires. The final prototype of the game was tested with 10 participants at the 4th WATERAGRI stakeholder consultation workshop organized in February 2023 in Delft, The Netherlands where the impact of the game was tested using pre/post questionnaires. The results indicated modest improvements in self-reported awareness levels regarding WATERAGRI solutions and marginal changes in statements related to farming and uncertainties. The game received high ratings on aspects of fun, engagement and suitability as an engagement tool.

The potential limitations of "serious gaming" as a decision-making tool, noting that it may be a simplification of biophysics and the dependence on local data, is pertinent while applying this tool. Furthermore, more test sessions with real-world stakeholders external to the project are required to validate the initial findings, and gather nuanced feedback on aspects of play, learning goals, and realism.

Understanding the Criteria That Drive Decision-Making – Asking the Community

While the scientific literature has looked at individual pros and cons for the sustainable use of the different kinds of CWs (see Annex) little is known about the criteria that may drive decision-making. Thus, we conducted a Delphi-like exercise aimed at eliciting experts' opinions and consensus through a survey conducted in the summer of 2023 (July, 7th 2023 - September, 26th 2023). Of the 48 people that engaged in the survey, 22 completed it. These were mostly male (59%/42% m/f), largely from central Europe (38% Mediterranean, 27% Continental, 14% Boreal, 3% Pannonian, and 18% non-European), and still mostly from the research community (68% researchers, 17% advisory services, 5% farmers, % decision-makers and 5% others).

A vast majority of respondents (72%) ranked environmental sustainability as the most relevant aspect in the implementation of CW, followed by the economic (22%) and social (6%) dimensions (Figure 9). Similarly, individual aspects of sustainability that were ranked as important decision-making criteria for implementing CWs in general are largely environmental, such as nitrogen and phosphorous reductions, water reuse for irrigation, the improvement of ecosystem conditions and extent, as well as CO2 storage (Figure 10). Only one economic aspect, namely investment costs is deemed of relevance. Social aspects such as educational considerations are ranked as unimportant.

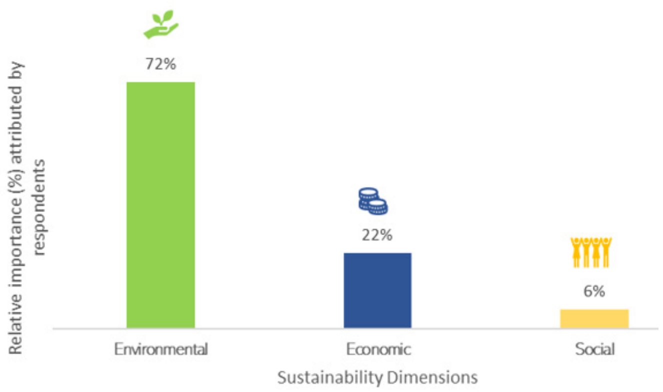


Figure 9. Relative importance (% of respondents ranked the dimension first) of sustainability dimensions.

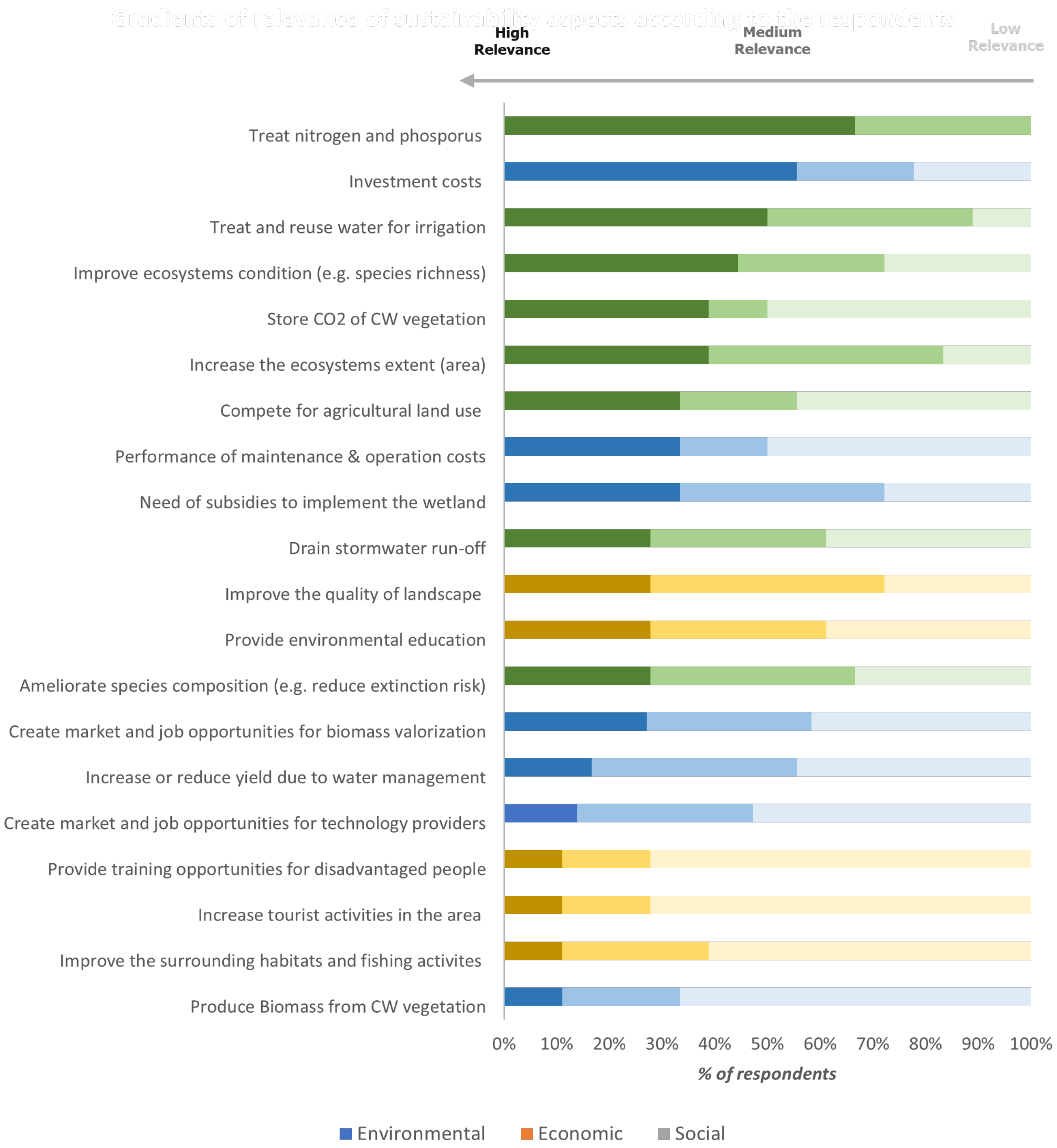


Figure 10. Gradient of the relevance of the perception of sustainability aspects according to respondents.

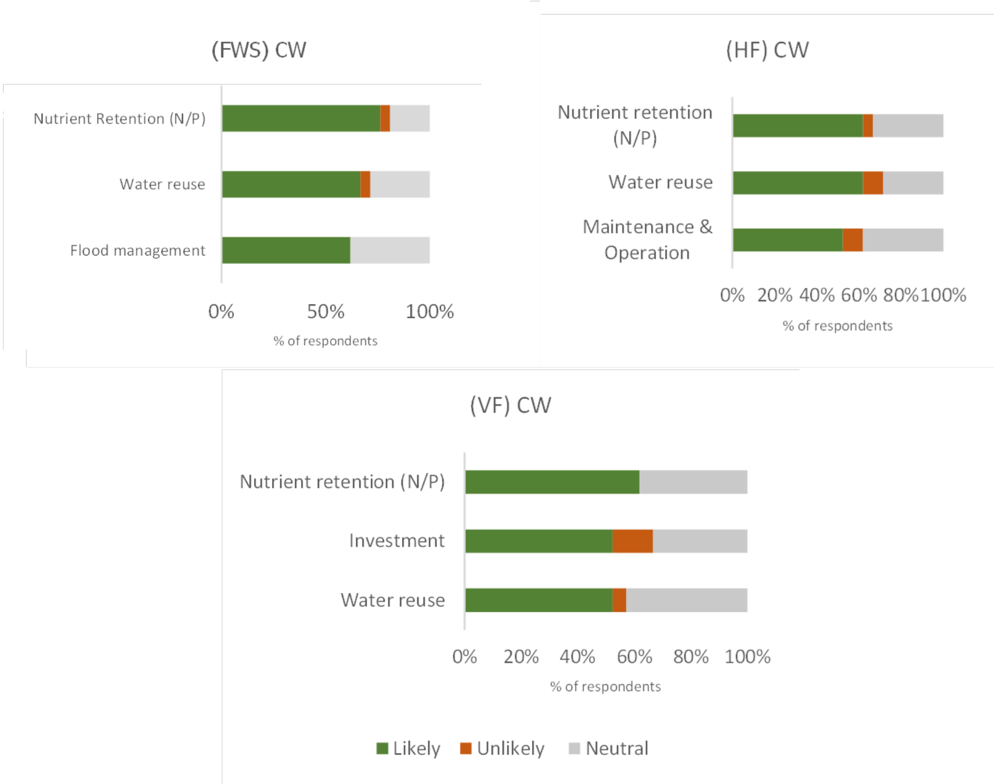


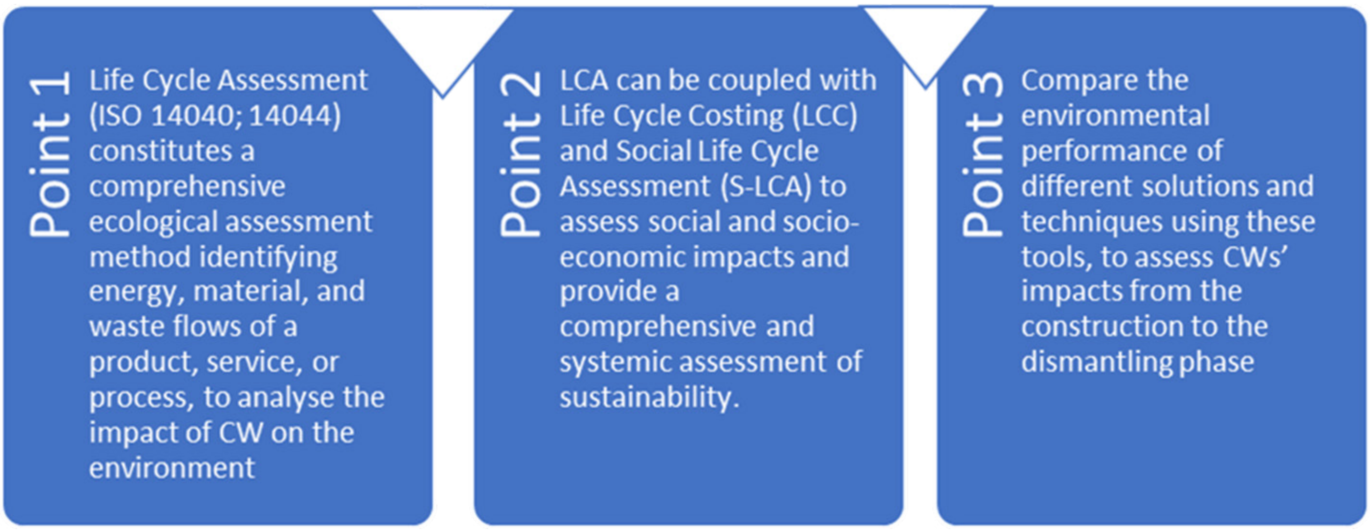
Figure 11. The three most relevant aspects to implementing different types of wetlands (FWS, HF, VF)

When looking at specific CW system and the top-three criteria to decide for a specific system, respondents continued agreeing on the nitrogen and phosphorous retention as the key criterion, followed with the possibility for water reuse (Figure 11). The three systems differed in their specificity only in one criterion each: (1) free water systems are considered useful for flood management as they can be used for water retention purposes, (2) horizontal flow systems are relatively lower in their maintenance and operation costs then other conventional systems, and (3) vertical flow systems need to be scrutinised against their relatively higher investment costs. Thus, for both horizontal and vertical flow systems, economic criteria come into play in the top three decision-making criteria.

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 the wetland is not an aspect they would consider when confronted with the opportunity to implement a FWS CW, while those percentages are around 40% for HF and VF CW. As a general trend, one-third of the respondents would not implement these infrastructures considering socio-economic aspects like association with tourist activities, yield increase, training opportunities and biomass production. As shown in the Annex, these aspects are also less investigated in the academic literature, except for biomass production. Further, 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 an opposition.

Regional Assessment of Sustainability of Constructed Wetlands

Implementing a CW system in the region is primarily motivated by environmental considerations, with economic factors playing a secondary role. In the WATERAGRI project, a sustainability assessment was applied to a Farm Constructed Wetland in Northern Italy (see box example 2), treating agricultural drainage water for a nearby 12.5 ha farm. Sustainability assessments comprehensively guide decisions toward sustainable development, addressing environmental, social, and economic aspects. These assessments align decisions with sustainable development principles, providing a strategic direction for policies and actions (J. Pope et al.



2017). Selecting an appropriate sustainability assessment methodology is crucial for demonstrating advantages and potential trade-offs. This facilitates evidence-based policy formulation and effective water resource management. It's noteworthy that many current tools, when used alone, fail to capture the multifaceted impacts of CWs on the environment and society.

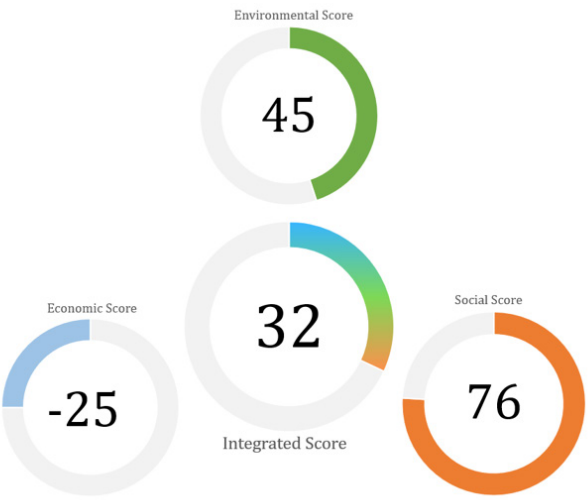


Figure 12. Integrated sustainability score for the WATERAGRI Scenario. (Source: WATERAGRI Deliverable 6.3)

To this need, three points are of key relevance:

In the WATERAGRI project, these three approaches have been combined and tested in the region. It was noted that when compared to a business-as-usual scenario where water is not treated and runs off on the fields, the wetland performed well in environmental terms (45% decrease of total negative impacts) and in social terms (+76% increase of total positive impact), and exhibited some negative monetary impacts (+25% of life cycle costs) (Figure 12).

The specific CW implementation in the region led to notable environmental benefits, including reduced land use, freshwater ecotoxicity, and marine and freshwater eutrophication. Moreover, it showcased social advantages, particularly in creating employment and training opportunities. Prioritising training initiatives and sustained employment for vulnerable populations is crucial to enhance these positive outcomes. Despite the environmental advantages, implementing and operating CWs can pose financial challenges for farmers. In the case of Itay, a one-time payment of 1791€ and an annual subsidy of 120€ are estimated to be necessary. This compensation aims to recognise the environmental and social benefits farmers provide by adopting green infrastructures. The subsidy is payment for various ecosystem services, including carbon sink creation, biodiversity site implementation, and nutrient and suspended solids reduction in freshwater systems.

CW Strategies and Related Subsidies Remain Vital in Promoting Sustainable Practices and Compensating Farmers for Their Contributions

We showcased various applications of CWs in the region, encompassing farm-level wastewater treatment and drainage water treatment. The designs are tailored to the specific needs of the site or country. Emphasising the significance of evaluating the ecohydrological characteristics of the site becomes essential to accurately assess the performance of CWs. Regular monitoring details, including information on water collection methods, system age, weather conditions, and pollutant efficiencies, should be considered as valid parameters in those assessments.

Context-Specific Recommendations on the Choice of Wetland Technology in the Region

This set of recommendations aims to ensure that the choice of CW technology is context-specific, socially beneficial, environmentally responsible, and economically viable.

Individual Farmers:

- Seek support from local authorities for CW implementation.
- Choose CW technologies adapted to farm size, water needs, and environmental conditions.
- Align CW use as a nature-based solution with co-benefits.
- Consider improved water quality, habitat preservation, and trade-offs.
- Understand that ROI may take time; benefits are realised at landscape/catchment levels.

Farm Cooperatives or Group Settings

- Encourage collaboration among farmers for collective CW implementation.
- Involve local regulatory and outreach authorities/ institutions.
- Shared CWs reduce costs, enhance water quality, and provide ecosystem services.
- Consider a mix of surface and subsurface flow wetlands for varied challenges.

Stakeholders Involved with CWs:

- Advocate for policies supporting financial subsidies for farmers or groups.
- Note that social and environmental benefits outweigh economic costs in many cases.

The integration of CW technology should be approached from a comprehensive standpoint that considers the environmental, social, and economic aspects of sustainability. Future endeavours in this field should strive for a more discerning analysis of CW performance, comparing it with alternative methods. This approach aims to contribute significantly to the ongoing dialogue on the potential of CW technology, enhancing its value as a resource for environmental decision-makers. It is crucial to include an examination of diverse techniques, such as the effectiveness of buffer strips along water courses. By evaluating and comparing the efficiency and sustainability of various nature-based pollutant reduction solutions, we can establish a robust foundation for decision-making in environmental management.

To deepen our understanding, incorporating serious gaming and comprehensive sustainability assessments can prove instrumental in aiding stakeholders in grasping the challenges and opportunities associated with wetland technology for achieving more sustainable farm management. While serious gaming holds the potential to enhance stakeholder knowledge and comprehension, its limitations in making precise decisions without adequate localised data should be carefully acknowledged.

References

Appel, F., Balmann, A., Dong, C., & Rommel, J. (2018). FarmAgriPoliS – An Agricultural Business Management Game for Behavioral Experiments, Teaching, and Gaming (Discussion Paper, No. 173).

Austin, David, and Jaime Nivala. “Energy requirements for nitrification and biological nitrogen removal in engineered wetlands.” Ecological Engineering 35, no. 2 (2009): 184-192.

Barreteau, O., & Dare, W. (2007). Role-Playing Games in a variety of cultures: experiences from the ComMod group. 38th Conference of the ISAGA, 9, 9–13. http://www.commod.org.

Bieroza, M. Z., R. Bol, and M. Glendell. 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 (October): 148080. https://doi.org/10.1016/j.scitotenv.2021.148080.

Boix-Fayos, Carolina, and Joris de Vente. 2023. ‘Challenges and Potential Pathways towards Sustainable Agriculture within the European Green Deal’. Agricultural Systems 207 (April): 103634. https://doi.org/10.1016/j.agsy.2023.103634.

Bruun, J., Puglisi, L., Hoffmann, C. C., & Kjaergaard, C. (2016). Solute transport and nitrate removal in full-scale subsurface flow constructed wetlands of various designs treating agricultural drainage water. Ecological Engineering, 97, 88-97.

Canga, E., Heckrath, G. J., & Kjaergaard, C. (2016). Agricultural drainage filters. II. Phosphorus retention and release at different flow rates. Water, Air, & Soil Pollution, 227, 1-13.

Cavalheri, P. S., M. A. Mello, A. L. Pereira, T. R. Marques, T. N. Moraes, G. H. Cavazzana, and F. J. C. Magalhães Filho. 2022. ‘Chapter 16 - Ecotoxicity Evaluation of Diclofenac Potassium in Vertical Flow Constructed Wetlands as Posttreatment of Septic Tank Effluent’. In Circular Economy and Sustainability, edited by Alexandros Stefanakis and Ioannis Nikolaou, 271–82. Elsevier. https://doi.org/10.1016/B978-0-12-821664-4.00028-5.

Dotro, Gabriela, Günter Langergraber, Pascal Molle, Jaime Nivala, Jaume

Puigagut, Otto Stein, and Marcos von Sperling. 2017. 'Treatment Wetlands'. Biological Wastewater Treatment Series, Volume 7, IWA Publishing, London, UK, 172p. eISBN: 9781780408774. https://doi.org/10.2166/9781780408774.

Dudley, Nigel. 2022. 'Impact of Agriculture on Insect Species Decline'. In Imperiled: The Encyclopedia of Conservation, edited by Dominick A. DellaSala and Michael I. Goldstein, 500–506. Oxford: Elsevier. https://doi.org/10.1016/B978-0-12-821139-7.00238-5.

Garcia, Joan, Diederik PL Rousseau, Jordi Morato, E. L. S. Lesage, Victor Matamoros, and Josep M. Bayona. "Contaminant removal processes in subsurface-flow constructed wetlands: a review." Critical reviews in environmental science and technology 40, no. 7 (2010): 561-661.

Garfí, M., Flores, L., and I. Ferrer. 2017. Life Cycle Assessment of wastewater treatment systems for small communities: Activated sludge, constructed wetlands and high rate algal ponds. Journal of Cleaner Production 161: 211-219. https://doi.org/10.1016/j.jclepro.2017.05.116.

Giannakis, Elias, Jonilda Kushta, Despina Giannadaki, George K. Georgiou, Adriana Bruggeman, and Jos Lelieveld. 2019. 'Exploring the Economy-Wide Effects of Agriculture on Air Quality and Health: Evidence from Europe'. Science of The Total Environment 663 (May): 889–900. https://doi.org/10.1016/j.scitotenv.2019.01.410.

Kadlec, Robert H., and Scott Wallace. 2008. Treatment Wetlands, Second Edition. CRC Press.

Langergraber, Gunter, and Raimund Haberl. "Constructed wetlands for water treatment." Minerva Biotecnologica 13, no. 2 (2001): 123.

Lavrnić S., Nan X., Blasioli S., Braschi I., Anconelli S., Toscano A. (2020) Performance of a full scale constructed wetland as ecological practice for agricultural drainage water treatment in Northern Italy. Ecological Engineering 154, 105927. https://doi.org/10.1016/j.ecoleng.2020.105927

Li, Yifei, Guibing Zhu, Wun Jern Ng, and Soon Keat Tan. 2014. 'A Review on Removing Pharmaceutical Contaminants from Wastewater by Constructed Wetlands: Design, Performance and Mechanism'. Science of The Total Environment 468–469 (January): 908–32. https://doi.org/10.1016/j.scitotenv.2013.09.018.

Mittal, A. (2023a). WATERAGRI D1.3 Serious Game. https://wateragri.eu/wp-content/uploads/2023/09/D1.3.pdf

Mittal, A. (2023b). WATERAGRI D1.6 Workshop 3 report. https://wateragri.eu/wp-content/uploads/2023/09/D1.6.pdf

Mittal, A., Scholten, L., & Kapelan, Z. (2022). A review of serious games for urban water management decisions: current gaps and future research directions. Water Research, 215, 118217. https://doi.org/10.1016/j.watres.2022.118217

Moreno et al. (2016). Gestión de la participación en humedales. Una aproximación desde el Life+Albufera. https://lifealbufera.webs.upv.es

Pope, Jenny, Alan Bond, Jean Hugé, and Angus Morrison-Saunders. 2017. 'Reconceptualising Sustainability Assessment'. Environmental Impact Assessment Review 62 (Supplement C): 205–15. https://doi.org/10.1016/j.eiar.2016.11.002.

Schäfer, Ralf Bernhard, Thierry Caquet, Katri Siimes, Ralf Mueller, Laurent Lagadic, and Matthias Liess. 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): 272–85. https://doi.org/10.1016/j.scitotenv.2007.04.040.

Seibert, J., & Vis, M. J. P. (2012). Irrigania - A web-based game about sharing water resources. Hydrology and Earth System Sciences, 16(8), 2523–2530. https://doi.org/10.5194/hess-16-2523-2012

Soldo, Cole, Robyn S. Wilson, Hugh Walpole, and C. Dale Shaffer-Morrison. 2022. 'Farmer Willingness to Implement Constructed Wetlands in the Western Lake Erie Basin'. Journal of Environmental Management 321 (November): 115928. https://doi.org/10.1016/j.jenvman.2022.115928.

Turcios, Ariel E., Rosa Miglio, Rosemary Vela, Giovanna Sánchez, Tomasz Bergier, Agnieszka Włodyka-Bergier, Jorge I. Cifuentes, Gabriela Pignataro, Tamara Avellan, and Jutta Papenbrock. 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 (October): 104583. https://doi.org/10.1016/j.envexpbot.2021.104583.

Vallés et al. (2016). Manual técnico para una gestión óptima de la hidráulica en humedales restaurados para mejora del hábitat y de la calidad del agua. Life+Albufera. España, ISBN: 978-84-945224-4-4. https://lifealbufera.webs.upv.es

Vymazal, Jan, and Lenka Kröpfelová. Wastewater treatment in constructed wetlands with horizontal sub-surface flow. Vol. 14. Springer science & business media, 2008.

Vymazal, Jan. "Removal of nutrients in various types of constructed wetlands." Science of the total environment 380, no. 1-3 (2007): 48-65.

Vymazal, Jan. "Constructed wetlands for wastewater treatment: five decades of experience." Environmental science & technology 45, no. 1 (2011): 61-69.

Waas, T., J. Hugé, A. Verbruggen, and T. Wright. 2011. 'Sustainable Development: A Bird's Eye View'. Sustainability 3 (10): 1637–61. https://doi.org/10.3390/su3101637.

ANNEX

Comparison of some technical and sustainability aspects among the main types of constructed wetlands. From Dotro et al. (2017) and Langergraber et al. (2019), supplemented with expert experiences.

	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	+++	++	++
CO2 storage	++		
Ecosystem condition	+++	+	+
Ecosystem extent	+++	+	+
Enhance biodiversity / Species composition	++	+	+

In partnership with:

Understanding Multifunctionality of Constructed Wetlands in Agricultural Settings in the European Region

Publisher: United Nations University Institute on Comparative Regional Integration Studies (UNU-CRIS), Bruges, Belgium

[1] University of Oulu, Oulu, Finland, tamara.avellan@oulu.fi

[2] University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, Austria

[3] Alchemia-nova, Institute for Circular Economy & Nature-based Solutions, Vienna, Austria

[4] Alma Mater Studiorum - University of Bologna, Bologna, Italy

[5] Delft University of Technology, Delft, The Netherlands

[6] UNU-CRIS, Bruges, Belgium

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 858375.

Kind appreciation to Carmen Hernandez-Crespo for providing the picture of CW in Tancat de la Pipa and reviewing that example. Many thanks to Alba Canet and the UNIBO Team for the great graphics of the constructed wetlands. Kind thanks to Andrew Dunn for his support in putting the Policy Brief into a digestible format. Many thanks also to the internal reviewer Dr Günter Langergraber (BOKU - University of Natural Resources and Life Sciences, Austria) and external reviewer Prof. Patrick Meire (University of Antwerp, Belgium) for the valuable comments.

Suggested citation: Avellan, Tamara., Alba Canet-Martí, Eriona Canga, Valentina Guerrieri, Simone Amadori, Aashna Mittal, Stevo Lavrnić, Marco Hartl, Nidhi Nagabhatla. 2024. Understanding Multifunctionality of Constructed Wetlands in Agricultural Settings in the European Region. PB-2024-01. Bruges: UNU-CRIS