Phytoremediation of Domestic Wastewater

Subjects: Engineering, Civil | Engineering, Environmental

Contributor: Hauwa Mohammed Mustafa , Gasim Hayder , Siti Indati Mustapa

A circular economy (CE) based strategy is essential to progress toward Sustainable Development Goals (SDG). CE is centered on the conversion of waste into meaningful products and resource efficiency with the objective of promoting resource reuse. This study presents the potential of CE approaches in the phytoremediation of wastewater and energy recovery using hydroponic tanks. The integration of phytoremediation with bioenergy, construction and lifespan of hydroponic tanks in phytoremediation of wastewater, selection of aquatic plants, and the expected challenges in the implementation of CE in phytoremediation of wastewater were discussed. It further elucidates a comprehensive circularity assessment methodology that would enable and support a strategic CE framework for phytoremediation techniques in wastewater treatment. Additionally, a complete view of the feedstock conversion process into valuable end products was discussed in this CE strategic study. The findings obtained provided insights into the relative growth rate of the plant-based biomass harvested from the phytoremediation of domestic wastewater. It also provided information on the economic and technical feasibility of wastewater phytoremediation using hydroponic tanks for simultaneous recovery of treated water and plants' biomass to enable large-scale implementation. Furthermore, optimizing resource recovery and bioenergy generation, developing new approaches and solutions, and improving process stability would help encourage and enhance the adoption of the CE framework in the phytoremediation of domestic wastewater.

circular economy (CE) phytoremediation techniques plant-based biomass wastewater treatment

1. Introduction

The circular economy (CE) approach has received a lot of attention from industries, academics and policy [1][2]. Circular flow models, sustainable concepts, as well as lifecycle thinking are all geared towards reducing environmental pollution while simultaneously opening up new commercial prospects through waste recycling, repair and reprocessing [3][4]. The main aim of CE is to eliminate or minimize waste generation [5]. Preventing waste generation and repurposing it has become a novel strategy in economy revitalization. Therefore, systems that allow total or partial circularity of materials have replaced linear waste processes, as their design and operations are necessary and socially mandated [6]. In CE framework, the materials and products remain in the economy and waste is considered as raw materials that can be recycled into new products [7]. This sets it apart from the "take-make-use-dispose" of the linear model, in which waste is typically the final stage of the product lifecycle [8]. CE also emphasizes on economy, environmental and social sustainability of the conventional economic system [9]. On the contrary, the linear model cannot be used in demonstrating the natural and social implications on the economy, as they are not oriented around minimizing the harmful elements in industrial systems. Therefore, CE is a component of the conventional economic system that emphasizes circularity in energy and materials in conjunction with natural resource conservation [10]. For instance, the European Union has found that the utilization of waste as raw materials by industries is important, as proven by a Dutch-based plant that successfully converted raw materials and energy to biomass, phosphate, exopolymers and bioplastics. This novel technique has the potential to boost alternative business models based on CE [11].

Moreover, the CE approach could pave the way for new inventions in hydrology that would aid in water restoration. Water has been a topic of contention in CE because it is one of the most critical resources for industrial activities. Agriculture and aquaculture, for example, are entirely reliant on it [12]. Additionally, incorporating energy production and resource recovery into clean water production and wastewater treatment is now part of the CE concept [13]. In this way, wastewater treatment and reuse can help increase agricultural productivity, provide new materials for industrial applications, or create new energy sources like methane and biofuels [12].

Furthermore, water, raw materials and energy are the three main pathways for CE in wastewater, and they are all supported by innovation [14]. The principle of reducing, reusing, recycling, recovery and restoring supports the link between waste-to-energy [15]. Energy consumption for wastewater treatment operations varies based on the process configurations, the treatment goals and effluent standards. Energy usage is often less than 0.5 kW h/m^3 for operations that do not include nutrient removal. Advanced treatment such as activated carbon filtration and membrane filtration are usually used in WWTPs for eliminating excess nutrient, pathogens and other contaminants present in wastewater. These procedures consume a significant amount of energy, ranging between 0.5 to 2.0 kW h/m^3 [16]. Nevertheless, biological methods of wastewater treatment such as phytoremediation can help reduce dependency on fossil fuel energy sources while increasing reliance on renewable energy sources, which can help reduce carbon emissions.

Integration of Phytoremediation with Bioenergy Production

One of the most effective approaches for the management of biomass from polluted sites is combining phytoremediation with bioenergy production, which is becoming increasingly popular. Zhao et al. [17], for example, discovered that plant biomass could fulfill a substantial amount of the world's energy needs. Hence, utilization of energy crops for phytoremediation can assist in meeting energy demands while also reducing greenhouse gas emissions by using a sustainable, environmentally benign and carbon-neutral biomass source. A variety of well-known crops have been recognized as having the potential to be utilized in the phytoremediation process as well as being a source of energy production. The integration of phytoremediation and bioenergy production using a single hemp crop has been reported to be a potential pathway to overcoming the economic limitations of phytoremediation schemes. Rheay et al. [18] investigated the potential of paired phytoremediation and bioenergy production using hemp crop (Cannabis sativa L.).

2. Anticipated Challenges in Implementation of CE in Phytoremediation of Wastewater

A CE-based strategy is essential to progress towards Sustainable Development Goals (SDG). CE is centered on the conversion of waste into meaningful products and resource efficiency with the objective of promoting resource reuse. Besides, adopting the CE concept in water and wastewater treatment would help in achieving several objectives of the SDGs, as one of the critical elements of the 2030 SDG is the improvement of water quality. Wastewater is a significant input resource and its adoption into the CE context should be advocated [19]. In this light, some of the constraints that may hinder the implementation of CE in phytoremediation wastewater treatments are highlighted below:

- Selection of suitable technology for phytoremediation of wastewater by stakeholders and industries is one of the impediments that would hinder the successful deployment of CE concept.

- Monitoring the processes of wastewater phytoremediation requires a long time and space. Thus, there might be an inconsistent flow of valid input information.

- Insufficient information on the capital for investment, policies and data availability are barriers that would hinder the implementation of CE strategies in wastewater phytoremediation, particularly on an industrial scale.

- Another problem is the interdependencies between the plants, microorganisms, treatment systems and the natural environment. Additionally, integrating these essential components requires easy data exchange for proper monitoring, control and manipulations that would promote the plant growth and wastewater treatment process.
- Lack of prior knowledge and competent human resources will have detrimental effects on the efficiency of the phytoremediation technique and, hence, CE adoption.
- Complex methods, costs and energy involving the conversion of the harvested plant biomass into other useful beneficial products such as biofuels, bionic liquids and chemicals.
- There is a lack of understanding and legislation that encourages the utilization of reclaimed resources. The incentives or benefits of reusing wastewater resources are not well articulated, which impedes the implementation of the CE model in wastewater treatment for energy recovery [20].

Future Perspective

In recent years, government agencies have expanded their commitment to using scientific research findings to influence policy decisions. As a result, a variety of scientific advisory systems have been established and developed throughout a number of countries [21]. Environmental sustainability, employment, healthy population and industrial processes can be obtained through a green and cleaner environment owing to academic scientific investigations that introduce new technologies and products to the market [22]. Moreover, the deployment of CE approaches in wastewater treatment and management would assist in preserving valuable resources including water, energy and nutrients while reducing pollution and waste from the environment [23]. The CE method illustrates a shift in the function of wastewater treatment systems, which has shifted from performing only the roles of wastewater treatment and disposal to an active strategy aimed at profit maximization. This repositioning will put an additional strain on traditional facilities built to satisfy water discharge limits set by law at a low cost. As a result, innovative wastewater treatment technologies could be a solid starting point for developing a more ecologically friendly water network within a regenerated water market [24]. The visible link between CE and water is the transition of WWTP to energy recovery facilities that encourages the recovery of treated water, energy, biomass and nutrients [25]. Therefore, future research should shift attention to CE measurement and application in phytoremediation of wastewater in real-life context and their prototypes which need to be proven by viable economic feasibility analysis at an industrial scale. This would promote the use of affordable and renewable biomass, growth opportunities for industries, cleaner environment, sustainable bioenergy and economic stability. Furthermore, future studies should focus on the relationship and impact of energy and water management, as well as potential improvements. The procedures should be evaluated and verified using case studies to demonstrate their suitability in different environments. Additionally, future studies in optimizing the operational processes for phytoremediation techniques of wastewater using innovative technology that will reduce the limitations associated with the techniques will be recommended. This would reduce the water footprint, decrease the use of harmful chemicals and energy requirements involved in conventional wastewater treatment methods. Hence, contributing to the achievement of SDG 6, which states ”Ensure availability and sustainable management of water and sanitation for everyone,” as well as, to some extent, SDG 7: ”Ensure that everyone has access to energy that is inexpensive, efficient and sustainable” [13].

References

1. Sassanelli, C.; Rosa, P.; Rocca, R.; Terzi, S. Circular economy performance assessment methods: A systematic literature review. J. Clean. Prod. 2019, 229, 440–453.
2. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.P.; Jan, E. The Circular Economy a new sustainability paradigm? J. Clean. Prod. 2017, 143, 757–768.
3. Newnes, A.T.; Marshall, Y.; Grainger, C.; Neal, M.; Scullion, J.; Gwynn-jones, D. A circular economi c approach to the phytoextraction of Zn from basic oxygen steelmaking filtercake using Lemna minor and CO 2. Sci. Total Environ. 2021, 766, 144256.
4. Korhonen, J.; Honkasalo, A.; Seppälä, J. Circular Economy: The Concept and its Limitations. Ecol. Econ. 2018, 143, 37–46.
5. Kyriakopoulos, G.L.; Kapsalis, V.C.; Aravossis, K.G.; Zamparas, M.; Mitsikas, A. Evaluating circular economy under a multi-parametric approach: A technological review. Sustain. 2019, 11, 6139.
6. Fogarassy, C.; Horvath, B. The development of a circular evaluation (cev) tool–case study for th e 2024 budapest olympics. Hung. Agric. Eng. 2017, 31, 10–20.
7. Ghisellini, P.; Cialani, C.; Ulgiati, S. A review on circular economy: The expected transition to a b alanced interplay of environmental and economic systems. J. Clean. Prod. 2016, 114, 11–32.
8. Neczaj, E.; Grosser, A. Circular economy in wastewater treatment plant–challenges and barriers. Proceedings 2018, 2, 614.
9. Mavragani, A.; Nikolaou, I.E.; Tsagarakis, K.P. Open economy, institutional quality, and environm ental performance: A macroeconomic approach. Sustainability 2016, 8, 601.
10. Michelini, G.; Moraes, R.N.; Cunha, R.N.; Costa, J.M.H.; Aldo, R. From linear to circular economy: PSS conducting the transition. Procedia CIRP 2017, 64, 2–6.
11. Hagenvoort, J.; Ortega-Reig, M.; Botella, S.; Garcia, C.; de Luis, A.; Palau-Salvador, G. Reusing tr eated waste—Water from a circular economy perspective — The case of the Real Acequia. Wate r 2019, 11, 1830.
12. Flores, C.; Bressers, H.; Gutierrez, C.; de Boer, C. Towards circular economy–a wastewater treat ment perspective, the Presa Guadalupe case. Manag. Res. Rev. 2018, 41, 554–571.
13. Nielsen, P.H. Microbial biotechnology and circular economy in wastewater treatment. Microb. Bio technol. 2017, 10, 1102–1105.
14. Zvimba, J.N.; Musvoto, E.V.; Nhamo, L.; Mabhaudhi, T.; Nyambiya, I.; Chapungu, L.; Sawunyama, L. Energy pathway for transitioning to a circular economy within wastewater services. Case Stud . Chem. Environ. Eng. 2021, 4, 100144.
15. Sharma, S.; Basu, S.; Shetti, N.P.; Kamali, M.; Walvekar, P.; Aminabhavi, T.M. Waste-to-energy ne xus: A sustainable development. Environ. Pollut. 2020, 267, 115501.
16. Ghimire, U.; Sarpong, G.; Gude, V.G. Transitioning wastewater treatment plants toward circular economy and energy sustainability. ACS Omega 2021, 6, 11794–11803.
17. Zhao, F.; Yang, W.; Zeng, Z.; Li, H.; Yang, X.; He, Z. Nutrient removal efficiency and biomass prod uction of different bioenergy plants in hypereutrophic water. Biomass and Bioenergy 2012, 42, 2 12–218.
18. Rheay, H.T.; Omondi, E.C.; Brewer, C.E. Potential of hemp (Cannabis sativa L.) for paired phytore mediation and bioenergy production. GCB Bioenergy 2021, 13, 525–536.
19. Arias, B.G.; Merayo, N.; Millán, A.; Negro, C. Sustainable recovery of wastewater to be reused in cooling towers: Towards circular economy approach. J. Water Process Eng. 2021, 41, 102064.
20. Kakwani, N.S.; Kalbar, P. Review of Circular Economy in Urban Water Sector: Challenges. J. Envir on. Manage. 2020, 271, 111010.

21. Bakan, B.; Bernet, N.; Bouchez, T.; Boutrou, R.; Choubert, J.M.; Dabert, P.; Duquennoi, C.; Ferraro, V.; García-Bernet, D.; Gillot, S.; et al. Circular economy applied to organic residues and wastewater: Research challenges. Waste and Biomass Valorization 2021.
22. Espíndola, G.J.A.; Cordova, F.; Casiano Flores, C. The importance of urban rainwater harvesting in circular economy: The case of Guadalajara city. Manag. Res. Rev. 2018, 41, 533–553.
23. Van Fan, Y.; Lee, C.T.; Lim, J.S.; Klemeš, J.J.; Le, P.T.K. Cross-disciplinary approaches towards smart, resilient and sustainable circular economy. J. Clean. Prod. 2019, 232, 1482–1491.
24. Somoza-Tornos, A.; Rives-Jiménez, M.; Espuña, A.; Graells, M. A circular economy approach to the design of a water network targeting the use of regenerated water. Comput. Aided Chem. Eng. 2019, 47, 119–124.
25. Voulvoulis, N. Water reuse from a circular economy perspective and potential risks from an unregulated approach. Curr. Opin. Environ. Sci. Heal. 2018, 2, 32–45.