Review



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# Circulatory Pathways in the Water and Wastewater Sector in the Latin-American Region (LAR)

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**Abstract:** Circular Economy (CE) is noted as an emerging tool or framework to support sustainable production and consumption agenda. In addition, CE is aiming to be a trigger for redefining economic growth pathways to be sustainable, inclusive, and sensitive to ecological and environmental agendas and to focus its operational standards on co-creating societal benefits. Concerning the guiding principles and the standards of practice applied to implement and scale circular economy, this study will provide an overview of the water sector-specific circularity roadmaps and strategies in the Latin American Region. By using a semi-systematic review, document analysis, and qualitative assessment approach, we highlight framings and operational pathways, gaps, and needs within existing practices of circularity in the water sector. The results provide an overview of CE pathways at the national level of selected countries in LAR iterating those nations reflect various levels of advancement (low to high) with CE-focused innovations and policy support structures specific to the water and wastewater sectors. Towards the closing, the study is pointing to the 'call for action' to integrate outstanding advances and innovations in the circular economy within sectoral mandates for water and wastewater management, making an argument that circularity in the water sector could serve as an accelerator toward implementing the agenda outlined in Sustainable Development Goals (SDGs) and in particular for SDG 6 (water security for all).

**Keywords:** circular economy; water; wastewater; resource use; Latin America

## 1. Introduction

Is it important that the sustainability agenda is multifaceted and reaches not only large regions but broad and geographically diverse sectors and actors? If so, scientific discovery alone is not sufficient. A dialogue between science and society can increase opportunities for sustainability agenda and with it, the income potential for various stakeholders, communities, and countries. This vision allows practitioners and policymakers to harmonize and prioritize overlapping and complementing agendas. As natural resources are becoming scarce and climate change impacts are escalating, closing resource use and reuse loops, and supporting innovative alternatives towards circular societies is becoming increasingly important [1]. In the last decade, Circular Economy (CE) has emerged as a tool or framework to look beyond the existing measure of production and consumption to redefine growth pathways, including economic, natural, and social capital and explicit focus on co-creating societal benefits. While CE principles offer an opportunity to recognize and capture the full value of water (as a service, an input to processes, a source of energy, and a carrier of nutrients and other materials), so far, the water sector in Latin

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America Region (LAR) has not been systematically included in high-level strategic discussions focusing on circularity, [2]. In this sense, agencies such as the World Bank with contributions from the CAF – the Development Bank of Latin America, are promoting CE on wastewater and recognizing its inherent value with the development of a conceptualization guide for wastewater treatment projects, promoting the vision of water management at the basin scale and the circular economy approach.

In 2020, a Global Alliance on Circular Economy and Resource Efficiency (GACERE) was proposed by European Commission to provide a global impetus for initiatives related to the circular economy transition, resource efficiency, and sustainable consumption and production, in this coalition Chile, Peru, and Colombia represent the presence of LAR. Building on the circularity efforts deployed internationally, GACERE members aim to work together and advocate at the political level and in multilateral forums such as at the United Nations General Assembly (UNGA), the United Nations Environment Assembly (UNEA), and in G7/G20 meetings and discussions [3].

Per the existing information and literature, the circular economy model framework for water-based waste management proposes six actions (ways) that can serve helpful in implementing CE principles in the water and wastewater sector, these are 1) reduction in wastewater generation, including reduction of water use and pollution at source; 2) reclamation (removal) referring to the application of effective technologies for the removal of pollutants from water and wastewater (sewage); 3) reuse of treated wastewater as an alternative source of water supply for non-potable usage; 4) recycling: recovery of water from wastewater for potable usage; 5) recovery of resources as nutrients and energy from water-based waste and 6) rethinking how to use resources ( in this case water) to create a sustainable economy which is free of waste and emissions [4].

In light of the above, this study will provide an overview of the CE roadmaps and strategies in LAR and highlight gaps and needs within existing CE practices. In addition, the overview will focus on innovations and advances in the circular economy within sectoral mandates of water and wastewater management. At the regional scale, this study will provide a wide-ranging summary of funding and investment trends in the CE water sector. The study also aims to generate an analysis of the current situation regarding policy formulation, institutional support structures, implementation challenges, and opportunities for integration of CE at the sectoral (water and wastewater sector) level for countries of Latin America, anticipating that such understanding could help address gaps and needs towards CE as an acceleration mechanism for achieving the SDGs, in particular, SDG 6 targets and indicators such as Target 6.3: calling to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

## 2. Materials and Methods

This script adopted a semi-systematic review constituting document analysis and qualitative assessment approach to address the objective of mapping the theoretical approaches and investigating how research and practice on circularity in the water and wastewater sector have evolved in the region. The approach applied in this study widely used search engines [EbscoHost Web, Gale in Context, Scopus, ScienceDirect, Web of Science, and Google Scholar] for mining data, information, and peer-reviewed papers about topics *viz* environmental science, earth science, social science and business, with documents, that particularly refer to water and wastewater context and in this way selected studies were retrieved for reference. In total, 34 full-text articles assessed were selected from 227 records identified through the database. The duplicates removed were 145. *31* numbers government documents from the main Latin American countries were reviewed. Among them are the roadmaps towards the transition towards the circular economy of Brazil, Mexico, Chile, Colombia, Ecuador, Republic Dominican Costa Rica

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In addition, the document analysis and qualitative assessment applied the use of "grey" literature as an information source, this was key to the process of analyzing the objectives as a large proportion of articles, documents, laws, and relevant reports are non-peer-reviewed, however, their role in understanding the trends and patterns of circularity in the region is pertinent. Overall, the keywords used were “Circular Economy”, “Wastewater” "Water" and “Latin America” for the development of the search process in the databases. The peer-reviewed search was restricted to review articles, research articles, and book chapters in the last 5 years (2017 June to 2022 June), in English in Academic Journals, magazines, and books. These keywords were also used in the google search engine to find information on the participation of the actors (the authorities, private companies, international cooperation, and academia) and outline key points that highlight framings and operational paradigms of circular economy in the region.

The body of knowledge that was extracted was analyzed to generate a narrative review of the progress of CE in the region and to examine how circularity innovations are steering the transformation of the water and wastewater sector. The main aspects that were assessed include but are not limited to a) renovation and integration of wastewater treatment plants to convert them into biorefineries; b) how treated water can support food production; c) sludge generated by wastewater used as fertilizer in agriculture; d) operation of wells and treatment plants used in renewable energies; e) rainwater harvesting promoted to reduce pressure on other sources of water supply. Additional dimensions that were assessed include the level of participation of stakeholders viz., authorities, private enterprises, international cooperation, and academia. Overall the above-outlined factor was organized into a conceptual framing, to support action research to address the site or context-specific problems and challenges in the integration of CE into the water sector and to support research-backed policy toward water circular economy in LAR.

## 3. Results

### *3.1. Framing and operational pathways of CE on LAR*

Unlike the conventional technocratic approach to the CE in Europe, the realities of social issues in Latin America require a different understanding and approach for circularity implementation. Stakeholders in the regions are starting to understand the complex relationship between sustainable development and economic growth and explore how CE pathways can provide longevity to the environment and the economy in tandem [5]. Figure 1 reflects on the approach that the region is adopting to embrace the circularity pathways in LAR, in particular the interventions and policy support structures. The countries in the region contemplate the challenge and have outlined practices, strategies, and regulations for the transitions to CE. The review of existing CE roadmaps summarized at the national level (Figure 1) serves as high-level documents to articulate how circularity strategies currently are being implemented and the general standards of practice that are integrated into planning and practice. In this study, we reflect on key CE approaches and pathways in selected states in LAR.

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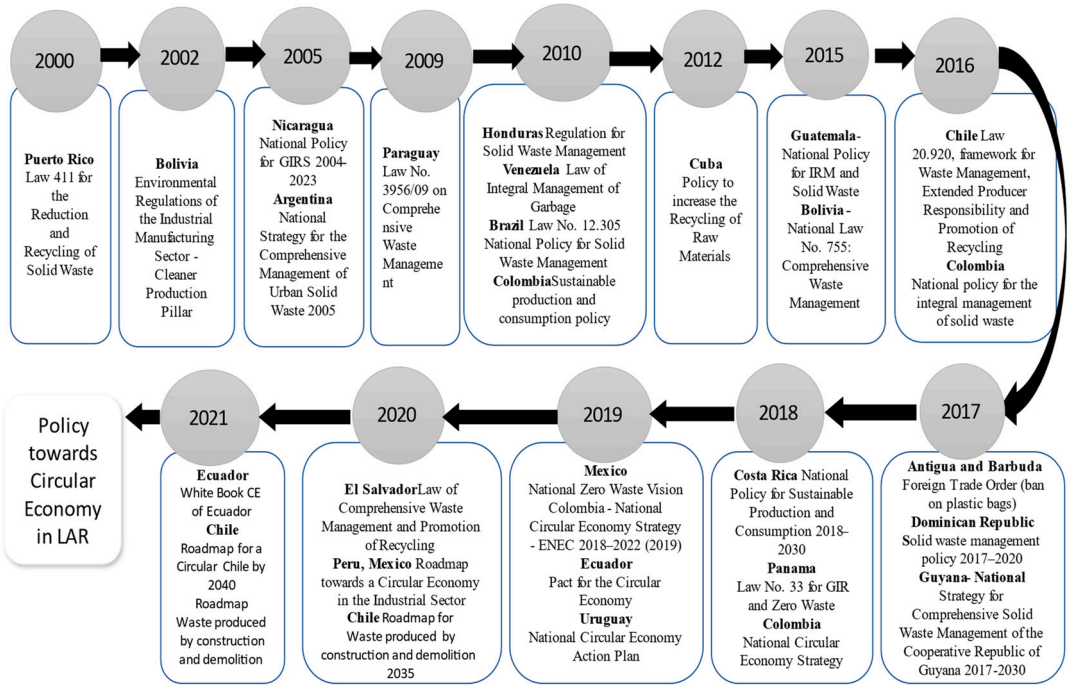


**Figure 1.** Timeline with the principal policies towards CE in LAC (Updated and adapted from [6]).

*Circularity Roadmap of Brazil*

The objective of the Brazilian Roadmap is to design a national development strategy for a circular economy that is shared among actors in all sectors to build knowledge about the CE potentials considering territory differences and local contexts of the country in all sectors, including in the water and wastewater sectors. This roadmap aims to build knowledge about the CE potentials considering territory differences and local contexts of the country to create national policies that favor more responsible and sustainable production and consumption trends and patterns. It is anticipated that this circularity roadmap will create financial mechanisms and improve enabling infrastructures that support CE initiatives at all levels and scales. Noting this, the framework prioritizes supporting Research and Development (R&D) oriented to systemic, cross-sector, socio-technical innovation processes; and strategic intervention areas [7].

The roadmap constitutes six guiding principles:

- Economic development associated with the conservation and restoration of natural ecosystems, including water ecosystems
- Industry and agriculture competitiveness in global supply chains committed to local sustainable development. Also, including the water-food nexus.
- Research and Development (R&D) and innovation, professional capacitation considering resources complete life cycles impacts for all sectors.
- Urban and regional planning integrating the economic, social, and environmental dimensions of development for all. Noting the crucial need for balancing tradeoffs in water use and provisioning systems in such settings.
- Broader adoption of clean and renewable energy in production and commercialization processes. This points directly or/and indirectly links with the water sector and water-energy nexus span.
- Integrated management for a more sustainable and beneficial circulation flow of the resources and waste: water, air, soil, and materials.

*Circularity Roadmap of Mexico*

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The Mexican National roadmap for the transition to CE consists of strategic lines and periods based on a two-stage evaluation, short and long-term. The indicators proposed as a baseline are divided into different domains.

- *Water*: percentage of anthropogenic wastewater.
- *Materials*: municipal solid waste generation, percentage of organic waste (food), percentage of solid urban waste.
- *Energy and climate change*: percentage of renewable energy in the national energy generation matrix, carbon footprint related to energy consumption, vulnerability index to climate change.
- *Gender perspective*: percentage of managerial positions held by women in the industry.

All the above dimensions are directly or indirectly connected with water and wastewater in multiple ways and various sectors i.e municipal, industrial, agriculture, and beyond. Taking note of these multidimensional aspects, the National Roadmap for the transition and adaptation of the CE in Mexico proposes 5 strategies: (1) reforming governance and public policy measures to support circularity, (2) understanding interconnections between CE and sustainable management, including the SDG agenda (3) Fitting CE into sectoral and national and fiscal frameworks in various sectors, including in the water sector, (4) support circularity oriented research, innovation, and entrepreneurship, and (5) interpreting agenda's and policies, for instance how CE fits/supports/synergies with National System of Innovation and Climate Change (SINACC).

And a period of 10 years has been established for the development of the strategic lines, their monitoring, evaluation, and adjustment of the model [8]. The industrial sector in the country identifies opportunities associated with the revaluation of materials that can be reincorporated into the economic cycle through new production processes, energy use of those who have lost their properties, the industrial symbiosis between different production processes, and even some projects of high urban impact [9,10]. The country is aiming to percolate the nationally established CE standards of practice to all sectors and clearly to the water sector

*Circularity Roadmap of Chile*

The CE agenda in the country is advancing and the state is well-positioned for sustainable development guidelines based on various macroeconomic indicators [11] to support its implementation. The Chilean Ministry of Environment created the "Circular Economy Office" in 2018, and in 2020 developed a strategy to introduce its implementation by 2040 with the Proposal "National Roadmap to the Circular Economy for a Chile Without Garbage 2020-2040" [12] and the Roadmap for Waste Produced by construction and demolition 2035 [13]. In the above context, the Roadmap For A Circular Chile calls that by 2040 a comprehensive plan for the implementation of efficient resource use, acknowledgment of interlinkages, and nexus is put in place for all sectors directly and indirectly linked to consumption and production value chains. The national agenda is also aiming to drive Chile towards sustainable, fair, and participatory development that puts people's well-being at the center; this, through the care of nature and its living beings, the responsible and efficient management of natural resources ( land, water, wetlands…), and creating a society that uses, consumes and produces sustainably and consciously, promoting the green jobs and opportunities for people and organizations throughout the country to be active stakeholders in implementing the circularity pathways [14].

This roadmap constitutes 27 initiatives and a timescale for completion (2022, 2026, or 2030). During the development of these initiatives, four key pillars were conceived, revealing some of the specific opportunities for Chile's circular economy transition: i.e innovation, culture, regulation, and territories. In Figure 2 we note seven intermediate and long-term goals at the center of this CE national framework serving as guiding principles, some of them such as increasing the recycling rate for sectors in production and supply apply to the water sector. In comparison with the CE roadmaps of other countries, this one outlines standard indicators to assess how the comparative advantage of the nation to implement circularity. The Roadmap also supports the implementation of existing

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policies such as Chile's 2020 action plan for the social, economic, and environmental inclusion of the informal waste sector [15,16].

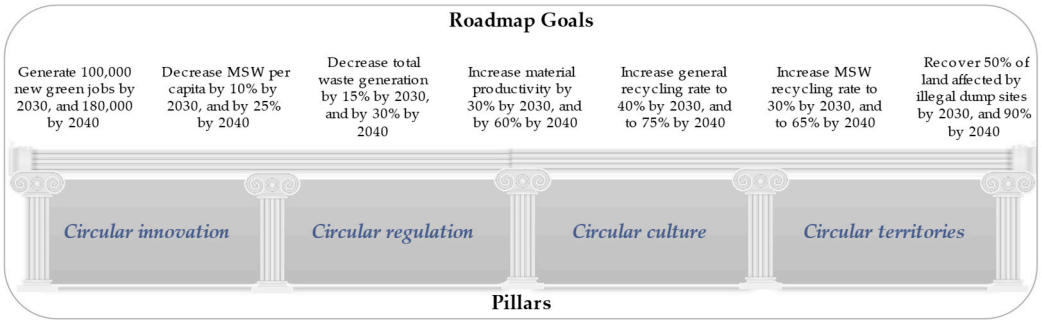


**Figure 2.** Roadmap For A Circular Chile By 2040.

*Circularity Roadmap of Ecuador*

In Ecuador, waste management is an exclusive competence of municipal administrations [17]. The White Book on Circular Economy in the country defines strategic lines and proposals for actions to achieve circularity and is divided into 4 key dimensions that lay out general guidelines for all sectors, including the water and wastewater systems:

- Policy and Financing.
- Sustainable Production.
- Responsible consumption; and,
- Comprehensive Management of Solid Waste.

Outlined to be deployed in two phases, the first 'research and workshops with the public and private sector", accounts for the influence and relevance of circularity reflected in the agendas and legislation of the country, prioritization of macroeconomic sectors, and analysis of waste management. The second "strategic lines of action suggest the participation of strategic lines of action in 4 pillars defined for the CE application in the country and comments combining top-down and bottom-up analysis. The process includes elements of divergence *i.e* broadening the focus and identifying best practices, benchmarks, visions of various actors, and convergence that is to propose the strategic lines and final actions [18]. The structural components of the circularity vision in the country seem fitting towards mitigating the challenges toward recycle, reusing, and rethinking water and wastewater use systems.

### *3.2. Latin-American and the Caribbean Regional Coalition on Circular Economy: Spotlight on selected five countries of the coalition*

The countries that are part of the regional coalition on CE include Colombia, Peru, Costa Rica, and the Dominican Republic with eight strategic partners: Inter-American Development Bank, Ellen MacArthur Foundation, World Economic Forum, Konrad Adenauer Foundation, United Nations Industrial Development Organization, Climate Technology Centre & Network, Partnership for Action on Computing Equipment and UNEP [19]. The regional coalition envisions providing science-based knowledge on opportunities and co-benefits by fostering an imperative resilient, sustainable, and inclusive economic recovery with best practices through collaborative work between governments, companies, and society. Its plan of action involves promoting eco-design and supporting CE innovation in the region. The advancement and investment sector of the coalition considers current challenges from diverse perspectives, including the challenges that the region faced during the COVID-19 pandemic [20]. Some specific examples and empirical details are provided below for selected countries of the coalition while presenting examples of how these nations are especially addressing water and wastewater management challenges by applying solutions that stem from CE.

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***Country 1: Peru***

The country developed a Circular Platform reflecting that the government is committed to regulating and promoting the CE. The Peru CE's Roadmap in the Industry Sector published through Supreme Decree No. 003-2020- Produce by the Ministry of Environment (MINAM) is promoting the signing of Clean Production Agreements (CPAs) and engaging with productive, extractive, or service businesses seeking to improve the production and environmental conditions of their value chains and overall to create alliances for CE implementation. The agenda includes promoting the minimization of waste, reuse, and recycling and to develop technical standards establishing packaging requirements that minimize environmental impact. Altogether, the roadmap includes short-term (1 year), medium (3 years), and long-term (5 years) actions and four approaches that seek to provide the conditions for companies to progressively migrate to the circular model while optimizing resource use, these are 1) sustainable industrial production; 2) sustainable consumption; 3) use of discarded material and industrial waste management, and 4) innovation and financing. The government also commits funding to develop specific projects such as coconut shells as an energy generator (eco carbon), and eggshells converted into calcium salts [25]. To summarize the CE approach of the country, it can be stated that the guiding structure to integrate CE practice into a specific sector is present and can be referred to while designing a standard of operation for the water sector.

**Country 2*: Colombia***

Columbia in its role as the president of the Caribbean Regional Coalition on Circular Economy is steering the CE agenda strategically, as the Ministry of Environment and Sustainable Development developed the National Circular Economy Strategy that outlines the agenda for new economic development by optimizing production efficiency and consumption of materials, including the continuous valorization of resources, closing the cycles of the materials, and generating new models of business and industrial symbiosis [21]. Alongside this, the agenda is reducing the carbon and the water footprint in production and consumption pathways. The management mechanisms include the below-listed dimensions:

- supporting innovations in regulatory mechanisms and generating a legal framework conducive to technological innovation, entrepreneurship, and investment in CE projects and programs- this point is very relevant for exploring the circularity potential for water quality management
- clarifying on CE incentives- as this dimension is currently under-reflected in CE operational principles, including in the water sector, therefore this mechanism holds the potential to scale 'buy-in' of circularity at the sectoral level
- research and training, through existing knowledge networks, and promoting the inclusion of circular economy content in existing programs.
- international cooperation, e) information, which involves the construction of a CE information system; and
- communication and citizen culture to ensure that society has a common objective in terms of efficiency in consumption and production models, and balanced participation of the public and private sectors.

The underlying pillar of the strategy allows progress in the productive transformation, in short, medium, and long-term scenarios [21]. Benson and Monciardini [22] outline how in Colombia, the National Circular Economy Strategy is initiating the transition from a linear to CE, pointing to recycling usable solid waste instead of throwing/burning as explained by Garcia and Cayzer [23]. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) partnered with the State, the private sector, and civil society to identify innovative business models in the recycling sector and influence consumer habits. Furthermore, this partnership in the state aims at the integration of recyclers who collect usable materials in Bogotá and Cúcuta into the CE value chains and supporting models for formalization and business management with inclusive participation of local stakeholders. The focus on the gender component is a significant point toward an inclusive CE

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transition in this country. To that context, the pilot programs seek to incorporate into the formal economic circuits of waste recycling a total of 1500 recyclers, of which at least 30% are women [24]. Noting the progress of CE guidelines in various sectors, the country seems to be having both experience and capacity to scale these practices for managing water and wastewater-related challenges.

***Country 3: Costa Rica***

The country is in a process of developing a CE policy and implementing supporting policy frameworks. Costa Rica institutionally established the Bioeconomy Strategy, an initiative based on existing CE knowledge, ecology, resilience, decarbonization frameworks, and healthy competition for resource use in production and consumption processes. The interventions involved the integration of public and private proposals, investment orientation, development of incentives, and articulation of production and the environment: the pathways hold significant value for scaling in the water sector. Faced with a post-pandemic scenario, Costa Rica has set up scenarios for production systems: the challenge of more efficient production (or economic reinvention) and that of maintaining value chains to preserve jobs and livelihoods. This implementation is projected for a 10-year tenure and comprises three phases: impulse, scaling, and consolidation [26]. The guide "*Step by Step to Facilitate the Transition of Local Governments Towards a Circular Economy: Case of Costa Rica*" [27] presents the importance of the role of stakeholders in the circularity transition and provides a methodology with the following 5 step-wise actions plan.

*Step 1*: Conduct a review of the regulatory framework and strategic policies together with the systematization of statistical information of a social, economic, and environmental nature, identifying the existing experiences in circular economy and actors.

*Step 2*: Applying the vision and local objectives aligned with the CE to guide the prioritization of sectors of focus through the diagnosis of circularity generated and participation of sectors of focus.

*Step 3*. Identification of circular opportunities in each focus sector by mapping and prioritizing CE opportunities in and for each sector.

*Step 4:* Identification of policy actions to support circularity opportunities, mapping of actions, and prioritization.

*Step 5*: Development of the roadmap through the determination of business models, and investment.

These steps provide a clear direction to shape the design, plan, and implementation process for most sectors and also the water and wastewater part of it.

***Country 4: Dominican Republic***

This nation is part of the first steering committee of the initiative that seeks to advance CE at the national scale. The country in its domestic development plan incorporated a strategy that envisions responsible citizenship and competitive placing in the global economy building on the fact that is resource-rich and its vision is to be innovative and sustainable is evident in its national circularity supporting strategy. The interest in water efficiencies such as energy efficiency and renewable energies are integral to the broader definitions of the nation's CE roadmap highlights the transformation frameworks outlined for technology application and Industry 4.0 vision toward CE agenda mainstreaming [28].

***Country 5: Ecuador***

The CE landscape in Ecuador shows that waste management is an exclusive competence of municipal administrations. Solid waste management includes the prevention of residue production, the classification of organic and inorganic waste, the organization of collection and transport, and the recycling and final disposal of materials [18]. The White Book on Circular Economy in the country defines the below listed four strategic dimensions for action:

- Policy and Financing.
- Sustainable Production.

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- Responsible consumption; and,
- Comprehensive Management of Solid Waste.

Divided into two phases, the first i.e. 'research and workshops with the public and private sector', wherein the agenda included analysis of the influence and relevance of circularity, along with discourse on state-level legislation, prioritization of macroeconomic sectors, and examination of waste management from December 2019 - June 2020. Consequently, several CE-related contributions were noted that were supporting the national development plan, as well as the degree of application of CE in all public policies. It was identified that 43% of the public policies evaluated make indirect or indirect mention of the concept. The second phase called "Strategic lines of action" was developed in the period from November 2020 - April 2021, suggesting the participation of strategic lines of action in 4 pillars defined for the application of CE in Ecuador executed through a combined top-down and the bottom-up analysis. The process included elements of divergence meaning broadening the focus and identifying best practices, benchmarks, visions of various actors, and convergence that is to propose the strategic lines and final actions [19]. The existing approaches to support and promote CE in the country are evolving, maturing, and finding a way to include sectoral processes, including solid waste and wastewater management.

### *3.3. Regional Review of Water Circular Economy in LAR*

For the long-term sustenance of water resources in the region, it is important to develop cost-effective, energy-sensitive, and environmentally reliable solutions, that are scalable and sustainable. Noting that CE is gaining attention in the water sector with the 6Rs strategy (reduce, reuse, recycle, reclaim, recover and restore) to keep water in circulation for longer and reduce the burden on natural systems [29], we are providing an overview as to how the concept of CE is integrated ( or not ) in the water sector in LA*R*. The key point from a review of existing information and publications suggests that CE is often generalized as an economical alternative for waste management [30]. The research in the past years carried focusing on circularity in the water sector reflects that on a macro-level it includes examining and assessing how industry, countries, and businesses are taking note of existing CE knowledge in the design and implementation of circular economy models, toward the management and handling of waste, however, in most instance the solid waste management challenges are often more explicitly considered than wastewater management [31]. To elaborate on the above statement, we identified key initiatives and opportunities for the water sector in LAR, mainly during the past 5 years, and those that contribute to improving wastewater management, water reuse, promoting water security, and generating regulations. These initiatives because of their high importance have already received significant support and funding commitments for development ( more details in Table 1).

**Table 1.** Overview of Circular Economy projects and programs in LAR focus on the water sector and the scale of investment.

| Project Name/Sectoral Focus | Promoter | Year | Country | Reference |
|---|---|---|---|---|
| Atotonilco WWTP project/Wastewater reuse | Mexican Federal Government | 2017 | Mexico | [32]. |
| Water Security, Circular Economy and Wastewater-to-Resource (WW2R) in Latin America and the Caribbean: Analytical Research and Case Study Implementation/ Water and Sanitation, Integral Management of Water Resources | Interamerican Development Bank (IDB) | 2019 | LAC | [33,34]. |
| Circular Economy in the Gastronomy Sector: An Innovative Food Recovery Model to Improve Lives/ Sanitation, Solid Waste, Food Recovery | Interamerican Development Bank (IDB) | 2020 | Peru | [35] |

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| | | | | |
|---|---|---|---|---|
| Optimizing Wastewater Treatment Plants in the Metropolitan Area of São Paulo | SABESP Interamerican Development Bank (IDB) | 2021 | Brazil | [36] |
| Right of Access to Goods: Water for Development (DAPED) | Institute of Scientific and Technological Studies from Quilmes National University (IESCT-UNQ) and the National Institute of Agricultural Technology (INTA | 2014 | Argentina | [37] |

Circularity in the region is also discussed concerning water crisis settings, building on the fact that critical cases of drought and dry conditions are reported in LAR: in Peru, 40% of its territory, home to > 80% of its population is classified as arid or semi-arid; in Argentina and Mexico, > 60% of its territories is classified as arid land. FAO, (2017) reports that droughts affect small farmers and drastically affect island lands, and significantly alter the provisions of water conservation and supply-demand dynamics [34]. Thus, it is important to consider that water reuse represents one of the most important alternatives to conventional freshwater sources to deal with water scarcity [38] and the water-related impacts of climate crises. Interestingly, some countries have started to use CE in the water sector as a pathway to reshape water management systems and manage water withdrawal required to level out pressure on water reserves [39].

The reclamation and reuse of wastewater is a priority for countries with significant problems of hydric stress /water scarcity. Of the countries in Latin America, Mexico is at the top of the list of countries reusing wastewater, with almost 15 hm3/d; however, this regeneration is happening without additional treatment. Chile, Peru, Argentina, and Colombia are reusing water although in less proportion when compared with Mexico. Bolivia is among the countries with a considerable ratio of water reuse in comparison to the overall withdrawal of water [40].

The rural waste management sector is also highlighted as key to reducing domestic plastic pollution sources at the downstream level. Rural water resources may vary regionally and include surface and groundwater, in addition to processed water in tanks or bottles. The storage, acquisition, and quality of water resources will likely have an impact on the prevalence of plastic contaminants. The rural population in Latin America and the Caribbean region accounts for around 19% of the total population. The countries with the highest percentage of the rural population are Guatemala (48%), Honduras (42%), Nicaragua (41%), Paraguay (38%), and Ecuador (36%). In rural communities, the main plastic pollution contamination routes are fed by domestic waste, tourism, agricultural activities, fishing, and regulated waste disposal. These routes are associated with uncontrolled disposal options in underdeveloped rural waste management infrastructure that pollutes the soil-air-water nexus. These countries have implemented important public policies regarding the use of plastic, and the impact of such can be noted in the water and wastewater sectors [41]. Some examples are explained to expand on that points

***Case 1: Brazil***

In this country, SABESP (Companhia de Saneamento Básico do Estado de São Paulo S.A.) is the state-owned water utility for São Paulo state, and it has been entrusted with the mission of universalizing wastewater collection and treatment by 2033. Consequently, SABESP faces the urgent

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need to expand its wastewater treatment capacity and improve the quality by using existing plants to receive and treat larger volumes of wastewater. A joint initiative between SABESP and the 2030 Water Resources Group (WRG) of São Paulo was to create a program defined as high-priority actions and investments to maximize the treatment capacity of existing infrastructure. The program is part of a CE strategy to reduce the generation of waste and pollution by improving both wastewater treatment processes and the quality of the final effluent. The program will also allow SABESP to adopt a "from waste to resource" strategy and recover and reuse wastewater treatment byproducts (water, energy, and biosolids) in the future.

It is noted that a closer look at changes in legislation accompanying CE programs that SABESP's operations must comply with the requirements, as well as with the conditions defined in the environmental operating licenses of the Wastewater Treatment Plants (WWTPs) [36]. Other actions aimed at implementing CE in the management of water resources could include managing the demand for irrigation water and matching crop type to local water availability to improve irrigation efficiency. In addition, there are "closing loop" practices, focused on the reuse of wastewater in industrial cycles and crop irrigation, as it is economically advantageous to reuse water in agriculture and the industrial cycle of sugarcane washing [42]. For Brazil, the institutional infrastructure is maturing to support CE adoption in various sectors, including in the water sector.

***Case 2: Argentina***

Due to the increasing impact of climate change, other indirect drivers like territorial conflicts pressure on freshwater sources, and overall, the challenges of water management have amplified thereby directly influencing the quality of human life, agricultural and industrial production, and the process of ecosystem regeneration. In Argentina, 22% of households currently lack access to a safe water network, and 41% lack access to the sanitation system. approximately 8 million inhabitants lack access to drinking water at home. About 448,000 of the households without access to drinking water are structurally poor and 82% of rural households lack drinking water.

A rural development program for isolated and scattered communities in the province of Chaco, Argentina started by the national agency the Water for Development (DAPED) in coordination with the Institute of Scientific and Technological Studies from Quilmes National University (IESCT-UNQ), and the support of Network of Technologies for Social Inclusion (RedTISA), the National Ministry of Social Development and the National Council of Social Policies and financing from the Science and Technology Ministry. It aimed to design, implement, and manage water via long-term participatory action research (PAR) projects that consisted creation of a multi-stakeholder team based on a long-standing collaborative and transformative approach oriented to the generation of practical solutions for social and environmental problems [43]. The strategy used in this program focus on 4 aspects:

1. Water for human consumption from rainwater collected in home cisterns.
2. Second use for water, that is, the greywater produced by personal hygiene activities, washing clothes, and utensils, is reused to flush the toilet.
3. Scaling measure for water conservation and reuse: such as a bio-digester that uses treated water, in combination with that from a well, to water orchards annually.
4. Water is used by animals and plantations.

Overarchingly, the nation seems prepared with a working strategy that can serve as a reference for sectoral commitment to adopt and apply circularity.

***Case 3* Mexico**

For the water sector in Mexico, in 1989, the National Water Commission (CONAGUA) was created by presidential decree as a decentralized agency of the Ministry of Agriculture and Hydraulic Resources. This agency is the only federal authority empowered to manage national waters. Currently, CONAGUA is a decentralized agency of the Ministry of the Environment and Natural Resources in charge, among other functions, of administering and preserving the national waters of Mexico, establishing the national hydraulic policy and strategies, operating the national

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meteorological service and liaising with the agencies authorities to work together on actions that benefit the water sector.

In 1992, the National Water Law (NWL) was created, which constituted an important turning point towards integrated water resources management (IWRM). In 2004, an important reform to this Law was carried out to strengthen the IWRM process, establishing a decentralization process of some key functions to municipalities, river basin organizations, and irrigation districts. The NWL includes obligations to CONAGUA to generate the participation of water users in the administration of the system and services. CONAGUA was then supported by significant investments to improve wastewater treatment plants, replace supply sources, and modernize the technology of the agricultural irrigation system. Until now, 13 river basin organizations have been created along with 26 river basin councils that work with 35 river basin commissions, 47 river basin committees, COTAS (Technical groundwater committee), and 39 local clean beach committees [44]. This way, the Basin Commission is composed of several actors.

Integration of water in the CE models is aimed at addressing wastewater reuse after treatment and plugging this process into IWRM implementation. Toward this, some case studies in Mexico, such as the CE pathways include CE innovations for wastewater treatment in the Presa Guadalupe [45]; CE and water supply for lodging companies in Acapulco, Guerrero [46]; CE in the Tourism Sector in Puerto Vallarta [47]; CE Good Practices in City Energy Efficiency [48,49], CE in boosting operational efficiency of the water sector [50] reflect that Mexico has the potential to apply the CE framework to water and wastewater management goals and targets. However, it is also noted that the federal government must commit to the transition of the wastewater treatment policy in supporting circularity mandate at multiple levels- municipalities, stakeholders, and water users.

While some regions in the country have decided to manage water at the subnational level, strengthening the decentralization process, for example in Baja California, Nuevo León, Tabasco, Oaxaca and Querétaro, San Luis Potosí [51] it can be interpreted that CE strategies have to be planned and adopted at that scale. The state government receives economic incentives for the operation of wastewater treatment plants, and they are trying to convince some farmers to use treated wastewater [42]. From the private sector perspective, companies in Mexico seek the benefits of integrating circularity frameworks water into their operations processes. For example, Audi México, to conserve natural resources while creating sustainable economic value for its market product, created 25,000 blind pits to recharge the aquifer, in the town of San José Ozumba and replaced the extraction of water from wells through the development of a lagoon to capture of rainwater (surface area 7 hectares and storage volume of 175,000 cubic meters ) to satisfy the demand of 100,000 m3. Also, the water used in its industrial and sanitary processes is treated in a biological plant located in the same facilities, favoring its reincorporation in the production processes [50].

For CE application in the wastewater sector, the Atotonilco treatment plant contributes to the sustainable use of water in the Metropolitan Area of the Valley of Mexico. It is the largest 261 wastewater treatment plant in LAR and one of the largest in the world. This plant depending on the origin and end-use of the wastewater, takes advantage of all the by-products and irrigates several hectares of production area in the Mezquital Valley, the sludge produced by the plant's processes is used to generate thermal energy and electricity and biosolids are produced that can be used for the improvement of soils in forest areas and agricultural uses [32]. However, the adoption of the CE in Mexico is still low, except for sectors that, due to their dynamic operations, have advanced in following international CE standards, such as the automotive or paper industry, as well as some industrial branches of global corporations that are trying to address competitiveness and profitability of their companies, while creating social value.

***Case 4: Chile***

The country incorporates CE in the water sector as prolonged drought and rainfall deficits are becoming common and frequent and significant drop in groundwater levels and average flows of surface water, along with the retreat of glaciers is sounding the water stress alarm [15]. A biofactory project was launched in 2017 as a pioneer in circular solutions for wastewater treatment in Santiago and the sector in general by promoting a paradigm shift from treatment to resource management,

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from a linear approach to a circular one. Herein, biofactories extract and supply new and valuable resources, such as electricity, natural gas, fertilizers agricultural or clean. water from what was previously considered waste. The company's goal is to be zero waste, energy self-sufficient, and carbon neutral in its three wastewater treatment plants in Santiago by 2022 [52]. Furthermore, the General Water Directorate (DGA) evaluate a pilot study in the Rapel river basin in a joint effort with Fundación Chile based on socioeconomic and environmental indicators to establish the areas wherein water consumption can follow sustainability guidelines. The evaluation of water consumption included all production sectors, such as domestic, forestry, agriculture, mining, energy, and industrial towards a comprehensive vision of improving sustainable water management [53].

**Case 5:** ***Peru***

In addition, the creation of the National Water Authority (ANA in Spanish) and the enactment of Law 29338, the Water Resources Law created in 2009, along with the incorporation of sustainable technical standards in the supply-demands landscape ( mostly of the private sector) of the water sector triggered good practices in the management of water resources since it went from an agrarian to multisectoral-modern vision. ANA instituted the Blue Certificate to certify companies that show efficient and less polluting standards in their operations. This action prompted an opportunity to boost CE in the water cycle and related operations [40,54]. This intervention helped Chili River to recover and benefit the city and its residents as the agreement between Cerro Verde a mining company near Arequipa and SEDAPAR, the municipal water utility was brokered. The mining company agreed to take responsibility for designing, financing, building, and operating a wastewater treatment plant to handle about 95 percent of the city's wastewater and to use some of the treated water for its mining processes and discharge the rest into the river to be used downstream by farmers. In tandem, the mining stakeholders with this agreement secured the rights to expand its operations, while the municipality could save costs and focus on building and operating wastewater treatment plants [55]. Another case of study is in the south of Peru, where 560,880 panels were installed to develop a CE process to obtain water from the atmospheric humidity, anticipating that the production of clean water could serve to create green spaces in the dry/desert environment with the use of clean energy, and thus with this technology closed loops system can be put into action [56].

***Case 6: Bolivia***

As we note circularity trends and patterns from LAR, the water sector-focused CE intervention in Bolivia is mainly focusing on the reuse of wastewater at the regional level between the collaboration of the municipal government and the industry. In Bolivia, Cochabamba, for example, wastewater is extensively used in urban and peri-urban agriculture. Both vegetable and fodder crops are irrigated with polluted water, diluted or partly treated municipal and industrial sewage containing high concentrations of pathogens, heavy metals, and salts [57]. In the country, the Municipality of Cliza was aware of the discharge of wastewater collected from the urban center (population of 10,000 people) directly into the Cliza River and decided then to implement a wastewater treatment plant. However, the settlements around the area opposed the construction because it would generate bad odors and diminish the value of their land. Noting that CE intervention can be sustainable over the long term in conflict with the community is resolved harmoniously. The Municipality and the NGO AGUATUYA proposed the implementation of a new treatment system capable of producing water that could be used for crop irrigation without creating odor or mosquito problems. A community of farmers provided the land needed (approx. 8,000 m2) in exchange for the right to use the treated water for irrigation. The Municipal system, built with the support of the Swedish International Development Cooperation Agency, currently treats and reuses 100 percent of the wastewater generated in the urban center for irrigation [58]. Another, CE example of wastewater is in El Alto city, where urine, feces, and graywater are separated at the household level. The urine is reused as liquid fertilizer, composted feces are reused as solid fertilizer, and greywater is reused after treatment to replenish wetlands and irrigate greenspaces [59]. For Bolivia, these examples are setting a reference and pace for national, regional, and international commitment

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to support, fund, and scale the CE practices demonstrating the potential for addressing environmental restoration and social impact.

## 4. Discussion

The transition from a linear make-use-dispose model to a CE requires a clear and inclusive economic justification, to project the rate of return on investment [60]. The COVID-19 pandemic has revealed significant shortcomings in the linear economy– calling for the need for new and innovative public initiatives and programs. We reiterate that CE offers an alternative framework for a more resilient and inclusive economic model for the region through technology and guarantees both added value and sustainability [61,62]. As noted by Savino et al, (2018) adequate management of waste is important and requires the backing of institutions responsible for managing them at the local level. In addition, the generation of a suitable body of law with feasible and effective regulations that are easy to apply, while avoiding overlaps between different agencies, and professionalizing the sector through appropriate training and creating information systems designed not only for reporting purposes but also for the effective decision-making and monitoring is crucial [63]. The above-stated points apply to water and wastewater systems [64,65], although we reckon context-specific solutions should be designed taking note of national and local settings and socioeconomics. The first step to developing a CE-pro developing wastewater treatment plant is to optimize the operations of the infrastructure already installed, so plants can reach maximum performance with the minimum capital and operational expenditure. It is suggested that the existing infrastructure could be considered before investing in new plans and designs as integration is key to better 'buy-in', scaling, and optimizing the cost-benefit equation.

Taking note of the CE trends in the water and wastewater sectors in various countries in LAR, in particular the Case of Mexico, it is recommended that long-term CE planning is put in place to promote and support IWRM, integrated implementation of SDGs. In many countries in LAR, the policy of delegating water-related services to companies at the municipal level has been criticized in recent years for being a short-term governance strategy and it is advised that CE could address the need for participatory and inclusive elements in water governance. Also, building on existing best practices at the regional and national level could add value towards the implementation of the circularity agenda, take, for instance, the program from Brazil that informs the logic underlying traditional expansion strategies, focusing instead on priority actions and investments to identify and eliminate bottlenecks and maximize efficient treatment processes of each plant [66]. The point is discussion is to identify context-specific strengths, gaps, and needs and channel efforts to systematically address them by boosting financial, technological, and human capacities.

## 5. Conclusions

The study examines the framings and operational pathways for circularity in the water and wastewater sector in LAR. We anticipate that examination of patterns, trends, opportunities, and barriers of CE at multiple scales can help to boost understanding of interlinkages and will support regional and national policies toward integration and implementation of the SDGs in the LAR region. Noting the alignment of CE principles with the SDG agenda such as SDG target 6.3 on water quality management by reducing pollution and release of hazardous chemicals and materials and boosting the proportion of untreated wastewater and considerably increasing recycling and safe reuse globally, it is clear the regional, national and context-specific ( socioeconomic, sociocultural and socio-political aspects) strategies should be put in place to support circularity. For each county and the specific/sectoral context in LAR, circularity models and practices have to be adjusted to fit the local needs, for instance, in Mexico, the areas of opportunity identified to promote the CE transition include investment in technology transfer, as well as mechanisms that allow the exchange of knowledge and between sectors and stakeholders already applying CE and other that are intending. Overall, our assessment elucidates the need to factor interlinkages and nexus between multiple sectors, for instance, while designing and operating the CE agenda for a specific sector like

water and wastewater management. In addition, financial pledges to achieve sustainability could be cognizant of the role of CE in achieving SDG goals and targets.

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