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Advancing circularity in a Chilean neighborhood through the water-waste-energy nexus: A stakeholder analysis

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ABSTRACT

The nexus approach supports the implementation of a circular economy in the built environment by leveraging synergies across water, waste and energy flows. Though the technical aspects of innovative water-waste-energy systems have been investigated, less attention has been given to how stakeholders can shape and drive the required circular transformation. This study systematically analyzed stakeholders' interest and influence, as well as their institutional interplay, through the use of a mixed-methods approach to a future urban household complex in Central Chile. The identified Key Players included governmental organizations with the potential to act as urban developers, technical advisors, regulators, and policy advocates. A stakeholder network analysis revealed the dynamics of cooperative interdependencies, as well as a need to strengthen and broaden cross-sectoral collaboration across water-waste-energy and housing and urbanism, especially at a regulatory level, to advance the nexus. These insights contribute to policymaking and the development of tailored stakeholder participation strategies.

1. Introduction

According to the most recent available source, cities are responsible for around 75 % of worldwide resource consumption (Dodman et al., 2017). In addition, it is expected that by 2050 nearly 70 % of the world's population will live in urban areas in comparison to today's 55 % (International Resource Panel, 2018). This will significantly escalate the demand for materials as well as water and energy flows to sustain the growing population (International Resource Panel, 2018). Given this trend and its associated impacts, circularity in the urban built environment has gained more attention among researchers and practitioners over the past few years (Bucci Ancapi et al., 2022; Pomponi and Moncaster, 2017). The term *Built environment* comprises a wide range of human-made spaces and supporting infrastructures (Seyedrezaei et al., 2023). Most research on this topic has focused on the sector of construction and demolition waste (Munaro et al., 2020). Yet, tapping the circularity potential in the built environment is not limited to waste or material use. It is also strongly related to other valuable and nowadays scarce resources such as water and energy (United Nations Environment Programme, 2021). Similarly, the transformation towards circular integrated systems cannot be based only on the latest technical developments. Collaboration across different stakeholders is critical for a successful transformation (Chen et al., 2022; Senaratne et al., 2023). However, less scholarly attention has been given to the power of stakeholders to shape and drive these circular transformation processes in the built environment (Christensen, 2021; Guerra and Leite, 2021; Owojori and Okoro, 2022). Even less attention has been given to this stakeholder dynamic within the context of water-waste-energy (WWE) nexus when applied to the built environment (Gómez et al., 2017; Gondhalekar and Erlbeck, 2021; Schramm et al., 2018). Within this study, the *Water-waste-energy nexus* refers to the implementation of innovative source separation systems for domestic wastewater management that integrate the management of household organic waste for the recovery of water, energy, and nutrients. The latter poses challenges for cross-collaboration across stakeholders as a myriad of sectors that usually act independently need to be involved.

Stakeholder analysis has its origins in Strategic Management research. There, it emerged as an approach to improve companies' performance, considering not only shareholders but also stakeholders that can affect or be affected by the achievement of companies' objectives (Freeman and McVea, 2001; Freeman and Reed, 1983). Over the years, its applications have been extended to political science and natural resource

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management. For instance, as a tool to analyze interest groups influencing the policymaking process (Brugha and Varvasovszky, 2000). At the beginning of the 21st century, stakeholder analysis started to be used to identify power structures across stakeholders who used a natural resource (Reed et al., 2009). Participatory resource management also investigated stakeholderś needs and interests across all project stages (Fraser et al., 2006). Stakeholder analysis has been used in water resource governance to study stakeholders‘ perceptions and interrelationships. Some studies also used this approach to assess nexus governance between water and energy generation, agriculture, and mining within the limits of a basin or a province (Salmoral et al., 2020; Stein et al., 2014, 2011). However, according to our knowledge, these methods have seldom been used in the field of the WWE nexus in the built environment due to a predominantly techno-centric perspective that left out stakeholders. Social network analysis has so far only been used for mapping the social context of a research project that focuses on the technical implementation of source-separated sanitation and resource recovery along four demonstration sites in Europe (Gómez et al., 2017). In Latin America, no related studies can be found. In this study, *Stakeholder Analysis* is used as a participatory approach to help identify the interests and influences of stakeholders potentially involved in a future WWE transformation. It also assesses their existing interrelationships, serving as the basis for the transformation.

The *nexus* emerged as a novel sustainability approach focused on understanding and analyzing resource interrelationships (Parsa et al., 2021). Recently, it has been investigated that this approach can support the implementation of a circular economy by leveraging potential synergies across resource flows such as water and energy in cities (Paiho et al., 2020). Additionally, it addresses the cross-sectoral implications of closed-loop services (Greer et al., 2020). In this context, the aim of this study is to contribute to the advancement of the circular economy in the built environment through a WWE nexus approach with stakeholders as a central pillar for transformation. For that purpose, the present study has a prospective character and is guided by the following research questions: Which role can stakeholders play in this transformation process? Who are the Key Players, and how should they be engaged in this process? And finally, how can the existing formal and informal interrelationships across stakeholders help to foster or hinder the transformation process? *Built environment* research comprises three levels: urban agglomerates as macro-level, buildings as meso-level, and building components as micro-level (Pomponi and Manchester, 2017). Urban agglomerates can range from villages and neighborhoods to cities (Portella, 2014). Our case study focuses on a neighborhood planned for a future urban settlement in Central Chile, that includes housing units and supporting infrastructure. Chile was chosen due to both its political stability (Kaufmann and Kraay, 2023) and its pressing social and environmental challenges, which include reduced freshwater availability, rapid urbanization, and economic inequality, among others (Geirinhas et al., 2023; Hadzi-Vaskov and Ricci, 2021). Adopting stakeholder analysis for a WWE nexus challenge for the first time in Chile is especially important for future implementation of sustainable and circular solutions and policies. This can be expected also for the wider Latin American context due to comparable challenges and cultural backgrounds.

Section 2 describes the technical and institutional context in which the study is embedded. It presents and comprehensively discusses technical insights into an alternative WWE system based on the principle of source separation of urban household wastewater. Furthermore, it offers a brief sketch of the multi-sectoral stakeholders linked to the technical system. Section 3 presents the Materials and methods, which includes the mixed-methods approach used for the stakeholder analysis. This includes a systematic literature review, snowball sampling, the construction of an influence-interest matrix and an actor-linkage matrix, and the realization of a stakeholder network analysis (Reed et al., 2009). Section 4 provides an in-depth understanding of the complex relationships and institutional interplay between key stakeholders and their roles, influence and interest in the transformation process towards a sustainable circular WWE system, based on the selected study case in Chile. Section 5 discusses the implications of the results to foster nexus transformation. Finally, conclusions are offered.

2. Study context

2.1. Technical description of the conventional and the water-waste-energy (WWE) system

Water is conventionally sourced from nature, used, and generated wastewater is discharged into a combined sewer system. With the latter, the *wastewater management process* begins, which consists of collection, transport to wastewater treatment plants (WWTPs), and disposal (Corcoran et al., 2010). The sustainability of conventional wastewater management systems is increasingly being questioned (Poganietz et al., 2021; Stowa, 2012; Vergara-Araya et al., 2020). For instance, disposal of treated wastewater by discharging it into water bodies is a widely applied practice. This results in the loss of potential for direct wastewater reuse, which would support *circular economy* strategies such as narrowing, slowing, closing resource loops, and regenerating (Geissdoerfer et al., 2017; Konietzko et al., 2020; Mikosch et al., 2021). A circular Economy is a system that self-regenerates, optimizes the value of the input resources, and reduces waste and other negative emissions to the environment (Geissdoerfer et al., 2017; Konietzko et al., 2020). In Latin America, only 41 % of domestic wastewater receives adequate treatment (UN-Habitat and WHO, 2021). While the levels of treatment vary significantly between countries, it is common to design treatment systems in a linear way, which limits the potential for water, nutrients or energy recovery (Rodriguez et al., 2020).

The technical innovation of Waste-water-energy (WWE) systems discussed in this paper resides in the source separation of domestic wastewater, which has emerged as an alternative sanitation system. This enables more sustainable wastewater management reflected in water savings, better use of resources through enhanced energy and nutrients recovery, efficient treatment of new problematic substances, and cost savings, among others (Ferrer and Moreira, 2021; Kjerstadius et al., 2015; Poganietz et al., 2021; Stowa, 2012; Vergara-Araya et al., 2020). In addition, this WWE system innovates as it opens up possibilities for new integrated and circular systems that merge the wastewater, waste, and energy services in a more efficient way (Lehtoranta et al., 2022; Otterpohl et al., 2004; Poganietz et al., 2021; Vergara-Araya et al., 2020).

Source separation consists of collecting domestic wastewater into two or more pipes instead of a single combined pipe, both within households and in the public sewage pipes. Each pipe transports a specific wastewater stream with a similar composition. Even if this system can be more complex, source separation allows more efficient and targeted treatment for each stream (Larsen et al., 2013). In existing buildings, this could be done by implementing a second pipeline in the existing one (Friedrich, 2020). In new buildings, as in our case study, the second pipeline is installed completely separated from the first one.

Greywater (GW) is a less polluted wastewater stream generated from sources such as showers, household sinks, as well as washing machines (Hiessl and Hillenbrand, 2010) A GW pipe transports the GW by gravity to a GW treatment plant for the purpose of recycling (Li, 2009; Nolde, 2005; Tolksdorf et al., 2016). There is a variety of technologies that can be chosen for GW treatment depending on the GW composition, the intended final use of treated GW, and the local conditions such as available space. These technologies range from conventional aerated lagoons to wetlands or the use of more advanced systems such as a Membrane Bioreactor or Nanofiltration, among many others (Boano et al., 2020). Treated GW requires an additional pipe to transport it till the point of final use, e.g., toilet flushing, gardening, industry, agriculture, or a combination of them, among others. Previous studies have shown through GW recycling, that WWE systems can reduce freshwater consumption by up to 30 % (Friedrich et al., 2020; Vergara-Araya et al., 2020).

The second stream, Blackwater, contains feces, urine, and flush water, which is collected using either conventional or vacuum toilets and transported in a separate pipe (Ferrer and Moreira, 2021; Tolksdorf et al., 2016). Conventional toilets require around 49 L of fresh water per person per day (Ferrer and Moreira, 2021), and the transport takes place by gravity sewers or, if required by the terrain, the use of booster pumps. On the other side, vacuum toilets can require around 3 L of water per person per day, and their transport requires vacuum pipes and vacuum pumps (Oldenburg et al., 2019). Vacuum systems also require energy to keep a constant negative pressure (Mohr et al., 2018). However, the use of Vacuum systems in a WWE system, combined with GW recycling, provides additional water reduction of up to 50 % (Friedrich et al., 2020; Gómez et al., 2017).

Organic waste management refers to the collection, transport, treatment, disposal, and/or recycling of the Organic Fraction of Municipal Solid Waste (Kharola et al., 2022). Unlike conventional organic waste management systems, within the innovative WWE System, household organic waste (HOW) is source-separated at the household level and later treated together with the Blackwater stream to optimize resource recovery. HOW can be collected using a conventional “door to door”, characterized by a direct collection from households or commercial properties (Kranert, 2017). The collected household organic waste (HOW) that mainly contains food waste is transported by trucks to a Biogas Plant, where HOW will be shredded and digested with Blackwater. Alternatively, food grinders, also known as food waste disposers, can be installed in the Kitchen sinks of each household unit. In this case, the shredded food waste can either be transported directly with the Blackwater, or sent through a separate pipe to the Biogas plant. At the Biogas plant, anaerobic co-digestion of Blackwater and HOW takes place with the use of an up-flow anaerobic sludge blanket reactor (UASB Septik tank) or a Continuous Stirred Reactor (Ferrer and Moreira, 2021; Gao et al., 2020). The high concentration of organic load in both streams leads to methane yields of up to 80 % higher than in conventional WWTPs (Kjerstadius et al., 2015) In addition, the concentrated nutrients such as phosphorus or nitrogen that remain in the digestate, can be applied directly to the soil or undergo nutrients recovery processes such as Struvite recovery or Ammonium Stripping for the production of specialized fertilizers (Lorick et al., 2020)

The biogas plant with a combined heat and power system not only provides electricity for itself and the households, but also supplies a significant share of renewable thermal energy for heating (Hawkey et al., 2015; Steubing et al., 2020; Vergara-Araya et al., 2020). Since the end of the 20th century, these circular source separation systems with integrated HOW management have been implemented in household complexes in Germany, the Netherlands, and China at different plant scales and technical layouts (Kjerstadius et al., 2015; Skambraks et al., 2017; Tolksdorf et al., 2016). However, such systems have not yet been implemented in Latin America.

A diagram of a circular WWE system with source separation within a residential complex, which also represents the technical side of the nexus as defined within this study, is shown in Fig. 1. It is out of this paper's scope to scrutinize the selection of specific technologies for the greywater treatment or the biogas plant within the WWE system. Instead, our primary focus is to analyze the WWE nexus from a stakeholder perspective, focusing on their role as individuals and as a network in the transformation.

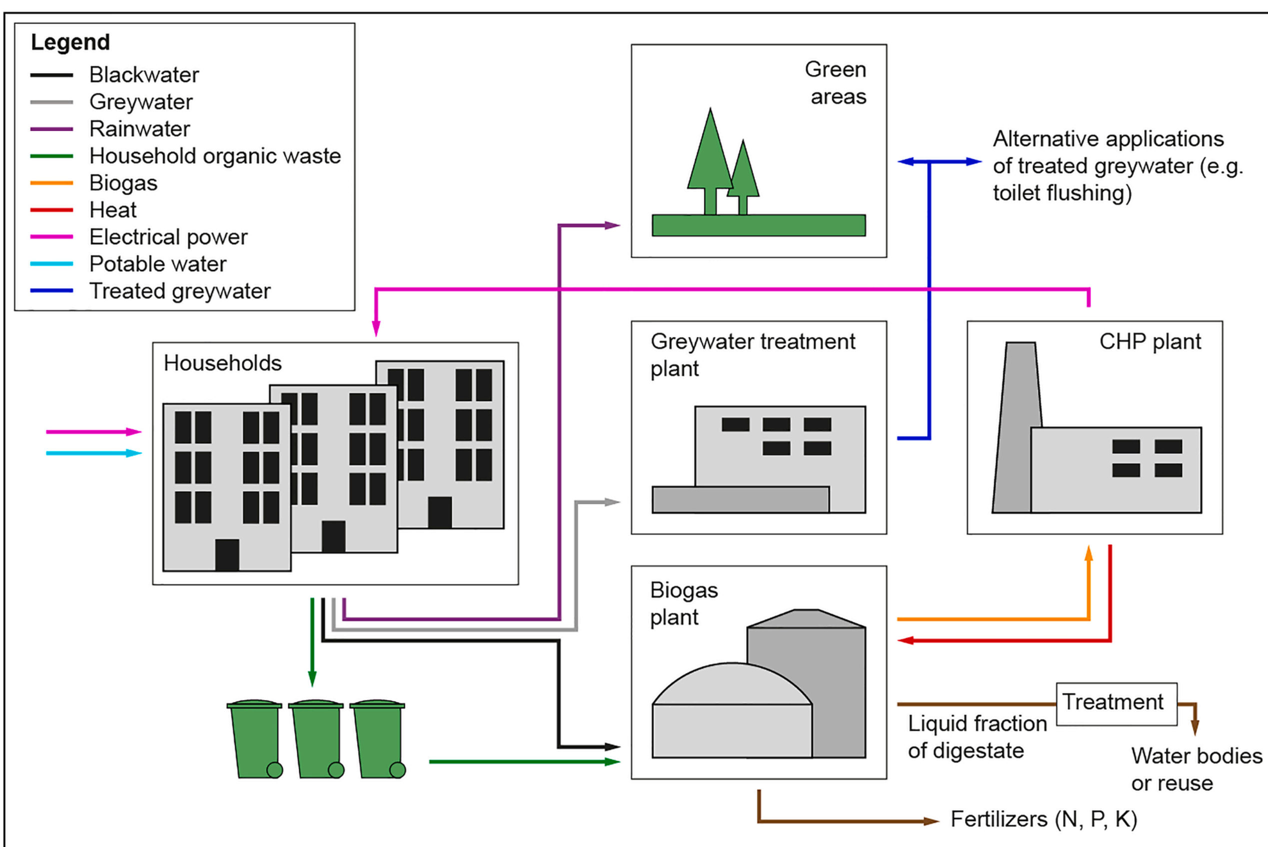

Fig. 1. Diagram of a circular water-waste-energy (WWE) system with source separation of urban wastewater and household biowaste within a residential complex. Note: Household wastewater is separated into greywater and blackwater for subsequent water, nutrients, and energy recovery.

2.2. Stakeholders and study context

The selected study case, in which a transformation towards a circular WWE system could occur, corresponds to a future urban settlement for around 2700 social housing (personal communication, December 16, 2021). Out of a total of 77 hectares of the terrain, around 45 are available for this urbanization (Servicio de vivienda y urbanismo, 2022). The site is located in the outskirts but within the urban limits of the city of Viña del Mar, Region of Valparaíso, in central Chile. The planned residential complex comprises multi-family residential buildings of up to 9 floors each, and recreational areas with needed infrastructures for the provision of energy and water as well as the collection and transport of waste and wastewater (Servicio de vivienda y urbanismo, 2022). Additionally, health and education facilities are planned to equip the new neighborhood.

Since 2010, Valparaíso region has been experiencing an intense megadrought, caused by both natural climate variability and anthropogenic climate change (Alvarez-Garreton et al., 2023). An excessive exploitation of water sources in some territories has also led to a high degree of water stress (Fundación Chile, 2019). In the water and sanitation sector, a privatization process began in 1998 and lasted until 2004 (OECD, 2017). Viña del Mar and other cities of the Valparaíso region, belongs to the 27 % of the Chilean population whose wastewater undergoes preliminary and primary treatment to be later discharged into the ocean (OECD, 2022). The private utility ESVAL S.A. (ESVAL) holds the concession for water and sanitation in Valparaíso region and is controlled by the Ontario Teachers ́Pension Plan. The Chilean Superintendence of Sanitary Services (SISS) supervises and regulates the whole water and sanitation sector, including ESVAL (Ministerio de Economía, 1990).

Waste management relies on the Direction of Environmental Services of the municipality of Viña del Mar (DES-Muni) (Municipalidad de Viña del Mar, 2024). Collection, transport and disposal of combined municipal solid waste (MSW) is provided by third-party companies, which are commissioned and supervised by the municipality. In Viña del Mar, the company COSEMAR transports the MSW to the sanitary landfill El Molle, which is operated by the company Veolia. Similarly to many other Latin American countries, in Chile around 58 % of MSW is organic and less than 1 % is recycled (Holland Circular Hotspot, 2021).

Public, residential, and commercial buildings account for 24 % of Chilean energy consumption, which is mainly fossil-based and imported (Ministerio de Energía, 2022). The Chilean National Electric System (SEN) is responsible for generating, transmitting, and distributing electricity to most of the country. The National Electricity Coordinator is responsible for the operation of the facilities of the national electricity system that operate interconnected among themselves in Chile (Ministerio de Energía, 2024). Conventional big Energy producer companies (EPC) such as the company ENEL Chile S.A. sell energy to the SEN. Non-conventional small-scale generation projects, also known as PMGD, whose surplus power for grid injection does not exceed 9000 kW are regulated by the Chilean law of PMGD (Ministerio de Energía, 2020). According to this law, PMGD can also use part of its electricity production for self-consumption. Chilquinta Distribución S.A. (Chilquinta) is a private company that has a concession for electrical energy distribution and sale in all Valparaíso region. In addition, Chiliquinta also evaluates the feasibility of potential PMGD and supervises the connection of the PMGD to their grid.

The Service of Social Housing and Urbanism of Valparaíso (SERVIU) acts as the urban developer of the future social residential complex. SERVIU leads the planning and construction of new urban settlements, including sanitary, electric, transport, and green infrastructure. For the construction of sanitary and electrical installations in the public space of the urban settlement, e.g. sewage pipes, SERVIU coordinates this task with ESVAL and Chilquinta. Persons with insufficient financial resources

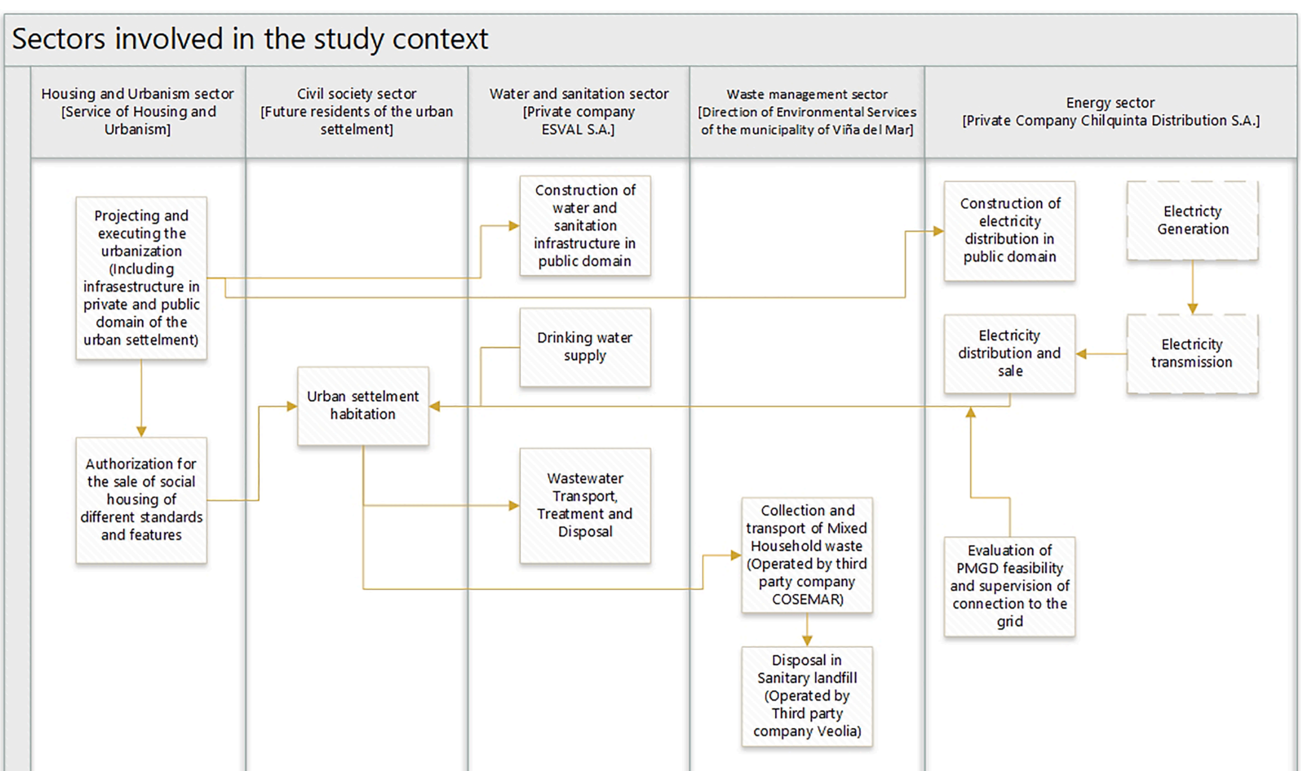

Fig. 2. Representation of key sectors involved in the study context. Note: A typical stakeholder of each sector is noted in brackets; white boxes represent their key process responsibilities, and arrows indicate the key interrelationships between them. Boxes with a dashed border represent processes executed by energy companies other than Chilquinta.

to purchase a home at market prices can apply for the purchase of a social housing unit (Ministerio de Vivienda y Urbanismo, 2016). People living in the surroundings of the future settlement are also organized in Neighborhood Councils. These associations can propose community projects to the authorities, as well as request infrastructure improvements such as green areas, sewers, etc. (Ministerio del Interior, 1996). At the same time, they are considered potential residents of the new urban settlement. A diagram that represents the sectors of water and sanitation, waste management, energy, housing, and urbanism that are involved in the study context is represented in Fig. 2.

3. Material and methods

3.1. Study design

We set the boundaries of the stakeholder analysis according to the geographical location of the study case. It was selected considering the Metropolitan Regulatory Plan of Valparaíso (Regional government of Valparaíso, 2021) and interviews with four Chilean experts in urbanism (See questionnaire in appendix A). Stakeholders that were considered include those with a radius of action over the city of Viña del Mar, where the future urban expansion will be built, and also those who have potential decision-making capacity over the study case.

Aligned with the sectors that shape the technical WWE system, a total of 47 stakeholders were identified based on regulatory and literature review as well as snowball sampling. Of these, 37 accepted to participate in semi-structured data collection interviews of 60 to 90 min duration (Table 1). For the first part of the study, the 37 stakeholders who participated in the interviews include the most relevant ones, which is confirmed by their high influence and interest regarding a future transformation. This was confirmed by four Chilean experts who validated the results. In the second part of the study, the stakeholders who participated included those who were previously identified as relevant or with a key role. In this way, the representativeness of the results of the network analysis was secured. In addition to this, each interviewed actor also reviewed the actor list listed in Annex 1, and if required by them, a relevant actor of their network was added to the list. This procedure deemed us to ensure the needed relevance of the findings. In addition, our sample size is consistent with other previous studies in the environmental field and stakeholder theory. For example, Salmoral et al. (2020) used a sized cohort of 38 stakeholders for a study in a Peruvian city, while Guo and Chen (2022) conducted 42 stakeholder interviews for a city in China.

Since a circular WWE system has not yet been implemented in Chile, at the beginning of each interview stakeholders received a briefing about the technical system. The interviews were guided by a questionnaire (see Appendix B), which was composed of two main parts aligned with the research questions of this study (cf. Sections 3.2 and 3.3).

3.2. Interest and influence

To identify the stakeholders' roles in the transformation process and

Table 1
Interviewed stakeholders. W: Water and Wastewater, WE: Waste and Environment, E: Energy, U: Housing and Urbanism, O: Others, N: Number of interviewees. *Contact only through written communication.

Stakeholders groups/Organizations	Abbreviation	Sector of work					N
		W	WE	E	U	O	
Local Government Agencies							
Municipal Department of Environmental Services	DES-Muni		X				1
Municipal Secretariat of Planning	SECPLA-Muni					X	1
Regional Government Agencies							
Regional Directorate of Hydraulic Works SEREMI MOP*	DHW-S.MOP	X					1
Regional Directorate for Planning SEREMI MOP	DP-S.MOP	X					1
Regional Superintendence of Sanitation Services	SISS	X					1
Regional Ministerial Environment Secretariat	SEREMI-Env.		X				1
Regional Ministerial Housing & Urbanism Secretariat	SEREMI-MINVU				X		1
Regional Service of Housing & Urbanism	SERVIU				X		1
Regional Ministerial Energy Secretariat	SEREMI-Energy			X			1
Regional Ministerial Health Secretariat	SEREMI-Health	X	X				1
Regional Directorate of Agriculture and Livestock Service	DALS					X	2
Central Government Agencies							
Office of Circular Economy – Ministry of Environment	CE Office		X				1
Sustainable Energy Division – Ministry of Energy	SED			X			2
Undersecretariat of regional and administrative development – Ministry of the Interior and Public Security	SUBDERE					X	1
Chilean economic development agency – Ministry of Economy, Development and Tourism.	CORFO					X	1
Water, wastewater, waste, energy utilities							
Sanitary company ESVAL S.A.	ESVAL	X					1
Waste company COSEMAR	COSEMAR		X				1
National Association of sanitary companies	ANDESS	X					1
Energy generation company Enel Chile S.A.	ENEL			X			1
Energy distribution company Chilquinta Distribución	Chilquinta			X			1
Enerquinta, subsidiary company of Chilquinta group	Enerquinta			X			1
Gas distribution company	GDC			X			1
Water user organization (WUO)							
Branch Canal Water User Associations	WUOs	X					1
Academia and Civil society							
Pontifical Catholic University of Valparaíso	PUCV		X	X	X	X	4
Universidad de Chile	UCH	X				X	1
Universidad Técnica Federico Santa María	UTFSM			X		X	1
Fundación Chile	FCh	X	X			X	1
Sustainable Energy Agency of Chile	SEA			X			1
Neighborhood Councils of Surrounding Settlements	NCS					X	2
International organizations							
German association for international cooperation	GIZ			X			1
World Bank – Circular economy in water sector	World Bank	X				X	1
Total of participants in the interviews							**37**

categorize them, a method known as the interest-influence matrix (Reed et al., 2009) was selected. From previous studies, there is no single definition for the terms interest and influence, which is defined by authors depending on their analytical purpose (Ackermann and Eden, 2011; De Lopez, 2001; Salmoral et al., 2020). Within the present study, "Interest" refers to the stakeholder's interest in achieving the implementation of a future integrated and circular WWE system in a future urban development, while "Influence" is defined as the capacity of the stakeholder to influence the implementation.

In the first part of the interviews (see Part 1 of appendix B), we used a questionnaire to ask each stakeholder to self-assess their potential interest and influence on a numeric scale between 0 and 3, indicating nonexistent, low, medium and high interest or influence, respectively. Four Chilean senior experts from the fields of waste, water, and energy validated the gathered data. In a few cases collected figures were adjusted and data for missing stakeholders was completed based on the experts' feedback.[1] Subsequently, a stakeholder interest-influence matrix was built. Making use of the categorization frameworks from the fields of conservation and business administration (De Lopez, 2001; Eden and Ackermann, 1998), stakeholder categories were defined as:

- Key Players, i.e., stakeholders with high level of interest and influence. They are considered as "transformation enablers" with a high relevance for the decision-making process
- Subjects, i.e., actors whose influence is currently limited but due to their high interest, they could have a supportive role if they are engaged in the process by Key Players
- Context setters, i.e., stakeholders with high influence but little interest. They are considered as "transformation blockers"
- Crowd, i.e., stakeholders with low interest and influence.

3.3. Stakeholders' institutional interplay

In order to investigate the relational ties between stakeholders in the context of the nexus, we conducted a combination and adaptation of the methods of actor-linkage matrix (Biggs and Matsaert, 1999) and stakeholder network analysis (Reed et al., 2009; Wasserman and Faust, 1994). During the second part of the interviews (see Part 2 of Appendix B), we used a questionnaire to ask each interviewee to self-assess the level and type of institutional interplay (relational tie) that exists with the stakeholders considered in Section 3.2. Some of the 37 interviewees indicated that they were also socially related to further relevant stakeholders not listed in the questionnaire. These were then added to the data,[2] leading to a final network of 42 stakeholders.

For the level of relational tie, a numeric scale from 0 to 3 was defined. 0 corresponds to a nonexistent tie, while 1 corresponds to a low or weak interplay that happens once a year or less, e.g., yearly for compulsory legal permits. 2 indicates a medium level of interplay, which happens at least twice yearly. Finally, 3 corresponds to frequent or strong interplay, which means at least twice every month. The adapting of the definition of weak or strong interplay depends on the context, i.e. the stakeholder network analysis is vague when an interplay is valued. In this study, the authors follow the uses of existing cross-sectoral regional round tables working on topics such as water provision for water-scarce areas, which typically meet twice a month or more. The participants often view this schedule as very intensive.

Types of institutional interplay were defined based on Reed et al. (2009). Cooperative type involves relational ties in which both organizations collaborate or coordinate either in the planning, execution or follow-up of projects/initiatives. If one organization regulates and monitors compliance with regulations applicable to the other organization or vice versa, then the interplay is considered as regulatory type. If the interplay is limited to exchange of information between both organizations, e.g., communication regarding a recent report, then it is categorized as informational type. Conflicts between two organizations that prevent collaborative or informative work corresponded to conflict type.

All the gathered data was organized in a modified single actor-linkage matrix used to conduct the social network analysis (SNA). "SNA is concerned with understanding the linkages among social entities and the implications of these linkages" (Wasserman and Faust, 1994, p.17). For the SNA, the relationship mapping software Kumu (Kumu, 2024) was used. Centrality metrics were calculated to identify the most influential actors from a network perspective, see Table 2

Table 2
Social Network Analysis (SNA) Centrality Metrics. Table by authors based on the work of Arif (2015).

Metric	Formula	Definition *(Organizations are seen as nodes within SNA)*
Degree centrality	$C_D(v) = \deg(v)$ (1) Where $\deg(v)$ is the number of edges incident on the vertex (v).	Measures the number of linkages incident on a node or vertex of the network. Indicates the size of the organization's network.
Betweenness centrality	$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}$ (2) Where σ_{st} represents the number of shortest paths from node s to t and σ_{st} is the number of paths that pass through v	Measures how often a node acts as a bridge along the shortest path between two other nodes. Such nodes are also known as gatekeepers. A high value indicates a key role in the information flow and cohesiveness of the network.
Closeness centrality	$C_c(v) = \frac{n-1}{\sum_{k=1}^{n} d(u_i, v)}$ (3) Where n implies the number of nodes of a social network while (u_i, v) represents the geodesic distance between u_i and v	Measures the distance between one node and the rest of the nodes within the network. High values indicate which nodes can quickly spread information.

[1] The interest and influence of missing stakeholders (who could not be reached for an interview) were completed by experts. These stakeholders were: The Municipal Work Directorate (MWD), the central agencies of Environmental Evaluation Service (EES), the Citizen participation and Education Division (CED), Superintendence of Environment (SOE) and the General Water Directorate (GWD).

[2] These included Regional Ministerial Secretariat of Public Works (SEREMI MOP), Regional Ministerial Secretariat of Agriculture (SEREMI Agri.), Superintendence of Electricity and Fuels (SEF), Real Estate Companies (REC), Waste Foundation (Fou. Waste), Foundation Amulen (Fou. Amulen) and Un techo para mi país (NGO Techo), and other NGOs.

4. Results

4.1. Interest and influence

The high interest of the majority of the Key Players and Subjects is motivated by the creation of alternative water sources to face the current megadrought in the region. They manifested their willingness to directly or indirectly contribute to transform the system, if the alternative system proves to be more environmentally and economically sound than the current one, or than other alternatives e.g., seawater desalination. Key Players are mainly composed of regional and central government authorities (Fig. 3). For instance, SERVIU could play a significant role. Its high influence is expressed by its function to make the decision to migrate to a source separation system, not only in the public space (sewage canalization) but also in the private space (domestic sanitation infrastructure). Another potential Key Player is SISS, which exerts influence at regulatory level. Although the current concession regime does not contemplate source separation systems, implementation of the Chilean greywater law (Ministerio de Obras Públicas, 2018) might also be subject to control (e.g., through water tariff regulation) and supervision by the SISS. SISS further stated that they might also have influence on the approval of the WWE systems. The latter in coordination with the Sanitary authority SEREMI Health.

From the civil society side, Neighborhood Councils of surrounding areas (NCS) were identified as Key Players. They indicated having slightly less influence than government agencies, as the final decision regarding execution and investment in such new systems for social housing depends purely on the SERVIU. NCS representatives indicated that young residents of the vicinities could be potential users of the new system if they become co-owners of the future household complex. In that case, they will influence the successful source separation of the wastewater and the organic waste. In addition, they also mentioned that Neighborhood Councils could act as a bridge of information between SERVIU and potential new users. For instance, to gather them to discuss or inform them about the introduction of new rules such as waste source separation.

Within the Subjects, there are mainly private service providers of water, waste or energy. For example, ESVAL indicated a high interest in ensuring water security and improving the efficiency of water management in the region of Valparaíso, including Viña del Mar, which is its legal concessional area. However, this type of wastewater-waste-energy system is not contemplated in its actual line of business, therefore the medium level of interest. Regarding their influence, grey- and/or blackwater treatment could be a service provided by ESVAL and operated by a contractor, as stated during the interview. If that is the case, then ESVAL could have a higher level of influence. However, this would mostly depend on the decision of the urban developer and on other factors such as the economic feasibility of the integrated system. The latter was a common statement across the interviewed Subjects.

The category Crowd includes, among others, private companies and regional authorities with limited decision-making power for implementation and low interest, as their scope does not involve the waste or

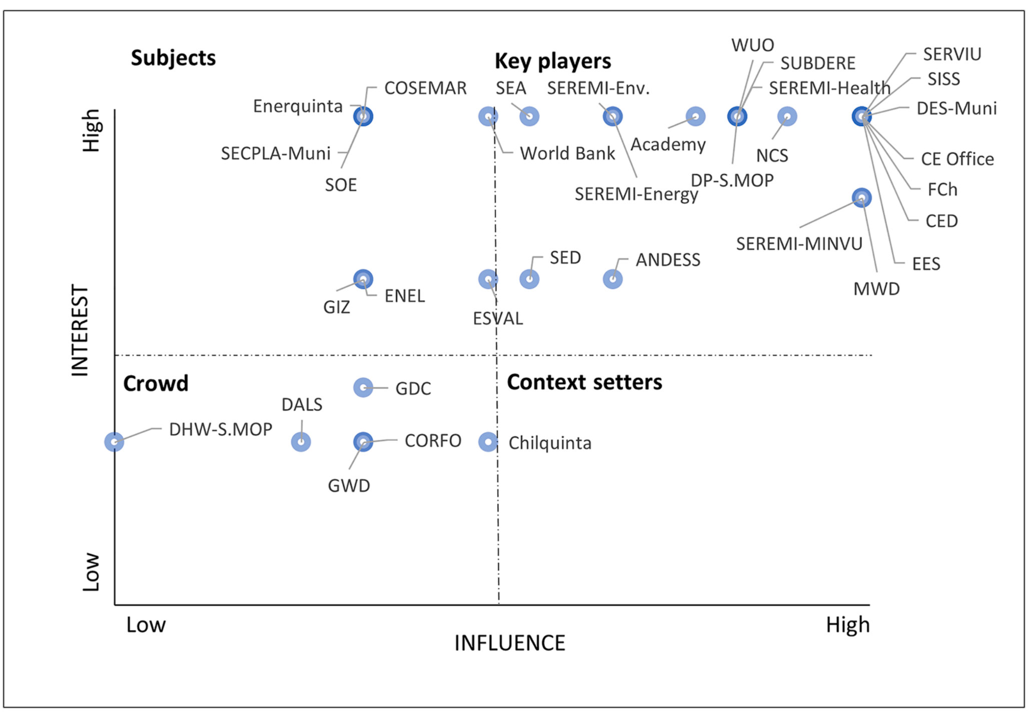

Fig. 3. Stakeholders' influence and interest over the transformation towards a circular and integrated water-waste-energy system. Note: Municipal Department of Environmental Services (DES-Muni), Municipal Secretariat of Planning (SECPLA-Muni), Regional Directorate of Hydraulic Works (DHW-S.MOP), Regional Directorate for Planning (DP-S.MOP), Regional Superintendence of Sanitation Services (SISS), Regional Ministerial Environment Secretariat (SEREMI-Env.), Regional Ministerial Housing & Urbanism Secretariat (SEREMI-MINVU), Regional Service of Housing & Urbanism (SERVIU), Regional Ministerial Energy Secretariat (SEREMI-Energy), Regional Ministerial Health Secretariat (SEREMI-Health), Regional Directorate of Agriculture and Livestock Service (DALS), Office of Circular Economy – Ministry of Environment (CE Office), Sustainable Energy Division – Ministry of Energy (SED), Undersecretariat of regional and administrative development – Ministry of the Interior and Public Security (SUBDERE), Chilean economic development agency – Ministry of Economy, Development and Tourism (CORFO), Sanitary company ESVAL S.A. (ESVAL), Waste company COSEMAR (COSEMAR), National Association of sanitary companies (ANDESS), Energy generation company Enel Chile S.A. (ENEL), Energy distribution company Chilquinta Distribución (Chilquinta), Enerquinta, subsidiary company of Chilquinta group (Enerquinta), Gas distribution company (GDC), Water user organization (WUO), Branch Canal Water User Associations (WUOs), Universities (Academy), Fundación Chile (FCh), Sustainable Energy Agency of Chile (SEA), Neighborhood Councils of Surrounding Settlements (NCS), German association for international cooperation (GIZ), World Bank – Circular economy in water sector(World Bank), The Municipal Work Directorate (MWD), the central agencies of Environmental Evaluation Service (EES), the Citizen participation and Education Division (CED), Superintendence of Environment (SOE) and the General Water Directorate (GWD).

wastewater sector in urban areas. No Context Setters were identified.

4.2. Stakeholders ́ institutional interplay

It was found that cooperative interdependencies dominate the stakeholder network (~81 %), while regulatory (~9 %), informative (~6 %), others (~3 %) and conflict type interdependencies (~1 %) form the minor part, see Fig. 4. Around half of the cooperative and regulatory interdependencies were characterized by a strong institutional interplay, the rest being medium (~30 %) and weak (20 %). Informative ties were predominantly medium and weak (~90 %). The single conflict interdependence was weak, as it happened only once between a WUO and a Real Estate Company (REC) and therefore is considered not relevant.[3]

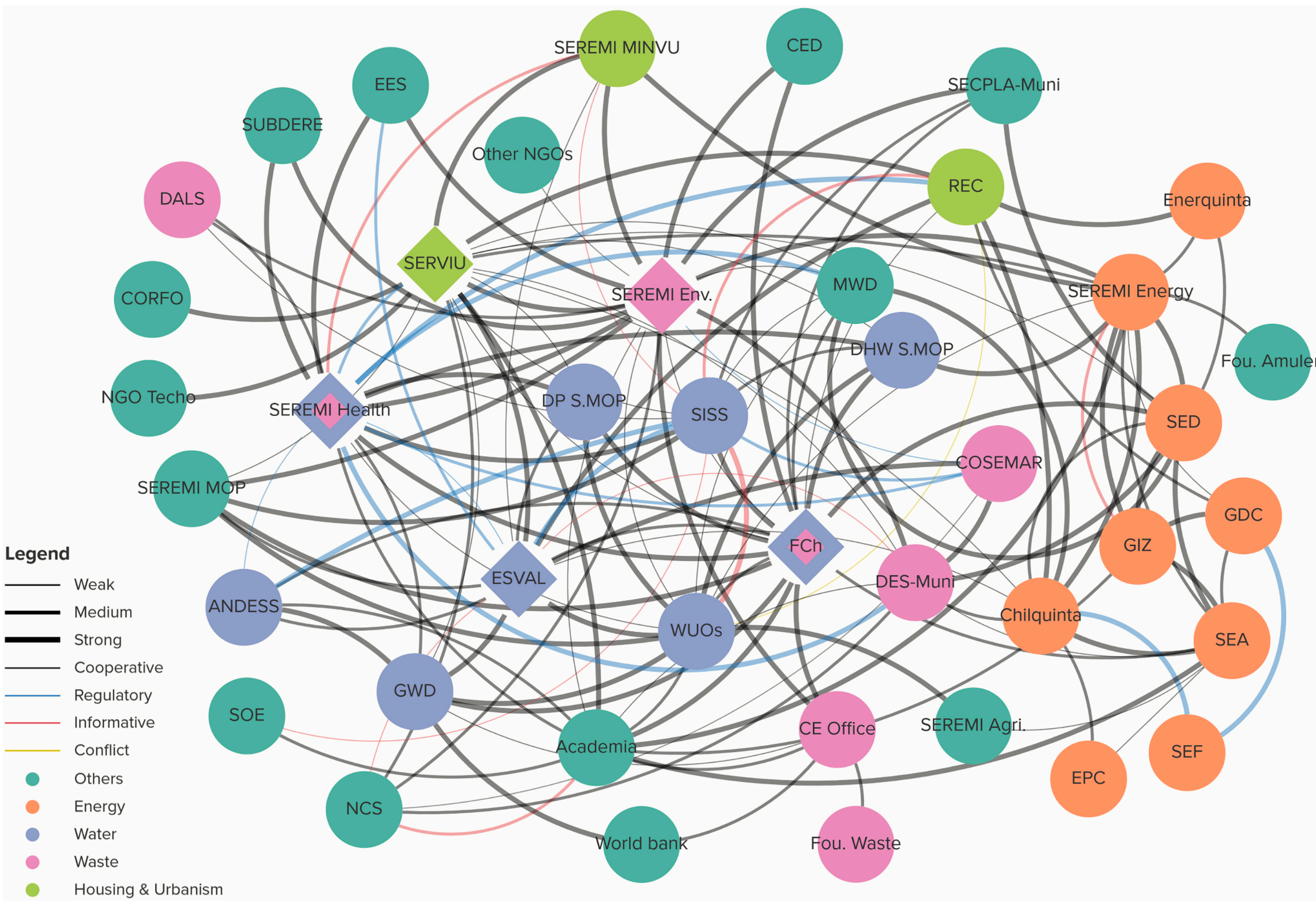

Fig. 4. Stakeholder network according to the level and type of existing interdependencies. Note: Stakeholders with diamond shape represent Stakeholder Hubs. Note: Municipal Department of Environmental Services (DES-Muni), Municipal Secretariat of Planning (SECPLA-Muni), Regional Directorate of Hydraulic Works (DHW-S.MOP), Regional Directorate for Planning (DP-S.MOP), Regional Superintendence of Sanitation Services (SISS), Regional Ministerial Environment Secretariat (SEREMI-Env.), Regional Ministerial Housing & Urbanism Secretariat (SEREMI-MINVU), Regional Service of Housing & Urbanism (SERVIU), Regional Ministerial Energy Secretariat (SEREMI-Energy), Regional Ministerial Health Secretariat (SEREMI-Health), Regional Directorate of Agriculture and Livestock Service (DALS), Office of Circular Economy – Ministry of Environment (CE Office), Sustainable Energy Division – Ministry of Energy (SED), Undersecretariat of regional and administrative development – Ministry of the Interior and Public Security (SUBDERE), Chilean economic development agency – Ministry of Economy, Development and Tourism (CORFO), Sanitary company ESVAL S.A. (ESVAL), Waste company COSEMAR (COSEMAR), National Association of sanitary companies (ANDESS), Energy generation company Enel Chile S.A. (ENEL), Energy distribution company Chilquinta Distribución (Chilquinta), Enerquinta, subsidiary company of Chilquinta group (Enerquinta), Gas distribution company (GDC), Water user organization (WUO), Branch Canal Water User Associations (WUOs), Universities (Academy), Fundación Chile (FCh), Sustainable Energy Agency of Chile (SEA), Neighborhood Councils of Surrounding Settlements (NCS), German association for international cooperation (GIZ), World Bank – Circular economy in water sector(World Bank), The Municipal Work Directorate (MWD), the central agencies of Environmental Evaluation Service (EES), the Citizen participation and Education Division (CED), Superintendence of Environment (SOE) and the General Water Directorate (GWD), Regional Ministerial Secretariat of Public Works (SEREMI MOP), Regional Ministerial Secretariat of Agriculture (SEREMI Agri.), Superintendence of Electricity and Fuels (SEF), Real Estate Companies (REC), Waste Foundation (Fou. Waste), Foundation Amulen (Fou. Amulen) and Un techo para mi país (NGO Techo), and other NGOs.

[3] In a single case, a Real Estate Company used water for residential purposes, without respecting the water rights allocated to a user of a water channel. In this study, a similar potential conflict could be neglected as Real Estate Companies are subordinated to the lead urbanizer which is the public authority SERVIU.

Table 3
Stakeholders with the highest values for the centrality metrics. KP: Key player, SJ: Subject.

Rank	Degree Centrality			Closeness Centrality			Betweenness centrality		
	Label	Category	Value	Label	Category	Value	Label	Category	Value
#1	SERVIU	KP	20	SERVIU	KP	0.736	SEREMI Env.	KP	0.173
#2	SEREMI Env.	KP	19	SEREMI Env.	KP	0.724	SERVIU	KP	0.156
#3	SEREMI Health	KP	19	FCh	KP	0.724	SEREMI Energy	KP	0.112
#4	FCh	KP	19	SEREMI Health	KP	0.715	FCh	KP	0.108
#5	ESVAL	SJ	16	ESVAL	SJ	0.679	SEREMI Health	KP	0.077

From the cooperative interdependencies with a medium to strong interplay, the majority is intra-sectoral collaboration (~60 %), which means between organizations that belong to the same sector. The rest of these interdependencies are intersectoral with ~20 % occurring between organizations from water, waste, energy, and housing and urbanism sectors, and ~20 % with organizations of other sectors, e.g., public investment. For instance, within the urbanism-water-energy nexus, as one of the Key Players SERVIU regularly coordinates with the Subject actor ESVAL and Crowd actor Chilquinta regarding service provision for their urbanizations. However, SERVIU has a weak interplay with DES-Muni, another Key Player for the planning of waste infrastructure within their household complexes. Regarding the waste-water nexus, few interdependencies were found. For instance, SEREMI Env. regularly holds meetings with the SEREMI MOP (linked to water and sanitation issues) in the framework of the Regional Climate Change Committee (CORECC). However, strategies for water reuse within the built environment have not yet been considered within their agenda. Moreover, there is a weak interplay between ESVAL and DES-Muni, addressing infrequent failures within the water-wastewater infrastructure that cause environmental impacts.

The water-energy link also exhibits few interdependencies, though these are a little stronger than the waste-water link. This is represented in the collaboration between SEREMI Energy with different actors such as the WUOs and the DHW-S.MOP for powering water infrastructure projects, especially in rural areas, where independent water supply and sanitation systems can be constructed. There, SEREMI acts as a provider of technical assistance.

From the analysis of the central metrics, the top five stakeholders with the highest values belong in the majority to the Key Players and one to the Subjects, see Table 3. The other Subjects and Crowd actors, in that order, in general scored lower centrality values.

In most cases, the ranked stakeholders for each metric were the same. This overlap reveals that these actors not only act as Stakeholder Hubs with an active interplay but can also quickly reach other stakeholders or spread information within the network. An example of a Stakeholder Hub is SEREMI Health, a Key Player which is institutionally well connected with public and private entities from the water and waste sectors. This mainly plays a regulatory role, e.g., with the DES-Muni and ESVAL. In spite of not having a direct connection with the energy sector, SEREMI-Health is able to reach out to such organizations through its relationship with SERVIU, SEREMI Environment or FCh. These three Stakeholder Hubs with the highest values for Betweenness centrality also play an important role in the information flow and cohesiveness of the network, building bridges between certain sectors such as water, waste, and energy. It is important to note that their Betweenness centrality not being close to the maximum value of 1 can be an indicator of them not having to handle the overall traffic on the network, which can be seen as positive (Prell et al., 2009; Zabka et al., 2024).

Unlike the other actors in the top five, the private sanitary company ESVAL acts more noticeably as a Stakeholder Hub within its own water and wastewater sector than as a bridge to other sectors. This is due to its weak relational ties to actors of the waste or energy sector. Regarding Neighborhood Councils, they lack centrality within the network due to a reduced number of connections. However, if connections to Stakeholder Hubs such as SEREMI-Environment or SERVIU were strengthened, then a bridge for further interactions with other Key Players from the water, waste, and energy sectors could be created.

5. Discussion

The Key Players found to have the highest leverage to drive the transformation towards a circular WWE system come from governmental sectors such as water and sanitation, waste, and housing and urbanism. Also belonging to this stakeholder category, but with slightly less influence are actors from the energy sector. This is due to their more complementary role in the implementation of the technical system. The aforementioned Key Players are predominantly from regional and central levels, with a single representation of the municipality at the local level. Based on the elicited influences, they can be potentially engaged either as urban developers, inspectors, regulators, technical advisors, policy advocates, or potential funding agencies, depending on the project stage. However, stakeholders‘ answers did not elucidate the key role of who should be in charge of coordinating the operation and maintenance of the new technical system, once implemented. Nevertheless, definition of responsibilities should be the result of Key Players deciding to actively involve Subject stakeholders as well as a nexus-specific regulatory framework. For instance, highly interested private actors could then increase their level of influence and engage in key operative roles, given their sector expertise. Yet for them, market incentives remain pertinent, to encourage private participation (Skambraks et al., 2017).

Results from a study about governance structures of a decentralized WWE system in Germany indicated that public wastewater utilities have a central role in their capacity as innovation leaders (Schramm et al., 2018). However, unlike in Germany, Chilean wastewater utilities do not belong to the public sector and therefore their involvement would mean higher coordination efforts between the public and private sectors for nexus implementation. According to Salmoral et al. (2020), who analyzed nexus governance between water, agriculture and mining in a basin in Arequipa, Perú, governmental agencies are the Key Players. The latter coincides with our findings, even though the nexus sectors are different. Further similar studies in the region are not known to the authors.

The medium- to strong level of institutional interplay that characterizes cooperative interdependencies between water-energy or housing-urbanism-energy would be beneficial for the implementation of the nexus approach. In that case stakeholders can more likely influence each other, following existing informational and coordination channels (Reed et al., 2009). However, the scope of their cooperation should be broadened: For instance, from energy efficiency in urban buildings or energization of water supply systems to coordinated efforts for energy recovery from integrated management of household organic waste (HOW) with blackwater. In addition to this, the weak interplay seen at the interface between waste-water would have to be strengthened in order to make use of the nexus possible. However, this could represent a challenge as no precedent for integrated projects of HOW with wastewater has yet taken place. For that purpose, new mechanisms of cooperation should be created, ranging from initial nexus related discussion to a later co-design or co-decision-making (Basco-Carrera et al., 2017) about the technical layout and business model. For instance, between the municipality responsible for HOW management and the blackwater management responsible, e. g., concession holder and/or government agency in charge, such as SERVIU. A key barrier to WWE cross-collaboration is the lack of nexus-specific regulatory relational ties that go beyond current governance boundaries at the interface of wastewater-waste and waste-energy. For instance, a co-digestion of HOW with blackwater is neither regulated by the sanitary authority nor contemplated in the Chilean National Strategy of HOW (Ministerio del Medio Ambiente, 2020). The Chilean greywater law 21075 (Ministerio de Obras Públicas, 2018) exclusively adresses greywater. This implies that, so far, blackwater should continue being transported to the sanitary services concessionaire of the region, such as ESVAL. According to Decree 1199 (Ministerio de Obras Públicas, 2005), the regional private concessionaire is responsible for wastewater disposal but not for HOW. Organic waste management currently falls under the responsibility of the municipality. Also, the uncertainty regarding the authorization for the use and commercialization of digestate from WWE systems as fertilizer presents a barrier. Current Chilean legislation permits only the soil application of sludge or digestate generated in conventional wastewater treatment plants (Ministerio secretaría general de la Presidencia, 2010). As stated by the stakeholders during the interviews, another barrier to current cross-collaboration, particularly among private actors, is the absence of precedents for a WWE system in Chile or the lack of awareness of studies that can prove its economic feasibility within the Chilean context. Such integrated markets have also not been explored yet as a business line, also in part because current business lines as separated water, waste or energy markets are performing satisfactorily. Therefore, the creation of regulatory ties for tariff regulation within WWE would also be essential. The network analysis showed that once they exist, regulatory ties tend to be strong due to efficient law enforcement. The housing and urbanism sector, on the other side, already cross-collaborate with water, waste, and energy individually during the planning of sanitary and electrical infrastructures. The latter represents an opportunity for WWE transformation. The absence of relevant conflict type relations and the general predominance of cooperative ties is a good indicator of a network based on collaboration and trust. Both aspects are favorable conditions for advancing the nexus.

Centrality metrics proved to be an effective way to identify multi-sectoral actors such as SERVIU, SEREMI Env. or Fundación Chile, who act as both Stakeholder Hubs and as a bridge between more disconnected sectors. Therefore, engaging them especially in the early phases would be key as they have the potential to mobilize and motivate the network towards the transformation, especially considering that the majority of central actors are also Key Players. Key Players with lower centrality such as the Neighborhood Councils should increase their visibility in the network, for example by Stakeholder Hubs engaging them through participatory processes, especially in the design phase of the nexus system.

The present study addresses a system that has yet to be implemented, thus making its stakeholder dynamics challenging to capture. Although these complexities, the methodological approach used in this study can be extrapolated to other contexts. The present findings should be seen in the context of this study case, i.e. on the one hand of the Chilean context and on the other hand of the residential area under review. The interrelations between those stakeholders acting on a national level, could be valid also in other Chilean regions. The regional and locally bounded stakeholder are specific to the situation in their region and in Vina del Mar. This is (among other reasons), because an actor's level of interest can be driven by specific current events, and actors have unique profiles. As an example, in the present study SISS and SERVIU are motivated by the current megadrought, while the municipality of Viña del Mar stands out for its dedication to environmental stewardship among Chilean municipalities (El Observador, 2020).

In addition, to capture the stakeholder dynamics, the method could prove to be beneficial in the case of adapting transformation strategies to new network configurations. While not having been defined originally as an aim of this study, some of the interactions and influences across stakeholders are of multi-scale type, i.e., there are stakeholder pairs from the same sector, but different governance levels. When carried out thoroughly, such a multi-scale approach (Fares, 2024), can bring additional insights. For instance, to answer the question of how a top-down approach could foster the transformation to nexus.

Previous studies have highlighted the relevance of stakeholders' involvement to assure that future-oriented scenarios are meaningful for society (Andersen et al., 2021). Aligned with this and the fact that the proposed circular system has not yet been implemented in Chile, the results of this study can be of good use in stakeholder-based scenario making. Moreover, these results could also be used within Multi Criteria Decision Analysis (MCDA) and sustainability assessment of the alternative nexus systems. In MCDA studies, integration of key stakeholders is of high relevance, but at the same time represents a challenge (Estrada et al., 2024). The prioritization of stakeholders, through stakeholder analysis, will help to overcome challenges regarding time and resources.

6. Conclusions

This research provides novel insights into advancing circularity in the built environment through a WWE nexus approach involving Stakeholders as drivers for the transformation. We used Stakeholder analysis methods, most importantly Influence-Interest Matrix and Social Network Analysis, to systematically identify the Key Players of a future transformation and its narratives and gain a deeper understanding of institutional dynamics within and across nexus-related sectors. This paper contributes to knowledge by demonstrating that combining these methods effectively analyzes complex nexus stakeholder constellations.

Present findings also contribute to policymaking and the development of targeted stakeholder engagement strategies. To formulate appropriate nexus-related policies, not only stakeholders from the water, waste, and energy sectors should be included, but also those from housing and urbanism, public investment, and civil society due to their relevance in the transformation process. Furthermore, the existing interplay across stakeholders and the existing gaps among more disconnected sectors need to be considered when defining future strategies. To advance circularity in the built environment under the nexus approach, cross-sectoral collaboration is a key lever, and therefore, current governance structures should be adapted accordingly, and existing weak-medium relational ties between wastewater-waste and waste-energy should be strengthened. Furthermore, new cooperative interdependencies need to be established. For that purpose, regulatory schemes are of special significance. Certain actors - private and public - have roles that might evolve over time, depending on external factors, e. g., commodity prices, legislation, etc., as well as internal organizational factors, such as introducing new business strategies. Consequently, it is relevant for decision-makers to use stakeholder analysis as a tool throughout the stages of the project implementation. This study also provides a foundation for the further development of stakeholder-based scenarios for the implementation of wastewater-waste-energy systems and the integration of stakeholders in a posterior MCDA model. This study focused on the role of stakeholders in a future transformation, from a stakeholder perspective and considering their social networks. Nevertheless, further research into the impediments to the transformation towards WWE systems should be conducted from economic, regulatory, technological, and social perspectives, while also considering how each of these factors influences one another.

Since water scarcity is the main root of stakeholders ́ interest within this study, other Latin American countries with similar challenges might potentially have high interest as well, which is a lever for advancing these alternative systems in the region. Even though the obtained results refer to a specific study case, the applied framework could be further used in another Latin American context. Moreover, its application could be broadened to other circular transformation cases that deal with a complex set of stakeholders from different sectors.

CRediT authorship contribution statement

Vanessa Bolivar: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Witold-Roger Poganietz:** Writing – review & editing, Resources, Conceptualization. **Magnus Fröhling:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix A. Sample of the questionnaire used during the semi structure interviews with urban planners

General data:
Date:
Position:
Organization:
Role of the organization:
Part 0 Short briefing about the technical system
Part I Urbanization (New cities)
A pool of questions was prepared which were selected interchangeably, depending on the knowledge and time constraints of the interviewee:

- Regarding site selection for the proposed water-waste-energy systems in the urban sector. Which sites within the region would you find suitable for implementation and why? Do you know if the population size is more than 10 000 inhabitants?
- Which criteria would you recommend to consider for site selection?
- Which other policy instruments, apart from the Regulatory Plan of Valparaíso (PRV), regulate future urban expansions in cities or communities?
- The PRV includes new urban settlements in a map. Where can I find detailed information about the maximum population size of these future settlements and who is in charge for that?
- The city of Curauma was initially designed for 150 000 inhabitants, currently around 30 000 persons live there. According to the PRV no future urban settlements in Curauma are planned in the next 30 years. Is this information up to date? Would you recommend Curauma as potential site for the proposed system and why or why not?
- What is the process for urbanizing the public space e.g. sewage infrastructure in which a household complex is located? Does it differ if the owner of the land is a public or private entity?

Part II Water-Waste-Energy Nexus

This part was conditional if interviewees had additional time for the interview. However, this was not the main scope of the interview with urban planners.

- About your organization, please indicate:

Attributes	None (0)	Low (1)	Medium (2)	High (3)	Comments
Influence					
Interest					

Para

- Who could be affected by these alternative systems?
- Who has the power to influence the outcome?
- Could you please suggest key contact names (snowball sampling)?

Para

Appendix B. Sample of the questionnaire used during the semi-structured interviews with stakeholders

Questionnaire 'Analysis of interest, influence and institutional interplay with a Water-Waste-Energy Nexus approach'.

- Organization:
- Position (Interviewee):
- Date:

Objective of the questionnaire: To identify stakeholders׳potential interest and influence with regards to the transformation towards a sustainable and circular water-waste-energy system. To gain an in-depth understanding of the complex relationships and institutional interplay between key stakeholders in the water, waste and energy sector, among others, with the overarching aim to address the big challenge of water scarcity in urban areas through a nexus perspective. The latter builds upon the interdependencies and potential synergies across water, waste and energy sectors at the local urban level to achieve common sustainable goals.

Part 0. Briefing about the technical system for the interviewee

Part 1. Role, Interest and Influence:

Here the interviewee is asked about their influence and level of interest his/her organization has with respect to the transformation towards a future sustainable and circular water-waste-energy system. The interviewees are also asked to further elaborate on the arguments that justify their answers.

Influence	Value: (0: nonexistent, 1: low, 2: medium, 3: high)	Justification:
Interest	**Value: (0: nonexistent, 1: low, 2: medium, 3: high)**	**Justification:**

Part 2. Institutional interplay

In this part, the interviewee is asked about the current institutional interplay or relational tie between her/his organization and the other organizations listed in the table. They were asked about the strength of the relation and the type as well as an explanation.

No	Organisations	Level of the relational tie (0: non-existent, 1: few, 2: regular, 3: frequent)	Type of relational tie (Cooperative, Regulatory, Informational, Conflict)	Further explanation/additional comments How does the stakeholder relate to the other stakeholder? Here the interviewee is asked to further explain the existing relational tie
1	General Water Directorate			
2	Regional Directorate of Hydraulic Works - SEREMI MOP			
3	Regional Directorate for Planning SEREMI MOP			
4	Superintendence of Sanitary Services SISS			
5	*Regional Secretariat of Public Works SEREMI MOP			
6	Superintendence of Environment			
7	Environmental Evaluation Service			
8	Education and Citizen Participation Division			
9	National Waste Executive Secretariat			
10	Regional Secretariat of the Ministry of the Environment			
11	Regional Secretariat of Housing and Urban Development			
12	Regional Service of Housing and Urban Development			
13	Sustainable Energy Division of the Ministry of Energy			
14	Regional Ministerial Energy Secretariat			
15	Regional Ministerial Health Secretariat			
16	Regional Directorate of the Agriculture and Livestock Service			
17	Municipal Work Directorate			
18	Municipal Department of Environmental Services			
19	Municipal Secretariat of Planning			
20	Chilean Economic Development Agency			
21	Undersecretariat of regional and administrative development			
22	Sanitary company ESVAL S.A.			
23	Waste company COSEMAR			
24	National Association of Sanitary Companies (ANDESS)			
25	Energy generation companies e.g. Enel Chile S.A.			
26	Energy distribution company: Chilquinta Distribución			
27	Enerquinta S.A.			
28	Gas distribution companies			
29	*Real state companies			
30	Water User Organizations			
31	Academia, e.g. universities, research institutes, research centers, etc.			
32	Neighborhood Councils			
33	Chile Foundation			
34	Sustainable Energy Agency			

(*continued on next page*)

(*continued*)

No	Organisations	Level of the relational tie (0: non-existent, 1: few, 2: regular, 3: frequent)	Type of relational tie (Cooperative, Regulatory, Informational, Conflict)	Further explanation/additional comments How does the stakeholder relate to the other stakeholder? Here the interviewee is asked to further explain the existing relational tie
35	German association for international cooperation			
36	World Bank			
37	*Other governmental agencies: Regional Ministerial Secretariat of Agriculture, Superintendence of electricity and fuels.			
38	*Other non-profit organizations or foundations: Techo, Waste foundation, Amulen Foundation, others.			

*Note: These stakeholders were added during the interviews, as the interviewees could also describe interdependencies with other relevant stakeholders who were not on the initial list.

Bonus questions, depending on the time and openness of the interviewee, the following questions were formulated:

- Which other stakeholders could be affected by these alternative systems?
- Who else has the power to influence the outcome?
- Could you please suggest key contact names (snowball sampling)?

Data availability

Data will be made available on request.

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