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Identification and Evaluation of Determining Factors and Actors in the Management and Use of Biosolids through Prospective Analysis (MicMac and Mactor) and Social Networks

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Abstract: The reuse of biosolids in agriculture and its inclusion within the circular economy model requires evaluating and analyzing factors that intervene in its management. The objective of the study was to analyze those factors that influence the management and use of biosolids. Fifty-three actors were questioned, and their answers were analyzed using two prospective methods and Social Network Analysis (SNA) identifying between 14 and 19 variables. Six should be prioritized due to their criticality and potential in management and reuse scenarios. It was observed that the formulation of objectives, such as the improvement of infrastructure, creation of an institutional policy, and the establishment of definitions for the kinds of biosolids, are opposed by internal agents. Seven key actors and four to six determining agents were identified in the scenarios. The network of management and use of biosolids in agriculture presented low density (0.28) and the exclusive action of three key actors. Consequently, the participation of a greater number of better-connected actors is required to project networks with a higher density (between 0.49 and 0.57), facilitating the diffusion of information and the inclusion of new actors not previously contemplated. The application of prospective and SNA methodologies focused on biosolids allows the prioritization of determinants, the evaluation of the level of involvement and communication between actors, and other aspects that have not been considered previously in the management of WWTPs in Colombia.

Keywords: centrality measures; interest group; key variables; scenario-based planning; stakeholder analysis; waste management; wastewater treatment plants (WTTPs)

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1. Introduction

The management of solid waste, as biosolids, is one of the main challenges for developing countries, due to the complexity and risk that this process represents in making decisions to develop an efficient, effective, and sustainable process [1,2]. Biosolids are a complex heterogeneous matrix and are the product of wastewater treatment. This product has received one or more stabilization treatments that would allow safe handling to be used [3–5]. Annually, around 2.5×10^7 to 6.0×10^7 tons of dry biosolids from Wastewater Treatment Plants (WWTP) are generated in the world [6]. In Colombia, lately, there has been an increase in the production of sludge and biosolids of domestic origin [7]. This is because of the improvement of the coverage, construction, expansion, and update rates of

the infrastructure of wastewater treatment plants (WWTPs) in the country [8–10], although some impoverished areas still have low rates of coverage [11–14].

The use of biosolids in developed countries and some Latin American regions presents a greater preference for reuse in agricultural activities or direct application to the soil [4,15,16]. In Santiago de Chile, between 2009 and 2017 the use of biosolids in agriculture increased, taking advantage of close to 75% of the biosolids produced [17–19]. In the case of Brazil, in the decade from 2007 to 2017, in the state of Paraná, about 285,836 tons of biosolids were disposed of on agricultural land [20]. While in the case of Colombia the use of these residues in agriculture is almost null, despite having regulations that control this activity, such as Decree 1287 of 2014 [21] and the Colombian Technical Standard (NTC) 5167 (2011) [22].

Decree 1287 of 2017 establishes the determination and quantification of ten heavy metals, Arsenic (As), Cadmium (Cd), Copper (Cu), Chromium (Cr), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Selenium (Se) and Zinc (Zn), as well as thermotolerant coliforms, viable helminth eggs, *Salmonella* sp., enteric and somatic viruses, and phages as an alternative viral indicator. The permissible limits will vary depending on the quality of the biosolids reached (Class A or B), with class B being the one that will present greater restrictions of use compared to type A sludge [21]. The NTC 5167 standard determines the requirements and tests under which solid organic-mineral fertilizers or fertilizers, including biosolids, must be analyzed [22].

However, since 2002 research has been carried out in which this type of use has been evaluated [23]. The main activities of reuse currently carried out by the main WWTPs in Colombia are concentrated on restoring the soil in quarries, improving degraded soils, and preparing land for the entry of livestock, stabilizing slopes, seeding plants and shrubs [24–27]. Unfortunately, in the case of WWTPs in municipalities or other cities that have technical, operational, economic, and infrastructure limitations, it is difficult for them to obtain a Class B biosolid [21], which prevents its use.

In recent years, countries have focused on the acquisition of the circular economy model that includes the promotion of reuse, recycling, and recovery of waste. Thus, changing from the classic vision of the activities carried out by WWTPs towards an "ecologically sustainable system" can be influential and key within the process of wastewater treatment, by-products, use, and environmental sustainability [28–31]. Particularly in Colombia, through CONPES policy 4004 [32], it is projected that in the period from 2022 to 2025 biosolids will be included in the production cycle and their business opportunities will be defined. The use of biosolids in agriculture could become one of the most relevant options in the country, since it is one of the most sustainable and economical methods, especially for areas with technical and economic limitations [33–36]. In addition, taking this type of practice to the countryside, farmers, producers, and transformers would bring great benefits considering the vocation and agricultural capacity of the country [37].

To achieve this type of improvement, traditional management that has been implemented in Colombia must be put aside. This has been characterized by a focus on the evaluation of stabilization processes and the reduction in pathogens, the evaluation of alternatives for reuse or exploitation, and the updating of guidelines or regulations, among others [23]. For this reason, it is essential to identify, evaluate, and analyze other factors that may be affecting and limiting the management and use of biosolids. In research by Venegas et al. [23] through SWOT analysis, it was identified that the management of biosolids has been characterized by low cooperation, association, communication between actors and stakeholders, lack of updated and available information for decision-making, and a low level of use of this type of waste at a national level. Furthermore, the application of the SWOT methodology limited the consideration of other scenarios, because it was analyzed from a current vision or context and did not evaluate the focus and effectiveness of each of the proposed strategies, nor contrast the positions of favorability, disagreement, or neutrality of the different actors and institutions identified in this study [23].

According to the above, it is important to evaluate scenarios through methodologies that identify determinants and positions (neutrality/favorability/disagreement) of the

different actors in the face of the proposed strategies, as well as the degrees of association of the networks of work and communication of one actor with another, regardless of power and influence, and their abilities to play the role of intermediaries, keys, and disseminators of information.

The application of different methodologies, such as social network analysis (SRA), and prospective analyses, including MicMac (Matrix of Cross Impacts Multiplication Applied to a Classification) which focuses on structural analysis and Mactor (Method, Actors, Objectives, Ratio on force) which evaluates stakeholders (actors) for the understanding of the management and use of biosolids in agriculture, would facilitate and strengthen the conversion from a linear model to a circular business model. The contribution and consideration of elements that have not been used or evaluated within the management and use of biosolids in Colombia and the possibility of being applied in sites with similar conditions and difficulties are factors that should be considered. This would open a framework of possibilities and considerations for the reuse of a material and its inclusion in an essential economic activity, such as the agricultural sector.

Prospective analysis is a method of reflection that allows the visualization of future scenarios about a specific subject. This encompasses making decisions that help to reduce possible risks and to pursue opportunities that others have not identified before. On one hand, the MicMac method aims to identify key, motor skills, and dependent variables that are typical of a system, distributed on a plane, and are classified according to their level of motor skills and dependence, based on the degree of influence perceived by the evaluators. On the other hand, from the key variables obtained by MicMac, the Mactor method allows the identification and evaluation of each of the actors along with their position (favorable, neutral, or disagreeing) in the face of a series of challenges or objectives proposed as transformative within the process of change or evolution of a system or scenario [38,39].

The analysis of social networks (SNA) is a tool that focuses on determining, identifying, and comparing the relationships within and between individuals, groups, and systems through the modeling or mapping of the different interactions that may be involved and related to "who knows who" and "who shares with whom" [40,41]. For the graphical representation of the analysis of the networks, nodes represent the actors or institutions, which are connected by edges, and these represent the relationships or flows existing between the nodes [42–44]. To identify which actors are essential in the network, the following metric evaluations are suggested [45,46]: degree of centrality, betweenness centrality, closeness of centrality, and density.

Consequently, the objectives of this study were: (I) to identify and analyze the factors that determine the management and use of biosolids from a WWTP in Colombia through prospective analysis (MicMac); (II) to evaluate stakeholders interested in the management and use of biosolids based on their influence/dependence on other actors and their positions of favorability, disagreement, or neutrality in the face of set objectives (Mactor); and (III) to map and analyze the type of social networks developed and projected by the different actors involved through the two systems.

2. Materials and Methods

2.1. Location and Characteristics of the WWTP

The evaluated WWTP is in the department of Boyacá, Colombia, which receives water collected by the sewerage network municipally from domestic, industrial, and rainwater wastewater. The treatment is an aerobic biological type; it is carried out using the activated sludge process in a Sequential Batch Reactor (SBR). The resulting sludge from the sedimentation process goes through a stabilization process and the biosolid is disposed of directly in the soil surrounding the WWTP infrastructure (Figure 1 and Table 1). In previous studies, it was determined that the quality of the biosolids produced by this WWTP makes their use difficult since the concentration of viable helminth eggs (VHE) [7] exceeds the limits established in Decree 1287 of 2014 [21] of the Ministry of the Environment

of Colombia, without fulfilling the characteristics and parameters to classify the biosolids as class B.

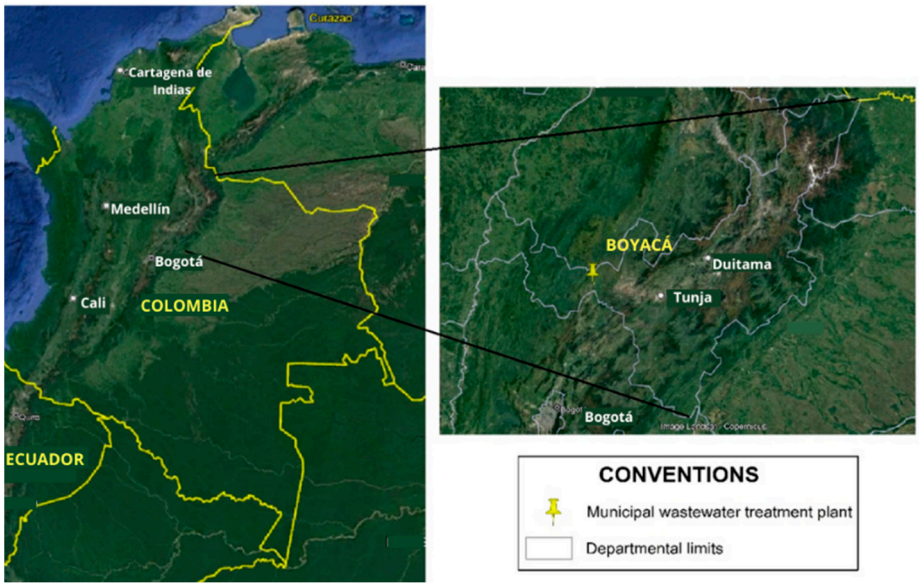

Figure 1. Location of the study area.

Table 1. Description of the WWTP treatment evaluated.

Treatment/Flow Treatment	Population Served	Water Line	Sludge Treatment	Type of Sludge Stabilization	Time of Treatment or Stabilization	Quantity of Treated Sludge Generated
SBR, AS/240 to 252 lps	~72.770 people	Pretreatment, primary, secondary, tertiary (UV light) treatment	Thickeners (polymers) and dewatering	Lime-treated	~1 month	~480 tons/year

~: Approximately, SBR: Sequencing Batch Reactor, AS: Activated sludge.

Average heavy metal concentrations in lime-treated biosolid for Cd, Cu, Cr, Mo, Ni, Pb, and Zn were 46.3, 61.4, 10.5, 4.4, 21.9, 17.2, and 1.1 mg/kg, respectively. Selenium was only detected in one sample, which presented a maximal concentration of 4.0 mg/kg. Furthermore, Ar (<4 mg/kg) and Hg (<0.5 mg/kg) were not detected. On the other hand, the levels of total, thermotolerant coliforms, and *E. coli* are 6.4, 5.9, and 5.4 Log10 CFU/g, respectively. For *Salmonella* spp., the values were 3.1 MPN/25 g, total helminth eggs 53.9 (HET)/4 g, and viable 19.9 (VHE)/4 g. In contrast, the concentration of viral indicators (Somatic Coliphages) corresponds to 5.6 Log10 PFU/g [7].

2.2. Identification of Actors in the Management and Use of Biosolids

The identification of actors was carried out at the national, departmental, and municipal levels, selecting those that were or could be related to the management practices and use of this type of waste. Subsequently, each of the interested parties was characterized according to their functions and roles [23] (Appendix A—Table A1). A survey designed through the Google forms© platform was sent to the different public and private entities that agreed to participate in the current study (Figure 2).

Fifty-three stakeholders participated, these belonging to the following different entities: WWTP of cities and municipalities, control or surveillance agencies (Corporación Autónoma Regional de Cundinamarca—CAR, Instituto Colombiano Agropecuario—ICA), farmers or associations, agroindustry, academia (Acad_), waste managers, national entities (Departamento Nacional de Planeación—DNP), Municipal and city WWTPs, and the

Economic and Agricultural Development area (Area de Desarrollo Económico y Agrícola—DEyA) of the municipality understudy (Appendix A—Table A1).

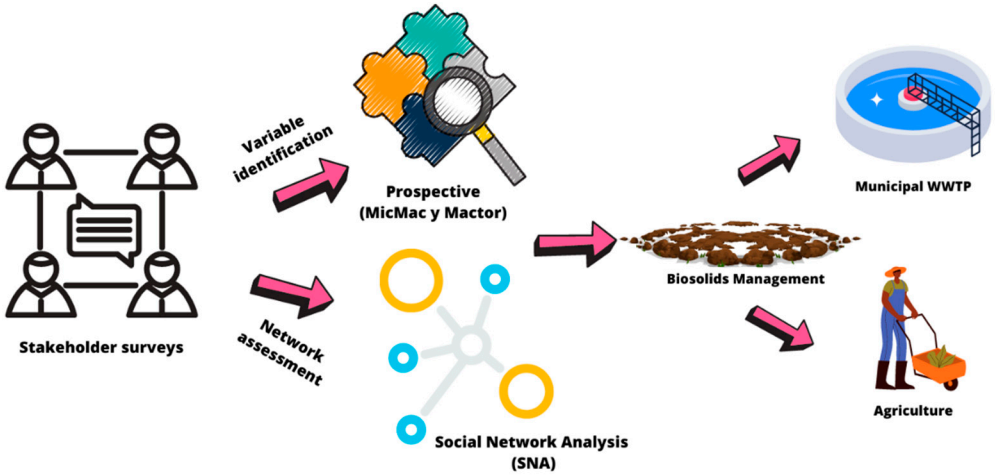

Figure 2. Methodological diagram.

2.3. Surveys and Private Interviews

The survey was conducted from January to July 2021. Its objective was to evaluate the incidence of a series of variables or determinants related to the management of sludges and biosolids in the WWTP and the use of these wastes in agriculture. Through the specific interviews, the objective was to determine and characterize the different actors regarding their influence/dependence and their position of agreement or disagreement in the face of a series of challenges posed. Finally, the type of network connections was determined based on the exchange of information and collaboration between actors (Figure 2).

2.4. Data Analyses

The different data collected from the surveys were consolidated in Microsoft Excel© (Version 2110) and the qualitative evaluations were categorized by establishing numerical scales for the MicMac software (Version 5.3.0) [47], and Mactor (Version 5.3.0) [47] analyses. Gephi (Version 0.9.2) software was used for SNA [48]. Acronyms were used, facilitating the visualization and understanding of the distribution of the variables (Table 2 and Figure 2).

2.4.1. MicMac Method: Variables Identification and Structural Analysis

The formulation and identification of the variables or factors of change were carried out through interviews, literature review, and the results of the SWOT analysis described in Venegas et al. [23], which focused on the evaluation of Colombian regulations and management with the same WWTP objective of this study. The following two questions were analyzed: (I) What are the factors that condition the management of biosolids? (II) What are the factors that determine its subsequent use in agriculture? A total of 14 and 19 variables were obtained, respectively, for each question, which was entered in the survey and interviews (Table 3), and evaluated using a numerical scale. This was followed by the consolidation of all the evaluations and the development of the MicMac methodology proposed by Godeth et al. [38,47].

Table 2. List of acronyms and definitions of the variables or stakeholders.

Short Form	Long Title	Short Form	Long Title	Short Form	Long Title	Short Form	Long Title
AA	Available area	ESPB	Departmental Public Utility Company	SSPD	Superintendency of Domiciliary Public Utilities	WWTP-OTD	Operational and Technical Division of the WWTP
Acad_	Academia	F/A	Farmes or Associations	Risk	Risk		
AI	Agro-industry	ICA	Colombian Agricultural Institute	SA	Stakeholder Articulation		
AQ	Affluent Quality	IEP	Institutional environmental policy	ST	Stabilization time		
AS	Agronomic Studies	Inf_	Information	TE	Treatment Efficiency		
BM	Business Model	Inst_	Institutionality	TK	Traditional Knowledge		
BT	Biosolid Type	IPU	Institutional Policy of Use	Tra_	Training		
CAR	Regional Autonomous Corporation of Cundinamarca	May_	Mayoralty	TSR	Treatment System Renewal		
Cert_	Certifications	MC	Municipal Council	WM_	Waste Managers		
Comm_	Community	MinA_	Department of Environment and Sustainable Development	WWTP(s)	Wastewater Treatment Plants		
Commun_	Communication	MinV_	Department of Housing, City and Territory	WWTP-EM	Environmental manager of the WWTP		
Cost	Cost	Ope_	Operability of the WWTP	WWTP-FA	Financial Area of the WWTP		
DEyA	Economic and Agricultural Development Area	Pers_	Persons	WWTP-Infr_	The infrastructure of the WWTP		
DNP	National Planning Department	PS	Product Satisfaction	WWTP-Manag	Manager of the WTTP		
EI	Environmental Incentives	Reg_	Regulations	WWTP-Op	Operators of the WTTP		

CAR: Corporación Autónoma Regional de Cundinamarca, DEyA: Área de Desarrollo Económico y Agropecuario, DNP: Departamento Nacional de Planeación, ESPB: Empresa Departamental de Servicios Públicos, MinA_: Ministerio de Ambiente y Desarrollo Sostenible, MinV: Ministerio de Vivienda, Ciudad y Territorio, SSPD: Superintendencia de Servicios Públicos Domiciliarios.

Furthermore, the double-entry matrix (structural analysis matrix) was used for the evaluation of the effect and interactions of the study variables. The qualification of each of the variables (Table 3) was carried out according to the following question: Is there a direct influence relationship between variable i and variable j? The rating was used according to the influence scale of 0 to 4 proposed by Godet et al. [38,47]. The assessment obtained was entered into the MicMac software [38,47]. Finally, the identification of subgroups of variables (environment variables, regulators, objective, keys, outcome, autonomous, determinants, and secondary levers) was inferred from their location and distribution in the influence and dependence plot.

Table 3. Variables or factors for the management of biosolids in the WWTP and their subsequent use in agriculture.

Short-Form	I	II	Definitions
AQ	X	X	Presence of organic and inorganic compounds in the water that enters the WWTP for treatment
AS		X	Studies to determine the type of soil and quantity of biosolids to be added according to the conditions and requirements of the soil and the type of crop
AA	X		Space available to the WWTP to carry out stabilization processes and temporary or final disposal of sludge and/or biosolids
BT		X	Class or type of biosolid generated by the WWTP for its use
BM		X	Definition and establishment of the form of distribution and destination of the profits of the stakeholders involved
Cert_		X	Obtaining the endorsement or authorization for the distribution of the stabilized product for use in the agricultural sector
Commun_		X	Disclosure of the management, results, and quality of the biosolids obtained
Comm_	X	X	Inclusion of the communities or group of people involved in the management of sludge and biosolids and in processes that lead to acceptance of reuse in agriculture.
Cost	X		Final treatment costs passed on to the aqueduct and sewer users
Cost		X	Costs of biosolid stabilization treatment to class A and B and compliance with decree 1287
EI	X		Incentives that the WWTP receive for the proper management and disposal of sludge and biosolids
Inf_	X	X	Availability of updated information on aspects related to the management of biosolids for both control entities and interested stakeholders
WWTP-Infr_	X		Current conditions of operation and proper functioning of the WWTP
IEP	X		Adoption and fulfillment of an institutional mission and vision focused on adequate management of biosolids
IPU		X	Adoption and fulfillment of a mission and vision by public service institutions focused on the proper use, control, and monitoring of biosolids in agriculture
Inst_	X	X	Presence and coordination of public and private entities to control compliance with current regulations related to sludge management and the use of biosolids.
Ope_	X	X	Correct operation of the WWTP complying with the times and other parameters established from the design, instructions given by the manufacturer, and operation manual
PS		X	Satisfaction of the people who use the product
Reg_	X	X	Compliance with the requirements or parameters indicated in the standards or decrees that regulate sludge management and the production, classification, and reuse of biosolids in agriculture
Risk		X	Detection and reporting of the presence of emerging persistent pollutants in biosolids
ST		X	Additional time is required for the product to exhibit Class A or B biosolids characteristics
SA		X	Linking public and private actors for the management, commercialization, and use of biosolids in agriculture
TK		X	The difference in perceptions between actors regarding the use of biosolids in agriculture
Tra_	X		Training of personnel for the treatment and control of the stabilization process of sludge and biosolids
TE	X	X	The efficiency of a team or a series of processes to obtain usable waste under Decree 1287 of 2014
TSR	X		Degree of updating or renovation of sewage and sludge treatment system

(I) factors that condition or affect the management of biosolids, (II) factors that condition or affect the use of biosolids in agriculture.

2.4.2. Mactor Method: Stakeholder Strategies Analysis

The different phases to carry out the identification and evaluation between actors and the analysis of the positions of disagreement/agreement with the challenges and objectives are described below. This is based on two types of rating scales that correspond to the influence between actors and the intensity of positioning against the proposed objectives.

Identification of Actors, Strategic Challenges, and Associated Objectives

The actors that could influence the 26 variables identified and listed in the MicMac methodology (Table 3). Based on the six key variables identified, six strategic challenges and 12 associated objectives were proposed to later expose them to each of the actors, to obtain and identify their position of neutrality, disagreement, or favorability (Table 4).

Table 4. Challenges and objectives associated with the key variables of the management and use of biosolids in the WWTP understudy.

Challenges and Objectives of Biosolids Management in the WWTP Understudy	
Short-Form	**Description of the Proposed Objectives**
TE	• Document and implement mechanisms for the control, monitoring, and verification of sludge production with its stabilization processes within the second half of 2021.
IEP	• Prepare and adopt an institutional policy for the company that operates the WWTP that allows the stabilization of sludge until achieving 10% class B biosolids. • Define a policy for the use of biosolids within the company that operates the WWTP projected for the first half of 2022. • Involve municipal institutions or entities in the study area in the institutional policy of use within the first semester of 2022. • Initiate the dissemination and integration of the institutional policy built, with 30% of the officials of the PTAR operating company
WWTP-Infr_	• Implement the necessary adjustments for stabilization using drying beds together with the addition of lime in the next 12 months. • Implement corrective maintenance for 50% of the equipment that has failures as of 2021 and that are currently operated manually.
Challenges and objectives for the use of biosolids in agriculture	
BM	• By 2022, start conversations and activities with the different actors involved in the distribution and use of biosolids. • Define the mechanism or form of distribution of biosolids to start with the use in agriculture in 2022.
Cert_	• Request to the ICA the registration of producer and/or distributor of biosolids as agricultural input and obtain it before the end of 2022.
BT	• Define the type or class of biosolid that is chosen in agriculture for the year 2022. • Establish monitoring mechanisms for 10% of the substances evaluated in other international regulations.

Assessment of Influences between Actors

After the evaluation of influence and dependence from zero to four, proposed by Godet et al. [38,47], the values obtained were consolidated according to the power relationships of one actor over another, directly or by a third party. Then the middle values were entered into the Mactor software [47] obtaining a representation of Actors × Actors according to their influence-dependence level, classifying the actors as determining, liaison, dominated, or autonomous.

Ranking of Each Actor According to Their Priorities by Objectives

The evaluation of the strength of positioning of each of the identified actors in the face of the previously proposed challenges was carried out through an assessment from zero to four together with the +/− signs that signify favorability and disagreement, allowing us to obtain a representation of Actors x Objectives [38].

2.4.3. Social Network Analysis (SNA)

Based on the evaluations obtained from the surveys carried out for the 53 stakeholders in which the level of work or communication with the different entities was determined, the average of each of the relationships was entered through adjacency matrices to the Gephi software [48] (Version 0.9.2). The three types of social networks obtained and analyzed corresponded to: (I) Level of communication and work of the WWTP, (II) Desired level of communication and work in the management of the WWTP, and (III) Desired level of communication and work for the use of biosolids in agriculture. The analysis metrics chosen were as follows:

Betweenness centrality: This value is used to determine the role of the actors that become bridges or links of interactions in the "middlemen" network. That is, it shows when a person is an intermediary between two other people in the same group who do not

know each other [45,46,49]. Degree centrality: It is defined as the number of links that a node has. In a network, the actor with the highest degree of centrality is considered the key actor in the network. Closeness centrality: Represents the ability of a node to reach others through a reduced number of routes or paths and the possibility of efficiently disseminating information [45,46,49]. Density: degree of network connection, where a value of zero (0) represents a total disconnection, while a value of one (1) indicates all network actors are directly linked to each other information [45,46,49].

3. Results

3.1. Identification of the Factors That Determine the Management of Biosolids, MicMac

Fourteen variables were identified in the management of biosolids and sludges in the WWTP of the current study, which was plotted in the influence-dependence map (Figure 3A). As key variables, treatment efficiency (TE), infrastructure (WWTP-Infr_), and institu-tional environmental policy (IEP) were identified. For fulfilling the system improvement with the key variables, those should work together with the following objective variables: regulations (Reg_), institutional participation (Inst_), and design/use of environmental incentives (EI) (Figure 3A).

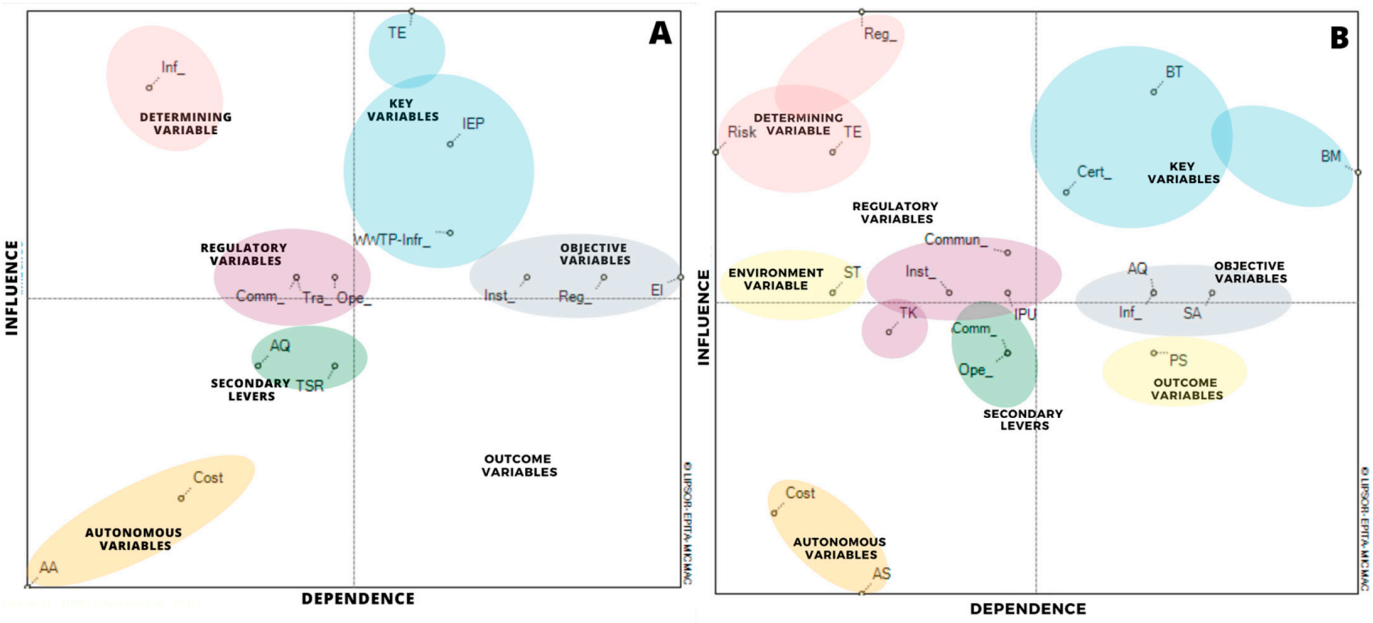

Figure 3. MicMac variables are distributed in the influence-dependence map. (**A**) Management of biosolids in the WWTP. (**B**) Agricultural biosolids utilization.

Other important variables which will impact the system performance and/or fulfillment of key variables are regulatory variables: communication (Commun_), operability of the WWTP (Ope_), and training (Tra_). However, treatment renewal system or biosolids stabilization variables (TSR) and affluent quality (AQ) could work together with the identified regulatory variables (Figure 3A). Information (Inf_) was identified among the determining variables as one that could act as a promoting or inhibitory factor depending on its evolution. Finally, cost (Cost) and available area (AA) were classified as autonomous variables, which are non-determining variables for the future of the system.

On the other hand, 19 variables that could influence the biosolids utilization were identified and distributed in the four quadrants of the influence-dependence map (Figure 3B). Key variables included: certification for distribution or commercialization (Cert_), biosolid type after stabilization (BT), and business model (BM), related to the product distribution and costs. Within the objective variables, information (Inf_), affluent quality (AQ), and stakeholders articulation (SA) were identified. The development of those variables could influence the positive evolution of the system (Figure 3B).

In addition, communication (Commun_), institutionality (Inst_), the institutional policy of use (IPU), and traditional knowledge (TK) were identified as regulatory variables. Community (Comm_) and operability of the WWTP (Ope_) were found as secondary lev-ers. Determining variables were risk (Risk), treatment efficiency (TE), and regulations (Reg_), the latter with a higher degree of influence (Figure 3B). Stabilization time (ST) was identified as an environmental variable, with few impacts on the improvement of the system (Figure 3B).

Cost (Cost) and agronomic studies (AS) were categorized as autonomous variables. Product satisfaction (PS) was found to be an outcome variable. Variables in this area give a descriptive indication of the system evolution, although it is not possible to approach them directly through those depending on the system (Figure 3B).

3.2. Evaluation of Stakeholders in the Management and Use of Biosolids, Mactor

Direct and indirect influences in the management of sludges and biosolids of the WWTP were determined for the 19 actors identified in the influence/dependence assessment (based on their interests in the development of the system) (Figure 4A). Determining, liaison, autonomous, and internal actors were identified.

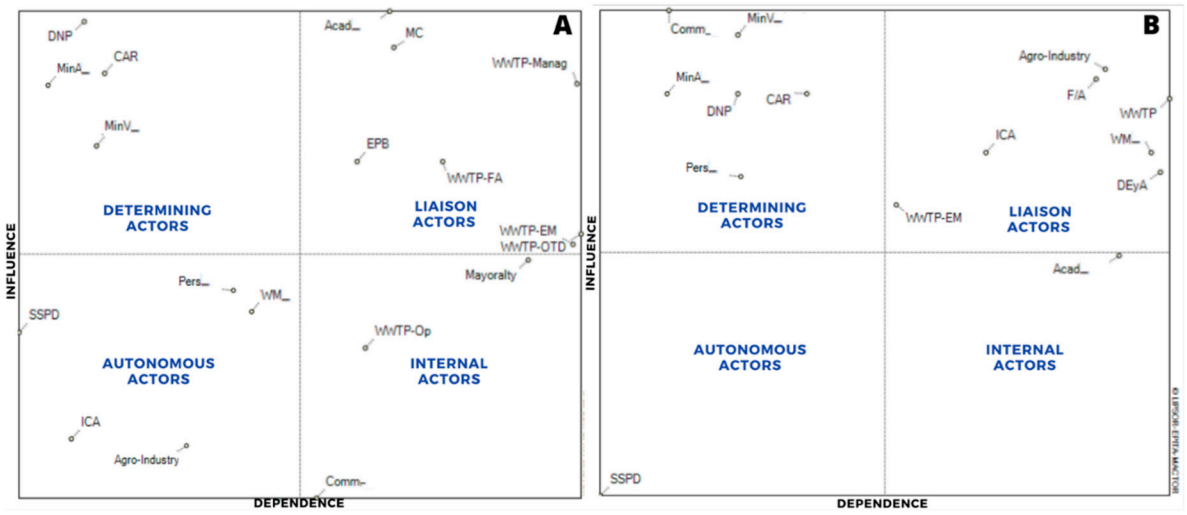

Figure 4. Results of the plane of influences and dependencies between actors of the management of sludge and biosolids in the studied WWTP and the use of biosolids in agriculture. Mactor influence/dependence map of the actors involved in the management of sludges and biosolids (**A**) and agricultural use of biosolids (**B**).

As shown in Figure 4A, determining actors included the National Planning Department (DNP), the Regional Autonomous Corporation of Cundinamarca (CAR), the Department of Housing, City and Territory (MinV_), and the Department of Environment and Sustainable Development (MinA_). The seven liaison actors were as follows: (I) Company in charge of WWTP management (WWTP-Mang), (II) Financial area of the WWTP (WWTP-FA), (III) Public Utilities Departamental Company—Boyacá (EPB), (IV) Academia (Acad_), (V) Municipal Council of the WWTP (MC), (VI) Environmental manager of the WWTP (WWTP-EM), and (VII) Technical and Operational Director (WWTP-OTD).

The actors with low influence and dependence, but that could act as secondary leverage, were also identified: Persons (Pers_), Waste Managers (WM), Superintendency of Domiciliary Public Utilities (SSPD), Colombian Agricultural Institute (ICA), and Agro-Industry (AI). Finally, Mayoralty (May_), WWTP operators (WWTP-Op), and Community (Comm_) were grouped as internal actors (Figure 4A).

Figure 4B shows the categorization and distribution of the 15 actors considered for the agricultural use of biosolids, distributed as follows: (I) Determining actors: community (Comm_), Department of Housing (MinV_), Department of Environment (MinA_),

DNP, CAR and Persons (Pers_); (II) Liaison actors: Agro-industry (AI), Farmers or Associations (F/A), Waste managers (WM_), ICA, Economic and Agricultural Development Area (DEyA), Environmental Manager of the WWTP (WWTP-EM) and WWTP; (III) Autonomous actor: Superintendency of Domiciliary Public Utilities (SSPD); (IV) Internal actor: Academia (Acad_).

Considering the objectives proposed in Table 4 and power relationships between different actors both in the management of biosolids at the WWTP and its use in agriculture, it is shown in Figure 5 that the strategic challenges present a favorable position. The values observed on the X-axis indicate the strength or level of commitment of the stakeholder towards the proposed objectives—the higher the level, the more affinity.

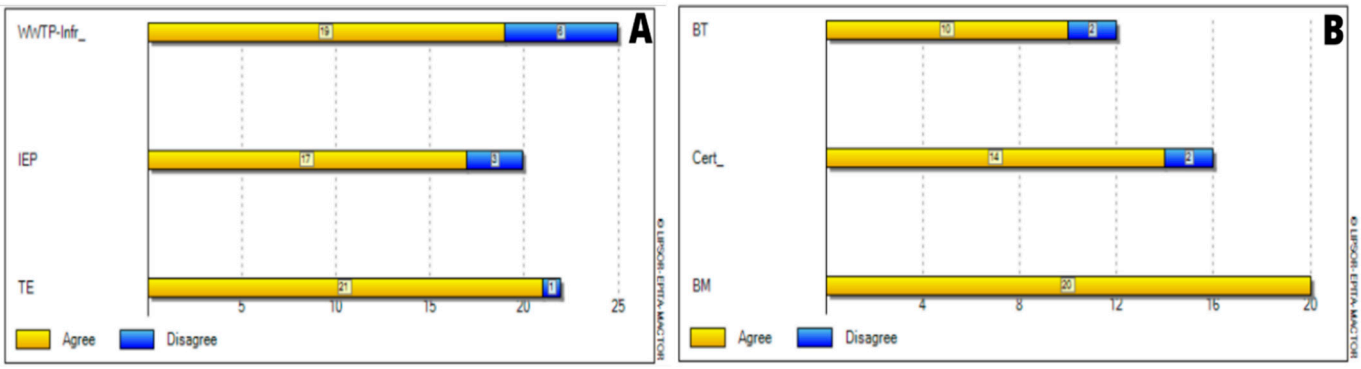

Figure 5. Histogram of stakeholder involvement on objectives. (**A**) WWTP management. (**B**) Agricultural use of biosolids.

The WWTP infrastructure (WWTP-Infr_) and the Institutional Environmental Policy (IEP), showed a lower level of commitment, and followed by Treatment Efficiency (TE) (Figure 5A). For the biosolids utilization scenario, the Business Model (BM) had a higher power relationship, while obtaining certifications (Cert_) and determining the Biosolids Type (BT) were not favorable for the study (Figure 5B).

3.3. Mapping of Social Networks Analysis (SNA) for the Management and Use of Biosolids

From the responses and ratings obtained from the stakeholders (actors) involved in both the management of the WWTP and the agricultural use of the biosolids, three network diagrams were obtained. Figure 6 represents the current communication and work state of the actors, the WWTP management, and biosolids use. Figures 7 and 8 show the desired level of communication and work for both internal WWTP management and agricultural use of biosolids, respectively.

According to Figure 6, the current management of biosolids carried out in the WWTPs of some cities and municipalities is focused on three key actors which belong to the nodes of WWTPs, waste managers (WM_) and CAR, in which the degrees of centrality were 20 and 17. On the other hand, the highest betweenness centrality level was obtained with the WWTPs (32.8), which makes them an intermediary actor in management. In contrast, the community (Comm_) and the waste managers (WM_) were identified as the closest actors to the others and acted as information disseminators, based on the closeness degree reached by each one (1.0 and 0.83).

Figure 7 showed that the central node belongs to WWTPs as well, although a higher number of key actors were involved in this network (WWTPs, CAR, Acad_, WWTP-EM, Comm_, WM_, and Pers_), indicating a stronger centrality degree (Degree: 19–14). In terms of closeness, the same key actors were identified, and the appearance of the Mayoralty is highlighted. However, a higher affinity is observed between CAR, Mayoralty, Environmental Manager of the WTTP (WTTP-EM), Academy, and the WWTPs, which could be connected to the other nodes without covering long distances within the same identified network. In contrast, it could be inferred that CAR and WWTPs could become

liaison actors with the other stakeholders of the network, due to the values obtained for the betweenness degree (2.25 and 2.05).

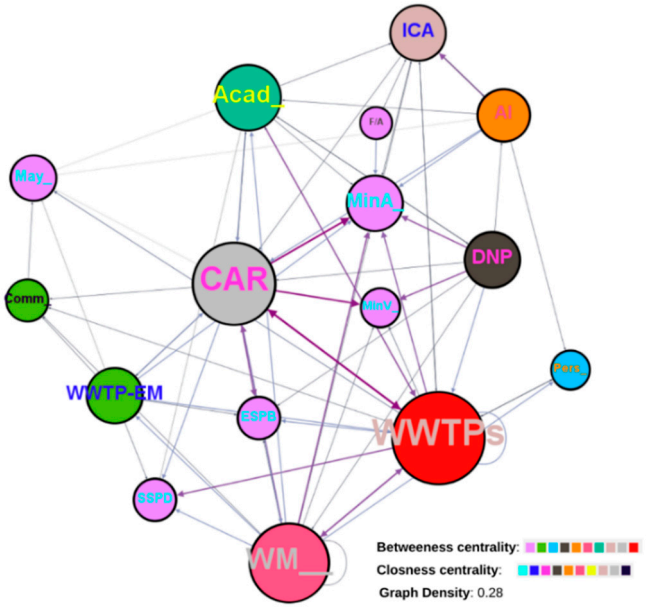

Figure 6. Communication and work level among different actors, management of the WWTP, and agricultural use of biosolids. The intensity of the colors of the edges represents stronger connections (weight). The larger the size of the nodes, the higher the degree level (degree). The colors of the node names represent the closeness centrality, with black being a higher closeness centrality value. Betweenness centrality is represented by the range of colors of the nodes from lilac to red, with the latter being the one with the highest valuation.

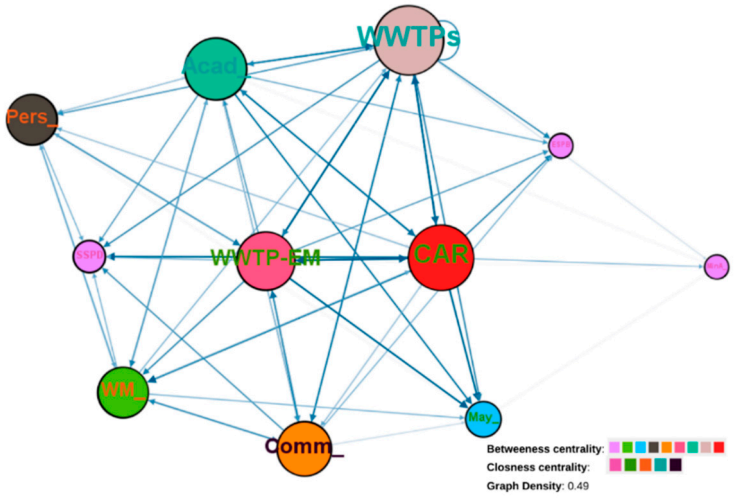

Figure 7. Desired levels of communication and work for the internal management of biosolids and sludges in the WWTP. The intensity of the colors of the edges represents stronger connections (weight). The larger the size of the nodes, the higher the degree level (degree). The colors of the node names represent the closeness centrality, with black being a higher closeness centrality value. Betweenness centrality is represented by the range of colors of the nodes from lilac to red, with the latter being the one with the highest valuation.

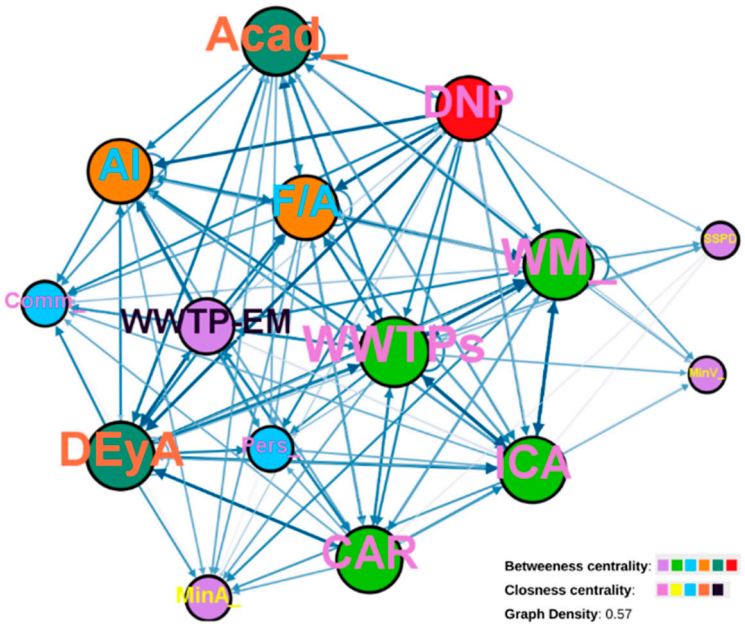

Figure 8. Desired level of communication and work between the different actors involved in the agricultural use of the biosolids. The intensity of the colors of the edges represents stronger connections (weight). The larger the size of the nodes, the higher the degree level (degree). The colors of the node names represent the closeness centrality, with black being a higher closeness centrality value. Betweenness centrality is represented by the range of colors of the nodes from lilac to red, with the latter being the one with the highest valuation.

Finally, Figure 8 indicates the desired level of engagement of the different actors for the utilization of the biosolids for agricultural purposes, which was focused on six key actors with a strength range between 25 and 27 (Degree) including: WWTPs, waste managers, academies, the Economic and Agricultural Development Area (DEyA), ICA, and CAR. The actors WWTPs, Waste Managers, ICA, and CAR, with a betweenness degree of 2 were also notable.

As for the density, scores close to 0 represent weak connections while scores close to 1 represent strong connections. In the case of the current management carried out in the WWTPs, a density score of 0.28 (Figure 6) was obtained, indicating a low and weak degree of integration between the existing actors in the management network. In contrast, desired networks of work and communication for both the management and utilization of biosolids revealed density scores of 0.49 and 0.57 in Figures 7 and 8, respectively, which were higher than the current density score of the WWTP management network. These results show opportunities for improvement in WWTP management and biosolids utilization supported by a better connection between actors in the proposed/desired networks, which could be enhanced with the participation of other stakeholders.

4. Discussion

4.1. Analysis of the Identification of the Factors That Determine the Management of Biosolids, MicMac

4.1.1. Management of the WWTP

According to the results obtained in the current study (Figure 3A), the high level of influence and dependence of the key variables (TE, EIP, and WWTP_Infr) could be explained due to the current conditions of operation and management of the WWTP. The lack of an organizational structure (policy, mission, vision, and objectives) focused on biosolids and sludges as well as the deficiency in the stabilization of sludges and conditions of the machinery of the WWTP could lead to the low quality of the obtained sludges interfering with further applications [50]. Thus, these key variables are considered by

the different stakeholders as a priority and a key opportunity for the improvement of the WWTP.

On the other hand, objective (Inst_, EI, and Reg) and regulatory (Comm_, Ope, and TRA) variables were identified as essential tools that could act as enhancers to improve the management and operation of the WWTP. From those, it is important to highlight the impact of periodic training on all the employees and the community involved with the WWTP, as it leads to a better appropriation and knowledge of the system, resulting in a more proper operation of the processes carried out in the WWTP, with the final endpoint being an improvement in the decision-making of the WWTP [51,52]. Likewise, the environmental incentives (EI) for the management of sludges and biosolids became relevant in Colombia as governmental parties have encouraged companies to implement national policies which lead to better conversion and good use of biosolids and sludges [53–55].

In addition, secondary levers variables (TSR and AQ) could act as a complement for the system as these could impact both key and regulatory variables. Treatment system renewal (TSR) could favor the stabilization processes, nutrients' recovery, and enhancement of derived products, such as fertilizers obtained from the sludges [56]. Furthermore, affluent quality (AQ) has a direct impact on the biosolid types obtained after processing, which in some cases could increase the costs of the overall process depending on its quality, and the amount of trace elements, such as heavy metals and pesticides, among others [57–59], affecting about the 20–60% of the total budget of the WWTP [60,61]. Thus, AQ should be considered an essential variable that should be monitored in terms of Emerging Organic Compounds (EOC) and other residues present in the biosolids and sludges as a result of nearby industrial activities or other external contamination sources, even if it is not included in the regulations of most of the Latin American countries [21,62–64] except for Brazil [65–67].

Finally, the identification of "information" (Inf_) as a determining variable is crucial as the accessibility and availability of updated information could impact (positive or negative) the decision-making parties and planners for the management of the WWTP. Similarly, information should be available for the community, encouraging their participation and ensuring that the decision-making process is clear and sustained, increasing the effectiveness and efficacy of public policies and regulations [68,69].

4.1.2. Agricultural Use of Biosolids

In terms of the use of the biosolids (Figure 3B), biosolid type, business model, and certifications (BT, BM, and Cert_) were identified as key variables, which means that if those gain intervention, it will affect the overall performance of the system, likely resulting in an improvement in the use of biosolids (Figure 3B). Defining a business model (BM) and the articulation of public and private entities under the companionship of local governments favors access to the biological fertilizers market and direct application in the soil for agricultural practices [70,71]. Strategical alliances between different organizations could benefit the management and use of biosolids [72]. Obtaining certifications for the final products provide an advantage for the commercialization of fertilizers and direct use in the soil, as it represents an aggregated value and differential factor for the final product [73].

Actions between objective variables (AQ and Inf_) in this case represent a higher level of influence and dependence compared with the impact in the management of the WWTP in which those were identified as secondary and determining levers (Figure 3A). Interestingly, here stakeholders' articulation (SA) was identified as another objective variable in contrast with the WWTP management, as several direct and indirect actors are interested in biosolids utilization [36]. The articulation and integration of the different stakeholders in which responsibilities and functions are established will pave the way for the achievement of the objectives and challenges proposed for wastes management with an effective and sustainable process [74]. As an example of third parties' participation in Colombia, certain public and private companies are willing to provide consulting services for biosolids

management [23], as well as current national policies willing to include WWTP by-products in the circular economy model [32].

On the other hand, secondary (Comm_ and Ope_) and regulatory (Commun_, Inst_, TK, and IPU) variables would help key and objective variables to work properly, as a clear institutional policy in conjunction with assertive communication will articulate individual efforts towards the same objective. In terms of the traditional knowledge (TK) of the community, and agreement with a previous study [23], it is a favorable position due to the interest in further applications of biosolids in agriculture for both the community and stakeholders.

The determining variables (Reg_, Risk, TE) become crucial factors for the system and could lead to opposite positions in the stakeholders and management of the biosolids [36,75–78]. One of the most important is risk perception/assessment, as the incorporation of biosolids in agriculture and soil could represent a hazard for some parties due to the incorporation of chemical or biological residues obtained after the treatment of wastewaters even after the stabilization process [3,4,79], leading to the acceptance or rejection for the incorporation in agriculture in agreement with the regulatory policies. In the case of the WWTP of the current study, it is not possible to use the by-products after the stabilization process, because it exceeds the maximum limit of microorganisms allowed [7,21]. Stabilization Time (ST) was identified as an environmental variable, that even if it did not have a high dependence level for the system, it could be considered, as it might affect other variables involved in the reutilization process.

4.2. Evaluation of Stakeholders in the Management and Use of Biosolids, Mactor

The influence and dependence positions of the determining actors for the management and use of biosolids (Figure 4) mainly showed the impact of institutional and control parties which were identified as high influence/low dependence actors highlighting their importance for the system. This makes them key players in the system as are involved in the strategic planning and regulations for the field, approving or revoking processes among the WWTPs [80]. Additionally, it is important to keep in mind considerations of the community and the people as their participations are relevant in terms of establishing objectives, interests, concerns, or restrictions on the use of the biosolids and by-products and could exert some pressure on the field (Figure 4B).

Liaison actors identified for both management and use of biosolids (Figure 4A,B) require adequate coordination and agreements between the parties, since they are prone to generate conflicts among themselves, giving, as a result, isolated and discontinuous participation [81]. Moreover, internal variables (Figure 4), including Community, Mayoralty, and WWTP operators for the WWTP management and academia for biosolids use, are conceived as dependent actors due to the subordinated conditions that some may have, depending on the actions, projects, and decision-making from the stakeholders of the liaison. Biosolids management had led to the identification and achievement of goals and opportunities for improvement based on the interaction of different stakeholders which had some levels of resilience to the application of these by-products as reported in previous studies [75,82].

As for the six challenges proposed in Table 4, disagreements regarding the development and fulfillment of those were concentrated on three main actors of the WWTP: WWTP-Mang, WWTP-FA, and WTTP-OTD. This opposition may be due to the additional costs that might need to be assumed for the proper and periodic maintenance of the infrastructure, the implementation of new systems, controls, and the certification of the by-products as organic. Thus, besides the main budget line for the sludges and biosolids treatment, entities should contemplate in their financial statements a budget line for contingencies, which increases the total budget, forcing them to seek and manage resources for both long- and short-term sustainability [60,61,72]. Another important factor for the economic impact of the WWTP is that the Water and Sewer Utility bills in Colombia do not include the total costs for adequate management of the WWTP, including the treatment

and stabilization of biosolids, apart from the administrative costs [83]. Keeping updated the information will favor the sustainability of the WWTPs along the country based on the needs of each region and its management of wastewaters.

4.3. Social Network Analysis (SNA) for the Management and Use of Biosolids in Agriculture

SNA analysis for the current study showed a low-density level (0.28) for the management of the WWTP and use of the biosolids, involving few actors in the degrees of centrality and betweenness levels based on the communication and interaction levels between WWTPs located in different cities/municipalities of Colombia and other stakeholders (Figure 6). These low-density values are the result of weak interactions among stakeholders in the systems leading to fragmentation issues, such as reduced feedback and low cooperation between the different actors, which could impact the operation of the WWTPs and the utilization of biosolids [80]. With these results, we identified one of the main concerns as the articulation and functionality of the WWTPs and their impact on the community. Low interactions and weak communication flux between parties result in the overall perception of the community as well as for other external entities. Currently, there is not a good perception of the system by the community, as some people describe it as having a poor (25.9%) or intermediate (37%) performance [23].

With the results obtained in this study, we identify good opportunities for improvement as the implementation of a new system in the future involving more novel actors could favor a better operation, management, and further applications of the WWTPs and their by-products. Figures 7 and 8 suggest that if working in collaboration with other stakeholders, it would be possible to improve the communication among them and to enhance networks among stakeholders obtaining density levels of about 0.49 or 0.57, and a higher closeness centrality and betweenness centrality. Giving, as a result, a direct interaction between parties for improving the performance of the system [84], facilitating access to the information, and acting as mediators for internal and external parties, even in the case of decision-making.

Implementing other actors for the management of the organizations favors the decentralization of the system leading to better organizational and planning opportunities and strengthening the networks at horizontal and vertical levels, causing significant changes in the systems. Despite this, there will still be other challenges to the articulation of the systems that will have to be mediated by key actors, intermediaries, and information disseminators [45,49,85]. The development of a network with better connections, density, and centrality values will be favorable for the system, since currently, most public and private entities have shown a willingness to participate in the improvement of biosolids management and quality, as well as a favorable position (>64%) regarding the use of biosolids in agriculture [23].

4.4. Management Framework and Methods Analysis (MicMac, Mactor, and SNA)

MicMac and Mactor analyses of the system based on the influence and dependence of variables and actors are good and useful prospective strategies, as those helped us to identify the determining variables and actors that have a real impact on the management of the WWTP and further use of biosolids. Key actors and variables would be the basis for the system to achieve and fulfill the proposed challenges and objectives, leading to an improvement and significant change in the functionality of the WWTP. However, one of the limitations of the Mactor strategy is that it only considers the incidence level of stakeholders in terms of existence, mission, projects, and processes that could be involved, leaving aside other aspects, such as communication and direct work. Levels of communication and direct execution that could carry out specific actors in the system, despite their power and influence, become important characteristics due to the operational capacities they could represent, changing the roles of key actors in terms of information dissemination and networking with other communities and stakeholders. Therefore, the consideration of

other method analyses, such as the SNA strategy, is essential for a better understanding of the role and interactions of stakeholders and variables for the evaluated systems.

The integrated analysis used in this study allowed us to identify the main factors related to the management of the WWTP and treatment of biosolids, related to influence and dependence of stakeholders as well as the identification of opportunities for improvement in the communication and workflow for the fulfillment of the objectives. Our results and the applications of the merged analysis of MicMac/Mactor and SNA will complement the traditional management of the WWTP in terms of (I) pathogens reduction, (II) further applications of biosolids, (III) operational skills, (IV) organic fertilizers market studies, and (V) possible applications of by-products to soils with agricultural and veterinarian approaches [23,86].

Our results are an essential contribution to the development of CONPES 4004 [32], aimed at identifying the potential use of wastewater by-products and integrating them under the circular economy strategy, as well as new business opportunities. This is the first study in Colombia in which prospective strategies are used and integrated with SNA in terms of management of sludges and biosolids with further applications in agriculture. Structural analysis, stakeholders' evaluation, and social network analysis allowed us to understand the current execution of the system, but also to identify future scenarios that may improve WWTP management and biosolids re-utilization, giving the basis for planning new challenges and breaking barriers for integration/articulation of interested parties and decision-making entities.

According to EU data, the use of dried sludge for agriculture has been increasing in recent years and is projected to keep growing in the coming years [13,16,87,88]. This effect is largely due to the existing legislation on the management of this waste and the formulation of a new regulation focused on the inclusion of solid waste in the circular economy model that would favor their production, recycling, and disposal on land suitable for agriculture [13]. Additionally, in recent years the European Union has adopted an ambitious circular economy plan that promotes the reuse, recycling, and recovery of waste, allowing the classic vision of WWTPs to be changed, projecting it towards a more sustainable model [28,29,89]. On the other hand, the approach taken by the European community is interdisciplinary, considering the economic and environmental complexities of the sites where waste management mechanisms are developed [90].

The opposite is the case in developing countries in which the management and use of solid waste (biosolids) are not one of the main objectives, even though these present high biological risks in various scenarios. Equally, this situation entails the formulation of challenges due to the complexity of this process in making decisions to develop an efficient, effective, and sustainable process [36,91–93]. Within the different improvement processes in waste management, the following have been proposed: coherent and effective governance models, the acceleration of the transition to a circular economy, the promotion of participation of local scenarios, the generation of data and information to understand and improve waste management, and the coordination of objectives between national, municipal and local entities [94–97].

The execution and analysis of future scenarios and the analysis of networks from the vision of a municipality in Colombia becomes a key that allows the relationship and prioritization of various variables, challenges or objectives, validation of the positions, and inclusion of new actors or decision-makers under the approach of improving the internal management of biosolids in a WWTP, as well as the subsequent use of these allowing the creation of bases for organization, participation, and recognition of new actors.

The analysis of this study corroborates that, although progress has been made in Latin America and specifically in Colombia, in the implementation of policies and regulations regarding the management, disposal, and reuse of biosolids, an organizational change must be achieved in which the actors involved understand the importance of adequate reuse of this waste to take advantage of it inland destined for agriculture and thus incorporate it into the productive cycle under the circular economy model.

The legislation in the country advanced in this specific aspect with the issuance of decree 1287 of 2014 [21] by which criteria are established for the use of biosolids generated in municipal wastewater treatment plants. However, this is not fully met due to the existence of technical, structural, financial, cultural, and social difficulties in the WWTPs and their areas and population of influence. On the other hand, currently in Colombia, there has been progress in the regulation of the reuse of wastewater (Resolution 1256 of 2021) [98]; with the implementation of this, a general cultural change is expected that will lead to the acceptance of these residues by the community, including both residual water and biosolids. Therefore, it is inferred that future studies and actions should be aimed at generating changes in the bases of the biosolids reuse model and system.

Nowadays, Colombia's economic and social policy CONPES 4004 [32] promotes the use of biosolids through the (I) analysis of biosolids as a potential element in the production cycle and (II) definition of business opportunities, which allows us to have future experiences of use, similar to countries such as Mexico, Chile, Argentina and Paraná (Brazil). Paraná is one of the main cities where biosolids tend to be used in agriculture as a priority disposal, thus favoring the agricultural potential of the area [13,99,100].

On the other hand, regulations in Latin America are mainly adaptations of regulations from industrialized countries. This type of the adoption of standards would not allow them to be adjusted to the needs and/or conditions of each region [101], so complementary guidelines have been presented to decree 1287 of 2014 [21], in which technical and methodological aspects are proposed, such as improving the storage, transport of biosolids, and application in degraded, agricultural, and forestry soils, allowing us to improve good management practices and reuse [102].

Although this research does not contemplate or evaluate Decision Support Systems (DSS), these are systems or methods that gain relevance for the information they can contribute to the solution of unstructured problems [103,104]. All this is from available models and data, which have improved the efficiency of decision-making in strategic issues, such as water and sewage sludge management [34,104–109], through the involvement of multiple variables, as well as the consideration of technical, regulatory, socio-environmental, economic, and administrative aspects. However, the availability and provision of data, as well as the interpretation, must be done from a holistic perspective, thus becoming fundamental agents for the correct formulation, optimization, interpretation, and application of the DSS [34,107], creating in the end a synergy between the different chains evaluated and analyzed.

5. Conclusions

Prospective analysis of the WWTP management and use of biosolids identified key variables and actors that require immediate action, especially with an integrated and articulated strategy for the improvement of the overall system.

Stakeholders within the WWTP will require special attention for the formulation, compliance, monitoring, and control of the objectives, mainly for the implementation of the institution's environmental policy (IEP) for sludge and biosolids, the improvement in infrastructure (WWTP- Infr_), and treatment efficiency (TE). On the other hand, at the agricultural level, the following are required: the certification of products (Cert_), the definitions of the classes of biosolids to be generated (BT) and their uses, and the establishment of the distribution mechanism for the waste as well as the benefits granted by management and use (BM).

As a low connectivity between stakeholders that are present today was identified in the SNA analysis, it is suggested to develop new connections encouraging the participation of novel stakeholders which could favor the system, improving the communication skills and collaborative work.

Our results provide new insights into the traditional management of sludges and biosolids in Colombia, which will help in the improvement of the WWTPs in the country and further applications of the biosolids in the agriculture field and some other scenarios.

Likewise, it makes visible the need for greater coordination and interaction between both traditional and new actors, which would improve the density of current networks for the management and use of biosolids, and strengthen the studies and evaluations in the future of the actions and the presence of a greater number of decision-making agents and stakeholders.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Roles of institutions and stakeholders involved in the management and use of biosolids for agriculture.

Stakeholders (n = 53)	Operating Level	Associated Functions
Acad_ (n = 7)	CM	Integrate research, academia, and social projection from teaching, education, and service.
AI (n = 9)	N	To provide economic income and support to the farmers. Reduce post-harvest losses in agricultural production. Develop new forms of production
CAR (n = 1)	N	"Maximum environmental authority under the criteria and guidelines established by the Ministry of Environment and sustainable development." "Promote and develop community participation in activities and programs for environmental protection, sustainable development, and adequate management of renewable natural resources."
DEyA (n = 1)	M	"Define programs for entrepreneurship and agricultural development, providing technical assistance to all the agents involved, adopting and directing the plans that the municipality needs to advance for the development of this sector, especially the farming sector." "Promote community participation and the social improvement of the agricultural activity of the residents of the municipality, taking into account the mechanisms of citizen participation and the needs of the community."

Table A1. *Cont.*

Stakeholders (n = 53)	Operating Level	Associated Functions
DNP (n = 1)	N	"To design, guide and evaluate Colombian public policies, the management, and allocation of public investment and the implementation of these in plans, programs and projects of the government in the social, economic and environmental fields."
ESPB	D	"Manage the provision and strengthening of public services in the department of Boyacá, providing support, advice, and technical assistance at the municipal and regional levels. "
F/A (n = 7)	N	Maintain agricultural activities and the development of the national and local economy.
WWTP-FA	D	"Optimize the company's own and financial resources to guarantee the fulfillment of its objectives."
ICA (n = 1)	N	"Exercise technical control over the production, importation, and commercialization of agricultural inputs to prevent risks that may affect agricultural health."
MinA_	N	"To design and regulate public policies and general conditions for environmental sanitation.... to prevent, repress, eliminate or mitigate the impact of polluting, deteriorating or destructive activities on the environment or natural heritage, in all economic and productive sectors."
MinV_	N	"Define feasibility and eligibility criteria for water, sewerage and sanitation projects and approve them, and provide technical assistance to territorial entities, environmental authorities, and public utility service providers."
Ope_	D	"Carry out all the necessary activities so that the wastewater treatment plant remains in good condition"
SSPD	N	"To monitor, inspect and control compliance by the supervised parties with the provisions that regulate the proper rendering of residential public utilities and the protection of users."
WWTP-OTD	D	"Project, carry out, and supervise the infrastructure works necessary for the efficient provision of services."
WM_ (n = 11)	N	Collect organic waste to be treated or disposed of correctly.
WWTP-EM (n = 3)	M	"Establish and implement actions aimed at directing the environmental management of the company operating the WWTP; ensure compliance with environmental standards; promote cleaner production practices and the rational use of natural resources."
WWTPs (n = 12)	CM	"Guarantee to the community the treatment of wastewater in the coverage area to reduce the environmental impact, through the correct operation of the WWTP and maintenance of its components."

CM: cities and Municipalities, D: departmental, and N: national.

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