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Key determinants for the economic and operational sustainability of sewerage services

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Abstract **This paper analyses the determinants of the economic and operational sustainability of sewerage services at the level of an economic operator, using data from an 11-year period, focusing on investments from European funds, network extension, environmental compliance and tariff policy. The results reveal uneven distribution of investments and high volumes of untreated wastewater, which reveal deficiencies in planning and infrastructure. Connected population is identified as a key factor for financial sustainability. Slow network expansion and tariff stability limit the ability of operators to invest in modernization. The results provide practical directions for improving the management of sewerage services in the long term.**

Keywords – key determinants, sewerage services, sustainability.

1. INTRODUCTION

The economic and operational sustainability of sewage services is a fundamental element of the global sustainable development strategy, especially in the European context and, more specifically, in Romania. The integration of sustainability objectives into the management of sewage services requires a comprehensive approach, which includes both economic and financial aspects, as well as those related to operational efficiency, social equity and compliance with environmental regulations [1]. In this context, the analysis of the determinants that influence these dimensions of sustainability becomes essential to respond to the challenges generated by outdated infrastructure, financial pressure and strict regulations imposed by the European Union.

In Europe, the water and sewage sector has undergone substantial reforms in recent decades. Rising environmental standards have put significant pressure on operators in the sector, emphasizing the need for considerable investment to modernize infrastructure and reduce environmental impacts [1]. These demands are superimposed on a generalized public financial crisis, which limits the resources available for financing from traditional public budgets. In this context, sewerage operators face dilemmas related to managing investment risks, sharing responsibilities among stakeholders and maintaining long-term sustainability.

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The challenges of aging infrastructure are particularly acute. Sewerage networks, in many cases, have exceeded their projected lifespan, and the need for significant investment for renewal is becoming increasingly pressing [2]. In the absence of coordinated and effective interventions, these deficiencies can affect both the quality of services provided and the financial sustainability of operators. The economic sustainability of sewerage services is directly influenced by the ability of operators to manage operational costs, optimize available resources and implement fair pricing policies.

On the other hand, operational sustainability implies not only economic efficiency but also compliance with technical and environmental standards. Measures to reduce losses, such as the management of unrecovered water, are essential to maintain a high level of operational performance [3]. In addition, the quality of services, the affordability of tariffs and the social impact of the policies adopted are complementary aspects that must be taken into account in any sustainability analysis.

Reforms in the sewage sector have led to a diversification of the actors involved and to the separation of managerial and regulatory functions, generating new sources of vulnerability and uncertainty [1]. These structural changes have brought to the fore issues related to the distribution of investment risks and the efficient management of financial and human resources. The new institutional arrangements, which involve both public-private partnerships and collaborations between different actors, raise questions about the sustainability of investments in capacity and infrastructure. From the perspective of Romanian operators, these reforms involve adapting to a constantly changing institutional and economic environment. Thus, the lack of a coherent investment strategy can amplify regional disparities and undermine overall progress in improving sewage services. Therefore, an integrated approach, which includes both economic and social perspectives, is essential to ensure sustainability.

The efficiency of sewage services has been the subject of numerous comparative studies at the international level, becoming an essential aspect in the context of global pressures on water resources, accentuated by climate change, demographic growth and economic expansion. In Europe, regional variations in water consumption highlight specific challenges: in the south, demand is dominated by agriculture, tourism and domestic use, while in the north, industry is the main consumer [4]. In this context, [5] propose an approach that correlates the internal performance of operators – including profitability and human resource management – with external indicators such as user satisfaction and regulatory compliance.

Reference [6] emphasizes that the sustainability of communities depends not only on the quantity, but also on the quality, reliability and economic accessibility of water resources, aspects that must be integrated into the management policies of sewage services. Similarly, [7] and [8] point out that access to safe water and efficient sanitation is essential for poverty reduction, especially in arid areas, but that these services are often limited by the unequal distribution of financial resources and the high demands of environmental standards.

In Romania, European funds have supported the modernization of networks and the expansion of access to services, but the process has often been hampered by the lack of adequate administrative capacity and deficiencies in strategic planning [9]. Reference [10] highlight that the regionalization process of sewage services aimed to create a more solid institutional framework for the management of investment projects, but the results obtained have not been uniform, due to the lack of a coherent strategy and weak coordination between the authorities involved. On the other hand, the involvement of the private sector through public-private partnerships (PPPs) is frequently discussed in the literature as a way to supplement limited public resources and attract additional investments [11]. Reference [12] highlight that these partnerships can bring significant benefits, such as improved

operational efficiency and access to modern technologies. However, the success of these initiatives depends on the existence of a well-defined regulatory framework that ensures equity of access and protection of users' interests. Reference [13] emphasize that these initiatives can only be effective if they are accompanied by regulatory measures that avoid social exclusion and ensure accessibility of services for all categories of the population.

The economic sustainability of sewerage services depends significantly on ensuring a balance between sources of financing - tariffs, taxes and transfers - which are essential for cost recovery and to support necessary infrastructure projects [14], [15]. The financial stability of public water and sewerage operators is also important to ensure the provision of services of general public interest. Economic instability, characterized by inability to pay or the risk of bankruptcy, can significantly compromise the ability of these operators to meet public service requirements [16]–[18]. Therefore, the economic and operational sustainability of sewerage services depends on a well-calibrated balance between funding sources, efficient resource management and the implementation of integrated strategies that support both financial viability and long-term sustainability objectives.

From an operational point of view, reducing unrecovered water losses is a major priority for operators in the sewerage sector. Reference [19] show that significant losses in water networks are a major problem in many regions, especially in the case of outdated infrastructure. The use of digital monitoring technologies and the implementation of intelligent network management solutions can significantly contribute to reducing losses and increasing operational efficiency. Technological progress in the field of water treatment and reuse, especially grey water from domestic uses, is a key solution to alleviate the water crisis. Reference [20] highlights that the reuse of treated water can be used in industrial or agricultural activities, reducing the impact on freshwater resources. However, these solutions involve high implementation costs and require adequate infrastructure, which is lacking in many regions.

In addition to the technological dimension, governance plays a key role in ensuring the sustainability of sewerage services. Reference [21] suggest that benchmarking can facilitate the comparison of operators' performance and the identification of best practices, contributing to increased efficiency and institutional accountability. Also, [22] complements this perspective, emphasizing that environmental policies need to be better integrated into infrastructure development strategies in order to minimize the negative impact of human activities on natural resources. The social dimension of sustainability is particularly highlighted by [23], who emphasize that without solid financial plans and clear risk management mechanisms, infrastructure projects remain vulnerable to financial fluctuations and economic uncertainties. This vulnerability highlights the need to strengthen governance, including regulatory mechanisms that promote economic sustainability and social protection. In this regard, [24] argue that institutional capacity development can make a significant contribution to reducing economic and social disparities, promoting social inclusion and community well-being. Sewerage services are fundamental to ensuring adequate standards of public health and environmental protection, and are a fundamental pillar of sustainable development. The literature highlights the complexity of the determinants of economic and operational sustainability, emphasizing the interdependencies between financial, technological, institutional and social factors [25]–[30]. To ensure the long-term viability of these services, an integrated framework of analysis is needed, linking the sustainability of water and sewerage systems with other sustainable development objectives, such as reducing inequalities, promoting responsible consumption and stimulating sustainable economic growth.

2. RESEARCH METHODOLOGY

By taking a multidimensional approach to the determinants of economic and operational sustainability, this study aims to highlight viable solutions for improving sewerage services in Romania.

In this respect, to assess the economic and operational sustainability of water and sewerage services, we used a series of specific indicators: a. *The total amount of investments from European funds made during the year for sewerage services*, which reflects the company's ability to attract external financing and invest in infrastructure (Vt). These investments are vital for the modernization and expansion of sewerage systems, leading to improved quality of service and increased operational efficiency; b. *Resident population connected to the sewerage systems managed by the company at the end of the year* indicating the level of community access to essential services (Pr). A high number of connected residents not only demonstrates the company's success in expanding the network, but also contributes to improved public health and environmental quality; c. *The volume of wastewater discharged to the outfall without treatment during the year assessed* is a critical indicator of environmental performance (Vau). Reducing this volume is essential for compliance with environmental legislation and for the protection of aquatic ecosystems. Efficient wastewater management prevents pollution and conserves natural resources; d. *The tariff for sewerage services provided to domestic, industrial and other consumers* is a key element in ensuring the financial sustainability of the utility (Tsc). Setting a fair and competitive tariff allows covering operational and maintenance costs while ensuring accessibility of services to all users; e. *Total operating revenues related to the wastewater activity* reflect the company's financial performance in the year under evaluation (Vte). These revenues are needed to sustain current operations and finance future investments; f. *Total operating and maintenance costs, including internal labor costs*, which directly influence the profitability and efficiency of the services provided (Ct); g. *Expenditure on penalties for non-compliance with environmental legislation* is a negative aspect that can affect both the company's image and its financial resources (Cp). Reducing or eliminating these penalties through strict compliance with regulations contributes to long-term sustainability and building trust among the community and authorities. By carefully monitoring and effectively managing these indicators, water and sewerage companies can ensure not only economic viability, but also a positive impact on the environment and society. For the analysis of the economic and operational sustainability of sewerage services, a methodology based on the statistical processing of indicators collected over a period of 11 years was used. This approach allowed the calculation of relevant descriptive statistics, such as mean and standard deviation, for each indicator, which provided a clear perspective on performance and fluctuations over time (Table 1). These indicators provide a solid framework for strategic decision-making and continuous improvement of the services provided.

3. FINDINGS

The analysis of relevant indicators highlights key factors influencing the economic and operational sustainability of sewerage services, reflecting both revenue and cost dynamics, as well as the impact of investments, tariffs and compliance with environmental regulations on the sector's performance.

Table 1 Descriptive Statistics

	Mean	Std. Deviation	Analysis N
Vt	49811282.36	65264032.760	11
Pr	496074.36	38585.046	11
Vau	940192.82	1706911.575	11
Tsc	3.815067272727273	.690637420229905	11
Vte	129585421.36	31750638.272	11
Ct	121576715.82	26835291.419	11
Cp	53921.45	98819.007	11

The annual average of investments is 49.811.282 lei, but the extremely high standard deviation (65.264.032 lei) indicates an uneven distribution of expenditures over the period analyzed. This discrepancy could be explained by the implementation cycles of projects financed from European funds, which often involve delays in public procurement procedures, sporadic budget allocations and dependence on approvals from central or European authorities. Another reason may be the lack of a consistent administrative capacity to attract and use funds efficiently. The average of 496.074 connected inhabitants suggests a relatively high degree of coverage for the service area analyzed, but the stability of the indicator (small standard deviation) indicates that infrastructure expansion was not a priority or that the pace of expansion was slow. This situation could be related to the operator's budgetary constraints, the lack of additional investments in network expansion, or socio-economic barriers that prevent connection in rural or poorer communities. The annual average of wastewater discharged untreated is very high (940.192 m^3) and the high variability (1.706.911 m^3) shows that in some periods the untreated volumes were significantly higher. This indicates critical deficiencies in the treatment infrastructure, either due to a lack of functional treatment plants or insufficient treatment plant capacities. Another possible explanation could be the prioritization of other investment areas at the expense of upgrading existing plants. This may also lead to significant environmental penalties and high social and environmental costs. The average tariff is 3,82 lei/m^3, with a relatively low variation (standard deviation of 0,69 lei) The stability of this tariff can be explained by legal regulations or by the local policy of keeping tariffs affordable for consumers. However, low tariffs may limit the operator's revenues and thus its ability to invest in modernization and expansion. An additional explanation may be consumer resistance to price increases, especially in low-income communities. The average annual revenues of 129.585.421 lei reflect significant economic activity, but the moderate variability (31.750.638 lei) could indicate a strong dependence on the volume of wastewater collected and treated. These variations can be explained by seasonal changes in consumption, population fluctuations or punctual network expansions. Revenues are also strongly influenced by the established tariff policy, which could limit their growth in the future. The average annual costs of 121.576.715 lei are very close to total revenues, suggesting a low profitability margin or even losses in some periods. Their relatively low variability (26.835.291 lei) indicates operational stability, but also the possible absence of cost optimization measures. This situation could be explained by the high fixed costs of network maintenance, salaries and energy consumption. The lack of technological innovation and digitalization may also contribute to keeping costs high. The annual average of penalties is relatively small (53.921 lei), but the high standard deviation (98.819 lei) indicates years with substantial expenditures in this regard. This can be explained by difficulties in complying with environmental regulations, perhaps due to high volumes of

untreated wastewater or the inability to quickly implement the necessary measures for compliance. These sporadic expenditures could be avoided by proactive investments in infrastructure and more effective management of compliance risks.

4. CONCLUSION

The results highlight that the economic and operational sustainability of sewage services is influenced by a series of interdependent factors. Constant and well-managed investments are a necessity, given the high fluctuations in European funding, which underlines the importance of rigorous planning and efficient project management. Extending network coverage is crucial for increasing the connected population, which can generate additional revenues. However, this expansion involves significant financial efforts, which must be supported by appropriate investment strategies. Reducing the volume of untreated wastewater is a priority for compliance with environmental requirements. Modern technological solutions for wastewater treatment could contribute not only to compliance with legislation, but also to reducing penalties. Cost optimization, through digitalization and streamlining operations, is essential to maintain a balance between revenues generated and operating costs. At the same time, tariff policy plays a vital role in financial stability, and it is important that tariffs are adjusted gradually, depending on the operator's needs and financial plans. This analysis underlines the need for an integrated, evidence-based approach to guarantee the sustainability of sewerage services, ensuring both economic viability and compliance with environmental standards and community needs.

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