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Water losses and sustainable development: antagonistic relations

Pérdidas de agua y desarrollo sostenible: relaciones antagónicas

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ABSTRACT

There is an antagonistic relationship between sustainable development and water losses. This paper aims to discuss the impact of water losses in water supply systems on SDG 6, as well as on other SDGs that are (in)directly associated with water. These relationships were structured based on a conceptual framework, including water losses, sustainability and sustainable development, water resource governance, and the Water-Energy-Food Nexus concepts. The study is original in presenting a comprehensive analysis of the influence that water losses exert on the achievement of the SDGs. The conclusions are that water losses can influence all SDG 6 targets (in)directly, as well as at least 10 other SDGs. It is concluded that an expansion of efforts to reduce water losses is necessary to accelerate sustainable development and the fulfillment of the SDGs, especially under the current pressures of climate change.

KEYWORDS: Sustainable Development Goals, Basic sanitation, Water losses, Water-Energy-Food Nexus, Sustainability.

RESUMEN

Existe una relación antagónica entre el desarrollo sostenible y las pérdidas de agua. Este artículo tiene como objetivo discutir el impacto de las pérdidas de agua en los sistemas de abastecimiento de agua sobre el ODS 6, así como en otros ODS que están (in)directamente asociados con el agua. Estas relaciones fueron estructuradas con base en un marco conceptual, que incluye pérdidas de agua, sostenibilidad y desarrollo sostenible, gobernanza de los recursos hídricos y los conceptos del Nexo Agua-Energía-Alimentos. El estudio es original en presentar un análisis integral de la influencia que las pérdidas de agua ejercen en el cumplimiento de los ODS. Las conclusiones indican que las pérdidas de agua pueden influir (in)directamente en todas las metas del ODS 6, así como en al menos 10 otros ODS. Se concluye que es necesaria una ampliación de los esfuerzos para reducir las pérdidas de agua con el fin de acelerar el desarrollo sostenible y el cumplimiento de los ODS, especialmente ante las presiones actuales del cambio climático.

PALABRAS CLAVE: Objetivos de Desarrollo Sostenible, Saneamiento básico, Pérdidas de agua, Nexo Agua-Energía-Alimentos, Sostenibilidad.

Perdas de água e desenvolvimento sustentável: relações antagônicas

RESUMO

Existe uma relação antagônica entre o desenvolvimento sustentável e as perdas de água. Este artigo tem como objetivo discutir o impacto das perdas de água nos sistemas de abastecimento sobre o ODS 6, bem como em outros ODS que estão (in)diretamente associados à água. Essas relações foram estruturadas com base em um arranjo conceitual, que inclui perdas de água, sustentabilidade e desenvolvimento sustentável, governança dos recursos hídricos e os conceitos do Nexus Água-Energia-Alimento. O estudo é original ao apresentar uma análise abrangente da influência que as perdas de água exercem na concretização dos ODS. As conclusões indicam que as perdas de água podem influenciar (in)diretamente todas as metas do ODS 6, assim como pelo menos 10 outros ODS. Conclui-se que é necessária uma ampliação dos esforços para reduzir as perdas de água, a fim de acelerar o desenvolvimento sustentável e o cumprimento dos ODS, especialmente diante das pressões atuais das mudanças climáticas.

PALAVRAS-CHAVE: Objetivos de Desenvolvimento Sustentável, Saneamento básico, Perdas de água, Nexus Água-Energia-Alimento, Sustentabilidade.

Pertes d'eau et développement durable: des relations antagonistes

RÉSUMÉ

Il existe une relation antagoniste entre le développement durable et les pertes d'eau. Cet article vise à discuter de l'impact des pertes d'eau dans les systèmes d'approvisionnement en eau sur l'ODD 6, ainsi que sur d'autres ODD qui sont (in)directement associés à l'eau. Ces relations ont été structurées sur la base d'un cadre conceptuel, incluant les pertes d'eau, la durabilité et le développement durable, la gouvernance des ressources en eau et les concepts du Nexus Eau-Énergie-Nourriture. L'étude est originale en présentant une analyse complète de l'influence que les pertes d'eau exercent sur la réalisation des ODD. Les conclusions indiquent que les pertes d'eau peuvent influencer (in)directement toutes les cibles de l'ODD 6, ainsi qu'au moins 10 autres ODD. Il est conclu qu'une expansion des efforts pour réduire les pertes d'eau est nécessaire pour accélérer le développement durable et la réalisation des ODD, surtout sous les pressions actuelles du changement climatique.

MOTS-CLÉ: Objectifs de Développement Durable, Assainissement de base, Pertes d'eau, Nexus Eau-Énergie-Nourriture, Durabilité.

Perdite d'acqua e sviluppo sostenibile: relazioni antagoniste

SOMMARIO

Esiste una relazione antagonista tra lo sviluppo sostenibile e le perdite d'acqua. Questo articolo mira a discutere l'impatto delle perdite d'acqua nei sistemi di approvvigionamento idrico sull'Obiettivo di Sviluppo Sostenibile (OSS) 6, così come su altri OSS (in)direttamente legati all'acqua. Queste relazioni sono state strutturate su una base concettuale che include le perdite d'acqua, la sostenibilità e lo sviluppo sostenibile, la governance delle risorse idriche e i concetti del Nesso Acqua-Energia-Cibo. Lo studio è originale in quanto presenta un'analisi completa dell'influenza che le perdite d'acqua esercitano sul raggiungimento degli OSS. Le conclusioni indicano che le perdite d'acqua possono influenzare (in)direttamente tutti gli obiettivi dell'OSS 6, oltre ad almeno altri 10 OSS. Si conclude che è necessaria un'espansione degli sforzi per ridurre le perdite d'acqua, al fine di accelerare lo sviluppo sostenibile e il raggiungimento degli OSS, specialmente sotto le pressioni attuali del cambia mento climatico.

PAROLE CHIAVE: Obiettivi di Sviluppo Sostenibile, Servizi igienico-sanitari di base, Perdite d'acqua, Nesso Acqua-Energia-Cibo, Sostenibilità.

Introduction

Water losses in water supply systems (WSS) are an obstacle to urban sustainability. WSS, which consumes significant water resources, includes infrastructure and services to fulfill multiple demands, such as domestic and industrial consumption[1]. Water losses are defined as the difference between the total volume distributed and the authorized consumption, which can be real (physical losses) or apparent (unauthorized consumption or inaccurate measurement)[2].

WSS can have three different water losses levels of water loss. The first is the current level of water losses, where these cause financial loss to the provider. The second is the economic level of water losses, where there is no longer any benefit in reducing losses due to the ratio of the cost and receipt for distribution of treated water at this level of loss. Finally, there is the unavoidable level of water losses, where regardless of the financial resources available to reduce water losses, it is impossible to reduce them beyond this level. Each WSS has its own unique characteristics and, as a result, each will have a different set of water loss levels[3].

To illustrate some of the results produced by water loss issues, a study aimed at quantifying the impacts arising from various levels of water loss. The study[4] indicate that if the global volume of non-revenue water (NRW) were reduced by only one-third, the savings could be sufficient to supply 800 million people, assuming a per capita consumption of 150 liters per day. They further note that numerous countries lack any data on water loss indicators, or, at best, provide no reliable information. According to the authors, the International Benchmarking Network for Water and Sanitation Utilities (IBNET) remains the only global source for NRW data. The study results reveal a considerable gradient in water loss levels among different countries. Nations with the lowest water loss rates include Australia and New Zealand, with values around 36 liters per capita per day, while the highest levels are seen in the Pacific Islands, at 211 liters per capita per day. Generally, the findings suggest that countries with lower water availability and higher economic development tend to exhibit lower water loss rates.

In addition to the variations among countries, water loss levels also differ significantly within regions of the same country, as illustrated by the case of Brazil, a country with continental proportions. In Brazil, 2022 data indicated a national water loss rate of 37.8 %, while the state of Goiás in the Midwest region showed a rate of 28.5 %. In contrast, Amapá in the North region had a notably high rate of 74.8 %. Thus, it can be inferred that within Brazil, regions with higher water availability and more limited economic conditions tend to have higher water loss levels. However, there are also cases where regions with low water availability still experience high water loss rates, particularly those with low economic potential, as in the Northeast region. Moreover, in some areas of the Southeast, where water availability is low and economic potential is high, water loss levels nonetheless remain elevated[5]. This scenario highlights the importance of aligning water governance practices, especially for a country like Brazil, of continental proportions, with the United Nations (UN) Sustainable Development Goals (SDGs). It demonstrates the relevance of highlighting in more depth the problems associated with the existence of water losses, especially for countries, like Brazil, where the entire population does not yet have access to water supply services.

Since the 1990s, sustainability has been a global issue, evolving from new technologies, programs and information. The UN Millennium Declaration in the early 2000s aimed to reduce extreme poverty through the Millennium Development Goals. Currently, the SDGs agenda aims to eradicate poverty, protect the environment and promote peace and quality of life by 2030[6]. Water is fundamental to these goals, driving the development of more efficient and sustainable water management practices[7].

The SDGs consist of 17 goals, 169 targets and 232 indicators, which serve to measure progress towards these goals[8]. The indicators are useful tools for identifying areas that need more attention at different levels - local, regional, national and international. While different stakeholders may focus on specific targets, the success of all the goals is in the interest of all nations[9]. This requires a multidimensional and cross-border

[1] Nathanson, 2023.
[2] Lambert; Hirner, 2000.
[3] Moslehi; Jalili-Ghazizadeh; Yousefi-Khoshqalb, 2021.
[4] Liemberger; Wyatt, 2019.
[5] Brasil, 2023.
[6] United Nations (UN), 2015.
[7] French; Kotzé, 2018.
[8] UN, 2015.
[9] Leite; Soares; Espíndola, 2023.

approach, involving politicians, businesses, academia and civil society[10].

A relevant chapter[11] conducts a qualitative assessment of the relationship between the SDGs and water, broadly distinguishing between direct and indirect connections. Water has a direct relationship with SDGs 6, 14, and 15, while its relationship is indirect with SDGs 2, 3, 7, 9, 11, 13, 16, and 17. Additionally, several challenges and gaps that hinder the successful achievement of the SDG targets are discussed, along with the various ways in which water influences these goals.

Water is essential for sustainable development, contributing to poverty reduction, economic development and environmental sustainability. It is intrinsically linked to food production, energy generation and environmental health. The success of SDG 6 is vital for the other SDGs, since inefficiency and lack of water and sanitation affects well-being, health and economic activities[12]. Sustainable water and sanitation management depends on the participation of civil society, integrated policies, public and private investment, education and the inclusion of science[13]. This success requires ecosystem and political-social transformations, directly impacting other SDGs[14]. Protecting water resources through native forest helps SDG 13 by storing carbon and SDG 15 by supporting biodiversity. SDG 6 influences SDGs 2 and 11, as food production depends on water availability and sustainable cities require efficient water management[15].

The sustainability of water for its use as a resource is threatened by five factors[16], which are simultaneously and intrinsically related: 1. extreme climatic events, such as floods and droughts, caused mainly by climate change and anomalies; 2. intense population growth; 3. rapid and extensive urbanization, often disorganized; 4. the emergence of megacities, which often require services that are beyond their carrying capacity; 5. aging and outdated infrastructure in the systems that use and transport water. To ensure water sustainability, cities and systems dependent on water resources must become more resilient through structural and non-structural actions, promoted by local governments and civil society[17]. Water governance must consider external pressures that threaten water sustainability and promote means to increase local resilience[18].

Another relevant study[19], structured similarly to this, examines the relationships between NRW and the SDGs. In this study, the authors explore connections with all targets of SDG 6, as well as with other SDGs impacted by water loss, particularly SDGs 3, 7, 8, 9, 11, 12, 13, 14, 15, 16, and 17. The study categorizes these connections into direct and indirect links and evaluates their level of influence, ranging from 1 to 3. The authors also present relevant discussions on the influence and relationship between NRW and the SDGs and their targets, drawing upon multiple significant references. Although the study does not directly develop the concept of the Water-Energy-Food nexus, its entire discussion is structured around this foundational idea.

This study aims to analyze the importance of water for sustainable development, focusing on the relationship between water losses in WSS and SDG 6, as well as other SDGs impacted by these losses. The study seeks to contribute to this relationship, which remains underexplored academically. Additionally, it aims to broaden the interpretation of the Water-Energy-Food Nexus by examining the impact of water losses in supply systems and how these losses interact with the energy and food sectors, thus expanding the nexus concept even further.

The role of water in sustainable development

The importance of water for human consumption, food production, aquatic life, production chains and electricity generation, among others, is widely recognized. There are various approaches to studying these complex interactions with water. In the context of sustainable development, it would be simplistic to assign a value to water, a crucial resource for the sustainability of the biosphere. However, the discussion in this research is essentially from the perspective of the Water-Energy-Food Nexus.

Water, food/materials and energy are intrinsically linked: water is needed for energy production and

[10] Malay, 2021.
[11] Alam, 2024.
[12] Sadoff; Borgomeo; Uhlenbrook, 2020.
[13] Mulligan et al., 2020.
[14] Sadoff; Borgomeo; Uhlenbrook, 2020.
[15] Mulligan et al., 2020.
[16] Di Vaio et al., 2021.
[17] Bayard; Luna, 2024.
[18] Organisation for Economic Co-operation and Development (OECD), 2015.
[19] AbuEltayef; AbuAlhin; Alastal, 2023.

transportation; energy is needed for water collection, treatment and distribution; food production, transportation and distribution require energy and water. This arrangement, known as the Water-Energy-Food Nexus, implies that actions in one domain affect the others. The Nexus intensifies as demand for resources increases due to population growth and changing consumption patterns. Global trends, such as climate anomalies and territorial conflicts, limit the capacity of current systems to meet demand in a secure and sustainable way. Thus, security in one domain contributes to security in others, as does insecurity[20].

The Water-Energy-Food Nexus highlights the indissociability of water, food and energy. This interconnection represents the evolution of scientific understanding towards integrated management of the different sectors. Indissociability is characterized by the identification of relationships between essential natural resource sectors and meticulous planning to maximize efficiency. Recently, the Nexus has been given a broader governance approach to ensure the sustainability of the natural resources linked to it. This governance approach is applied in various sectors related to the Nexus, including air pollution control, reducing biodiversity loss, mitigating climate change, containingdisease transmission and invasive species and managing water resources. The SDGs are a practical example of this governance, as their targets for signatory countries favor the efficient application of the Nexus[21].

Water security, alongside energy and food security, is essential for achieving sustainable development globally, as these resources are deeply interconnected. Effective governance requires science-based decision-making to address natural resource limits and to leverage technological advances that can expand these limits. Strengthening each sector —whether water, energy, or food— enhances the resilience of sustainable development. Achieving this resilience depends on reducing water losses and improving efficiency across all production chains. Consequently, managing these resources effectively is key to ensuring sustainability worldwide.

An example of successful implementation of technologies and methodologies aimed at maximizing water supply in the face of existing demand is Singapore. Singapore is a small, densely populated tropical island. While rainfall is abundant, Singapore is considered a water-scarce country due to the limited land area available for water catchment, the lack of groundwater resources, and a growing population. Singapore ensures the highly sustainable production of treated water through a holistic approach that combines water source diversification, efficient demand management, and reduction of water losses, known as NRW. The country has implemented advanced technologies, such as desalination and the use of reclaimed water (NEWater), which together are expected to meet up to 85 % of its water demand by 2060. Furthermore, Singapore's Public Utility Board (PUB) enforces strict infrastructure monitoring and maintenance programs to minimize water losses, which stood at 5.6 % in 2018 —one of the lowest rates globally—. This combination of innovative technologies and proactive management allows Singapore not only to meet its water demand but also to position itself as a model of sustainability in water resource management[22].

Water losses and (in)sustainability

In hydrology, water flows in a closed cycle with an invariable quantity on a large time scale[23]. However, water quality, which is crucial for water security, is currently deteriorating. After its first use by humans, and even after treatment (at least conventional treatment), the quality of water decreases successively with each new use[24]. To fully meet its uses, water must be in satisfactory conditions of quality and quantity[25].

With the expanding knowledge of new pollutants that pose potential risks to human health, increased water demand, limited availability in various regions, and the reduced costs of advanced treatment technologies, potable water reuse is becoming more common worldwide. However, despite decreasing costs, advanced treatment remains considerably more expensive than conventional treatment. Given this, losing advanced-treated water could further distance systems from sustainability goals. It is therefore essential to minimize water losses, particularly when production processes are costly, to support the sustainability of

[20] Samberger, 2022.
[21] Yuan; Lo, 2022.
[22] Susantono; Li, 2021.
[23] Singh, 2017.
[24] Cheng et al., 2022.
[25] Castelletti et al., 2014.

the various resources and production chains involved in water treatment[26].

All natural resources are subject to market logic, including water. Water management varies globally, depending on the legal structures of each state. In Brazil, for example, the Participatory Integrated Assessment is adopted, characterized by a systemic management structure and the adoption of three instruments: strategic planning by river basin; decision-making through multilateral and decentralized releases; and the establishment of legal and financial instruments[27]. Legally, in Brazil as example, water supply has preference in the use of water resources in conditions of low availability and high demand, as well as in critical events[28]. However, this preference may not be beneficial for the population in the medium and long term, in a wider context. This dynamic can discourage WSS from seeking operational improvements (reducing water losses), moving them away from sustainability.

Water losses in WSS can have impacts that extend beyond the systems themselves, generating chain reactions that transfer these impacts to a regional, and consequently: global scale. This stems from the nature of the inputs used in all the processes to supply treated water. To reverse or reduce this condition, it is prudent to focus on the treated water industry, to make it capable of operating with the most closed cycle possible, increasing its capacity to operate sustainably and autonomously[29].

Methodology

To evaluate and discuss the relationships between water losses and the SDGs, and additionally the impact of water losses on the Water-Energy-Food Nexus, a comprehensive literature review is necessary. This review should encompass all SDGs to assess which ones relate to water and water losses within supply systems. Supporting materials include articles and reports from the UN, SDG documents, scientific articles on the topic, and evaluations of databases such as the UN SDG Indicators Database[30], the World Bank's World Development Indicators[31], the IBNET[32], and the Brazilian National Sanitation Information System (SNIS) [33].

Virtually all the references used in developing this study were crucial for building the conceptual framework, providing support for the study's evaluation and discussion. The references contributed to the following topics: databases; water loss in supply systems; concepts, challenges, and assessments of water governance; the Water-Energy-Food Nexus; and the Sustainable Development Goals.

Based on a subjective assessment of various databases, along with a conceptual framework that addresses the nature of water losses, the functioning of supply systems, the concepts, challenges, and assessments of water governance, and the Water-Energy-Food Nexus, it became possible to develop more structured and well-founded discussions to trace the relationships between water losses and the achievement of the SDGs.

Following this framework, the present study adopts an inductive method. It assesses the individual characteristics resulting from water losses in supply systems and their global implications, relevant to all supply systems. This method relies on observing and analyzing specific cases to build a broader understanding of the impact of water losses based on concrete examples and data. Through this approach, patterns can be identified, and relationships proposed between water losses, the Water-Energy-Food Nexus, and the fulfillment of the SDGs, allowing generalizations to be drawn from observed particularities in different supply contexts.

The choice of the inductive method is due to the study's exploratory nature, which seeks to outline relationships and understand impacts without relying on a predefined hypothesis. Rather than proving a specific theory, the inductive approach allows for the observation of real data on supply systems and their water losses, from which broader conclusions applicable to various contexts can be drawn. This process is essential for capturing the complexity of the phenomenon under study, as inductive analysis enables understanding the repercussions of water losses based on evidence gathered and contextualized throughout the study.

The discussion focuses on qualitative issues regarding the impacts caused by water losses, without covering

[26] Sim; Mauter, 2021.
[27] Villamor et al., 2022.
[28] Brasil, 1997.
[29] Kusterko et al., 2018.
[30] UN, 2024.
[31] World Bank Group (WBG), 2024.
[32] Danilenko et al., 2014.
[33] Brasil, 2024.

quantitative influences. For the purposes of the analysis, the influences associated with SDS and water losses under the unavoidable level of water losses were considered. Although the assessment from economic level makes more sense to establish a state of sustainability for the supply system, the unavoidable level can address broader issues linked to global sustainability, which is the focus of the proposed assessment. Relationships identified between water losses and the targets of SDG 6, as well as SDGs 1, 2, 3, 7, 9, 11, 12, 13, and 15, were discussed. Additionally, the main progress points recorded or the current status in 2023, as noted in the UN report[34], were presented.

Results and Discussion

The relationship between water losses and SDG 6

The UN[35] presents the proposed SDG Agenda. Of the 17 goals, SDG 6, which deals with clean water and sanitation and aims to ensure the availability and sustainable management of drinking water and sanitation for all, is subdivided into 8 targets:

6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all. 6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations. 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. 6.4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate. 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes. 6.a: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies. 6.b: Support and strengthen the participation of local communities in improving water and sanitation management.

The implementation of the 2030 Agenda, governance by goals, has unique and common characteristics for its success. There is also synergy between the SDGs, and SDG 6 stands out as one of the central objectives in the synergy axis. The existence of water losses around the world is characterized as a variable capable of hindering or delaying the success of the targets for SDG 6 and the other SDGs that are synergistic.

Water losses have the potential to negatively influence almost the entire performance of the Agenda, which is strongly based on promoting resilience (so that various WSS can overcome various pressures exerted on societies and the environment)[36]. This is because inefficiency, losses and wastage of resources create distancing between meeting targets and promoting sustainable development. Thus, water losses prevent systems (cities and river basins) from developing a state of resilience and, consequently, from operating sustainably[37], deviating from the success proposed by the Agenda[38].

According to the UN[39], the postulate for meeting SDG 6 is: Billions of people still lack access to safe water, sanitation, and hygiene, despite improvement in the provision of these basic services. Water scarcity is a growing problem in many parts of the world, and conflicts and climate change are exacerbating the issue. In addition, water pollution is a significant challenge which affects both human health and the environment in many countries. Achieving universal coverage by 2030 will require a 6-fold increase in current global rates of progress on drinking water, a 5-fold increase for sanitation, and an 8-fold increase for hygiene. Boosting infrastructure investment, improving cross-sectoral coordination, and addressing climate change are key to getting SDG6 back on track.

Table 1 shows the relationship between meeting the targets of SDG 6 and the influence that WSS have within their context of water losses for systems that are not at the unavoidable level of water losses, the target for all

[34] UN, 2023.
[35] UN, 2015.
[36] Assarkhaniki et al., 2023.
[37] Bayard; Luna, 2024.
[38] Kumar; Mehany, 2022.
[39] UN, 2023.

Table 1. Relationship between the influence of water losses on the different SDG 6 targets and progress made by 2023

TARGET	INFLUENCE OF WATER LOSSES	UN REGISTERED PROGRESS OR STATUS (2023)
6.1	In many regions, significant conflicts arise over water use due to its local availability[40]. These conflicts are intensified by water losses, which necessitate immediate adjustments to the water supply regime. With substantial water losses, particularly in developing countries, achieving water access goals becomes challenging[41]. Water losses lead to reduced revenues for suppliers, diminishing their financial capacity to invest in infrastructure expansion and improvements to ensure access for those who still lack it.	• 2,2 billion without safe drinking water. • 3,5 billion without safe sanitation. • 2,0 billion without basic hygiene. • Decrease in unserved population in rural areas and stagnation in urban areas. • A 5 to 8-fold increase in the current rate is needed for universal coverage by 2030.
6.2	Water losses generate a deficit for companies, limiting their investments to guarantee access to sanitation now and in the future. Hygiene standards vary according to the culture of each country and the household structures of different social classes[42], making this aspect more challenging for companies that must at least provide access to the hygiene-promoting resource: treated water[43]. In addition, companies must collect and treat water after domestic use in order to maintain better quality water sources, protecting the environment and reducing the costs of treatment processes[44].	
6.3	In surface water catchment systems, water losses result in the need for higher catchment, reducing the immediately available flow. If these flows were higher, they could withstand greater loads of pollutants without necessarily degrading water resources, according to legal definitions for the discharge of treated effluents. With lower flows, wastewater treatment must be more efficient and therefore more expensive. Developing countries, which tend to have higher rates of water loss, face difficulties in building and operating treatment plants that guarantee effluent quality at the appropriate environmental levels[45]. Often, the same company is responsible for both the distribution system and the collection and treatment system. This makes it possible for the revenues obtained from the supply service to be used to expand and improve the wastewater collection and treatment service. Therefore, water losses have an impact on the capacity to invest in wastewater treatment systems.	• 58 % of domestic wastewater safely treated by 2022. • Little or no progress towards halving unsafe dumping by 2030.
6.4	Reducing water losses in WSS to unavoidable levels would lead them to the greatest possible efficiency. This would result in a substantial reduction in spending on inputs, which are often non-renewable, with complex, costly and impactful chains, and on energy. In addition, it would increase water availability, promoting greater supply capacity and reducing the number of people suffering from water scarcity. Economic water production makes the process more accessible and robust, making it more resilient and able to supply water continuously and safely[46].	• Water use efficiency increased from US$ 17,4/m³ in 2015 to US$ 18,9/m³ in 2020. • 57 % of countries had efficiency of US$ 20/m³ or less in 2020, compared to 58 % in 2015.
6.5	Reducing water losses to unavoidable levels could mitigate conflicts over water use, positively influencing the integrated management of water resources[47]. It makes management easier to carry out, bringing higher water availability to places of major conflict that previously had higher levels of water loss[48]. There are surface water sources around the world that supply various WSS. Water losses in upstream WSS tend to increase the pressure on downstream WSS catchments, as the immediate flow available is reduced with each new catchment[49].	• Half of the countries lack effective structures for sustainable water management. • Lack of intersectoral coordination threatens the achievement of several SDGs. • Global progress from 49 % in 2017 to 54 % in 2020 but needs to double to reach target. • Only 32 out of 153 countries with transboundary water resources have 90 % or more of these waters covered by operational agreements.
6.6	Ecosystem restoration involves the use of water. Ecosystems are degraded due to economic pressures and can have their restoration processes accelerated with higher water availability, resulting from reduced losses. Increased water catchment, which can be reduced, contributes to a reduction in the flow of surface streams, essential habitats or resources for maintaining other ecosystems[50]. The need to reserve water through dams creates flooded areas that alter ecological balance[51]. If some WSS with higher amounts of losses operated with lower losses, artificial reservoirs might not be necessary, or the volume to be reserved could be reduced, resulting in lower environmental impacts from damming the river[52]. However, this determination depends on specific analyses for each system. Nevertheless, considering climate change effects, the use of artificial reservoirs is becoming increasingly necessary, even in cases of very low water losses[53].	• One in five river basins has shown above-natural fluctuations in surface water over the last five years.

[40] Gleick; Shimabuku, 2023.
[41] Stevović; Nestorović; Lutovac, 2018.
[42] Rosaneli et al., 2021.
[43] Kumwenda, 2019.
[44] Sadoff; Borgomeo; Uhlenbrook, 2020.
[45] Von Sperling, 2014.
[46] Frauendorfer; Liemberger, 2010.
[47] Leite; Soares; Espíndola, 2023.
[48] Stevović; Nestorović; Lutovac, 2018.
[49] Gleick; Shimabuku, 2023.
[50] Bozelli, 2019.
[51] Wu et al., 2019.
[52] Plantak et al., 2021.
[53] Bernabé-Crespo; Loáiciga, 2024.

TARGET	INFLUENCE OF WATER LOSSES	UN REGISTERED PROGRESS OR STATUS (2023)
6.a	Developing countries tend to have higher water losses[54], which could be reduced more quickly with cooperation and capacitation from developed countries to reduce these losses. Many WSS have high levels of losses, making them financially and technically insufficient to manage these losses. In these cases, external assistance is extremely necessary for these WSS to overcome this situation[55]. Managing water losses largely requires investments in assets that depend on financial resources. Systems that need to contain their losses generally do not have the financial resources available to acquire new assets and therefore depend on financing and credits for such investments[56].	• Official development assistance disbursements for the water sector reduced by 15 % between 2015 - 2021, from $9,6 to $8,1 billion. • Total commitments for the water sector reduced by 12 %, from US$ 11,2 (2015) to US$ 9,8 billion (2021). • Commitments peaked at US$ 13,5 billion in 2017 and have decreased every year.
6.b		• More than 70 % of countries have procedures for local community participation defined in law or policy since 2016, both for rural drinking water and for water resource management. • Countries with high levels of participation are low (40 %).

Source: Own elaboration.

WSS, and the current progress or status made available by the UN for the year 2023.

SDG 6 is made up of a series of interrelated targets aimed at universal access to water; universal implementation of access to domestic wastewater disposal and treatment; protection of water sources; efficiency in the use of water for various demands; protection of water resources and ecosystems; and integrated water resource management, which refers to the state of governance at all levels of application, from the macro to the micro systems that use water. Water losses have a significant impact on all the processes required to execute and achieve all the targets of SDG 6.

Although only target 6.4 explicitly mentions the need for more efficient use of water, it is essential to recognize that water losses affect all the targets of the Goal, to varying extents. Therefore, it is imperative that any effort to achieve the targets of SDG 6 also includes strategies to reduce water losses to at least economic levels, to ensure the sustainability of WSS, and later, to aim for the broader sustainability that comes from the inevitable level of water losses. This will not only improve the efficiency of water use, as outlined in target 6.4, but will also have a positive impact on all other targets.

The identification of influences in study[57] aligns with the findings of this study; however, the authors explored the influences between water losses and each target of SDG 6 in a more superficial manner.

Relationship between water losses and different SDGs

Notably, the existence of water losses and their respective reductions can increase the chances of success of the different targets of SDG 6. As recognized by the UN[58] the pursuit of meeting the SDG 6 targets would be able to contribute substantially to the development and success of meeting the other SDGs.

Even though water is a matrix resource for practically all the other resources, not all the SDGs, given the way they have been structured and arranged, could be directly or even indirectly linked to this synergy. Within the context of water losses and their (in)direct impacts, it is possible to develop a discussion and analysis of how losses negatively influence the development and successful achievement of the other SDGs, with influence on SDGs 1, 2, 3, 7, 9, 11, 12, 13, 15 and 17, which deal with. respectively: No Poverty; Zero Hunger; Good Health and Well-being; Affordable and Clean Energy; Industry, Innovation and Infrastructure; Sustainable Cities and Communities; Responsible Consumption and Production; Climate Action; Life on Land; and Partnerships for the Goals.

Table 2 shows the relationship between the SDGs mentioned above, with the respective target influenced, and the influence that WSS have within their context of water losses for systems that are not at the unavoidable level of water losses and the current progress made available by the UN for the year 2023.

Differently from what can be seen in Table 1, Table 2 only shows the SDGs that could be related to water losses in some way, even when considering the targets that make up each of the other SDGs. However, it must be acknowledged that the influence of the existence of water losses, at least above economic levels, for the other SDGs is not as influential as it is for SDG 6. The influence on the other SDGs can be considered

[54] Liemberger; Wyatt, 2019.
[55] Heidler et al., 2023.
[56] Dolores et al., 2021.
[57] AbuEltayef; AbuAlhin; Alastal, 2023.
[58] UN, 2015.

Table 2. Relationship between the influence of water losses on the different SDGs and progress made by 2023

GOAL	INFLUENCE OF WATER LOSSES	UN REGISTERED PROGRESS OR STATUS (2023)
1	Resilience and vulnerability in water security can be compared to socio-economic security. The crises cited by the UN highlight that many people are in a situation of vulnerability and that States do not have the resilience to withstand crises with global impacts and, at the same time, people in a situation of vulnerability - extreme poverty[59]. Conditions of extreme poverty generate (in) direct impacts in various spheres. The increase in poverty has been more pronounced in developing countries, which tend to have higher rates of apparent losses due to irregular use. The initial reduction in poverty can generate reductions in water losses, which in turn can contribute to increasing the resilience of WSS, perpetuating more sustainable conditions[60].	• Global poverty reduction has been set back by COVID-19, reversing three decades of progress. • People in extreme poverty increased for the first time in a generation. • Slow and unequal recovery, the world faces geopolitical, socioeconomic and climate risks. • Tendentially, around 575 million people will still be living in extreme poverty in 2030, compared to 800 million in 2015. • Increasing actions and investments to expand employment opportunities and social services for the most excluded is crucial to the success of the SDGs.
2	In the context of the Water-Energy-Food Nexus[61], reducing water losses can positively influence water security, which in turn is closely linked to energy and food security[62]. Food production chains, which are extremely dependent on the availability of water, energy and soil, have become globally consolidated. Therefore, reducing water losses is an additional option to contribute to the robustness of food production in the world, especially for places that have food production close to urban centers[63].	• People facing hunger and food insecurity have increased since 2015, reaching 768 million in 2021; • Projections indicate that around 8 % of the world's population will remain hungry in 2030, the same % as in 2015; • Many children suffer from malnutrition, the annual rate of stunting needs to increase 2.2 times for the global goal; • To eradicate hunger by 2030, efforts are needed to transform food systems, ensure food security and invest in sustainable agricultural practices.
3	The pandemic has highlighted the importance of hand washing as a prophylaxis, an option unavailable to millions of people without access to sanitation[64]. The health benefits of basic sanitation are widely recognized. Achieving this goal without universal sanitation is impossible[65], and reducing water losses can make this more accessible and safer. Therefore, there is a direct relationship between reducing losses, improving sanitation and promoting health and well-being.	• Pandemics and other crises undermine progress on SDG 3, exacerbating health inequalities and threatening universal health coverage. • In 2021, 25 million children did not have access to routine immunization services. • Pandemic highlighted the need for more robust global health security systems to prevent and respond to future pandemics.
7	Brazil is a notable example of the Water-Energy-Food Nexus, due to the fact that the electricity matrix is predominantly based on hydroelectric plants distributed all over the national territory[66] and the large amount of food produced throughout the country[67]. In countries where the electricity matrix has a considerable share coming from hydroelectric plants, or which are considering implementing this source, reducing water losses, especially in WSS that draw water from surface sources, can bring benefits for water availability and provide greater electrical security[68]. Many hydroelectric plants, generally older ones, operate with high dam levels and can generate conflicts with water supply, depending on population density and local or even regional water security. By reducing water losses, there is also a reduction in the electricity required for the operation of the WSS, contributing to the decreased demand in the electricity market, which implies a lower need for electricity production. The less renewable the energy matrix is, the greater the benefits of reducing water losses.	• There are 675 million people without access to electricity and 2.3 billion who cook with unsafe and polluting sources. • War in Ukraine and global economic uncertainty cause instability in energy prices. Varied responses from countries: increased investment in renewable energies and even increased use of coal, which threaten the green transition. • As a result, around 660 million people will still have no access to electricity and around 2 billion will continue to rely on polluting fuels and technologies for cooking by 2030. • To guarantee access to energy for all by 2030, it is necessary to accelerate electrification, increase investments in renewable energy sources and improve electricity grids.
9	Reducing water losses is directly linked to the implementation of resilient infrastructure, promoting greater sustainability in a system that operates incessantly[69]. The infrastructure of a WSS has a limited lifespan, especially in a context of low sustainability, making it necessary to constantly encourage innovation in order to find physical means of extending its lifespan. These actions stimulate and strengthen the industrial sectors linked to WSS[70]. In addition, reducing water losses can increase local water availability that can be used in new industries, optimizing the logistics of products and workers.	• The post-pandemic recovery of the manufacturing industry is unequal. • Some high-income regions reached record per capita value added in 2022. Less developed countries barely surpassed 2015 levels. • High-tech sectors have proved more resilient post-pandemic. The importance of promoting innovation and technology transfer to benefit all countries is highlighted. • It is crucial to support the least developed countries, invest in advanced technologies, reduce carbon emissions and increase global access to mobile broadband, in order to achieve SDG 9.
11	The dynamics of a city depend directly on its WSS, which can become more resilient as it reduces its losses. There is a relationship between apparent losses and the population living in substandard housing[71]. The sustainability of the WSS is (in)directly linked to public policies for settlements, which is beyond the reach of sanitation companies, as it is the responsibility of local governments. It is recognized that the problem of subnormal settlements generates various impacts on urban systems. However, many actions are aimed at attenuating or mitigating these impacts, but not at solving the matrix problem. A city can only be truly sustainable if its water supply system and sewage collection and treatment systems are sustainable.	• The pandemic has resulted in major changes in migration patterns, with displacement into and out of urban areas. • Cities tend to be disproportionately impacted by climate change and conflicts. • In developing countries, slum populations are increasing, threatening the goal of adequate housing. • Since 2015, the number of countries with national disaster risk reduction strategies has more than doubled. • It is necessary to focus on strengthening urban development planning capacities, improving access to public transportation and improving waste management, in order to achieve SDG 11.

[59] Adams; Stoler; Adams, 2020.
[60] Sadoff; Borgomeo; Uhlenbrook, 2020.
[61] Yuan; Lo, 2022.
[62] Samberger, 2022.
[63] Stevović; Nestorović; Lutovac, 2018.
[64] Mishra et al., 2017.
[65] Sadoff; Borgomeo; Uhlenbrook, 2020.
[66] Empresa de Pesquisa Energética, 2023.
[67] Brasil, 2022.
[68] Samberger, 2022.
[69] Kloosterman; Veeneman; Van Der Hoek, 2020.
[70] Zhironkin, 2022.
[71] Adams; Stoler; Adams, 2020.

GOAL	INFLUENCE OF WATER LOSSES	UN REGISTERED PROGRESS OR STATUS (2023)
12	A WSS has input chains that constitute other chains. All production chains make (in)direct use of water. Reducing water losses (in)directly raises all local, regional and, consequently, global chains — due to the consolidation of global production of commodities and services — to levels closer to sustainability. Analogous to water losses, all production chains (systems) have loss levels that can be reduced to the inevitable loss levels. As water is a key resource in these production systems, it is essential that these systems operate at unavoidable levels, in order to contribute to responsible consumption and production[72]. Reducing water losses also leads to a reduction in the non-renewable inputs required for the treated water production process, allowing the production system to extend the useful lifespan of these inputs until transitions to fully renewable resources become feasible.	• World significantly behind in efforts to reduce food waste and losses per capita. • Pandemic has profoundly impacted consumption and production patterns, causing disruptions in global supply chains and changes in consumer behavior. Responsible consumption and production must be an essential part of the recovery from the pandemic. • It is necessary to accelerate the dissociation between economic growth and resource use, maximizing the socio-economic benefits of resources and minimizing their negative impacts. • It is crucial to implement policies that promote a shift to sustainable practices and dissociate economic growth from the use of non-renewable resources in order to achieve SDG 12.
13	Academically, it is more accepted that climate change is the result of various human actions on the environment, especially in the energy sphere. WSS are heavily dependent on electricity[73] — which in many countries comes from non-renewable and polluting sources — and therefore any physical loss of water or waste necessarily involves higher electricity consumption. Thus, losses contribute (in)directly to the inefficiency of electricity-dependent systems, the production of which contributes to worsening climate change. Losses influence the energy market, contributing to increased demand[74] which, for example, in Brazil still makes use of non-renewable sources and which also has the National Interconnected System, supplied by renewable and non-renewable sources.	• With the world on the brink of a climate catastrophe, current actions and plans to tackle the crisis are insufficient. • Without immediate and transformative action within this decade to deeply and rapidly reduce greenhouse gas emissions in all sectors, the 1.5°C target will be at risk. Affecting the lives of more than 3 billion people. • Inaction leads to worsening heatwaves, droughts, floods, forest fires, rising sea levels and famine. • Emissions should be falling now and need to be cut by almost half by 2030. • Urgent and transformative action is needed to meet the commitments made in the Paris Agreement regarding mitigation and adaptation efforts.
15	The maintenance capacity of various terrestrial ecosystems is directly related to water availability[75], which can be increased by reducing water losses, especially in WSS that catch water from surface sources. Water availability can also increase with the consolidation of new forests[76], as vegetation contributes directly to the hydrological cycle, thus favoring water security and the resilience of the different systems involved[77].	• The world is facing a triple planetary crisis of climate change, pollution and biodiversity loss. • The trend of forest loss, land degradation and species extinction is worsening. It poses a serious threat to the health of the planet and people. • SDG 15 will not be achieved without a radical change in our relationship with the natural environment.
17	When the sustainability of the planet is put into perspective, it is impossible to ignore the leading role of developed countries, which have lower rates of water loss, often due to low water availability and high resources for investment in infrastructure[78]. This role is further underscored by the exploitation of natural resources by developing countries over the centuries and their history of pollutant emissions[79]. In order to reach a level of global sustainability, a drastic reduction in water losses worldwide is essential. If most of the SDGs are to be met by the deadline (2030), developed countries will need to contribute to developing countries in order to universalize sanitation (and reduce losses), through financial credits and technical cooperation strategies[80].	• Progress towards SDG 17 is varied, with advances in areas such as development aid, remittance flows and access to technology. • Financing for development remains a major challenge, especially in low-income countries. • Geopolitical tensions and rising nationalism in parts of the world have hampered international cooperation and coordination. • Many developing countries are struggling with record inflation, rising interest rates and looming debt, competing priorities and limited fiscal space. • Increased joint action is needed to ensure that developing countries have access to the finance and technologies needed to accelerate the implementation of all the SDGs.

Source: Own elaboration.

relevant when approached from the perspective of the Water-Energy-Food Nexus.

This study, compared to study[81], did not include SDGs 8, 14, and 16. Although these three SDGs were not incorporated into the evaluation and discussion, the approaches presented in the other study that assessed the relationships between SDGs 8 and 16 align with what was developed in the conceptual framework of this work. The other study develops 7 fundamental topics based on specific relationships that were comprehensively addressed in this study. That study did not engage with these SDGs due to how their targets are structured by the UN. For example, SDG 14, which is "Life Below Water," although it has this title, is not structured around freshwater environments, focusing solely on oceans, seas, and marine environments. That study also presents an extremely indirect relationship, which, from the perspective of water losses and their effects on SDG 14, was not sufficient to be included in this study. Reducing water losses could financially benefit systems, enabling them to better treat the effluents they produce and thereby improve the quality of ocean water. The evaluation of this influence depends on the proximity of the systems

[72] Zhironkin, 2022.
[73] Duraisamy; Beni; Henni, 2013.
[74] Samberger, 2022.
[75] Bozelli, 2019.
[76] Westall; Brack, 2018.
[77] Bayard; Luna, 2024.
[78] Machete; Marques, 2023.
[79] Heidler et al., 2023.
[80] Rosaneli et al., 2021.
[81] AbuEltayef; AbuAlhin; Alastal, 2023.

to the coast. While almost all water flows to the oceans, this led to the decision not to include SDG 14 in this study.

On the other hand, study[82] did not consider SDGs 1 and 2 in their evaluations. By comparing the positions of the studies regarding the highlighted influences, it is possible to infer that study did not consider the direct dynamics of informal settlements and water losses for SDG 1, although it must be recognized that this is a sensitive topic to address. Regarding the absence of an approach to SDG 2, the focus of their research was limited to the Water-Energy nexus, whereas this study was grounded in the Water-Energy-Food nexus. This reinforces the importance of expanding the conception of this nexus so that the various relationships within it are more widely considered in academic works and, eventually, by decision-makers.

Discussion on water losses with SDGs and climate change

Climate change poses a significant pressure on achieving the SDGs and threatens the maintenance of these advancements, even if the targets are initially reached. Due to the broad and unpredictable impacts of climate change[83], achievements in areas such as sanitation, access to drinking water, and water resource management will progressively face risks of regression[84]. Therefore, ensuring the success and sustainability of the SDGs requires not only achieving the targets but also continuously reinforcing them to withstand the challenges that climate change will continue to impose. In the context of WSS, this means maximizing efforts to reduce water losses.

Water losses present a challenge that, while contributing only marginally to climate change, is particularly vulnerable to its effects. In regions facing projected decreases in average precipitation and prolonged dry periods, such as Southeastern Brazil—where a reduction in rainfall of up to 50 % is expected by the end of the century[85]—the impacts of water losses on supply systems are intensified by climate change. In these contexts, water losses exacerbate water deficits and disrupt regional water balances, increasing pressure on available resources and challenging water security.

A study[86] evaluated the solutions adopted by three major metropolitan areas located in regions with low water availability. Additionally, these areas are projected to experience a decrease in annual precipitation and an increase in dry periods. The study identified that, over recent years, these cities' water systems have invested in diversifying water sources, including basin transfers, desalination, and water recycling. There were also numerous incentives aimed at reducing consumption through non-structural measures and decreasing water losses via structural interventions. This study underscores the need for implementing a range of strategies to enhance the resilience of water systems against current challenges and future pressures arising from the intensification of climate change.

Reducing water losses becomes a crucial strategy not only to mitigate emissions that contribute to climate change but also to strengthen the resilience of WSS against the pressures resulting from these changes. Striving for minimal levels of water loss is imperative, especially in areas with significant projections of declining average annual precipitation.

Final considerations and recommendations

This study presented a qualitative analysis of the relationship between the existence of water losses in WSS and sustainable development. From the perspective of the Water-Energy-Food Nexus, in the context of WSS operating above unavoidable levels, these water losses lead to unsustainable maintenance of the micro and macrosystems in which these WSS are installed: cities and river basins. They also influence the dynamics of food production and electricity generation. WSS exist all over the planet, so it is possible to consider the relationship between water losses and the achievement of the SDGs on a global scale. It is therefore crucial to focus more attention on the water industry and to operate WSS in a sustainable way.

Water losses in WSS can make it impossible or slow down the achievement of SDG 6 targets and jeopardize the success of other goals that depend on this synergy. Reducing water losses in WSS not only increases the chances of achieving the goals of SDG 6, but also contributes substantially to the development and success of the other goals of the 2030 Agenda. Although not all the SDGs have been structured to emphasize synergy with water, it is important to analyze how water

[82] Abueltayef; AbuAlhin; Alastal, 2023.
[83] Intergovernmental Panel on Climate Change (IPCC), 2023.
[84] Mukherjee; Dash, 2024.
[85] Lyra et al., 2018. Avila-Diaz et al., 2020.
[86] Bernabé-Crespo; Loáiciga, 2024.

losses in WSS negatively influence, even minimally, the achievement and success of these.

To further support and reinforce what has been discussed throughout the study, it is pertinent to develop specific studies that can develop objective and quantitative results on the influence of water losses on the success of each SDG, especially SDG 6. An analysis of this nature at a national level could be better developed, especially in countries that suffer from high levels of water loss, providing evidence that corroborates the quest to reduce losses through greater investment, given that this is an action to promote resilience and sustainability, not only financially for the service provider, but especially at an ecological level.

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