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Water management technology for implementing a water culture for bus operators

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ABSTRACT

Transit operators' concerns regarding water resources are minimal. No standards or policies are available for managing water in washing operations, which are currently accomplished according to local practices. This paper presents a cost-benefit scenario assessment in which an innovative water-reclamation and harvesting technology for the bus sector is applied to washing operations within the European Commission's LIFEH2OBUS project. The theoretical approach (coherent with consolidated methodologies applied in transportation studies developed within past European research projects) is aimed at assessing the performance trends and impacts (associated with several evaluation categories, such as society, environment, operations, and energy) in various scenarios and via cost-benefit and sensitivity analyses. Furthermore, a performance threshold was designed to successfully implement the innovative technology outside the LIFEH2OBUS project. The scenario's results show a 92% reduction in water consumption after one year of implementation; that is, 21,528,000 L saved for a fleet of 500 buses. If this technology can be implemented in 50% of the European transit fleet in five years (342,143 buses), 14,731,309,008 L/year can be saved, along with a 29 GWh/year reduction in energy consumption and 74 ktCO_2eq/year fewer greenhouse gas emissions. The research goal is to evidence water saving potential and pioneer a new field of study on water management, thereby launching a new "Water Culture" among bus operators.

1. Introduction

Less pollution and consumption have become central elements in the efforts to make European bus fleets more sustainable. Over the last decades, these elements have driven the research and development (R&D) sectors to shape the so-called European "bus of the future." Crucially, the European Union (EU) has been instrumental in funding a series of successful research projects in this field. Numerous areas of innovation have emerged with a significant focus on energy management. These include electrification, cleaner engines, and alternative fuels, all of which have received significant attention. These advances owe their success largely to a series of pioneering demonstrators, initially involving mixed bus fleets (Musso and Corazza, 2015) and later, specifically electric vehicles (Bousse et al., 2018) within the EU research projects EBSF – *European Bus System of the Future* (2008–2013) and ELIPTIC – *Electrification of Public Transport in Cities* (2012–2016), respectively. In this context, several driving factors exert influence: uncertainties in energy supply (Johnstone and McLeish, 2022), increasingly stringent European environmental regulations, and a growing consensus for green economy tools (Moretti et al., 2017). These factors steer R&D efforts, with a significant interest in the design of vehicle components and parts, particularly in reducing emissions and energy consumption.

Several studies have demonstrated advantages and benefits, particularly in terms of increased productivity and reliability, resource optimization, cost reduction, and environmentally conscious performance and operations. Notable studies include Campos et al. (2021), who emphasized the importance of appropriate design and operation parameters to successfully implement cleaner buses, as demonstrated in the Barcelona case study, and Meishner and Sauer (2020), who specifically analyzed transit electrification from a technical and economic perspective. Thus, the operators' willingness to innovate may often be driven by the need to save and meet stringent environmental requirements. Fuel and pollution reduction are at the center of this trend, overshadowing potential improvements in other resources such as water. However, unlike emission reduction and exploitation of alternative fuels, water management and consumption raise fewer concerns among transport operators, decision-makers, and researchers in the transport field. The problem is so underrated that there is a significant

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dearth of statistics, recommendations, guidelines, and organized data at the EU level concerning water consumption by the public transport sector.

To the best of the authors' knowledge, these issues are also poorly described in the literature on transportation, and in fact, there are no consolidated contributions aside from gray literature for water management. To address this critical gap, the EU recently provided funding for the project: LIFEH2OBUS - *Best practices for H2O management and savings for bus operators* (2022–2025). This project seeks to find solutions by testing water-saving technologies in three European bus garages and evaluating their performances. LIFEH2OBUS is part of the EU LIFE program (a plan to promote environmental and climate actions) with the goal of creating, for the first time, a European culture of water management among bus operators based on best practices to reach the lowest possible water consumption. Therefore, several state-of-the-art water-saving solutions have been explored. Among them, a demanding wastewater treatment and recycling facility combined with a rainwater harvesting system will undergo a year-long trial in three bus garages located in Italy, Hungary, and Croatia, with performance variations assessed, especially in terms of the amount of water saved, which has a promising average of 84% reduction. During the test period, software designed to optimize maintenance operations will collect data, enabling a before-vs-during performance comparison, and assess the most efficient among the proposed technologies. By the end of 2023, the measurement plan and construction phases are expected to be completed to launch test activities in the first half of 2024.

The LIFEH2OBUS research background is the same as that of the previously mentioned EU-funded series of successful research projects (not just ELIPTIC and EBSF, but also the follow-up of EBSF_2, along with 3iBS – *The intelligent, innovative, integrated Bus Systems*, and ZeEUS – *Zero Emission Urban Bus System*), motivated by the need to develop solutions to improve the environmental quality of performance in the bus sector. Evaluation methodologies based on data collected from real environmental demonstrations are one more common trait. However, unlike previous projects, LIFEH2OBUS significance relies on the acknowledgment, for the first time in this sector, that water is as important as emission mitigation or energy saving if the goal is to provide a more sustainable transit supply.

Water scarcity is a global problem with reported stress situations worldwide (Ungureanu et al., 2020). According to the European Environmental Agency, approximately 224 million people in Europe are exposed to water stress (European Environment Agency - – EEA, 2021). Over the last 50 years, the increasing water demand has coincided with a decrease in the availability of renewable water, which is now 24% per capita. Climatic changes such as recurring droughts and a general decrease in precipitation in Europe (European Environmental Agency – EEA, 2018) contribute to this challenge. In terms of annual water use, the sector with the highest demand is agriculture (40%), followed by energy production (28%), with households accounting for only 12% (European Environmental Agency – EEA, 2018). However, while water consumption for these sectors is well documented in the statistics and literature, the same cannot be stated for public transport. In practice, the typical water consumption for washing a single bus is approximately 300 L, with a washing frequency of three times per week (Arriva, 2019). This results in an annual water requirement of approximately 46,800 L. To put this into perspective, the average daily water consumption per individual in Western countries amounts to 54,750 L annually. Upscaling the vehicle-specific water requirement to the entire European bus fleet, that is, 684,285 registered vehicles (Automobile Manufacturers' Association – ACEA, 2022), a staggering total of approximately 32 million m^3 of fresh water is necessary for washing operations.

Another factor to consider is the energy required for washing. Based on practical data, 1.9864 kWh is required to pump 1 m^3 of water (Arriva, 2019). Consequently, approximately 63.4 GWh of energy is expended annually to wash European bus fleets. Regarding CO_2eq emissions, approximately 0.005 t CO2eq is produced for each cubic meter of pumped water (EPA, 2021). Thus, at the European level, it is safe to assume that 160 kt CO_2eq is emitted annually by the bus sector for washing operations.

Moreover, despite the lack of concerns among the main actors in bus management, supranational environmental regulations now demand more stringent actions regarding water treatment and conservation and more awareness at the national and local levels, thus highlighting a discrepancy between policy development and current knowledge and practice.

The rationale of this study is to introduce the LIFEH2OBUS research project and generate interest in the relevance of water as a resource for bus operations. Coherently, the paper initially describes typical water usage in bus maintenance operations and highlights the general underestimation of water as a resource in the transport sector, as reflected in the current practice and scientific literature on the topic (Section 2). Subsequently, the results of a cost-benefit analysis developed for the LIFEH2OBUS real case study, where the wastewater treatment and recycling facility combined with a rainwater harvesting system are being tested, are presented (Sections 3 and 4) and elaborated (Section 5). The need to perform a cost-benefit analysis before the test is due to the complexity of installing such a technology in a fully operational garage as a prerequisite for its actual implementation. The goal is to prove that water can generate sound savings, thus paving the way for more case studies and advancements in scientific knowledge in this field.

2. Literature review

Although the commercial web literature offers extensive information on various bus washing and wastewater systems and equipment, scientific literature addresses water consumption within the broader context of commercial car washing operations. This includes concerns about risks to public health from pathogenic organisms released into the water (Zaneti et al., 2012), quantifying pollution loads generated by wastewater from the carwash industry (Monney et al., 2020), and comparative research studies on car wash wastewater quality, treatment techniques, and costs, with the goal of stressing the need for wastewater treatment and recycling (Kuan et al., 2022). However, specific attention to the bus sector seems marginal, with only a few notable case studies, such as that of São Paulo, Brazil, because of the large size of the bus fleet analyzed (Almeida et al., 2010), and the one in Newcastle, Australia, addressing the bus-washing demand in the general local water-saving program (Coombes et al., 2000).

In contrast, there is greater interest in water treatment practices and technologies, although they are not always strictly related to transit operations. For example, water recycling systems for large urbanized areas (Hatt et al., 2006), water recovery from specific operations in industrial areas (Ruffino, 2020), and the comparison of treatment and recycling options for commercial carwash wastewater (Ibrahim, 2021) are relevant topics. Moreover, there has been a focus on specific chemical features and processes, including pretreatment methods (Breton et al., 2010), general removal of heavy metals (Tajuddin et al., 2020) and specific coagulation, flocculation, and aerobic biological treatments (Buitrago et al., 2020). The environmental implications of carwash wastewater treatments, for instance, when specific pollutants are detected like metals, organic matter, oils and grease (Rosa et al., 2011), calling for their full degradation to develop an efficient approach for waste management (Dadebo et al., 2022), are also generally underlined, accenting their economic potential, like hydrogen production (Hatch et al., 2013), but again with virtually no interest for the transit sectors.

All of the above underscore the need to build more specific knowledge regarding the potential for more sustainable water management practices for bus operators. More evidence of this can be found in the current development of policies for sustainable transportation. For example, the recent European Green Deal (European Commission, 2019) aims to achieve a 90% reduction in greenhouse gas emissions in the transportation sector by 2050. This goal is expected to accelerate bus fleet conversion towards cleaner propulsion systems, although the higher costs of these innovative vehicles thwart the process. Consequently, transit operators are called on to explore alternative ways to mitigate pollution, including waste processing, utilities and facilities organization, and water management. The former two are well documented in the literature in several research fields such as economic assessment (Anser et al., 2020), organization of operations (Demirbas, 2011), and associated climate change mitigation policies (Ramanditya et al., 2021). However, water management for transit has been neglected.

The United Nations (UN) recognized this underestimation, and in the 2018 International Decade for Action, Water for Sustainable Development supported knowledge of water management. The UN's 6th Sustainable Development Goal also stresses the interest in water when tackling inefficiencies in water use and wastewater-generated pollution. The European Parliament's Water Directive specifically aims to reduce water consumption (Regulation EU, 2020/741), and its reuse is in line with the new EU Circular Economy Action Plan, which stresses the need to prevent water extraction and reuse rainwater. From a climate change perspective, transit is a strategic sector in water management. Extreme hydrological events cause service disruptions, as evidenced in the literature (Markolf et al., 2019), emphasizing the need for proper water management to mitigate tolls in urban communities. This approach also aligns with the EU Zero Pollution Action Plan, which aims to reduce greenhouse gas emissions resulting from the energy spent to pump or purify water. Nevertheless, when developing policies for green public procurement criteria for road transport (European Commission, 2021), the EU misses addressing this specific point, focusing once more on air and noise pollution reduction as well as on other measures to mitigate energy consumption, such as the management of auxiliaries, fuels, and tires.

However, for transit companies, the goal of operating "green" necessitates a re-evaluation of current water management practice, with particular emphasis on the wastewater process. Urgent research is warranted in this field to bridge the existing knowledge gaps. Some pioneering EU-funded projects (CANALS - *Changing Water Cultures*; SAID - *SmArt water management with Integrated Decision* support *systems*) explore water optimization from different perspectives, including urban and public health studies and the environmental benefits of appropriate usage of water, but many more are needed in a sector such as transit, where significant amounts of water are required to keep vehicles clean.

Last to consider is the 2020 pandemic, which also triggered a vast body of literature on the spread and travel behaviors. Cleanliness has emerged as a major factor in orienting travel choices (Abdullah et al., 2020), resulting in a general reorganization of the transit supply (Shortall et al., 2022), with the deployment of specific anti-spread measures, such as touchless services (Benita, 2021). The focus is clearly on the effects of non-pharmaceutical interventions (including touchless operations, onboard personal protection equipment, and physical distancing), with vehicle washing remaining neglected (Corazza et al., 2021a). Moreover, the need to increase fresh air intake on-board might seem to be in contrast with the last decade's R&D efforts to manage energy for buses, especially when designing a "sealed" travel environment to maximize energy savings at stops and avoid heat losses (Corazza et al., 2021b). Once more, this highlights the relevance of water when sanitizing buses to provide healthy onboard environments, as non-pharmaceutical interventions are no longer compulsory, and energy-saving is still imperative.

In summary, it is clear that upon analyzing the aforementioned literature sources, there are some substantial research gaps and limitations. Foremost is the lack of a specific and self-standing line of research on water management for transit operations developed in transportation studies. Several facts and figures can be inferred from research on commercial carwash operations and water treatment processes. However, transit vehicles, as generators of water pollution, are poorly represented or ignored because they are analyzed within different fields and goals rather than transportation. This also explains why although the sources mentioned above present accurate methodologies and scientifically sound results, they do not specifically introduce operational and environmental implications for transit operations.

Likewise, these studies, developed to contribute to improving public health by mitigating water and soil pollution, frequently emphasize regulatory compliance in this field, but do not consider the gap in current transit regulations concerning water usage. This oversight results in an underestimation of the consequences of missing stringent mitigation measures for specific water needs for transit. On the other hand, the lack of transportation studies pointing to this is an additional gap in the available literature. Instead, emphasis is placed on air quality, emissions, and innovations to mitigate them, both from the R&D and operators' sides, with water never considered an "item" in the economic and environmental assessments of transit operations.

However, the sources mentioned earlier and the interpretation of these gaps are instrumental in identifying a vicious circle that prevents water from being adequately considered in transportation studies. The absence of regulations that compel efficient water treatment for transit operators and researchers has created a lack of perception regarding the potential of water to generate savings and more environmentally friendly operations. This limited perception explains both the lack of progress in the R&D sector to address water in the transit field and the unawareness of the public; but with poor or no advances and awareness, regulations stay "stuck" in consolidated practice, do not evolve to consider new requirements, thus replicating and fostering the steps of such vicious circle. Based on this interpretation, the results presented in the following sections serve a dual purpose. On the one hand, breaking such a vicious circle by raising interest and launching a new field in transportation studies and quantitatively showing, for the first time, the operational and economic potential of water saving in bus operations. On the other hand, washing operations are expected to evolve from local maintenance practices to general environmental-friendly interventions in fleet management, thanks to the technologies tested within LIFE-H2OBUS, and originate the "Water Culture" among transit operators.

This last point is raised by the observation that, due to the lack of national or supranational regulations on "cleaning" standards for public transport vehicles, washing operations usually depend on the conditions agreed in the public tender documents between the transport operator and the local authority assigning the service. Consequently, washing relies only on consolidated local maintenance operations, and less frequently tackled at the company level. Conventional washing equipment in bus garages is not significantly different from ordinary car washing equipment. These "car wash depots" (similar to car wash lanes) feature drive-through automated brush washers with water and detergents sprayed to clean the vehicle (Schiavone, 1995). However, these washing facilities were initially designed without wastewater treatment systems, resulting in the direct discharge of used water into the sewage system. Currently, the only treatment often involves an oil separator to extract oil and other substances, such as metal particles, from wastewater. These substances are usually stored in sludge wells, and their disposal is performed by specialized companies, representing an additional cost for transport operators. The negative effects of discharging highly polluted and foul-smelling wastewater on soil and aquatic life are intuitive. However, the presence of non-specific pollutants in water can be detrimental. For instance, salts can increase the alkalinity of soils unsuitable for agricultural use.

Bus operations are "dictated" by budgets, revenues, and subsidies, with staff representing the highest expenditure. However, as previously mentioned, energy saving is also central when managing operations, as is water, which can no longer be considered a minor cost item if only because in Europe the cost of water escalated in the last decade, and the price for sewage and wastewater services followed a similar upward trend (OECD, 2013). Consequently, if bus operators want to meet environmental requirements and save resources, switching from conventional washing systems to new technologies can be an opportunity and alternative to more demanding fleet renewal processes. Although state-of-the-art solutions are available (Table 1), they have limited adoption levels. As for any innovation, the reasons for this could be high capital costs and more general garage managers' reluctance to operate more technologies simultaneously in a single garage. Costs can also be associated with a lack of available space to accommodate new technologies if garages are located in consolidated urban areas, with no opportunity to expand if not at higher costs (by creating additional underground or elevated areas). The same problems apply to their replicability in metropolitan areas in the case of operators managing multiple garages, which further complicates the installation of new technologies in all facilities within a short timeframe.

As observed from Table 1, the keywords for innovative washing technologies rely on processing water in a more environment-friendly manner. This is achieved either via "reclamation" (recycling water) and "use of natural resources" (rainwater harvesting) or improved "rinsing quality" (fewer chemicals) and exploring waterless alternatives like waxing vehicles, as observed in the aviation sector. Moving from this palette of available technologies, the LIFEH2OBUS project aims to provide bus operators with tangible facts and figures on the benefits achievable from the most demanding, that is, reclamation, harvesting, and wastewater treatment for washing buses. This approach presents major challenges because of the need to install a treatment and recycling process in already operational bus garages with all the typical limitations of retrofitting (adaptation of existing infrastructure, uncertainties of costs, risks of disruptions, etc.).

3. Assessing the potential from reclamation and harvesting wastewater treatment: methodology and case study features

To demonstrate the advantages of technologies based on water reclamation and harvesting, LIFEH2OBUS's initial step is to assess the potential of this wastewater treatment and recycling facility combined with a rainwater harvesting system (RWH + TRWW) in a real operational environment (a bus garage in northern Italy) by studying performance variations from the comparison between the business-as-usual (BAU) scenario (current washing operations without any type of water reuse) and a do-something situation (RWH + TRWW scenario), with a focus on water savings specifically from bus washing operations. A prerequisite in the project dictated the assessment of the feasibility of introducing RWH + TRWW technology in a given facility, based on quantitative facts from a cost-benefit analysis (CBA). Although the CBA is a consolidated procedure, that for the LIFEH2OBUS was the first to specifically assess the water-saving potential for bus operations.

The LIFEH2OBUS CBA was developed according to the TIDE methodology (Dagmar, 2015), which is strongly recommended for the assessment of EU-funded projects in the field of public transport, and is therefore already largely and successfully applied. Opting for the CBA as a LIFEH2OBUS evaluation tool is also dictated by the fact that a significant portion of funding in the European Union is conditional on the CBA (Sartori et al., 2015).

The entire methodology (Fig. 1) was developed according to the "onion model" (Saunders and Tosey, 2013) to consider the underlying complexity of developing a new "Water Culture" for the management and maintenance of vehicles in the transit sector as a research goal. Thus, the steering research question is whether optimized water management for bus operations, specifically for washing operations, can generate savings, and of what magnitude.

This also explains why selecting Key Performance Indicators (KPIs) is central to performance assessment. Three KPIs are mandatory for quantifying performance variations: water consumption, energy consumption, and CO_2 emissions generated, which synthesize the environmental impacts of different scenarios. To complement the three core LIFEH2OBUS KPIs, a series of context parameters were used as input data (with values reported in Table 2) to perform the CBA.

Along with the BAU vs do-something scenario comparison, it also planned to have a BAU-vs-"during-the-project" performance assessment after twelve months of operations with the new RWH + TRWW system in place, and for which it is expected a 92% of reduction in freshwater consumption. This step is expected to be completed in the case study described in the last quarter of 2024, making the CBA results even more essential for the current assessment of the feasibility of the RWH + TRWW system.

3.1. Case study and the installed technology

The case study is located in Turin-Grugliasco in northern Italy, where a bus garage serves an urban area (approximately 800,000 inhabitants) with a fleet of 500 vehicles. The fleet comprised diesel-fueled buses, all servicing the suburban districts. The area faces several regional climate challenges, such as water shortages due to long periods of drought and excess water due to frequent downpours, resulting in floods and recurring snowy winters, leading to alternating periods of water abundance and shortage. Resorting to reclamation and harvesting for washing operations, in this case, represents not only a way to optimize water as a resource, but also a contribution to increasing local resilience thanks to the possibility of reaching, or getting close to, water self-sufficiency. According to the 3-times a week consolidated practice in the Turin-Grugliasco garage, washing operations per year generate over 23 million litres of wasted water (enough to fill more than nine Olympic pools), 92% of which, as said, are planned to be saved by the RWH + TRWW system.

The RWH + TRWW technology includes a tank system to collect both rain and post-washing wastewater, which after the treatment, can "feed" the washing plant (a typical car wash depot, as previously described). The tank system comprises underground lamination and accumulation tanks or basins with variable capacities (usually from 200 to 40 m^3, although smaller 2 m^3 tanks are used with a buffer function); some are usually left empty, pending rainy months. The water process starts with water collection via road gullies and pipes in the underground tanks, from which the water is pumped to buffer tanks, having been previously treated, and made available for washing operations. Cleaning treatment is to be performed through sand filtration with a preprogrammed rinse cycle, an ultraviolet process, and neutralization to create a pH-neutral environment. The water level in the buffer tanks is continuously monitored using floats to ensure that the water from the underground tanks is pumped in a timely manner. The Programmable Logic Controller manages the entire process.

Table 1
State-of-the-art washing technologies.

Type	Process
Partial and total water reclamation	Partial reclamation relies on recycled water for washing with fresh water just for final rinsing, thus reducing water requirement on average by 85%; total reclamation may recycle up to 95% of the water used by processing water as in a closed loop.
Rainwater harvesting	Use of naturally soft rainwater to wash buses with 25% fewer chemicals compared to the same process via naturally hard waters, thanks to more efficient spray nozzles reducing the amount of sprayed water.
Chemical and biological water reclamation	Recycling effluents and detergents so to reduce the amount of chemicals released in the wastewater, with clear savings in the amount of detergents needed for each washing operation.
Reverse Osmosis	During final rinsing, it eliminates mineral salts in water, thus avoiding streaking or spots on the vehicles.
Waxing	Widely applied in the aviation sector, dry waxing instead of washing should keep the exterior of buses clean like that of aircraft. No water is needed; never applied in the bus sector.

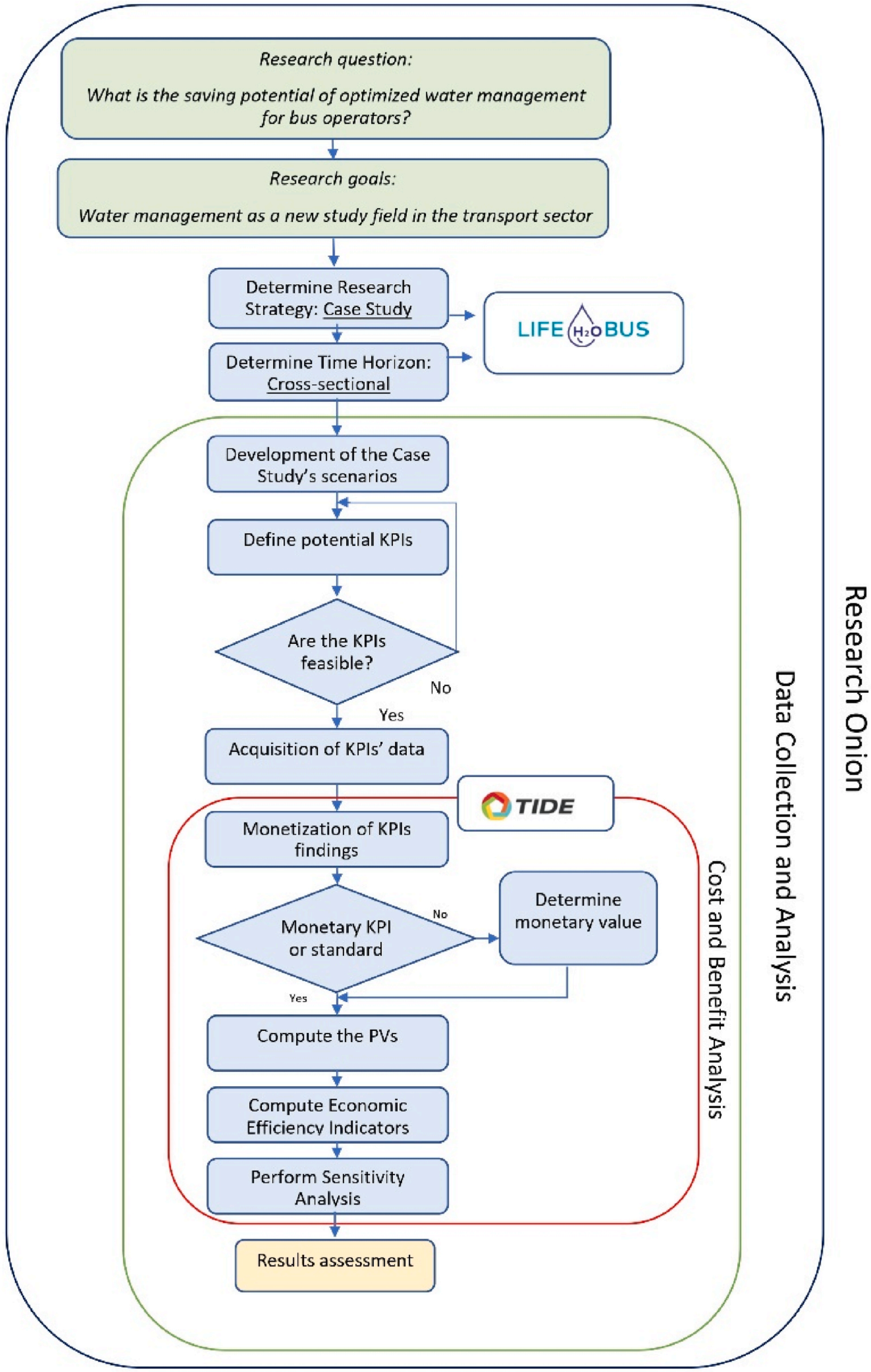

Fig. 1. Adopted methodology.

Table 2
Context parameters as CBA input data.

Parameters	
Number of Vehicles (unit)	500
Installation Costs (Euro)	260,000
Added Maintenance Costs (Euro/year)	7500
Water Amount per Wash (litre/wash)	300
Water Costs (Euro/wash)	0.47
Washes per Week (wash/week)	3
Electricity Costs (Euro/wash)	0.25
Energy Consumption (kWh/wash)	1.98
Water Reduction (%)	92
Energy and CO_2 Estimated Reduction (%)	10
Passenger Awareness (%)	71
Passenger Acceptance (%)	67
Passenger Attractiveness (%)	69
Passenger Travel Comfort (%)	75
Staff Comfort (%)	85
Staff Acceptance (%)	85
CO_2 costs 2022 (Euro/tCO_2eq)	37
Annual Adder Costs CO_2 (Euro/year)	1
Inflation (%)	2
Social Discount Rate (%)	5

3.2. Cost-benefit analysis approach

The CBA was developed considering the typical operations occurring at Turin-Grugliasco for a fleet of 500 vehicles, the LIFEH2OBUS fleet. Coherent with the TIDE CBA approach and procedure, the two alternative scenarios, that is, the BAU and RWH + TRWW scenarios, are compared based on the assumption of a 15-year lifespan of the reclamation and harvesting wastewater treatment technology to install. The context input parameters are reported in Table 2, and some of these values may appear to be underestimated or modest. This is due to the novelty of this type of computation that relies on field data, particularly water-related data, which in this case were provided by the bus operator at the test site, according to local garage practices (for example, the 10% CO_2 reduction is strictly related to energy consumption).

Accordingly, each alternative's present value (PV) is calculated with a 5% discount rate, as suggested by the TIDE (Dagmar, 2015). Specifically, PV is calculated as follows:

$$C_{PV} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{1}$$

$$B_{PV} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} \tag{2}$$

where C_{PV} and B_{PV} represent the present value of the stream of costs and benefits from year t to year T, respectively; C_t, and B_t represent the cost and benefit experienced in year t, respectively; and r represents the discount rate.

Economic efficiency is determined by utilizing the net present value (NPV) to assess the difference between a measure's benefits and costs at their discounted (present) value, as shown in Equation (3), according to the same discount rate:

$$NPV = B_{PV} – C_{PV} \tag{3}$$

When deciding between two incompatible alternatives, the alternative with the highest NPV should be selected. The CBA for the assessment of the RWH + TRWW technology in the case study was developed with a specific focus on the typical evaluation categories for operators to support or hinder the installation of new technologies: i) Installation and added maintenance costs, water and energy supply to operate the reclamation, and harvesting wastewater treatment (internal costs); and ii) CO_2 emissions and societal effects (as external costs).

Monetizing external costs and calculating time–dependent parameters are the most challenging parts. For the latter, the appropriate inflation rate for the Turin-Grugliasco case study was determined by selecting the 2% inflation target set by the European Central Bank (European Central Bank - ECB, 2022). Similarly, although the internal traits of the garage were either already measured in monetary terms or required simple conversion, the parameters for the external costs had to be further processed. For example, most bus garages across Europe do not "pay" directly for the pollution they produce, with the burden falling on local communities. Therefore, to monetize CO_2 emissions, a standard value from the European Commission's recommendations was used, corresponding to an initial cost in 2022 being 37 euros per ton of CO_2eq, with an annual increase of 1 euro per year (Bua et al., 2021). Likewise, external impacts on stakeholders and local communities require a collaborative method with the local operator. To this end, results and experiences from past sustainability-related transportation projects available in the literature were used, specifically in terms of operators' acceptance of new technologies for mixed bus fleets (Musso and Corazza, 2015) and electrified ones (Bousse et al., 2018). The latter, associated with the results from the EU-funded ELIPTIC project, provides specific directions for the quantification of economic parameters (Meishner and Sauer, 2020) and those associated with operations (Corazza et al., 2020). The ELIPTIC results also facilitated monetization of the various social parameters used to consider passenger and staff perceptions of the RWH + TRWW technology, as depicted in Table 2. The results were collected using surveys that asked staff and passengers about their perceptions of the introduction of green technology by bus operators. An example of a survey question is: "*this innovative [electric] technology contributes to the environmental safeguard*," with respondents given the option to select from a 5-point Likert scale, ranging from 1 being "strongly disagree" to 5 being "strongly agree." More specifically, they can be assumed to be valid in this case, as they describe the general levels of awareness, acceptance, attractiveness, and comfort perceived by staff and passengers before introducing a given technological innovation in a bus operational environment. Using their proportional monetary contributions, it was possible to estimate their contribution to this project, which was determined to be approximately 19% of the absolute running costs and benefits. The benefits related to society are calculated as follows:

$$B_S = \sum_{t=0}^{T} \left(C_{Rt} - \frac{C_{Rt}}{(1-s)^t} \right) \tag{4}$$

where B_S represents the stream of benefits related to society from year t to year T; C_{Rt} represents the total running cost experienced in year t; and s represents the proportional monetary contribution.

The CBA's concluding sensitivity investigation was specifically targeted to quantify the magnitude of parameter variations crucial in a bus garage when it comes to washing operations, typically washing frequency and water consumption, as described in Section 2. This is specifically required within the TIDE approach in the case of non–robust underlying assumptions (Dagmar 2015) but, for the case in hand, it was specifically needed given the novelty of the research focus.

4. Results: feasibility of the reclamation and harvesting wastewater treatment

The findings calculated for the CBA with the resulting costs (negative) and benefits (positive) items are presented in Table 3. In the BAU and RWH + TRWW scenarios, expenses constituted the most significant component. The most considerable expense for the BAU was the internal water costs associated with an estimated present value of −454,152.92 euros. Water costs accounted for approximately 60% of all the costs attributed to the alternative. Electricity is the second largest expense (−244,542.55 euros). The only contributing external factor in this alternative is the cost of CO_2 emissions (−62,755.18 euros), which makes the smallest contribution to the total expenditure (just above 8%).

Table 3
CBA findings.

Net Present Value (Euro)	Internal: *89,713.69*			External: *99,414.34*			Overall: *189,128.03*		
Scenarios	Costs and Benefits (Euro)	Installation*	Added Maintenance*	Water*	Electricity*	CO_2**	Society**	Yearly Total	Cumulative
BAU	Year 1			−36,798.84	−19,814.65	−4329.00		−60,942.49	−60,942.49
	Year 2			−35,747.44	−19,248.52	−4318.97		−59,314.94	−120,257.43
	Year 3			−34,726.09	−18,698.56	−4305.98		−57,730.63	−177,988.06
	Year 4			−33,733.92	−18,164.32	−4290.21		−56,188.44	−234,176.50
	Year 5			−32,770.09	−17,645.34	−4271.82		−54,687.25	−288,863.75
	Year 6			−31,833.80	−17,141.18	−4250.98		−53,225.97	−342,089.72
	Year 7			−30,924.26	−16,651.44	−4227.85		−51,803.55	−393,893.27
	Year 8			−30,040.71	−16,175.68	−4202.57		−50,418.96	−444,312.23
	Year 9			−29,182.41	−15,713.52	−4175.28		−49,071.20	−493,383.43
	Year 10			−28,348.62	−15,264.56	−4146.12		−47,759.30	−541,142.73
	Year 11			−27,538.66	−14,828.43	−4115.21		−46,482.31	−587,625.04
	Year 12			−26,751.84	−14,404.76	−4082.69		−45,239.30	−632,864.34
	Year 13			−25,987.51	−13,993.20	−4048.67		−44,029.37	−676,893.71
	Year 14			−25,245.01	−13,593.39	−4013.26		−42,851.66	−719,745.36
	Year 15			−24,523.72	−13,205.01	−3976.57		−41,705.29	−761,450.66
	Total	**0**	**0**	**−454,152.92**	**−244,542.55**	**−62,755.18**	**0**	***−761,450.66***	
RWH + TRWW	*Costs and Benefits (Euro)*	*Installation**	*Added Maintenance**	*Water**	*Electricity**	*CO_2***	*Society***	*Yearly Total*	*Cumulative*
	Year 1	−260,000	−7500.00	−2943.91	−17,833.19	−3896.10	7546.80	−284,626.40	−284,626.40
	Year 2		−7285.71	−2859.80	−17,323.67	−3887.07	7331.18	−24,025.08	−308,651.47
	Year 3		−7077.55	−2778.09	−16,828.71	−3875.38	7121.71	−23,438.01	−332,089.48
	Year 4		−6875.34	−2698.71	−16,347.89	−3861.19	6918.24	−22,864.89	−354,954.37
	Year 5		−6678.90	−2621.61	−15,880.80	−3844.64	6720.57	−22,305.38	−377,259.75
	Year 6		−6488.07	−2546.70	−15,427.07	−3825.89	6528.56	−21,759.17	−399,018.92
	Year 7		−6302.70	−2473.94	−14,986.29	−3805.06	6342.03	−21,225.97	−420,244.89
	Year 8		−6122.62	−2403.26	−14,558.11	−3782.31	6160.82	−20,705.48	−440,950.36
	Year 9		−5947.69	−2334.59	−14,142.17	−3757.75	5984.80	−20,197.40	−461,147.76
	Year 10		−5777.75	−2267.89	−13,738.10	−3731.51	5813.81	−19,701.45	−480,849.21
	Year 11		−5612.68	−2203.09	−13,345.59	−3703.69	5647.70	−19,217.35	−500,066.56
	Year 12		−5452.31	−2140.15	−12,964.28	−3674.42	5486.34	−18,744.83	−518,811.39
	Year 13		−5296.53	−2079.00	−12,593.88	−3643.80	5329.58	−18,283.63	−537,095.02
	Year 14		−5145.20	−2019.60	−12,234.05	−3611.93	5177.31	−17,833.48	−554,928.50
	Year 15		−4998.20	−1961.90	−11,884.51	−3578.91	5029.39	−17,394.13	−572,322.63
	Total	**−260,000**	**−92,561.26**	**−36,332.23**	**−220,088.29**	**−56,479.67**	**93,138.82**	***−572,322.63***	
Key	** Internal Costs*				*** External Costs*				

Concerning RWH + TRWW, the lead impact is an installation cost of 260,000 euros, corresponding to over 34% of the balance. The other additional internal cost compared to the BAU consists of the added maintenance cost of the new technology; this is the third highest cost overall at −92,561.26 euros. The three areas also present in the BAU alternative (water, electricity, and CO_2) were all reduced in comparison, especially the cost of water, which was reduced by 92%. In RWH + TRWW, the "society" was the only aspect that added a positive monetary balance to the CBA, and this is also valid for the BAU. Its magnitude (93,138.82 euros) was less prominent in the two areas for the novel scenario of Installation and Electricity. The NPV of both alternatives was summarized and found to be −761,450.66 euros for the BAU alternative, while the RWH + TRWW alternative was −572,322.63 euros. As shown in the top-right corner of Table 3, the difference between the two was 189,128.03 euros. Table 3 also shows the difference in NPV between the two scenarios when considering internal costs (−89,713.69 euros) or external costs (−99,414.34 euros).

From the findings, various breakeven analyses were performed to determine when or if one alternative becomes more beneficial with respect to another within a predetermined amount of time. For instance, a project with a higher upfront cost, such as the observed RWH + TRWW alternative, is due to the initial installation cost compared with the BAU. This process was repeated three times to assess the differences between the alternative perspectives: internal bus garage costs and benefits, external community costs and benefits, and overall costs and benefits for the entire case. The breakeven analysis for the internal purpose (Fig. 2) highlights that, for bus garages under similar conditions, it should take around 10.5 years of operations for the RWH + TRWW alternative to better the BAU option.

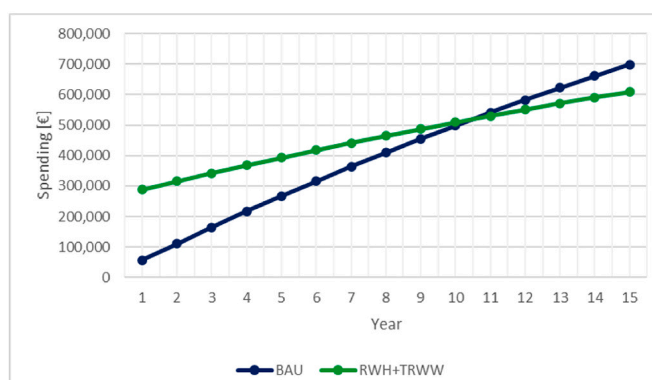

Fig. 2. Internal break-even analysis.

In turn, the break-even analysis for external purposes (Fig. 3) indicates an immediate beneficial impact for the RWH + TRWW alternative compared to the BAU, with a clear estimated net positive contribution due to the novel technology. Likewise, from a financial perspective, the break-even analysis for the overall purpose (Fig. 4) indicates a beneficial impact starting from approximately the eighth year after the implementation of the RWH + TRWW alternative in comparison with the BAU.

A sensitivity analysis was performed to complete the assessment. The impact variables were changed by ±20% each with each change

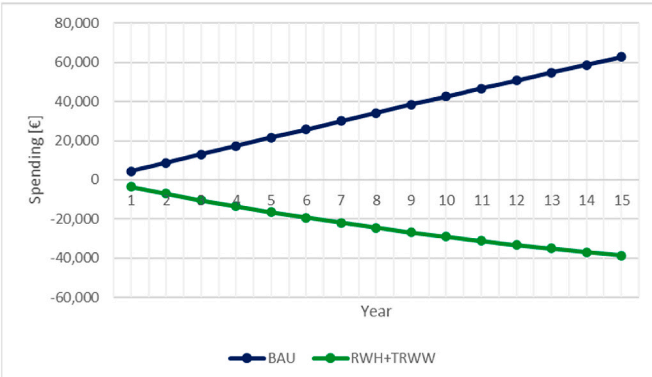

Fig. 3. External break-even analysis.

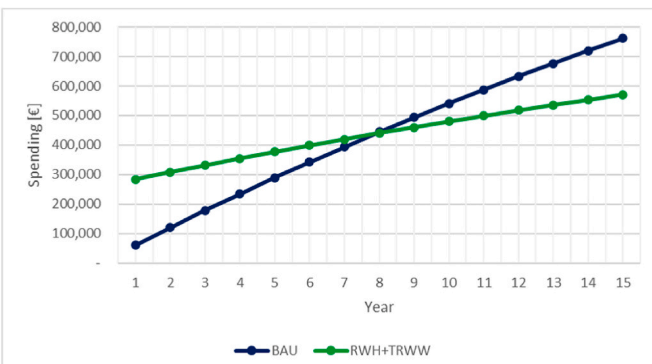

Fig. 4. Overall break-even analysis.

recorded in Table 4, coherently with Dagmar (2015), which uses a One-at-a-Time approach. This is a common approach for linear models because of its practicality and effectiveness in analyzing each input. As shown in Table 4, several impact variables varied the results by relatively large amounts. The most volatile are the Water Amount per Wash and Washes per Week, which all cross the ±20% threshold for the Overall value. Notably, despite the large fluctuations caused by some variables during the sensitivity analysis, none of the Internal, External, or Overall values were negative. This is a critical remark, as single-value divergence should not affect the final decision of the CBA. The possibility of considering the value effect of some multifactor linkage on the Internal, External and Overall values can be contemplated, but this implies moving from the One-at-a-Time (e.g., TIDE approach) to nonlinear models (as described by Czitrom, 1999), which usually implies typical multifaceted case studies developed within complex sensitivity analyses, as reported by Razavi and Gupta (2015).

5. Discussing the potential: applicability of results

When analyzing the findings provided by the CBA applied to the case study, the better alternative is the RWH + TRWW system. While neither alternative generates an overall profit, this system provides significant savings compared with the current status quo offered by the BAU alternative. Fig. 5 compares the net spending of the two alternatives, from which the BAU scenario should be more expensive from all three perspectives (internal, external, and overall) explored in the analysis, the data evaluated being indisputably in favor of implementing the new system. The cost of operating a BAU is severe because the external stakeholders' experience impact is net-negative, with no perceived gain for their local bus garage to participate in the BAU alternative.

However, from an internal perspective, the BAU scenario would be almost 1.15 times more expensive than the RWH + TRWW system. Yet, as seen in the previous section, according to the break-even analysis, it would take just over 10 years of the expected lifespan of 15 years for the system before the RWH + TRWW system supplants the BAU alternative. From the bus operator's perspective, returns are not as immediate as they are from an external perspective. Naturally, with both the internal and external impacts being positive, the overall impact of each scenario would also be positive; therefore, the RWH + TRWW system remains the better choice.

Thus, considering these findings, the CBA appears to unambiguously demonstrate that RWH + TRWW is a superior alternative to BAU. The

Table 4
Sensitivity analysis.

Input	Sensitivity (%)	Internal (Euro)	External (Euro)	Overall (Euro)	Internal (%)	External (%)	Overall (%)
Installation Costs	−20	141,713.69	99,414.34	241,128.03	57.96	0.00	27.49
	20	37,713.69	99,414.34	137,128.03	−57.96	0.00	−22.58
Added Maintenance Costs	−20	108,225.94	95,071.96	203,297.90	20.63	−4.37	7.49
	20	71,201.44	103,756.72	174,958.16	−20.63	4.37	−7.49
Water Amount per Wash	−20	−65,592.61	82,510.27	16,917.66	−173.11	−17.00	−91.05
	20	278,445.64	117,000.20	395,445.84	210.37	17.69	109.09
Water Costs	−20	6149.55	97,709.87	103,859.42	−93.15	−1.71	−45.09
	20	173,277.83	101,118.82	274,396.64	93.15	1.71	45.09
Washes per Week	−20	1258.70	83,873.85	85,132.55	−98.60	−15.63	−54.99
	20	178,168.68	114,954.83	293,123.51	98.60	15.63	54.99
Electricity Costs	−20	84,822.84	89,089.21	173,912.05	−5.45	−10.39	−8.05
	20	94,604.54	109,739.47	204,344.01	5.45	10.39	8.05
Energy Consumption	−20	84,822.84	85,578.33	170,401.16	−5.45	−13.92	−9.90
	20	94,604.54	113,250.35	207,854.89	5.45	13.92	9.90
Water Reduction	−20	82,447.24	101,118.82	183,566.06	−8.10	1.71	−2.94
	20	96,980.13	97,709.87	194,690.00	8.10	−1.71	2.94
Society	−20	89,713.69	77,447.64	167,161.33	0.00	−22.10	−11.61
	20	89,713.69	123,543.57	213,257.26	0.00	24.27	12.76
CO_2 costs 2022	−20	89,713.69	98,336.19	188,049.88	0.00	−1.08	−0.57
	20	89,713.69	100,492.50	190,206.18	0.00	1.08	0.57
Annual Adder Costs CO_2	−20	89,713.69	98,149.61	187,863.30	0.00	−1.27	−0.67
	20	89,713.69	100,679.07	190,392.76	0.00	1.27	0.67
Inflation	−20	80,996.39	96,926.03	177,922.42	−9.72	−2.50	−5.92
	20	98,720.19	101,985.39	200,705.58	10.04	2.59	6.12
Social Discount Rate	−20	112,332.58	105,871.57	218,204.15	25.21	6.50	15.37
	20	69,213.08	93,562.82	162,775.89	−22.85	−5.89	−13.93

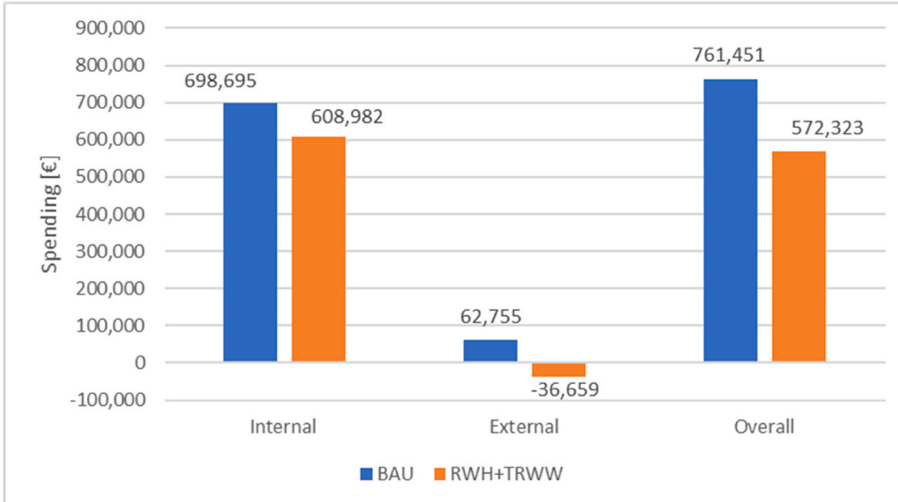

Fig. 5. Spending comparison.

value of incorporating novel technology increases with more buses if the other circumstances remain largely unchanged. If the circumstances differ, it is possible that in a bus garage with a more extensive fleet, the RWH + TRWW system could be less beneficial than in a garage with fewer vehicles. The reason for this could depend on numerous factors, but the most influential variables were the Water Amount per Wash and the Washes per Week, as shown in the sensitivity analysis. These variables significantly influenced the total amount of water used. Washing systems that use low amounts of water will experience diminishing benefits when integrating RWH + TRWW technology. However, as shown in the sensitivity analysis, even with substantial decreases (20%), the CBA deemed the RWH + TRWW system to be the most valuable alternative from an overall perspective. The data would have to deviate even further, or unobserved data would have to be introduced for the analyzed case to favor the BAU alternative overall.

5.1. Threshold definition

Considering the variability in fleets' size, a litmus test was conducted to determine whether the number of buses in a fleet of a bus garage that operates under similar conditions would affect the desirability of the RWH + TRWW alternative in comparison to the BAU alternative, thus progressing from the TIDE methodology and the classical CBA assessment. The rationale for developing such a test is due to the need to identify a threshold for the successful feasibility of RWH + TRWW technology by simply calculating the minimum number of vehicles in a given fleet to achieve such a result, or in other words, to reply to the simple question: "where this innovation is going to work successfully?".

Unlike the TIDE-based CBA, where 20% is assumed as the variation rate (Dagmar, 2015), this test was conducted by changing the total number of LIFEH2OBUS fleets of 500 vehicles in small decremental steps and monitoring if the values changed from different perspectives, while assuming that the rest of the data remained constant. As the number of buses decreases, the required time for break-even increases.

Eventually, the internal costs of the novel technology will not recover from the high initial investment and maintenance costs in the 15-year timeframe, outperforming the BAU scenario. This event occurred when the fleet size was reduced to 398 buses (Fig. 6).

As observed from Fig. 6, under the same conditions analyzed, a fleet of 398 is required for the RWH + TRWW to be no longer preferable internally because it is approximately 510 euros more expensive than the BAU alternative. Although it remains cheaper overall, even with a drastically reduced fleet, internal aspects cannot be ignored. The importance of the internal perspective reflects the costs and benefits for the transport operator. In the absence of subsidies or other benefits, adopting water management technology would be counterintuitive for

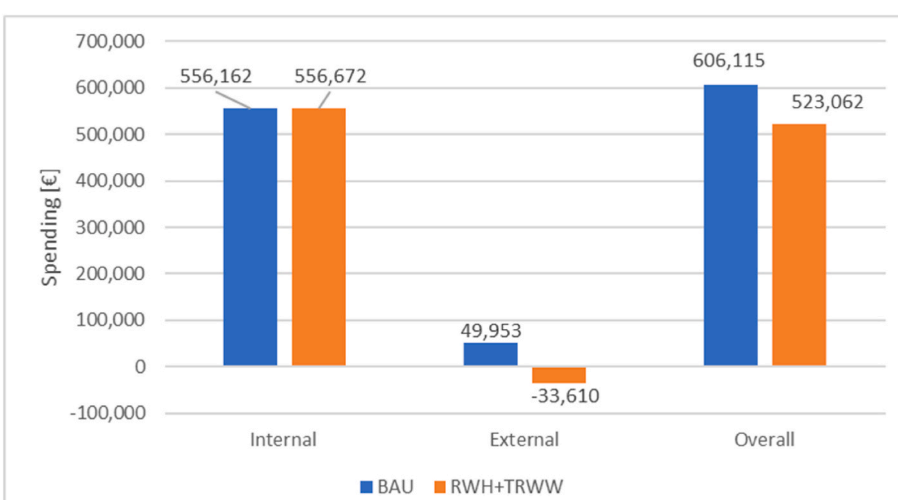

Fig. 6. Spending comparison for 398 buses.

the operator. Private operators are less inclined to assume all the costs of investing in a project if the internal balance is not financially advantageous from their perspective, even if the external impact prevails over the internal impact. Therefore, although from an overall perspective, it might prevail, it will likely not be selected because, at the moment, the primary decision makers will be the operators for whom the BAU alternative is, from their viewpoint, the better cause of action unless adequately incentivized.

For the proposed project alternative to become unviable, even from an overall perspective, the fleet would have to be scaled down further by 80 buses to reach a fleet size of 318 buses. Fig. 7 presents the CBA findings for that fleet size.

Operating under the same conditions as the LIFEH2OBUS fleet, it would take an extensive reduction in the number of vehicles for the RWH + TRWW alternative to become impractical compared to the BAU alternative. Although the external perspective is still positive, the overall performance of the water management technology is inferior to that of the BAU scenario. As the NPV is higher in the BAU scenario by approximately 144 euros, the RWH + TRWW scenario should be rejected. However, it should be emphasized that all these calculations were based on the data collected in the case study. A smaller garage with 318 buses can differ from the conditions experienced in the case study.

If analyzed at the national level, the 398-vehicle threshold to successfully implement RWH + TRWW provides further results. For example, in 2021, in Italy (where, apart from a few exceptions, transit is managed by a single company at the local level), the fleets operating public transport services in the 109 urban areas are composed of an average of 457 vehicles, with the 12 metropolitan areas having the largest share (less than 25,000 vehicles), according to the 2022 national statistics (Automobil Club d'Italia – ACI, 2022). Urban areas below the 398-vehicle threshold account for a total fleet of 13,588 vehicles, which means that the RWH + TRWW alternative is virtually viable for all Italian metropolitan areas and a large part of the urban areas.

5.2. Further considerations

From an environmental point of view, CO_2 emissions are, in this case study, purely an external impact, as there are no internal repercussions for them, at least regarding the Turin-Grugliasco site. However, some European countries have incorporated policies such as a carbon tax to stimulate private organizations to curb their greenhouse-gas emissions (Asen, 2021), in line with similar initiatives started in the U.S. in recent decades (Marron and Toder, 2014). Private operators in these European countries (Fig. 8) could consider this aspect when evaluating the

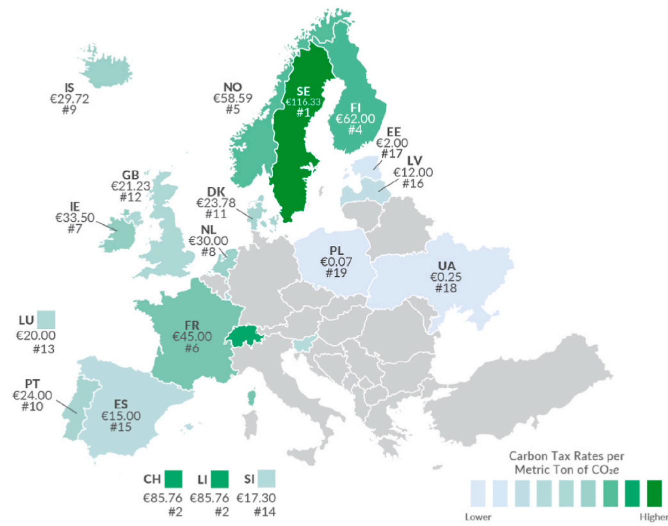

Fig. 8. Distribution of carbon taxes in Europe (Asen, 2021).

transferability of the RWH + TRWW system to their operations. The CO_2 emissions in a country with high carbon taxation (e.g., Sweden in Fig. 8) would shift the perceived purely external burden, as in the case of Turin-Grugliasco, to be internal. With the higher cost due to emission charges, an operator in Sweden with a fleet size of 398 vehicles or less may prefer to adopt this novel technology. While this study's focus was to evaluate a particular case study, as discussed, bus garages of similar sizes could diverge in performance due to intrinsic circumstances related to their location. Therefore, considering the effects of changing locations on climate and policy, in the decision process for evaluating the adoption of a novel technology, it is crucial to have a firm understanding of the local context. For example, the performance of rainwater harvesting can vary under different climatic conditions.

However, independent of local conditions, in the longer run, the awareness that wasting water is detrimental to the communities' sustainability (also prompted by experiences like the LIFEH2OBUS') could give rise to a novel Water Culture and develop tools similar to the carbon tax, as mentioned above, to commit bus operators to optimize water as they currently do when optimizing the service to decrease emissions. Aside from its cost-effectiveness, which can vary on a case-by-case basis, the RWH + TRWW system significantly diminishes the impact of washing operations and might drastically improve environmental impacts in multiple facets. Table 5 shows the amount of water and energy

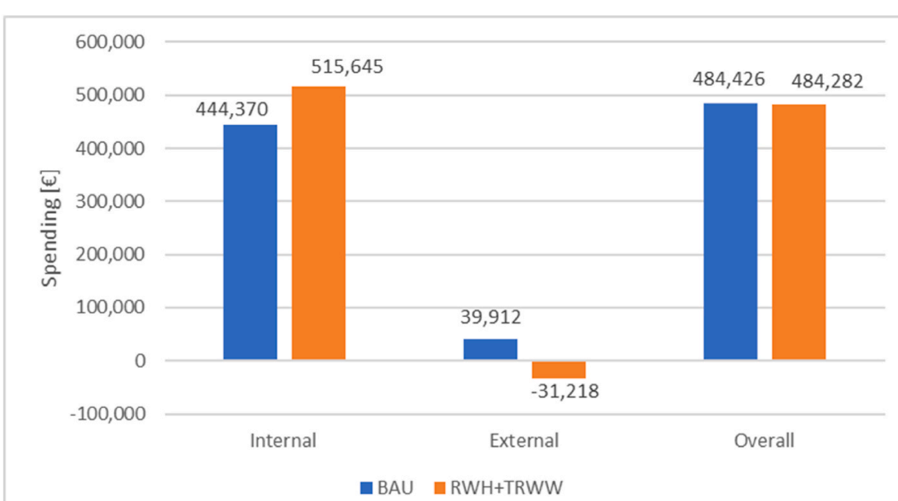

Fig. 7. Spending comparison for 318 buses.

Table 5
Estimated environmental impact for the test case fleet (annual values).

Key Indicators	BAU (Fleet)	BAU (Vehicle)	RWH + TRWW (Fleet)	RWH + TRWW (Vehicle)
Water consumption (litres)	23,400,000	46,800	1,872,000	3744
Energy consumption (kWh)	46,332	92.66	41,699	83.40
Emission generation (tCO2eq)	117	0.23	105.30	0.21

consumed, and emission reductions projected annually for the LIFE-H2OBUS fleet.

The estimates show a drastic decrease in the environmental impact of water management technology compared with industry standards. Throughout the technology's 15-year lifespan, the minimizing effects of washing operations on the environment would be considerable. Assuming that 50% of the European fleet adopts this technology, Table 6 lists the potential benefits at the supranational level.

For transit, the considerations above can lead to the creation of a new Water Culture inspired by the circular economy concept, in line with the overarching "nexus approach" (Brouwer et al., 2018), that is, the synergetic management of energy, water, and climate-related issues.

It is also necessary to consider the potential of transferring new technologies to other transport fleets and fields, such as logistics and paratransit, where vehicles are still washed according to the conventional carwash practice, such as passenger cars. In such scenarios, companies can install washing systems including wastewater treatment, recycling, and rainwater harvesting facilities and replicate the LIFE-H2OBUS experience, with no specific requirements owing to the smaller size of vehicles and fleets or additional efforts, pumping and storage equipment being easily designable and installable for every type of garage. Notably, from the regulatory perspective, the transferability process of the LIFEH2OBUS practice and results to logistics and paratransit companies can be facilitated by the approach already enforced in some European countries including Austria, Germany, Belgium, and Scandinavia for commercial car wash operations, where partial or full water recycling is compulsory (MacErlean, 2022). This can pave the way for further studies beyond the few available on commercial car wash facilities. A larger-scale application can further demonstrate that optimized water management could represent not only an important saving resource but also increase resilience and improve the quality of corporate culture in the field of social commitment.

This approach also sheds lights on the potential of improved washing operations on the quality of "maintenance" as an alternative to rejuvenate fleets and retrofit instead of "buy new." In other words, operators for which fleet conversions might be unaffordable due to subsidy scarcity and/or higher costs of innovative vehicles can look at "water" for saving resources and mitigating negative impacts by optimizing garage operations and reducing their costs.

Technologies, such as rainwater harvesting systems, strictly depend on weather conditions. Facilities such as those based on RWH + TRWW can be crucial in providing water in case of prolonged water shortage, especially in summer periods, thus contributing to reducing the water intake in the communities in which they operate and increasing the local resilience in case of extreme phenomena, such as drought, which are becoming increasingly frequent. Thus, the results from the CBA and Turin -Grugliasco case study can be a forefront example in pioneering the relevance of water management and showcase opportunities for sustainable growth at the local level. All of the above is just a "drop" in a sea of more significant commitment to reaching sustainability, coherently with the words of the UN Secretary-General's Message for 2023 on

Table 6
Estimated environmental impact of 50% of the European fleet (annual values).

Key Indicators	BAU	RWH + TRWW
Water consumption (litres)	16,012,292,400	1,280,983,392
Energy consumption (kWh)	31,704,339	28,533,906
Emission generation (tCO2eq)	80,061	72,055

World Water Day reminding: "us of our individual and collective roles to protect and sustainably use and manage humanity's lifeblood [*water*] for present and future generations" (Guterres, 2023).

6. Conclusions

The study findings verify that for transit companies, the goal of operating "green" necessarily includes a revision of current water management, especially for the wastewater process, and reveal that further research must be conducted in this field. The do-something scenario with the RWH + TRWW technology proves the centrality of water in mitigating the negative impacts of transit; this might contribute to including water management in the overall assessment of sustainable transport modes, similar to air quality or noise management. Moreover, the CBA results show the possibility of generating savings of non-negligible magnitude, satisfying an objective of this study, that is, water management is a reliable method of cost-savings for bus operators even when installing technologies such as RWH + TRWW, which is totally innovative in bus garages.

Although the CBA already confirmed that the RWH + TRWW technology is a viable route for water conservation, future work within the LIFEH2OBUS project will be aimed at progressing from this preliminary assessment and installing the RWH + TRWW solution in real bus garages. This will be complemented by the installation of two more water-saving technologies (simple water harvesting, as a less demanding infrastructural solution, and waxing), thereby enabling a before-vs-during performance comparison in terms of both single technology and across various technologies. The 12-month testing period will provide more data to "feed" the CBA, which will be updated and consolidate results. This will allow for overcoming the typical caveat of studies focused on introducing innovations, wherein specific field data are not yet available, and contribute to achieving the long-term goal of the present study, aligning with the LIFEH2OBUS project. The aim is to enhance overall interest in saving water, akin to other research fields, and to serve as a reference for establishing a framework to determine the accurate specifications for water requirements within each fleet. This represents a new contribution to the European standardization programs, which is particularly crucial given the current absence of standards on this topic.

CRediT authorship contribution statement

Maria Vittoria Corazza: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Matthew Robinson:** Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

Data availability

The authors do not have permission to share data.

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