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Original Research Article

Water supply and sewerage: Path to Net Zero Organizational Emissions

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ABSTRACT

Societal pressure to reduce greenhouse gas emissions has compelled organizations to actively manage their carbon footprint. In this paper, investigated the calculation of the carbon footprint for the company Prague Water Supply and Sewerage, which serves as an example of a water management organization in Central Europe. The specificity of the research lies in the consideration of characteristics related to the energy balance, water sources, climate, the number of consumers, and the political situation, which are most characteristic of the chosen location but may differ from the characteristics of organizations in other parts of the world.A comprehensive assessment of the carbon footprint of the investigated organization is based on the methodology of life cycle assessment . The results of this study show three main directions that significantly impact the carbon footprint of the water management organization, namely: process emissions (Scope 1) amounting to 100,015.9 tons of $CO_{2\ eq}$/year, purchased energy (Scope 2) contributing 45,144.3 tons of $CO_{2\ eq}$/year, and purchased services (Scope 3) responsible for 25,801.3 tons of $CO_{2\ eq}$/year. The recommendations developed based on the obtained results include: the replacement of outdated equipment with more modern and energy-efficient alternatives, transitioning to renewable energy sources, the implementation of energy recovery technologies, the investigation of alternative processing methods that use fewer chemicals and energy, and giving preference to suppliers of goods and services with good environmental characteristics.

KEYWORDS

Carbon footprint, Carbon neutrality, Life cycle assessment, Net-zero strategy, Municipal water management, Organizational Emissions.

INTRODUCTION

The issue of climate change is becoming increasingly pressing, and society is putting pressure on organizations to reduce greenhouse gas (GHG) emissions [1]. The European Green Deal promotes and supports this initiative [2]. One of the main goals of the European Commission is for Europe to become a climate-neutral continent by 2050. The deal encompasses areas of activity such as the economy, energy, transportation, and more [3]. In this way, organizations strive to control their carbon footprint. The carbon footprint is a measure of the amount of GHG emissions, primarily carbon dioxide, associated with an activity or product [4]. The carbon footprint serves as a fundamental basis for quantitatively assessing

the environmental impact by combining direct and indirect GHG emissions, expressed as carbon dioxide equivalent ($CO_{2\ eq}$) [5].

Despite all the documents and plans provided by European member states and the European Commission, it is challenging to determine how the European Union has positioned itself to achieve the goals of the Green Deal [6]. Relying solely on general recommendations and methods is insufficient to attain this objective [7]. There is a need to implement ecological sustainability and resilience in water supply projects and encourage organizations and local communities to support this initiative [8]. It is crucial to consider the specificities of the industry or organization under investigation. Working towards achieving this goal should be done directly, with a comprehensive understanding of all the details pertaining to the chosen field of activity.

A range of risk reduction strategies related to global warming focus on reducing GHG emissions, a significant cause of climate change [9]. Moving forward, it is necessary to consider indicators that relate not only to the method of their calculation but also to the interpretation of the results [10]. To achieve this goal, a series of frameworks and standards have been developed to assist organizations in measuring, reporting, and reducing their carbon footprint [11]. The GHG Protocol recommends that organizations measure and report both direct and indirect emissions, providing guidelines on how to do so using standardized methodologies [12]. In their study, [13] considered both direct and indirect emissions. Direct emissions can be described as the release of emissions in each process or activity of the investigated company. Indirect emissions result from energy consumption in each process or activity of the company [14]. Scope 1 represents all direct emissions from sources owned or controlled by the company, and their investigation was carried out by L. Vasquez et al. [15]. Scope 2 represents indirect emissions from purchased/acquired electricity, steam, heat or cooling. N. Ibrahim et al. studied these emissions in their work [16]. Scope 3 encompasses other indirect emissions arising from the consequences of various value chain activities of the company. J. Downie and W. Stubbs described the importance of considering emissions from this Scope in detail [17]. Until recently, emissions from Scope 3 did not receive much attention. However, today increased organizations are trying to account for these emissions to calculate their carbon footprint as accurately as possible. In the study by R. Shin and C. Searcy, Scope 3 accounted for 46.4% of the total carbon footprint [18].

Global sustainability challenges depend on the ability of urban systems to provide innovative urban solutions and approaches [19]. Water and energy are two pivotal areas for future sustainable development [20]. Global water use, storage, and distribution account for approximately 10 percent of global GHG emissions [21]. Water resources management is a complex sector that encompasses various processes, infrastructures, and interactions with the surrounding environment [22]. As water management organizations contribute to the overall carbon footprint through various activities, controlling and reducing their emissions play a significant role in mitigating climate change and achieving the goals of the Green Deal [23]. Research in this sector provides valuable information about the overall environmental efficiency of organizations and identifies areas that require improvement [24]. It is important to identify key areas with high GHG emissions or other environmental problems and propose measures to reduce them [25].

The path to net zero is typically complex and involves difficult compromises between regional improvement and global sustainability [26]. In this situation, it is important to choose the right methodology to work with in this research. The management of a water network metabolism depends on the estimate of incoming and outgoing flows related to the life cycle of the products and processes involved [27]. Based on a review of methods proposed by modern science and considering knowledge from experience, it was decided to work with the LCA methodology in this study. S. W. Bai et al. consider life cycle assessment (LCA) to be a promising tool for supporting such compromises [28]. L. Corominas et al. believed that for a more environmentally sustainable water supply and sanitation, it is evident that LCA is a

valuable tool for identifying the broader impact of design and operational decisions on the environment [29]. In their work, Y. Lorenzo-Toja et al. adhered to the view that LCA is the most common method for assessing environmental impact, allowing for a comprehensive analysis of all elements of the wastewater treatment (WWT) system [30]. It is these characteristics of the method that have prompted us to use this methodology. During the calculation of the carbon footprint for similar organizations, it is necessary to consider all energy, material, and human factors involved in this process. The LCA methodology can sometimes be a complex choice, as it requires specific data that may not always be readily available. Therefore, it is necessary to make assumptions, gather data from the literature or similar cost chains, or use models that contain standard values [31]. The LCA methodology works with data that allows us to assess resource use and the volume of pollution generated, such as solid waste and emissions released into the environment [32]. One of the advantages of the chosen method is the convenience of conducting comparative analysis for different scenarios of the selected process. It is possible to use the information obtained through LCA as part of a more comprehensive decision-making process and to understand broader and more general changes during the relative comparison of products or processes [33]. A. Paulu et al. applied LCA to model material and energy flow processes to better understand the impact of WWT technologies and the correct direction of their development [34].

The water management sector is currently facing a challenging task. On one hand, there are stricter water quality standards and increasing demand for water, and on the other hand, the need to adapt to climate change and reduce greenhouse gas emissions [35]. It becomes evident that water supply will constrain the development of the energy sector both at the national and regional levels, thereby leading to increased emissions [36]. Researchers from [37] contend that the nexus between water and energy compels water industry professionals to support goals of water productivity with reduced energy consumption and lower greenhouse gas emissions. This also encourages the adoption of sustainable technologies. Recognizing the importance of their emissions on the environment, water management organizations are working on reducing their activities impact. For example, since 2010, British water supply companies have been required to report their emissions as part of their carbon reduction commitments [38]. Based on existing approaches, the industry has developed standardized carbon accounting methodologies to meet this requirement, but this process has revealed gaps in knowledge that require further research [39]. To identify the driving vectors that will lead an organization to reduce emissions, information about the organization's overall carbon footprint is required [40]. Xu used the LCA methodology to study the carbon footprint of two WWT plants in Madrid. The results showed that a massive portion of the carbon footprint from the treatment plants was due to indirect CO_2 emissions resulting from intensive energy consumption [41]. Maria Crocetta Sambito and Gabriele Freni studied GHG emissions from the life cycle of drinking water supplied through the water supply system. This study helped water resource management improve the current carbon footprint of the system, considering only the operational phase [42].

The municipal water resource management systems, the case study area considered in the present research, are complex and involve a wide range of diverse processes. Water management organizations are multifunctional and encompass numerous auxiliary processes [43]. One of the key processes of water management companies is WWT [44]. Emissions from treatment facilities have always been a concern. Parravicini V. et al evaluated direct and indirect GHG emissions from two municipal treatment plants using carbon footprint analysis. The results show that direct emissions of nitrous oxide from tanks with active sludge dominate the carbon footprint of treatment plants with moderate nitrogen removal [45]. Mannina G. also investigated direct and indirect GHG emissions associated with the biological and physical processes of a treatment plant and concluded that the ratio between the influential concentration of biodegradable carbon and nitrogen plays a key role in emissions from denitrification process [46]. Researchers [47] consider it essential to introduce new approaches to recover energy from wastewater sludge and have investigated the feasibility of implementing full-scale co-

fermentation of municipal wastewater sludge with fruit biowaste due to the synergistic effect observed at the laboratory scale. As a result, the energy potential and productivity of the anaerobic process increased. Additionally, in this situation, heat recovery from wastewater is worthy of attention, as it may become part of the solution to the climate crisis in the future [48].

This scientific research aims to provide a valuable resource for the water sector by offering a systematic approach to calculating the carbon footprint and providing recommendations for achieving zero emissions. The beginning of the article is dedicated to describing the selected organization, where the characteristics and specifics of the investigated organization are disclosed. Subsequently, the importance of the correct methodology choice is emphasized, and the chosen methodology is described. The article then provides information on data collection and the process of calculating the carbon footprint. Finally, an analysis of the obtained results is conducted, and a list of recommendations is presented to assist organizations in achieving carbon neutrality.

MATERIALS AND METHODS

Calculating an organization's carbon footprint is a crucial step in understanding and reducing its environmental impact. The information required for implementing this process should encompass data about the organization's activities, including details on electricity and fuel consumption, water usage, waste generation, and other significant factors contributing to carbon emissions. Significant attention should be given to the application of the chosen methodology, which also necessitates knowledge and skills. A comprehensive approach is required to achieve the desired outcome in this regard.

Description of the researched organization

The process of selecting the organization for the study involves assessing the organization's activities, experience, transparency, and alignment with our goals and interests. In this situation, it is worth paying attention to the company's experience and competence in implementing sustainable practices. For this research, the transparency of the organization's policies is crucial. Adherence to internationally recognized standards and guidelines for reporting and disclosure, such as the GHG Protocol or ISO 14064, was a significant argument in this situation.

The organization chosen for the study was Pražské vodovody a kanalizace, a.s. (Prague Water and Sewerage Company, hereinafter referred to as "PVK"), which is in Central Europe in Prague, the capital of Czech Republic. Their policy is oriented towards sustainability and conservation of natural resources. The organization has committed to achieving a net-zero operational CO_2 footprint by the year 2035. To accomplish this goal, they have developed a roadmap for a carbon reduction project. The first part of their work is dedicated to planning and analyzing their activities, including calculating the carbon footprint and final certification of annual reports in accordance with ČSN ISO 14064-1. The next step will involve the implementation of technical innovations and modifications in the company's operations. Special attention is given by the organization to enhancing the energy efficiency of WWT processes and providing a low-carbon heat supply.

This company operates the water infrastructure of the city of Prague and is the largest water supply and wastewater company in the Czech Republic. PVK is involved in the production and distribution of drinking water, as well as the removal and treatment of wastewater. Currently, the activities of this company provide water production for 1.33 million residents of Prague and another 225,000 inhabitants of the Central Bohemian Region. The activities of this company encompass a wide range of processes and services. Drinking water is produced in two water plants. A majority of wastewater is treated in the central WWT plant, which consists of the existing water line, the new water line and the common sludge management. In addition to this, PVK maintains 23 subsidiary treatment facilities, but these

plants mostly lack their own sludge management infrastructure [49]. In addition to the activities, the organization is also involved in biogas production, which contains methane, a by-product of the WWT process at central WWT. All the information presented above distinguishes PVK among other water management organizations in the Czech Republic and makes it an excellent option for further research.

The study of this company serves as an excellent example for water management organizations in Central Europe, which typically adopt a comprehensive approach to water resource management and consider all factors that impact their activities. Additionally, the investigated organization follows a river basin management approach, where water resources are managed at the basin or watershed level rather than individual water bodies. This approach recognizes the interconnectedness of water systems and encourages coordinated management practices within a specific river basin.

Life cycle assessment of the organization

The research's goal is to determine the carbon footprint, from which recommendations will be made to steer the company toward carbon neutrality. For the study, was used the LCA methodology. This methodology's choice is explained by its consideration of the impact of a specific product on the environment and the services and technologies associated with it. Conducting research on water management organizations using LCA can be particularly valuable due to the unique and specific aspects associated with water resources. Water resource management encompasses a complex and interconnected system, ranging from water supply, treatment, distribution, utilization, to its return to the environment. LCA can help analyze the environmental impact and resource utilization at each stage, taking into account their interdependencies. Furthermore, the chosen methodology considers various environmental impacts, including energy consumption, greenhouse gas emissions, water pollution, and habitat disruption. Importantly, the application of LCA methodology enables the identification of areas for optimization and reduction of environmental impact throughout the entire supply chain. This methodology should be applied when calculating the carbon footprint because it is characterized by its ability to account for the specificity of water management organizations. For instance, LCA can assist in evaluating the environmental consequences of utilizing water resources. Furthermore, this methodology serves as a tool for transparent communication with stakeholders, providing a quantitative assessment of environmental impact and improvements over time, thereby ensuring a systematic approach to environmental compliance assessment and demonstration. It aids organizations in avoiding legal issues and penalties, serving as a solid foundation for setting sustainable goals, implementing changes, and measuring progress over time. This methodology helps water management organizations make informed decisions regarding the reduction of their environmental impact and promotes responsible and sustainable management of this vital resource. The LCA methodology has four stages of development.

Stage I - goal and scope definition. Our goal is to calculate and analyze the carbon footprint of the water management organization. In this work, was calculated the number of emissions caused by PVK in 2022 in $CO_{2\ eq}$. The calculation includes all materials, technologies, and services necessary for the normal functioning of the organization. The work also considers the geographical location of materials, energy, and services the organization procured. The geographic scope of the study is continental in scale.

Stage II - life cycle inventory analysis. At this stage, an analysis of the organization's activities was conducted and defined the boundaries of the investigated system. The scopes of actions are depicted in Figure 1.

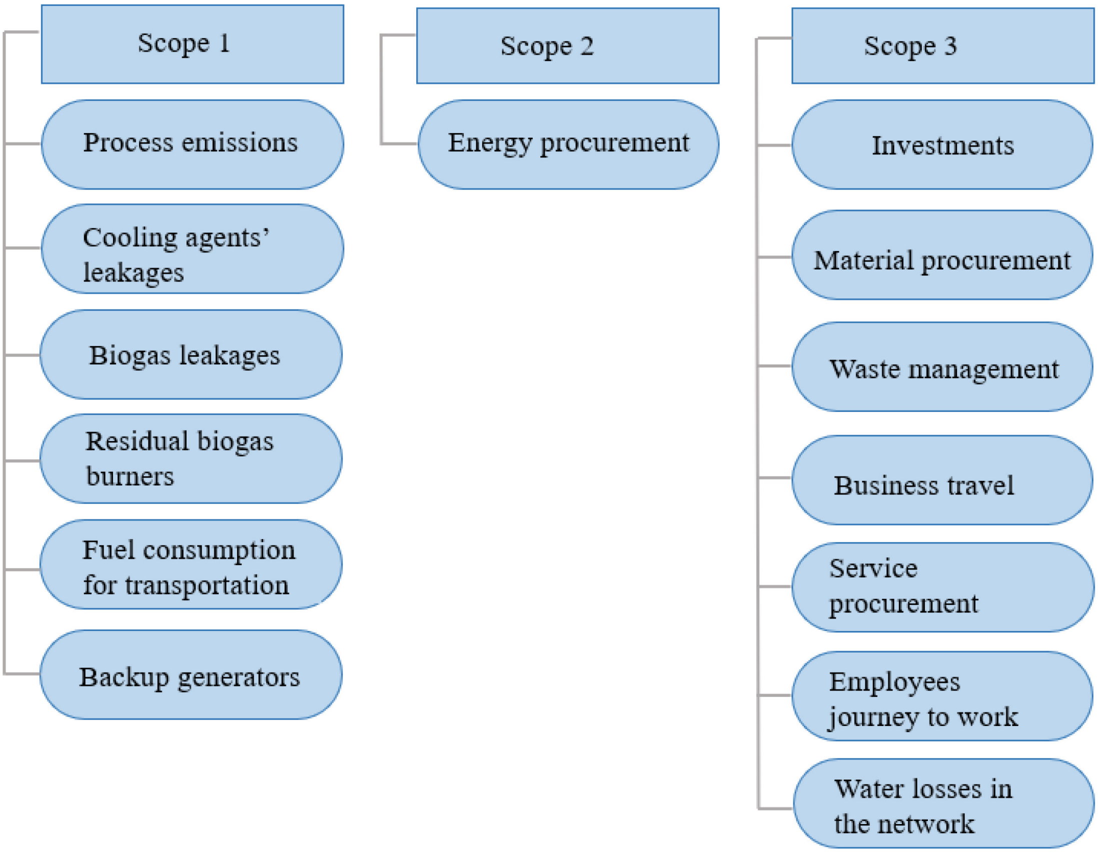

Figure 1. The boundaries of the investigated system

All GHG emissions were classified according to Scopes 1, 2, 3.

- Process emissions - this category includes emissions released during WWT.
- Cooling agents' leakages - here, emissions of cooling agents used in air conditioning systems were identified.
- Biogas leakages - these are emissions that occur during biogas production.
- Residual biogas burners - this category includes emissions associated with the combustion of residual biogas not used for energy production. Even these emissions are not originated in fossil fuels, they were included in CO_2 footprint calculation because this little share of biogas is wasted and not used in CHP units,
- Fuel consumption for transportation and diesel generators - this category calculates emissions associated with fuel usage for the organization's transportation needs and with fuel usage for diesel generators.
- Backup generators - these are backup generators owned by this organization
- Energy procurement - electricity required for the organization's operations. This category includes three types of energy: electricity, natural gas, and heat.
- Investments - this category includes emissions associated with material and non-material investments by PVK.
- Material procurement - this category includes all emissions related to materials necessary for the organization's normal functioning.
- Waste management - all emissions associated with waste handling.
- Business travel - emissions from work-related trips.

- Service procurement - all emissions related to the use of services necessary for the organization's normal functioning.
- Employee commuting- emissions from employees' commuting methods to work.
- Water losses in the network - emissions resulting from manufacture of water lost due to pipeline leakages.

Stage III - environmental impact assessment. At the third stage of the chosen methodology, the emissions generated by the organization's activities in $CO_{2\ eq}$ for each of the mentioned categories were calculated. To calculate $CO_{2\ eq}$ emissions, two methods were utilized. One part of the calculations was performed using the software "LCA for Experts," while the other emissions calculations were based on specialized literature.

Stage IV - Life Cycle Interpretation. After analyzing the obtained calculations, the results were compared with other water management organizations. The outcome of the analysis of the calculations is a system of recommendations aimed at reducing current emissions and moving closer to carbon neutrality.

Data collection

To calculate emissions and carbon footprint, it is essential to have the necessary information about all material and energy flows associated with this organization's activities. Data collection for this research involves various methods and sources. To ensure the accuracy and validity of the research results, obtaining precise measurements is crucial [50].

Data on the chemical oxygen demand (COD) and nitrogen quantity at the input, necessary for calculating process emissions, was collected from measuring devices and information records directly within the organization. Information for calculating cooling agent emissions was provided by the company supplying the material. Emissions from burning and biogas leakage are directly measured by gas meters at the central WWT plant. Information about the amount of consumed energy was obtained from respective meters. Data regarding investments, fuel expenses, and purchased materials and goods were provided by PVK in the form of tables extracted from their accounting information system. The information tables on purchased materials and goods did not include information about the weight of the products. Information about the weight of goods is crucial for accurately determining the carbon footprint, and thus, this data needs to be obtained directly from the manufacturers of the products. Information about the waste generated because of the company's activities was also provided in the form of a table containing all the necessary data on fuel consumption, types and quantities of waste, and the geographical location of disposal points. Data related to employee commuting within the organization were obtained through surveys of employees. All the above-mentioned information was consolidated into a unified database, which contains all the necessary data for further calculations.

Calculation of emission factors

The calculation of emission factors was performed using several methods. Particular attention was paid to the specifics of each investigated scope and utilized the most accessible method for calculating emission coefficients. The estimate of GHG emissions was cone according to SN EN ISO 14064-1 technical requirements. To calculate process emissions associated with the operation of WWT plants, was used available professional technical literature. Furthermore, a search was conducted for the requisite information in environmental databases and reports pertaining to environmental research linked to WWT processes. Upon obtaining the necessary emission factors, calculations were performed for emissions of each pollutant and subsequently expressed in $CO_{2\ eq}$. Further details on this process are described in our previous article: "Prague Water Net Zero Strategy 2025 - Methodology and Roadmap" [49].

The calculation of the carbon footprint from energy usage was conducted using emission factors. The emission factors were established through the utilization of an LCA scheme, with the "LCA for Experts" software employed in its creation. This software allows for the calculation of economic, environmental, and technological LCAs [51]. The diagram of the created plan in the software is shown in Figure 2.

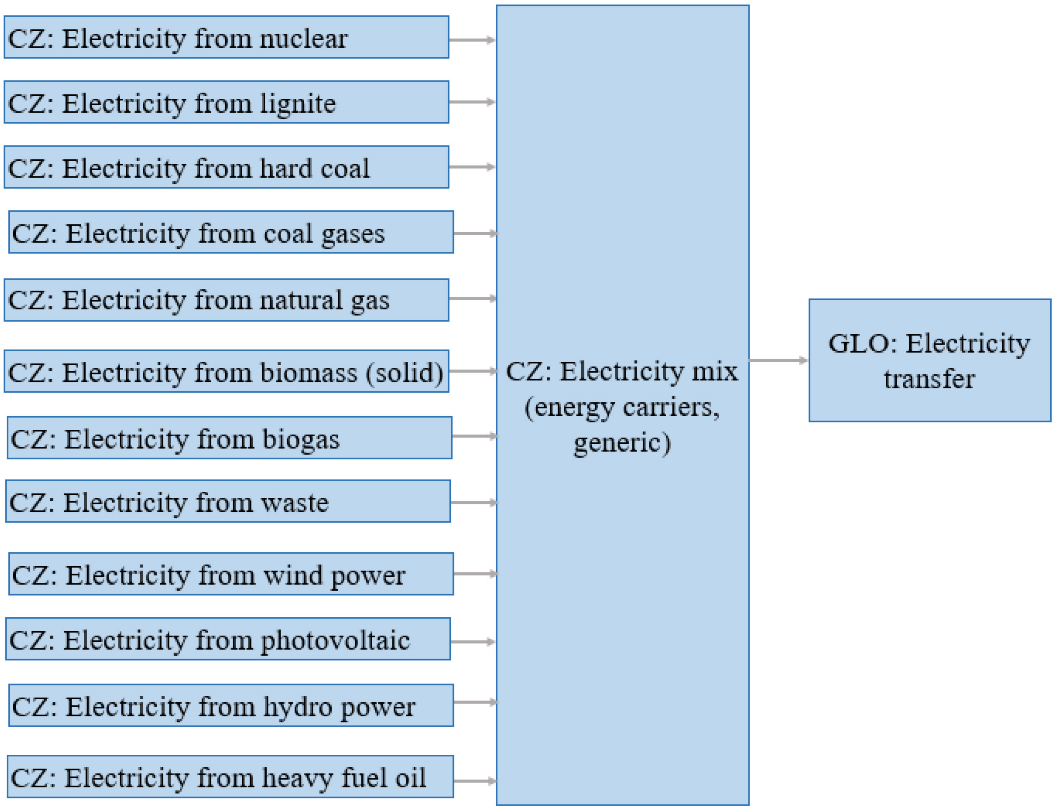

Figure 2. LCA scheme for consumed electricity.

To create this plan, was used the Sphere database. In this study, a specific type of electrical energy dependent on a single type of fuel was not utilized. Instead, a "blend" of energy sources was created for the purpose of this investigation. The blend created better corresponds to PVK's actual energy consumption. This approach is justified by the fact that the organization does not limit its energy choice to a single type and allows for the possibility of changing the type of electricity used if necessary. The created blend also includes electricity generated from biogas produced within the investigated organization. Using the scheme implemented in the LCA for Experts software, the necessary emission coefficient values have been calculated. The emission factor for electricity is 0.6128 kg $CO_{2\ eq}$ /kWh. Next, based on the information about the amount of electricity consumed, the carbon footprint of Scope 2 was calculated. Emission factors for category Scope 3 were conducted separately for each category. The category of purchased goods includes many products and materials. The approach of calculating emission factors was based on creating an LCA scheme for each product. Since this category encompasses more than 8000 items, assumptions were made and grouped related products into one subcategory each. For each group in this subcategory, an LCA scheme was developed. A schematic representation of the scheme is shown in Figure 3. To create the LCA scheme, were used the Sphera Professional database and the Ecoinvent database.

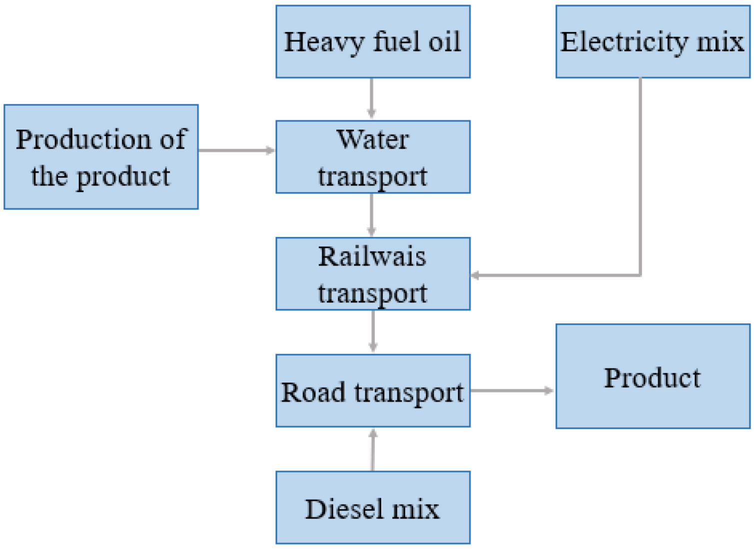

Figure 3. LCA scheme for materials from the purchased materials category.

The approach for creating the LCA scheme was based on three hypothetical stages. Firstly, it involved the production process of the product. This stage encompassed all the material and energy resources required for product creation and considered the emissions associated with this activity. The next process in this plan was the transportation of the manufactured product to the point of direct usage. During this stage's development, the place of production, the distance required for transportation, and the type of transportation and fuel needed for this process were considered. These variables were considered individually for each created plan. The final process involved the direct usage of the product for the company's needs. For these plans, a cradle-to-gate system boundary was chosen. To complete the life cycle of purchased goods, including their disposal, a simplified LCA scheme was developed that provides data on the organization's overall carbon footprint resulting from the exclusion of all purchased goods in 2022. While creating this plan, all the energy and material resource costs necessary for this process, as well as all associated emissions have been considered. The emission factors necessary for calculating the carbon footprint were determined from the LCA scheme created. In Table 1, for example, the determined emission factors for some products from the purchased items category was presented.

Table 1. Determined emission factors for some products from the purchased materials category.

Name of the product	Emission factor for 1 kg of goods (kg $CO_{2\ eq}$)
Light bulb	2,18
Monitor	8,31
Cable	2
Jackel	2,4
Sodium hydroxide 36%	0,44
Sulphuric acid 96%	0,256

Praestol	4,57
laboratory glass	1,84
Office chair	2,88
Wooden wardrobe	0,86
Metal wardrobe	2,89
Stainless steel rod	3,34
Electrode	0,14
Steel chain	2,87
Screw	0,66
Work footwear	4,23
Welding wire	2,3
Water meter	9,26
Metal seal	0,238
Copper Pipes	2,13
Cast Iron Pipes	2,02
Pipes brass	3,49
Stainless Steel Pipes	2,34
Pipes concrete	0,184
Disposal of used products	0,47

In addition to the emissions resulting from the potential disposal of purchased goods, the PVK organization generates other types of waste, from WWT process and civil works. It was conducted LCA analyses for these waste types as well. In this analysis, were considered the weight of the waste, the type and quantity of fuel used for their transportation, the distance over which the waste is transported, and the environmental impact caused by the disposal of this waste type. Concerning waste management, an analysis of three different scenarios was conducted. In the first scenario, the waste was transported to a landfill, while in the second scenario, it was incinerated. The third scenario involved sending the waste to a composting facility. The investigated organization employs each of the specified scenarios depending on the type of waste. Figure 4 illustrates the overarching framework utilized for the creation of LCA schemes for each waste type generated by the organization under investigation.

Figure 4. General scheme of waste management.

For each waste type, a meticulous evaluation was conducted, considering the geographical location of the facilities under investigation, waste volume, transportation method, and fuel consumption. The emission factors were derived from the generated plans. Table 2 presents the results of determining the emission factors for the waste management sector.

Table 2. Emission factors calculated for waste generated by the organization.

Name of the product	Emission factor for 1 kg of waste (kg $CO_{2\,eq}$)	Type of waste management
Asphalt	0.017	Solid waste landfill
Concrete	0.018	Solid waste landfill
Sludge from WWT Plant	0.006	Incineration plant
Sludge from WWT Plant	0.086	Compost plant
Sand from sand traps at WWT Plant	0.023	Solid waste landfill
Screened residues of WWT Plant	0.024	Solid waste landfill
Soil	0.017	Solid waste landfill

According to the information provided above, the highest emission factor corresponds to sludge from the treatment plant, which is then sent to composting.

The conversion factors for business trips were determined for individual transportation and hotel stays. The carbon footprint of transportation is based on 1 person-kilometer. To calculate the carbon footprint generated by an employee's stay in the hotel, an assumption was made that the most significant impact is associated with the laundering of bed linens. During this calculation, the amount of water, electricity, cosmetics, and the production of the product used in this process have been considered. An inflated weight of bed linen, which needs to be laundered per guest, was chosen - 5 kg. The results of these calculations are presented in Table 3.

Table 3. Emission factors for business travel.

Type of transport	Emission factor	Emission factor unit
Train	0.07542	kg $CO_{2\,eq}$ / 1 person*km
Coach bus	0.1092	
Airplane	0.09989	kg $CO_{2\,eq}$ / 1 person*km
Passenger car	0.3029	kg $CO_{2\,eq}$ / 1 person*km
Hotel, number of nights	1.506	kg $CO_{2\,eq}$ / one stay at the hotel

Having information about the number of business trips, the type of transportation used, and the duration of the trips extracted from organization´s accounting information system, the overall carbon footprint of this category has been calculated.

The services ordered by the PVK organization were of a diverse nature. A simplified way to assess this category needed to be determined. The basic element of the model was a 50-kilometer drive by an employee in a personal car to perform a service. A service completed in

one full working day was valued at 10,000 Czech crowns. With the information about the amount of money spent by PVK on services, the number of business trips made by employees on PVK's request has been determined. Based on the information above, an LCA plan was created, from which the emission factors necessary for calculating the carbon footprint have been derived. As a result, the emission factor for one service is estimated as 103.4 kg $CO_{2\ eq}$.

The next category for calculated emission factors was the employees' commute to work. The emission factor information was obtained from the eco-invent database.

To calculate water losses in the network, an LCA plan has been created and the emission factor coefficients have been determined using LCA software for experts. The next step was to determine the amount of GHGs per unit of lost water. Thus, the emission factor for 1 ton of lost water is 0.14 kg $CO_{2\ eq}$. In all cases, the carbon footprints were determined according to the IPCC methodology (version as of August 2021) without biogenic carbon with a global warming potential of 100 years.

RESULTS

Using the determined emission factors for each of the studied categories, the number of emissions and the overall carbon footprint of the investigated organization have been calculated. Therefore, the carbon footprint of PVK for 2022 amounted to 198,666.3 metric tons of $CO_{2\ eq}$. The carbon footprint of PVK for 2021 amounted to 185,631.4 metric tons of $CO_{2\ eq}$. Year-on-year increase of the carbon footprint is 7.0%. The total distribution of the operational carbon footprint of the PVK's for 2021 and 2022 is summarized in Figure 5 and Figure 6.

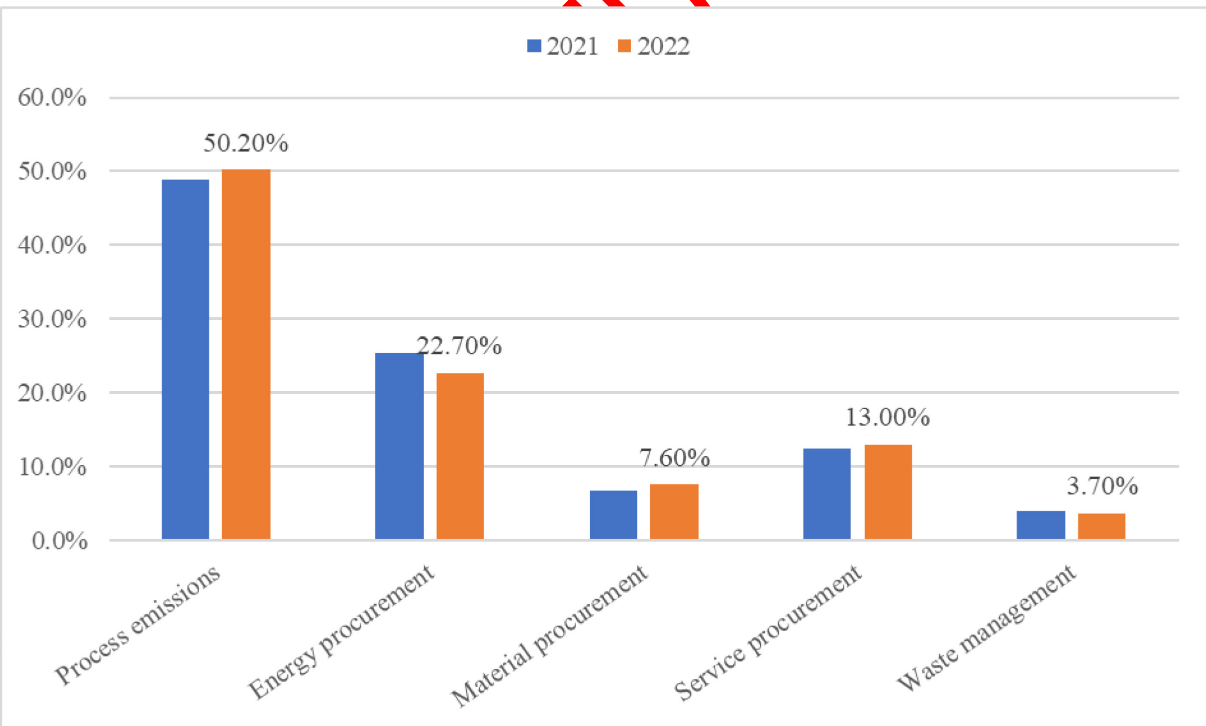

Figure 5. The PVK's carbon footprint distribution for 2021 and 2022 (categories with carbon footprint above 1%)

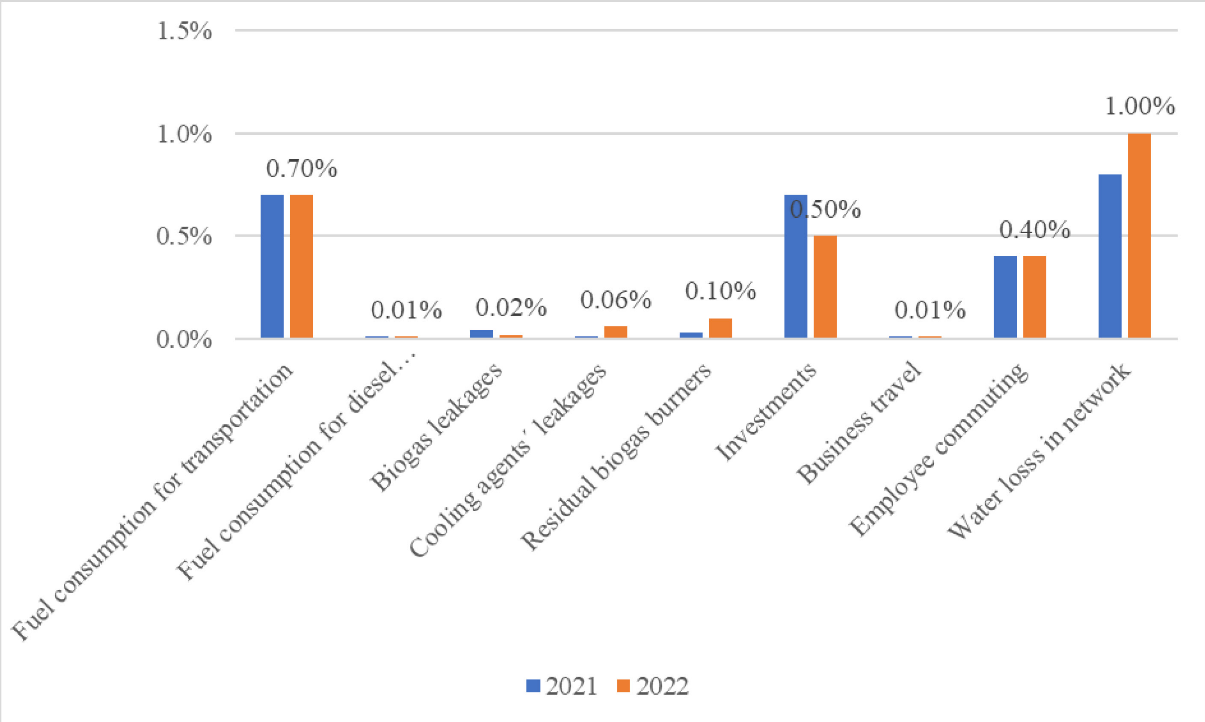

Figure 6. The PVK 's carbon footprint distribution for 2021 and 2022 (categories with carbon footprint below 1%)

Understanding the distribution in these areas, the organization can accurately identify emission hotspots to concentrate efforts on reducing emissions where they have the greatest impact. As illustrated in Figure 5, process emissions from WWT plants have the greatest impact on the company's overall carbon footprint, accounting for about half of the carbon footprint. Figure 7 illustrates the organization's carbon footprint with the distribution of GHG emissions under the Scopes 1, 2 and 3, according to the GHG Protocol.

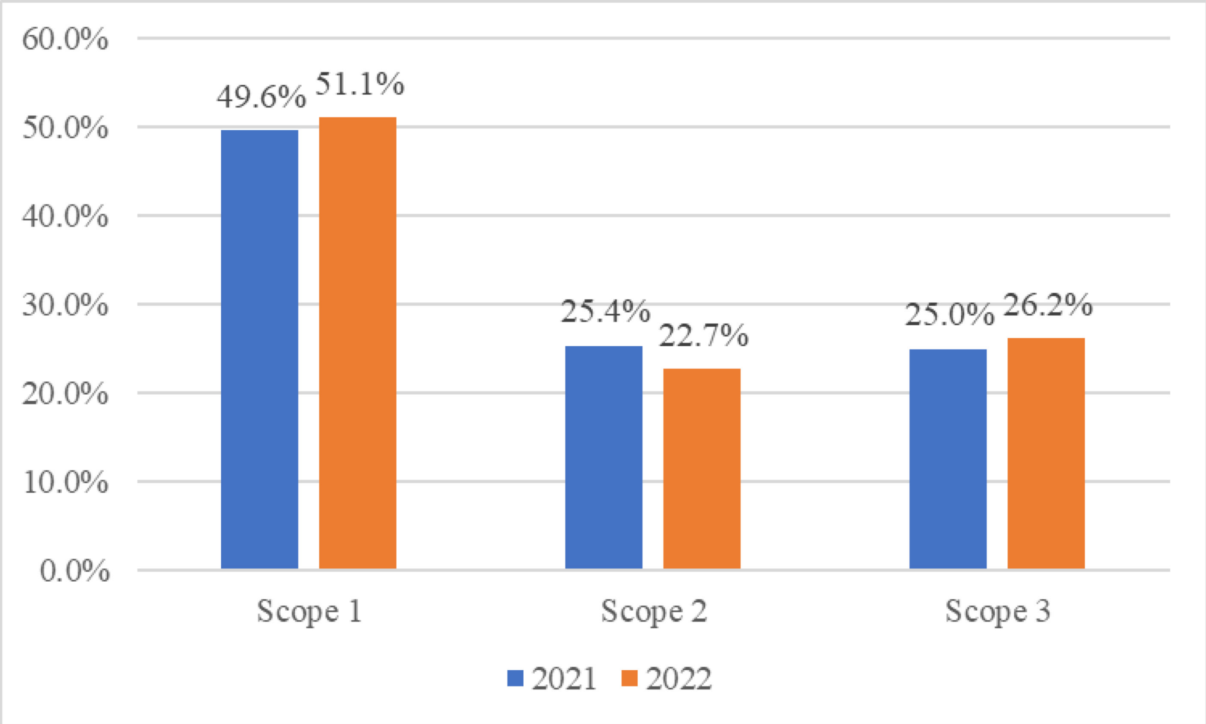

Figure 7. Distribution of the organization's carbon footprint according to the GHG protocol in 2021 and 2022.

This distribution indicates that emissions from each category are significant contributors to the carbon footprint, thus cannot be ignored. Figure 7 illustrates the importance of considering all emissions, even those not currently regulated by legislation if one aims to achieve the target of net-zero emissions.

DISCUSSION

The year-on-year increase of 7 % in the PVK carbon footprint was assessed. The primary contributors to this marginal increase are the rise in process emissions and the procurement of materials and services. Year-on-year increase of process emissions from WWT plants was 10.0% (48.8% in 2021 and 50.20% in 2022) due to higher COD and nitrogen quantity at the input of WWT plants. The increase in process emissions is attributed to the treatment of a higher load in wastewater treatment (WWT) plants, resulting in greater emissions despite employing the same technology. Emissions resulting from service usage also have a noticeable impact on the organization's carbon footprint, comprising 13.0% of the total amount. The escalation in material and service procurement costs can be attributed to the substantial inflationary trends in the Czech Republic. In quantifying these emissions, an emission factor based on expenditures was employed. Consequently, a 15.1% inflation-induced price surge leads to a proportional increase in calculated emissions, as the emission factor remains constant. Energy consumption constitutes 22.7% of the total carbon footprint in 2022 which is a 2.7% decrease compared to 2021 (25.4%) due to higher energy production from biogas [52]. Thus, it can be observed that 85.9% of the organization's total carbon footprint is the result of emissions from these three categories.

The total carbon footprint of PVK was compared to total carbon footprint of Severomoravské vodovody a kanalizace, a.s. (North Moravian-Silesian Water and Sewerage Company, hereinafter referred to as “SmVaK”), which is in northeast of Czech Republic. This company operates the water infrastructure of the Moravian-Silesian region (except Ostrava,

third largest city in Czech Republic, which is operated by different company) and is involved in the production and distribution of drinking water, as well as the removal and treatment of wastewater. The activities of SmVak provide water production for 711,264 residents and treatment of wastewater for 478,685 residents. The total carbon footprint of SmVak for 2022 amounted 35,350.4 metric tons of $CO_{2\ eq}$ [53]. It is not possible to directly compare the total emissions of the various companies due to disparities in their scale. Given that most emissions are associated with Wastewater Treatment (WWT), we opted to normalize emissions per cubic meter of treated wastewater. Carbon footprint of 1 treated cubic meter of wastewater of PVK is 1.7 metric kilogram of $CO_{2\text{-}eq}$ which is higher compared to SmVak´s 0.8 metric kilogram of $CO_{2\text{-}eq}$. According to the article SmVak took a different approach and process emissions from nitrogen quantity at the input of WWT plants counted as Scope 3, whether COD quantity was counted is not mentioned in the article nor is the amount of process emission from nitrogen quantity. In the article is not mentioned whether services are counted in Scope 3 which as ed above is 13.0% of total emissions of PVK.

Based on the analysis of the results obtained and their comparison with other water management organizations, PVK can create practical and effective methods to reduce its carbon footprint. Below are key recommendations for PVK and similar organizations to reduce carbon emissions and work towards achieving net-zero emissions. Considering that process emissions from WWT plants account for about half of the carbon footprint, it is crucial to optimize these processes to minimize emissions. Emissions in this sector are primarily associated with energy usage but are not the primary source. Therefore, to achieve this goal, it is necessary to prioritize increasing energy efficiency. A positive outcome in this situation can be achieved by replacing outdated equipment with more modern, energy-efficient alternatives. Special attention should be given to the implementation of new and more efficient pumps, engines, and compressors, which can significantly reduce emissions by reducing energy consumption. Energy costs can also be reduced through variable frequency drives (VFDs). Installing VFDs on pumps and motors allows for the regulation of their speed according to requirements, thereby reducing energy losses.

To enhance the energy efficiency of the water treatment plant, it is worth implementing energy recovery technologies, such as heat exchangers, to capture and utilize the waste heat generated during the WWT process. Wastewater serves as an ideal foundation for harnessing heat and serves as a renewable energy source. Research conducted by N. Mirl et al. indicates that 3% of all buildings can be supplied with heat or cooling using wastewater. According to Mirl, thanks to the optimal temperature of the source (10-25 degrees Celsius throughout the year), heat pumps for wastewater achieve elevated levels of productivity [54]. Furthermore, reducing the temperature of wastewater will minimize its impact on the aquatic environment. In addition, it is possible to consider the use of a heat pump in hot water supply systems. When using a heat pump in the heating system of a residential multi-story building during the inter heating season, it can lead to a reduction in network water consumption and centralized cooling [55]. Also of interest is the study , which discusses the possibility of reusing recovered heat in an aerated reservoir, resulting in a temperature increase of 6°C. This, in turn, can enhance the removal of ammonia by 61% [56].

Lowering emissions from biological treatment procedures, such as the activated sludge process, can also have a positive impact on the studied organization's carbon footprint. It is recommended that alternate treatment methods that use fewer chemicals and energy be investigated, or that dangerous chemicals be replaced with more ecologically friendly alternatives. The issue is that not all existing low-emission solutions, such as constructed wetlands, are suited for large cities. Other intense low-emissions wastewater treatment approaches, such as anaerobic digestion with biogas recovery in mainline, algae-based treatment systems, or membrane bioreactors with energy recovery, are under investigation.

Lowering GHG emissions trends sometimes conflict with increasing standards for removing so-called micropollutants. To remove these substances, modern technologies such as

the adoption of Advanced Oxidation Processes (AOPs) such as ozone or advanced ultraviolet (UV) systems or solutions are required. Although AOPs can successfully digest organic pollutants and toxins, they will raise energy requirements. In addition to this, one can consider the recovery of phosphorus and nitrogen from wastewater, which can then be reused or sold, thereby reducing the demand for energy-intensive energy processes.

Regarding the reduction of emissions in Scope 2, it is essential to transition to renewable energy sources, such as solar, wind, and hydroelectric power stations. A notable example is Scottish Water, which, after analyzing its carbon footprint, prioritized increasing energy efficiency, and gradually transitioning to renewable energy sources, resulting in an approximate 45% reduction in their carbon footprint [57]. Unfortunately, not always the geographical location and natural conditions allow organizations to fully rely on renewable energy sources. However, in this situation, it should be noted that in PVK, the most significant impact on the environment comes from process emissions, in comparison to water utilities organizations such as Scottish Water or Anglian Water, where energy-related emissions take precedence. Such a difference is due to the fact that part of the energy at PVK's treatment plants is generated from biogas. Despite this, most efforts for the investigated organization should still be directed towards improving water treatment processes to the options, the use of smart grid technology may also be beneficial for the organization. This technology optimizes energy consumption based on real-time data on demand and prices, or participation in demand response programs offered by utility companies. Maintaining an energy management system for active monitoring and control of energy consumption within the organization would also be a great approach. Real-time data and analytics can facilitate better decision-making for improving energy efficiency.

In Scope 3, the purchased services have the largest impact on the carbon footprint. By considering the environmental impact of our service providers and making informed choices, PVK's carbon footprint was significantly reduced. Currently, when ordering the necessary services, it is important to prioritize service providers with good environmental characteristics. Factors such as their carbon footprint, environmental certifications, and commitments to sustainable development should be considered. Depending on the type of service or service purchased, preference should also be given to virtual meetings or remote services, if possible.

An important aspect in this situation is to involve all employees in this goal. Therefore, training and awareness regarding emission reduction, sustainable development, and environmental issues play a crucial role in achieving the desired outcome. By fostering a culture of environmental responsibility and providing employees with the necessary knowledge and skills, the water management organization can implement effective strategies and practices to minimize its impact on the environment. When all employees understand the importance of the set objectives, they are more likely to actively participate in their achievement. Employee awareness can lead to positive changes in their behavior, both at work and in their personal lives, resulting in a cumulative effect of reducing the overall impact of the organization on the environment. Engaged and informed employees are more likely to propose innovative ideas for emission reduction and improved sustainable development. Additionally, an important aspect in this situation is feedback and support from consumers. Researchers [58] have developed an open management web platform that integrates real-time knowledge about water supply and demand from sources to users across various geographical and organizational scales. This platform is supported by a knowledge base where information is structured within a water resource management ontology to ensure compatibility and maximum usability.

The outcome can also be influenced by investments and regular political support. Investments in research and development of new, more energy-efficient, and environmentally friendly purification technologies and processes will contribute to achieving the set goal. Collaboration and support from governing bodies and political organizations will enhance motivation on the path to achieving net-zero emissions. In this situation, reaching the goal

requires a comprehensive approach and participation from all stakeholders, so any contribution will be beneficial.

CONCLUSIONS

The path to achieving carbon neutrality begins with the calculation and analysis of one's carbon footprint. Having an adequate amount of information and experience is crucial to reach this goal. This work serves as another example that acts as a driving force for other companies on the path to carbon neutrality. The practice has shown that LCA methodology is an important scientific tool through which the foundation for calculating greenhouse gas emissions can be obtained. According to the research results, the primary efforts for reducing greenhouse gas emissions should be directed in three directions: technological emissions, purchased electricity, and purchased services. Working on reducing emissions in these categories will yield visible results and provide a solid foundation for further goal attainment. Among the key strategies that can help in reducing their carbon footprint, organizations should focus on increasing energy efficiency, transitioning to renewable energy sources, implementing water efficiency programs, and monitoring emissions from WWT processes. Additionally, controlling the procurement of goods and services will have a noticeable impact on the path to cleaner emissions. This involves choosing certified products and services whose owners make efforts to control their carbon footprint. Equally important for achieving the goal is the training and development of employees, including the development of environmental awareness, familiarization with modern technologies, norms, and standards, and the integration of sustainability into the company's daily life. All these steps, one by one, bring the organization closer to achieving carbon neutrality. In comparison to 2021, there are noticeable changes in the organization's carbon footprint. To achieve more visible results on the path to net-zero emissions, more time is needed, as the aforementioned processes are typically long-term and require preparation. educing the carbon footprint of water management organizations requires a multifaceted approach that combines measures for energy efficiency, the adoption of renewable energy sources, process optimization, and a commitment to sustainable development. Continuous monitoring and adaptation to evolving technologies and regulations are crucial for achieving tangible results in this endeavor.

NOMENCLATURE

LCA	Life Cycle Assessment
$CO_{2\,eq}$	Carbon Dioxide Equivalent
GHG	Greenhouse Gas
PVK	Prague Water and Sewerage Company
IPCC	Intergovernmental Panel on Climate Change
WWT	Wastewater Treatment
AOP	Advanced Oxidation Processes
VFD	Variable Frequency Drives
COD	Chemical Oxygen Demand
UV	Ultraviolet

SmVaK	North Moravian-Silesian Water and Sewerage Company

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AUTHOR CONTRIBUTIONS

Conceptualization, VK; Funding acquisition, VK; Investigation, IH, NS, PS and MH; Methodology, IH and MH; Resources, VK and MS; Supervision, VK; Visualization, IH; Writing - original draft, IH; Writing - review & editing, IH and VK.

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DATA AVAILABILITY STATEMENT

The data presented in this study are available in the Supplementary Material.

CONFLICT OF INTEREST

The authors declare no conflict of interest.