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Electricity consumption in the municipal water sector in an oil-exporting, water-stressed country: the case of Bahrain

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ABSTRACT

Strong linkages exist between water and energy in the Gulf Cooperation Council countries, which are characterized by water scarcity and energy abundance. Dependence on fossil fuels for seawater desalination results in a high carbon footprint for municipal water production and treatment. Yet, quantification of how much energy is used is lacking. This paper aims to quantify the electricity consumption in the municipal water sector in Bahrain and investigate how water conservation contributes to electricity saving and climate change mitigation. Results revealed that around 8% of total electricity consumption in Bahrain is water-related, of which 89% is consumed in water desalination. A comparison of electricity-use performance indicators with existing global practices revealed the potential for energy efficiency improvements. Future scenarios demonstrate an increase of 27% in water demand in 2040 compared to 2019. Reducing the water demand can result in cumulative savings of 6,200 GWh of electricity, 1,800 million normal m^3 of natural gas, and 4,300 Gg of CO_2e emissions. Electricity demand should be considered in informing technology choices when planning new desalination and wastewater treatment plants. For existing plants, mandatory adoption of an energy system and raising awareness on the water-energy nexus are critical.

Keywords: Climate change mitigation; Desalination; GCC; Wastewater; Water-energy nexus; Water Evaluation And Planning (WEAP)

1. Introduction

In recent years, recognition of the need to adopt an integrated approach to natural resource management has led to the prioritization of the water-energy nexus concept [1,2]. Several nexus-based approaches have been developed, linking water, energy, food, and climate change [2]. Moreover, sub-nexuses of two or more of these aspects have been observed and their combined consideration within a "grand nexus" has been evident [3].

An understanding of the interlinkages between water and energy in water-scarce contexts is critical for achieving the sustainability of both sectors. Such understanding can help increase the water and energy sector policy coherence, reduce trade-offs, and build synergies between the two sectors. According to the United Nations Economic and Social Commission for Western Asia (ESCWA), all of the Gulf Cooperation Council (GCC) countries, which are major fossil fuel exporters, appear in the list of the

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most water-stressed[1] countries in the world, with four of these countries evidencing the highest scores for stress [4]. Desalinated water is the main source of water in these countries, and its production is highly energy-intensive.

Bahrain is positioned at the top of the list of water-stressed countries, implying the significance of its water-energy nexus [4]. Despite the identification of strong interlinkages between water and energy in countries characterized by water scarcity and energy abundance [5], a detailed exploration of the water-energy nexus remains to be conducted in Bahrain as well as in the other GCC countries. The literature indicates that there are only limited studies on the water-energy nexus in the GCC countries. For instance, the water-energy nexus in the Saudi Arabia Eastern Province has been studied [6]. In addition, two studies, aimed at identifying future energy consumption in the water sector have been conducted under the Abu Dhabi Global Environmental Data Initiative. The first study focused on the UAE [7] and the second on the GCC countries in general [8]. In Bahrain, an attempt to quantify energy use in the municipal water sector was carried out in Al-Sabbagh et al. [9]. Although all of these studies provide an important base for exploring the water-energy nexus in the region, most of them were not based on actual energy consumption data. Figures obtained from different and sometimes outdated references were utilized for making assumptions on energy use in the water sector. Other studies too have been conducted for the GCC region, and for other Arab countries, for example [4] and [10], but the same limitations apply.

The present study is aimed at addressing this specific knowledge gap through quantification of the magnitude and direction of electricity use in the Bahrain municipal water sector along with investigating how water conservation contributes to climate change mitigation. An understanding of the water-energy nexus entails several benefits for the GCC countries in general. First, the potential for electricity saving, and the consequent primary energy, through improved energy efficiency can be identified which contributes to achieving the national energy efficiency target. Additionally, reduced energy consumption contributes to a reduction in overhead costs for water production and wastewater treatment. From an environmental perspective, reduced electricity consumption contributes to the conservation of fossil fuel, which is a depleting natural resource in the specific context of Bahrain.[2] This implies that electricity conservation extends the lifetime of the resources and ensures fuel security to enable future water demands in Bahrain to be met. Moreover, because fossil fuel constitutes the main energy source used in the water sector in the GCC countries, a reduction in the energy consumption entails a direct reduction in the carbon dioxide equivalent (CO_2e) emissions, which is the main gas responsible for climate change [1]. Understanding and taking action pertaining to water-related electricity use in Bahrain will contribute to the achievement of several national, regional, and international commitments, as depicted in Fig. 1.

2. National context

Bahrain is a petroleum-exporting country. Published statistics [11] reveal that fossil fuel from the currently productive oil fields will be depleted soon; the new oil and gas discoveries are expected to offset this loss. In 2017, Bahrain produced 22.4 thousand tons of oil equivalent (kTOE), 55% of which were exported in the form of petroleum products [12]. Bahrain is primarily dependent on fossil fuels, although a trend toward the penetration of renewables is currently evident where a target of 5% of renewables is set for 2025.

The municipal water system in Bahrain comprises of two main stages: water supply and wastewater treatment (Fig. 2). The water supply consists of three main processes: water production, transmission, and distribution. The public sector is mainly responsible for managing these processes, with the exception of three water desalination plants, which are owned and operated by the private sector. However, the government is the sole buyer of the produced water.

Drinking water is mainly produced from seawater desalination in Bahrain. Given that desalination is highly energy-intensive, the availability of the required energy source has been a strong influencing factor in Bahrain decision to pursue this option.

To meet increasing water demands, total water production has increased incrementally by 4.6% on average each year during the period 2007–2016. A demand stability trend has been evident in recent years and can be attributed to water tariff reforms. Revising the water tariff over the period 2016–2019 entailed an annual increase of 18%–150%, depending on the water user and the amount of water used, to reflect the actual cost of water production (i.e., US\$1.99/m^3).[3]

As shown in Fig. 3, available statistics indicate that in 2018, the Bahrain domestic sector accounted for almost 77% of the water demand, followed by the commercial (20%) and industrial (3%) sectors [13,14]. The same data source suggests that there has been a loss of around 29% of the water produced[4] [13]. This water loss, which is also termed "non-revenue water" or "unaccounted for water," can be attributed to four main factors: water leakage, faulty meters, administrative errors, and illegal connections. However, the precise share of each factor contributing to water loss is not known. Last, as shown in Fig. 6, the per capita water consumption has fluctuated during the period 2008–2018. However, a marked reduction occurred in 2016 as a result of the water consumption tariff reforms.

As for the wastewater in Bahrain, it undergoes three stages before reaching its final destination (either the end-user or the sea): wastewater collection, treatment, and treated

[1] Water stress was calculated by dividing water withdrawals by renewable water supply in a given year [4].

[2] The discovery of a new oil shale and natural gas field in Bahrain was announced in April 2018. The government anticipates that production in this field will commence within 5 y.

[3] Excluding nationals whose water tariffs are subsidised for only one household per head of household.

[4] According to EWA [17], the volume of water produced in 2018 amounted to 260.7 million m^3, and the total consumption was 185.8 million m^3.

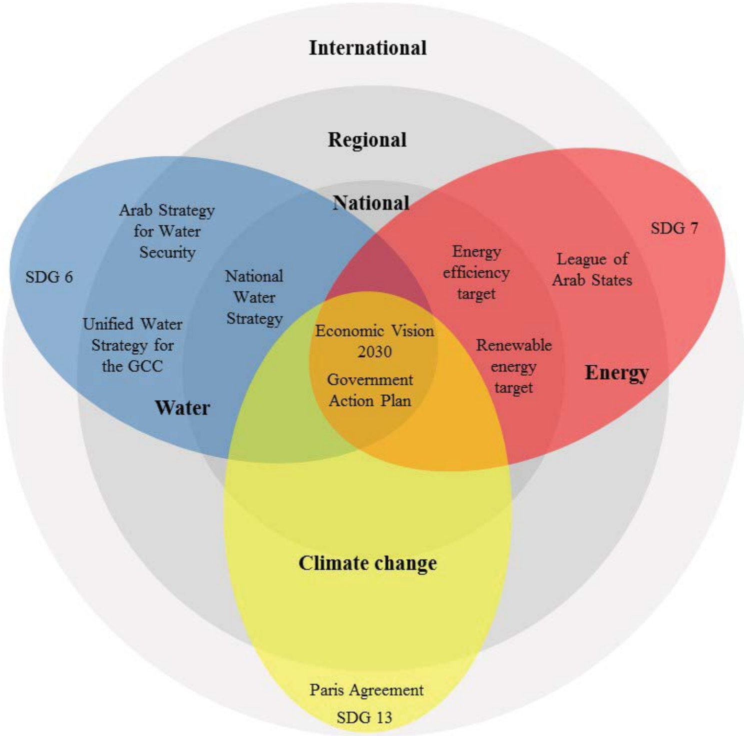

Fig. 1. Interlinkages between Bahrain's water, energy, and climate change commitments. SDG denotes a sustainable development goal.

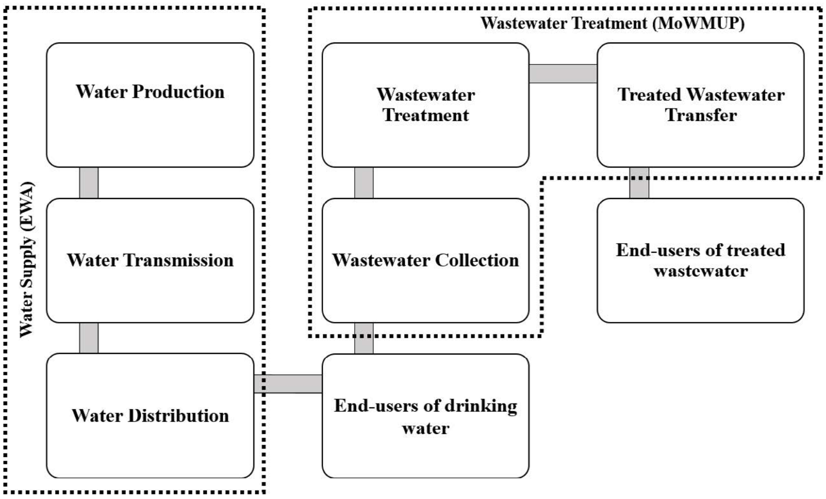

Fig. 2. Water system in Bahrain.

wastewater transfer (Fig. 2). The three stages are operated and managed by the Ministry of Works, Municipalities Affairs, and Urban Planning (MoWMUP), except for one wastewater treatment plant that is operated by the private sector. There are 13 sewage treatment plants in Bahrain, two of which are the main plants and the remainder are minor plants.

3. Methodology

A quantitative approach to data collection and analysis was adopted in this paper. The stages of the municipal water life cycle entailing electricity consumption were identified along with electricity consumption records, and electricity-consuming equipment and their technical specifications. This was conducted to enable a decision to be made on whether to opt for bottom–up or top–down data collection method, or both, depending on data availability.

A top–down approach for obtaining electricity consumption data was applied.[5] Details of the calculation and data management are depicted in Table 1 where electricity

[5] Exceptions are three desalination plants for which a bottom–up data collection approach was adopted from [15].

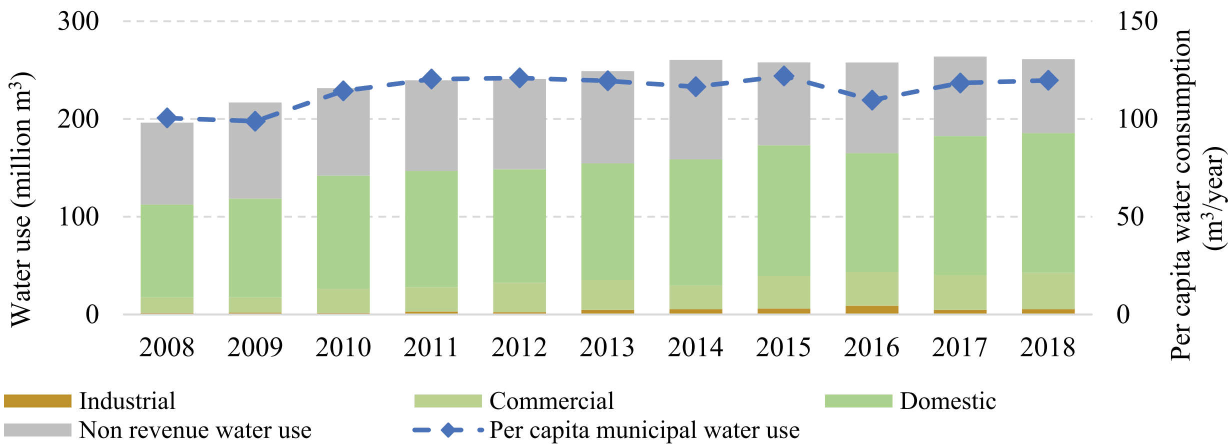

Fig. 3. Water use by sector in Bahrain for the period 2008–2018 (Sources: [12,13]).

consumption figures for each stage of the municipal water life cycle in Bahrain were aggregated for the years 2015, 2016, and 2017. It is noteworthy that the scope of this study was confined to the municipal sector only because of limited data availability, which was also the reason for the exclusive focus on electricity consumption. Most importantly, electricity is the main energy source used in the water system operation in Bahrain.

To determine electrical energy-use performance, two main inputs were obtained: electricity use and water production or wastewater treatment at a given time. The specific electrical energy use indicator was calculated as follows:

$$\text{Specific electrical energy use}\left(\text{kWh/m}^3\right)=\frac{\text{Electricity consumption}}{\text{Water produced or wastewater treated}} \tag{4}$$

The specific electrical energy use indicator was calculated for water production and wastewater treatment as a whole as well as for some specific phases, including water production, wastewater treatment, and treated wastewater transfer for reuse. The inclusion of the latter three indicators allowed for benchmarking with existing global practices. These data can serve as a baseline for future investigations using other methods of calculation and for assessing the effectiveness of implementing energy-saving measures.

A system dynamics model was built to explore the future municipal water demand and the consequent electricity consumption and CO_2e emissions. Water Evaluation and Planning (WEAP) modeling software was used to simulate the water production and wastewater treatment in 2018, and to build the reference scenario along with the policy scenario for the period 2019–2040. Assumptions used in the modeling are depicted in Table 2.

4. Results and discussion

4.1. Electricity consumption in the municipal water sector

There are three main types of energy that are consumed in the Bahrain water life cycle: electricity, thermal energy, and diesel, of which electricity is the primary energy source.

Quantification of electricity consumed in the municipal water sector in Bahrain revealed that the total water-related electricity consumption amounted to 1,424 GWh in 2017, reflecting an increase of 2.4% from 1,390 GWh in 2015. This consumption accounted for 8.6% of the total electricity consumption in Bahrain in 2017, which is slightly higher than the share in 2015 (8.4%). Most of the electricity consumption (89%) in 2017 was associated with water desalination, which has remained almost unchanged since 2015 (Fig. 4).

Electricity consumed in water desalination plants amounted to 1,260 GWh in 2017. Total electricity use differs significantly among the different desalination plants based on their water production capacities. For instance, as shown in Fig. 5, the Hidd desalination plant consumes the largest share (36%) of the total electricity consumption (for the water production stage) and generates the greatest volume of water (50% of the total water production). By contrast, the Alba desalination plant consumes the least share of electricity (3%) and also has the smallest water production capacity (3%). Electricity consumption in the different desalination plants also varies according to the desalination technology used. Specific electrical energy use in desalination plants where the multi-effect distillation desalination technology is adopted is the lowest. This is because the major energy source to produce desalinated water in thermal plants is not directly related to electricity. However, no clear differences in the efficiency of the multi-stage flashing and reverse osmosis (RO) desalination technologies could be distinguished. This comes in spite of evidence in the literature that suggests that the electricity requirement for the RO desalination technology is the lowest compared to that of other technologies [23].

As for the wastewater treatment, about 124 GWh of electricity were consumed in this process in 2017, accounting for 9% of the total water-related electricity use in

Table 1
Methodological steps applied to calculate water-related energy consumption in Bahrain

Stage		Data collection	Methodological steps	Data source
Water supply	Water production	• A top–down data collection approach was adopted. • Monthly electricity consumption figures for the Ras Abu Jarjur and ALBA plants were compiled for the period January 2015 to December 2017.	• The addresses of the two plants were obtained. • Electricity consumption figures were compiled. • The total electricity consumption for the two plants was calculated as follows: $E_i = \sum E_{m,i}$ (1) where E is the total electricity consumption for a plant for month m of year i. This equation was applied in relation to both plants. The total electricity consumption figures obtained for the Ras Abu Jarjur plant were used for the calculation. However, in the case of the ALBA plant, because the petroleum coke calciner also consumes electricity and is connected to the same power meter, it was assumed, based on the operators' inputs, that 48% of the monthly electricity consumption was consumed by the desalination plant.	EWA
		• A bottom–up data collection approach was adopted. • The technical specifications of the main energy consumers in the remaining three plants were obtained.	• Electricity consumption was calculated using the following equations: $P = V \times C$ (2) where P is the electrical power in kW, V is the voltage in volts, and C is the current in amperes. $E = P \times T$ (3) where E is the electricity consumption in kWh, P is the electrical power in kW, and T is the time or working hours in h.	[15]
	Water transmission		• The total number of water transmission stations was identified (54 stations). • The addresses of 46 stations were obtained; however, the addresses of the remaining stations were incorrect or incomplete. • After validating the EWA records using the billing system, the number of stations was reduced to 38. • The electricity consumption figures were retrieved for 38 stations.	EWA
	Water distribution	• A top–down data collection approach was adopted. • The monthly electricity consumption figures for the period January 2015 to December 2017 were compiled.	• The total number of water distribution pumping stations was nine. However, only six stations were accessible and were therefore included in this study. • The list of addresses of the pumping stations was obtained and checked for completion and duplication. • The electricity consumption figures were compiled.	
Wastewater treatment	Wastewater collection		• A list that included all plants and stations associated with the wastewater sector was obtained. • The addresses of the plants and stations were checked to ensure that they were complete, with no duplication, and to ensure that the spellings of the names of areas were consistent with those in the electricity billing system. • A total of 602 wastewater collection pumping stations were identified. However, addresses for only 553 were complete.	MoWMUP
	Wastewater treatment		• A total of 12 treated wastewater transfer pumping stations were identified. The addresses of these stations were complete. • A total of 13 wastewater treatment plants were identified, of which four were concerned with industrial wastewater (which is beyond the scope of this study). Addresses were available for 6 out of 13 wastewater treatment plants. Therefore, electricity consumption figures were compiled for these six plants.	
	Treated wastewater transfer		• The electricity consumption figures for these plants and stations were compiled.	

EWA denotes Electricity and Water Authority, MoWMUP denotes Ministry of Works, Municipalities Affairs, and Urban Planning.

Table 2
Assumptions used in building the current accounts [16–22]

Scenario	Variable	Assumption
Current accounts	Base year	2018
	Population	1,503,091
	Water production	261.15 million m^3, of which 99.8% is desalinated water and the remaining is groundwater
	Water consumption	185.812 million m^3, of which 97% is municipal consumption and the remaining industrial water consumption
	Per capita municipal water consumption (m^3/capita/y)	119.8
	Water desalination plants production (million m^3 in 2018)	Al Dur 74.6, Sitra 20, Hidd 138.3, Alba 4.4, Ras Abu Jarjur 23.2
	Electricity consumption in water desalination plants (kWh/m^3)	Al Dur 5.4, Sitra 5.3, Hidd (MSF) 3.8, Hidd (MED) 2.6, Alba 5.1, Ras Abu Jarjur 4.8
	Electricity consumption in water transmission and distribution (kWh/m^3)	0.14
	Non-revenue water (%)	28.8
	Wastewater treatment plants (actual flow m^3/d)	Tubli 300,000, Muharraq 71, Al Dur 153, Jau 494, Hamala 923, Askar 487, Jasra 726
	Treated wastewater	143.8 million m^3, of which 95.2% is being treated in the above-mentioned plants
	Electricity use in wastewater treatment plants (kWh/m^3)	Tubli 0.3, Muharraq 0.9, Al Dur 0.2, Jau 0.2, Hamala 2.2, Askar 0.1, Jasra 0.2
	Electricity use in wastewater network	0.5 kWh/m^3
	Natural gas used in electricity generation	0.3 normal m^3/kWh
	CO_2e emission factor for electricity generation	690.7 g/kWh
Reference scenario	First scenario year	2019
	End year	2040
	Population	2.2 million in 2040
	Growth rate of per capita municipal water consumption	–0.25%
	New desalination plants	Al Dur (2) 227.3 thousand m^3/d in 2022, Ras Abu Jarjur (2) 227.3 thousand m^3/d in 2024, Northern city 136.3 thousand m^3/d in 2028, Sitra (2) 113.6 thousand m^3/d in 2029
	Electricity consumption in water desalination	3.3 kWh/m^3 in thermal plants and 5 kWh/m^3 in RO plants
Policy scenario	Start year of the implementation	2022
	Electricity consumption in desalination plants	2.6 kWh/m^3 in thermal plants and 5 kWh/m^3 in RO plants.
	Non-revenue water	Gradual decreases reaching 12% in 2040
	Effectiveness of awareness programs and use of water conservation devices	Gradual decrease of per capita municipal water consumption to be 30% by 2040 compared to 2022

MSF denotes multi-stage flashing, MED means multi-effect distillation, RO denotes reverse osmosis.

Bahrain. More than 58 GWh of electricity were consumed in the sanitation network in 2017, amounting to 47% of the total electricity consumption during the stage of wastewater treatment. The highest share (50%) of the total electricity used in the overall process of wastewater treatment was consumed in wastewater treatment plants.

Similar to the desalination plants, wastewater treatment plants vary significantly in their electricity use according to the plant capacity. For instance, in 2017, a total of 57% of the total amount of electricity used in wastewater treatment plants was consumed in the Tubli wastewater treatment plant, which produced 78% of the total treated wastewater in Bahrain. Conversely, the smallest share of electricity (0.03%) was consumed by the Al Dur plant, which produced just 0.04% of the total treated wastewater. Thus, an economy of scale effect was evident (Fig. 6).

Specific electrical energy use also differed according to the level of wastewater treatment. Electricity consumption was around 0.1 kWh/m^3 in wastewater treatment plants where secondary treatments were applied, whereas

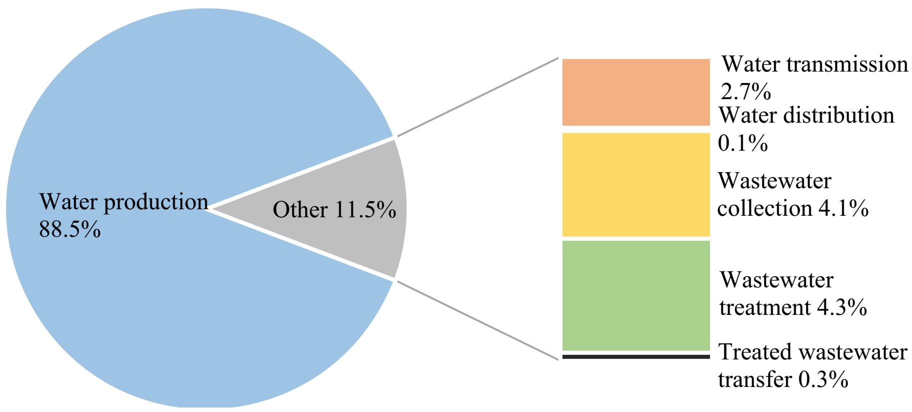

Fig. 4. Water-related electricity consumption in Bahrain in 2017.

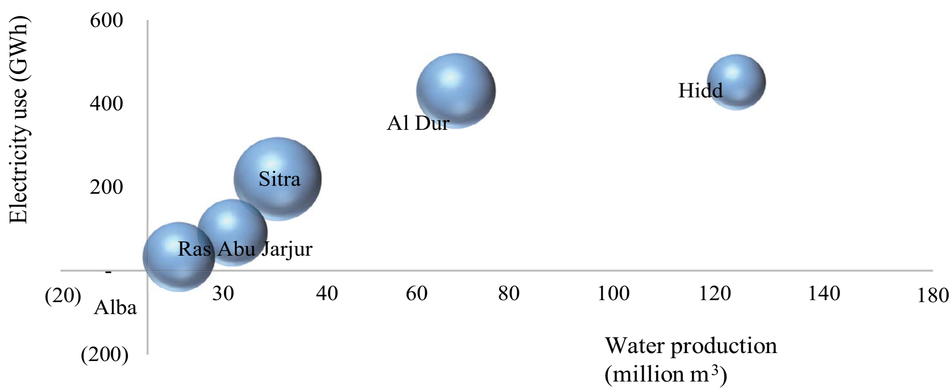

Fig. 5. Water production, electricity consumption, and specific electrical energy (illustrated in the bubble size) use in desalination plants in Bahrain in 2016 (Source: [13]; authors' calculations).

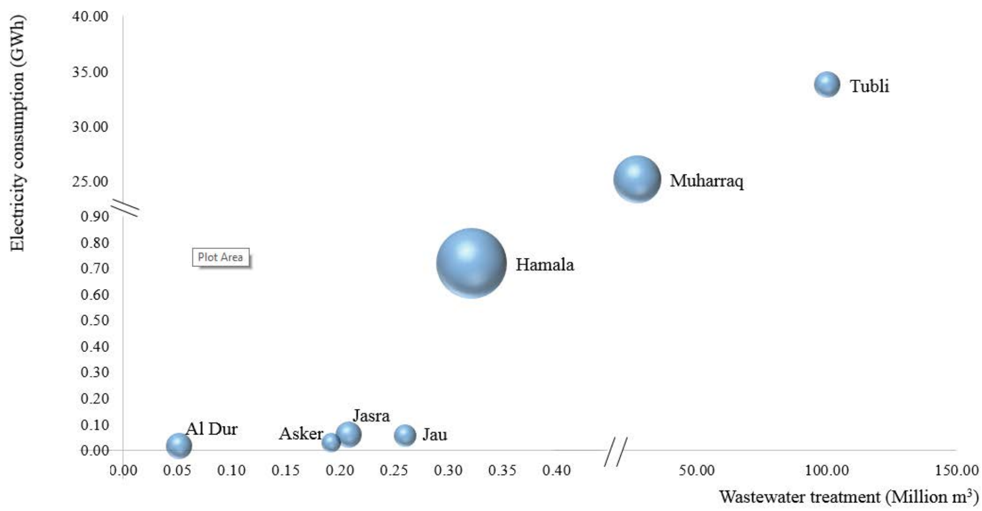

Fig. 6. Wastewater treatment, electricity consumption, and specific energy use (illustrated in the bubble size) in wastewater treatment plants in Bahrain in 2017.

electricity consumption was around 0.3 kWh/m^3 in plants where tertiary treatment is performed. However, consumption of electricity varied between 0.8 and 2 kWh/m^3 in plants with advanced tertiary treatment technologies, such as membrane bioreactor (MBR) and sequencing batch reactor (SBR).

A comparison of specific electrical energy use at the Tubli and Hamala plants clearly reveals these disparities, which can be attributed to the differing levels and technologies of wastewater treatment. In 2017, the Tubli plant consumed around 0.3 kWh/m³ of electricity, serving 60% of the population. Two-thirds of the wastewater underwent secondary treatment and one-third underwent tertiary treatment. By contrast, the Hamala plant consumed around 2.0 kWh/m³ of electricity, serving just 0.1% of the population. At this plant, wastewater mainly underwent tertiary treatment. The underlying reason for the marked disparity between the two plants lies in the type of treatment technology used in Hamala, which is MBR. Although this technology can be used for domestic and industrial inflow treatment, its use, primarily for domestic wastewater treatment, has led to excessive consumption of electricity.

As previously mentioned, water-related electricity consumption in Bahrain amounted to less than 9% of the total electricity consumption in 2017. This figure is relatively higher than that for developed countries in general (5%) [24] as well as the figures for the United States (<4% [25,27]), Spain (<6% [1]), and China (<1% [24]). However, it is considerably lower than the figure for California (<20% [1,27]). This is mainly because of the water source as the electricity consumption increases when the drinking water is produced by water desalination, and it decreases when surface or groundwater is treated. Therefore, the indicative distribution of energy use (a range of 69%–80%) for transmission and distribution suggested by the United Nations World Water Assessment Programme [26] is not applicable in a water-scarce context such as that of Bahrain, where the electricity share consumed for these phases was minimal at 3%.

Another difference can be observed at the wastewater treatment stage. The same indicative distribution pattern shows that only 10% of electricity is used for wastewater collection, with the remaining 90% used for the treatment of wastewater and sludge [27]. However, the electricity shares used for wastewater collection and treatment are nearly equal in Bahrain, indicating that the earlier decision to centralize wastewater treatment plants in the country may have resulted in increased consumption of energy used in the collection of wastewater.

In the Bahraini context of water desalination and wastewater treatment, opportunities exist to improve electrical energy use compared with water-related processes implemented in countries worldwide. Although available benchmarks indicate that specific electrical energy use associated with all technologies is almost within the same range of existing practices, potential opportunities exist for improving efficiency (Figs. 7 and 8).

4.2. Future water demand, electricity, and CO_2e emissions

Findings from the modeling of water production and wastewater treatment processes in Bahrain suggest that the municipal water demand would increase from

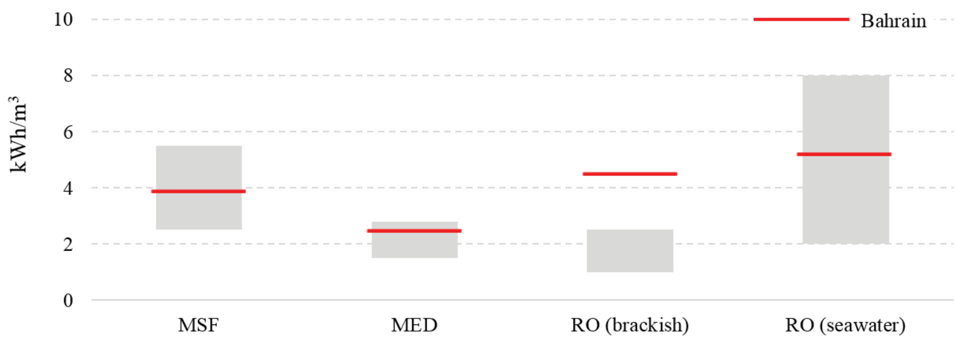

Fig. 7. Comparison of specific electrical energy consumption in desalination plants in Bahrain with existing water production-related processes in countries worldwide [4,10,27]. The major energy source used to produce desalinated water in thermal plants adopting MSF and MED technologies is not directly related to electricity.

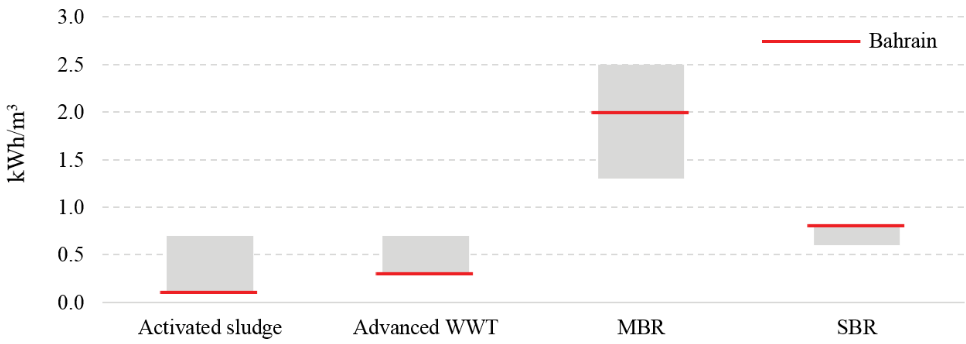

Fig. 8. Comparison of specific electrical energy use in wastewater treatment plants in Bahrain with existing wastewater treatment-related processes in countries worldwide [4,10,27].

196 million m^3 in 2019 to around 250 million m^3 in 2040 in the reference scenario (Fig. 9). This increase is mainly attributed to population growth, as the per capita water consumption is expected to decrease over the analysis period from 119.5 m^3/capita in 2019 to 113.4 m^3/capita in 2040 due to water tariff reforms (Fig. 10).

The adoption of various water conservation policies can achieve cumulative savings of up to 11% in the municipal water demand in the policy scenario compared to the reference scenario during 2022–2040 (Fig. 9). The cumulative saving in the water demand amounts to 587 million m^3, which is translated to 967 million m^3 of produced water when accounting for the non-revenue water (Fig. 10).

Using the specific electrical energy use indicators calculated in the previous section, water-related electricity demand is expected to grow by 20% in the reference scenario during the analysis period. Demand on natural gas is expected to increase from 388 million normal m^3 in 2019 to 467 million normal m^3 in 2040, considering that electricity is mainly generated using natural gas in Bahrain. This results in an increase of CO_2e emissions of 182 Gg CO_2e by 2040.

In the policy scenario, about 6,226 GWh of cumulative savings of electricity can be achieved along with 1,867 million normal m^3 of natural gas and 4,301 Gg of CO_2e emissions. On the annual level, these savings start at 6% in 2022 in the policy scenario and increase to reach 35% in 2040 compared to the reference scenario (Fig. 11). These savings highlight the potential role the water sector can play in climate change mitigation, where reducing the water demand reduces fossil fuel consumption and the consequent CO_2e emissions.

5. Policy implications and future research

The results of this study endorse the need to consider the energy consumption factor in the decision-making process relating to the selection of desalination technologies for new plants and infrastructure development. The impacts of these decisions do not only relate to the water sector but they also relate to energy resources and climate change mitigation.

Moreover, the results of this paper can influence decision making on the selection of technologies for wastewater treatment and management of these plants. Although the majority of wastewater treatment plants in Bahrain are aligned with global practices in this regard, markedly low

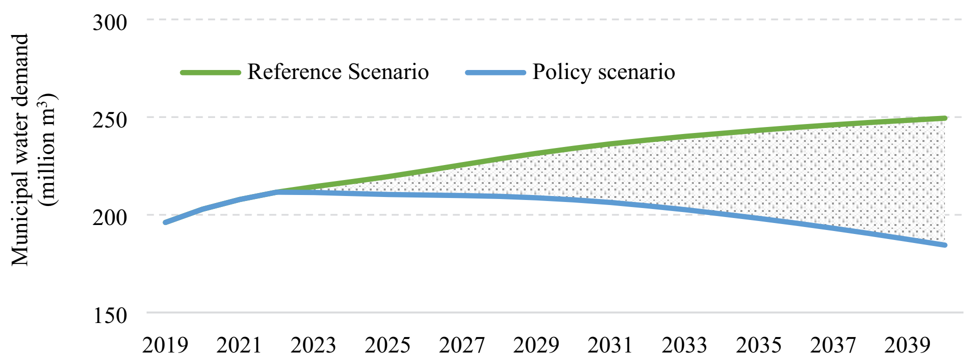

Fig. 9. Municipal water demand in the reference scenario and the policy scenario.

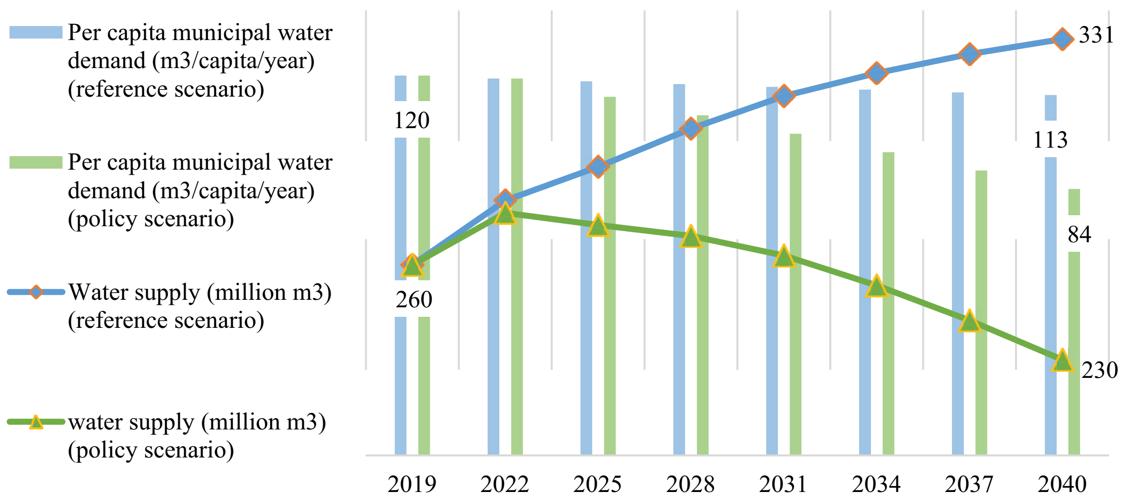

Fig. 10. Water supply and per capita municipal water demand in the reference scenario and policy scenario.

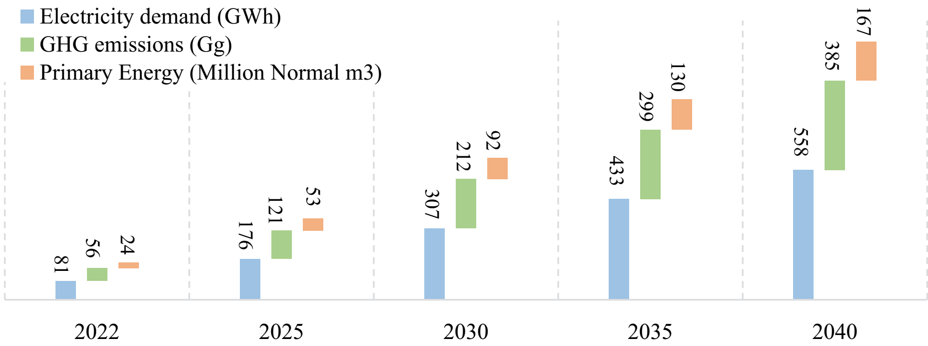

Fig. 11. Savings in electricity, natural gas, and CO_2e emissions in the policy scenario compared to the reference scenario.

levels of energy efficiency are apparent, specifically relating to the MBR and SBR technologies. There are two associated policy implications. The first is that these technologies should be selected according to specific requirements, which are determined by the source of the wastewater being treated. The second policy implication is that because these technologies appear to be energy-intensive, reuse of the treated wastewater as a substitute for desalinated water, is a recommended practice, particularly given the relatively low rate of reuse of treated wastewater in Bahrain.

Another recommendation is to enforce ISO 14001 certification for environmental management systems or ISO 50001 certification for energy management in water desalination and wastewater plants, to ensure compliance with environment-related legislation. This measure would also ensure that these plants set energy efficiency targets, keep records, and monitor and assess progress toward the achievement of the targets. Furthermore, the implementation of energy management programs and the development of a best practice handbook can be beneficial for those plants.

The diversification of the energy mix for water desalination and wastewater treatment plants is also recommended. Currently, these plants mainly depend on electricity generated from natural gas. Imposing specific shares of energy use from onsite-generated renewables can be considered as a requirement for new plants. This is especially important given that greater involvement of the private sector in Bahrain's water sector is being promoted along with efforts aimed at achieving the national energy efficiency and renewable energy targets.

Quantification of water-related energy use was not an easy task because data are dispersed within two ministries. Therefore, the development of a shared and integrated database that contains plants, verified locations, and unique addresses is essential. To allow for better monitoring and benchmarking, power meters should be installed for the different phases of water desalination and wastewater treatment. This is to foster a deeper understanding of how and where energy is used. As a next step, developing *key performance indicators* for the water desalination and wastewater treatment plants, and for pumping stations, is recommended to ensure more effective management of water-related energy use.

Coordination between water-related institutions and energy institutions has been recommended in the literature on the water-energy nexus. Accordingly, it is important to ensure coherence between water and energy policies. A GCC network could be initiated to share experiences, success stories, and the results of assessments of different measures.

Efficient energy use in the water sector can be achieved through several approaches, such as improving energy efficiency, promoting the penetration of renewables, and reducing the demand for water, which consequently reduces water production, primary energy consumption, and associated CO_2e emissions. The findings from future scenarios demonstrated how the adoption of water-saving devices/appliances and awareness campaigns related to water conservation can contribute to achieving cumulative electricity savings of about 6,200 GWh, along with 1,800 million normal m^3 of natural gas, and 4,300 Gg of CO_2e emissions by 2040.

This paper is the first to explore electricity use within the water sector as a whole in Bahrain. However, it had two main limitations. First, it focused on electricity use without addressing the consumption of other forms of energy, such as thermal energy and diesel. Second, it did not cover electricity use at the level of end-users. These two limitations can be addressed in future studies.

6. Conclusion

This paper presented a holistic overview of water-related electricity use in Bahrain, which has not previously been conducted. Data were collected on electricity consumption during different phases of the production of the water supply generation and wastewater treatment in Bahrain for the period 2015–2017. The findings of this study endorse those in the literature demonstrating that water desalination is highly energy-intensive. This implies the need to explore the potential for energy savings through the adoption of energy management systems, improvements in energy efficiency, and penetration of renewables within different processes and locations, including pumping stations, along with the promotion of water conservation. The quantification of electricity consumption in the municipal water sector in Bahrain contributes to making informed decisions in relation to natural resources management. Energy saving would entail multiple potential benefits, particularly in relation to climate change mitigation and reducing the use of fossil fuel.

Almost all of the GCC countries share a similar context characterized by reliance on water desalination for the generation of water and dependence on fossil fuels as the energy source powering water desalination. Therefore, initiating a network comprising authorities responsible for water management in the GCC countries aimed at sharing best practices and outcomes of assessments of energy-saving measures would be beneficial. The water-energy nexus is evident in all of the GCC countries, and they can collectively contribute to advancing understanding and collaborative action in relation to this nexus.

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