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Energy Use and Carbon Footprint for Potable Water Treatment in Haiderpur Water Treatment Plant, Delhi, India

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Abstract: With the advent of the environmentally conscious decision-making period, the carbon footprint of any engineering project becomes an important consideration. Despite this, the carbon footprint associated with water resource projects is often overlooked. Water production, its supply and treatment processes involve significant energy consumption and thus, are source of emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) which contribute to global warming. The emissions are not direct but come as a by-product of burning of fossil fuels to produce electricity to carry out these processes. Since water demand is continuous and keeps on rising, the quantification of carbon footprint associated with the water industry is vital. This paper studies and attempts to quantify the carbon footprint of one such urban water system, that is the Haiderpur Water Treatment Plant in Delhi, capital region of India by using the Life Cycle Assessment methodology and evaluate its performance from the point of view of energy consumption and make suggestions.

Key words: Carbon footprint, LCA, energy, water production, water treatment plant, sustainability.

Introduction

Water and energy resources are the essential assets that uphold the economic and social development of a nation. The current added concern is the impact of rising carbon dioxide emissions from water scarceness and energy utilisation. Regarding concern over climate change, the assessment of GHG emissions from the water industry has started gaining significant importance (Presura et al., 2017); in particular, the wastewater plant operations that produce CO_2, CH_4 and N_2O emissions. Quantification of these gases can help compute the level of environmental impact per unit of water treated as considered by Gupta et al. (2015, 2012). Similarly, however, arguably lesser, water abstraction and supply also contributes to significant carbon emissions, examining which shall form the scope of this paper.

Carbon footprint corresponds to the whole amount of gases, expressed as carbon dioxide equivalents (CO_2e), released into or removed from the environment due to a characterised activity over the life cycle of a process or a product. Scientists have recognised four fundamental types of gases referred to as greenhouse gases or GHGs that most contribute to carbon footprint: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (e.g., hydro-fluorocarbons, perfluorocarbons, sulfur hexafluoride, and others).

Carbon footprint is a vital tool for greenhouse gas management. It quantifies the emissions, helps identify the significant emission sources and maps out emission reduction areas which aid in reducing cost and increment environmental productivities (Benjaafar et al., 2013; Strutt et al., 2008).

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The demand for carbon footprint will increase in the water sector as more energy is required to meet the water demand. To correlate numerous water bodies with good quality water supply is an inaccurate assumption. The water quality of each source differs and needs to be evaluated and appropriate treatment is necessitated before it is supplied to the public, which is demonstrated in the study by Singh et al. (2020, 2015). Water production entails the process of water-extracting, treating, transmitting, distributing, consuming and then disposing off water, which requires a considerable amount of energy consumption (Gautam et al., 2012; Gleick, 1994). This high use of energy directly correlates to higher carbon emissions. Thus, reduction in energy use can help achieve sustainability in water supply systems (Vieira, 2019).

A few studies, such as those by Liu et al. (2015) and Gupta et al. (2015) demonstrate that one approach to effectively hypothesize the carbon footprint associated with water resources is to study and analyse the carbon emissions generated during the procurement of one cubic meter of water. Carbon emissions related to various kinds of projects and production processes, especially WWTPs and water supply/distribution systems, can be studied using the tool of carbon footprint as emphasised in various studies by Chilana et al. (2015), Friedrich et al. (2009), Gu et al. (2016), Gustavsson et al. (2013).

Although carbon footprint methodologies require standardisation and further development, they seem like a judicious and promising tool in minimising the potential environmental impacts of water engineering projects and related activities.

Henceforward, this paper aims to utilise a life cycle assessment (LCA) methodology to evaluate and quantify the carbon footprint associated with the water supply and treatment sources in Delhi by studying Haiderpur Water Treatment Plant in depth.

Methodology

Study Area

The region aimed in this study is Haiderpur Water Treatment Plant which is located at Outer Ring Road near Prashant Vihar, Rohini Sec-13 in Delhi, India (Figure 1). Water supply and wastewater infrastructure in Delhi is managed by the Delhi Jal Board (DJB), which is an autonomous department of the Delhi Government. The raw water sources of Haiderpur Water Treatment Plant are Bhakra Storage and Yamuna, the water is supplied to this WTP via the Carrier Lined Channel (CLC) and the Delhi Sub-Branch (DSB).

There are two treatment plants in Haiderpur Water Works of 100 MGD each in Phase-I and Phase-II, respectively, with an additional 16 MGD Recycling

Figure 1: Treatment process at Haiderpur water treatment plant.

plant which makes the capacity of the WTP to be 216 MGD. However, the annual average daily inflow in the water system is 237 MGD as, nowadays there is a shortage of water in the city subsequently the WTP runs at a higher capacity. In total, the area covered by Haiderpur Water Treatment Plant is about 100 acres and the water is supplied to parts of North West, West and parts of South Delhi.

DJB has been consuming a very high electricity demand to operate its WTPs and BPS (Booster Pumping Stations). To reduce the dependency on other sources of electricity and to lower pollution levels, DJB installed solar panels on its shadow-free rooftop areas to generate green electricity. Haiderpur Water Treatment Plant is generating 16000 kWp of solar power as green electricity by producing approximately 172000 units per month.

As shown in Figure 1, the treatment process at the plant is fairly systematic. Raw water enters the two water treatment plants through CLC and DSB. Screening is done with mechanical screens to remove wastes like plastics, wood, rags, stones and other debris from the influent raw water.

After screening, the water enters the raw water pump house. There are two raw water pump houses and each pump house has 12 pumps. The next step is pre-chlorination which is done by adding liquid chlorine for disinfection. After this, then the water is fed into clarifiers. There are eight clarifiers of 12.5 MGD capacity each in both phases. The necessitated amount of alum and PAC are added into the water before it enters into the clarifier to reduce the turbidity of the water. PAC and alum are positively charged and the negatively charged insoluble waste, respectively, that becomes flocculated and finally precipitates in the clarifier. Alum is generally used when the turbidity of water is extremely high, which happens usually in the rainy season. The clarifier is divided into three zones - innermost (where flocculation takes place), middle (where sedimentation takes place) and outermost (where filtration takes place).

The water remains in the clarifier for approximately 3-4 hours. From there the water is again released into the canal. The partially pure water from the outermost zone of the clarifier enters the rapid sand gravity filtration tank containing filter beds composed of rocks, sand, soil, gravel, etc. The water is made to pass the filter beds at a very high speed and the filtered water passes into the inspection box.

There are two filter houses in each phase each of 50 MGD capacity. One filter house has about 20 filters and the capacity of each filter is 2.5 MGD. After the water leaves the filter house, it is chlorinated again. Post-chlorination, the treated water is supplied to various underground reservoirs (UGR's) which transport water to households and industries as and when required through the pipeline networks.

Steps Followed for Preparing a GHG Footprint

In this present study, the energy and GHG footprint of the Haiderpur Water Treatment Plant are examined and calculated. The terminology energy is broadly inferred to incorporate electricity and diesel for the operation and transportation aspect of the plant together along with the energy embodied in materials throughout the construction phase of the plant and in the chemicals used throughout the operation of the plant. Likewise, GHG emissions include both direct and indirect emissions. Direct GHG Emissions comprise emissions that can be produced biologically and normally emitted in sewers. Indirect GHG emissions are associated with the consumption of electricity, the use of fossil fuel or diesel for transportation, or the use of chemicals that are used as disinfectants and during the disposal process (ISO/TS 14067:2013).

As comprehended in the study by Godskesen et al. (2010), Del Borghi et al. (2013) and Barjoveanu et al. (2013), the LCA approach plays a strategic role in the identification of essential processes and possible development methods for the urban water system. Accordingly, the life cycle assessment methodology has been employed to calculate the carbon footprint of the plant. The life cycle of the plant acquires carbon emission from the following stages:

i. *Construction* - Energy is utilised procuring the materials used in the construction of the structures.
ii. *Operations* - Energy is utilised to ensure the active running of the plant and its daily activities.
    a. Mechanical device employed - Energy is used to run the machines used in the treatment process as well as to power the administrative offices of the plant.
    b. Chemicals used - Energy is used to produce the chemicals used in the treatment process.
iii. *Transportation* - Diesel is consumed for the distribution of water via transports which causes direct emissions.

The method entails the calculation of energy for each of the four sources while using relevant conversion factors to find the carbon footprint, i.e. the GHG emissions responsible for each source.

Table 1: The models for estimation of energy consumption and GHG emissions

Source	*Method*	
	Energy *(kW/m³)*	*GHG Emissions* *(kg CO₂/m³)*
Mechanical devices used during operation	$E_1 = \sum_{i=0}^{n} Epi\,; Epi = \frac{pi \times Ti}{Q}$	$G_1 = 0.81 \times El$
Chemicals used during operation	$E_{ch} = \left(\frac{\sum_{i=0}^{n} Wi \times Eci}{Q}\right)$	$G_{ch} = \left(\frac{\sum_{i=0}^{n} Wi \times EFi}{Q}\right)$
Diesel used for water supply and transportation	$E_d = \left(\frac{\sum_{i=0}^{n} \left(\frac{Di}{Ei}\right) \times CF}{Q}\right)$	$G_d = 2.9\left(\frac{\sum_{i=0}^{n} \left(\frac{Di}{Ei}\right)}{Q}\right)$
Materials used during construction	$E_{mt} = \left(\frac{\sum_{i=0}^{n} \{(Vi \times \rho i) \times Emi\}/Ni}{F}\right)$	$G_{mt} = \left(\frac{\sum_{i=0}^{n} \{(Vi \times \rho i) \times EFi\}/Ni}{F}\right)$

Key: *CF* - energy conversion factor for diesel to electricity: 15.64 kWh/L; D_i - total distance travelled daily by i^{th} vehicle (km/day); E_i - fuel efficiency of the i^{th} vehicle (km/L); E_{ci} - unit energy consumption values of the i^{th} chemicals (kWh/kg); E_{mi} - unit energy consumed during manufacturing of i^{th} construction material (kWh/kg); EF_i - carbon (CO_2eq) embodied in the i^{th} chemical and construction material (kg/kg); Ep_i - electrical energy use of a unit (kWh/m^3); *F* - design capacity of the WTP (m^3/year); N_i - life of the i^{th} construction material (years); P_i - rated power of i^{th} electrical equipment (kW); *Q* - daily average inflow to WTP (m^3/day), *T* - duration of daily operation of i^{th} electrical equipment (hrs/day); V_i - volume of the i^{th} material (m^3); W_i - consumption of the i^{th} chemical (kg/d); ρ_i - density of the i^{th} material (kg/m^3).

(*Source:* Singh et al., 2018).

Table 1 explains the models used for estimating energy consumption and GHG emissions from different sources. These models are based on the mass balance approach and they shape the footing of the life cycle assessment (LCA) model (Singh et al., 2018).

For electrical energy consumption (E_1) the value of Ep_i was collected from the logbooks of DJB. The diesel energy consumption (E_d), is not applicable, as all transportation in this plant occurs through pipelines. For chemical energy consumption (E_{ch}), the quantity of chemicals used in this plant was also shared by DJB officials. The chemicals used were alum, poly aluminium chloride (PAC) and chlorine. For material energy consumption (E_{mi}), the details of each material used during the construction of this plant is a tedious task to collect, as this plant was constructed years ago, the values are not available readily and might not be accurate thus leading to undesired errors in the values of energy consumption and GHG emissions.

Indirect carbon emissions associated with electricity use were computed by taking the emission factor as 0.81 kg CO_2/kWh from a Ministry of Power, GOI report on CO_2 baseline database for the Indian Power Sector, 2018. As shown in Table 2, carbon emission values associated with chemicals were acquired from the literature (Haas et al., 2009; Zhang et al., 2010).

To obtain accurate energy and emission values associated with this plant, assumptions are put in place. While the plant uses solar panels to generate solar energy of 1,70,500 units/month in summer and 1,45,000

Table 2: Embodied energy and carbon emissions factors for chemicals

Chemicals	E_{ci} *(kWh/kg)*	EF_i *(kg/kg)*
PAC	10.93	13.54
Disinfectant	13.54	1.124
Alum	0.17	0.50

Source: Singh et al., 2018.

units/month in winter, it can be safely assumed that solar energy does not contribute to carbon footprint of the plant. Hence, only the electrical energy which the plant obtains from TPDDL is taken as electricity consumption for the plant.

Result and Discussion

In this paper, since Haiderpur WTP is studied, only two models (mechanical devices used during operation and chemicals used during operation) for estimating energy consumption and GHG emissions are considered due to the previously mentioned reasons. Data of water inflow (Q), electrical energy use of a unit (E_{pi}), chemical energy consumption (E_{ch}), consumption of chemicals used (W_i) such as alum, poly aluminium chloride (PAC) and chlorine was collected from DJB officials during the plant visit. The total inflow of water (Q) was be found as 237 MGD that is 897139.8 cubic meters/day while the electrical energy consumption was found to be 5,00,000 units a year. The daily consumption of PAC, alum and chlorine was found to be 7259.7 kg/day, 1103.8 kg/day and 1790.1 kg/day, respectively.

Through the models provided in Table 1, the values of embodied energy and carbon emission factors from different chemicals tabulated in Table 2 and data provided by DJB as mentioned above; the amount of energy use and GHG emissions were calculated and shown in Tables 3 and 4 and hence, finally represented in Table 5. The calculated total energy used by the water treatment plant is about 0.13093 kW/m^3 or if put in terms with the GHG emissions is 0.12476 kg CO_2 eq/m^3. In the operational phase, the chemicals used the account for about 88% of the energy while the rest of the energy is embodied by mechanical devices such as pumps, motors or aerators.

Furthermore, it can be seen that PAC contributes to energy the most whereas alum, the least. After acquiring the energy consumption, we can calculate the GHG emission, and it can be seen that about only 10% is contributed by mechanical devices, whereas major emissions are caused by the usage of chemicals.

It is apparent that water supply, in itself is a source of pollution but it is hard to deal with since water supply needs are increasing. The size of a water system's carbon footprint is directly related to the combination of types of fuels used to produce energy to power the system. There would be a smaller carbon footprint for water systems that use an increased percentage of fuel sources with a lower CO_2 emission rate.

It has been suggested through research that a water supply with a lower average unit cost is likely to have a higher carbon footprint. Therefore, higher emphasis is being laid on coming up with alternatives that produce a lower carbon footprint. Water use permit options and groundwater usage options are alternatives that should be preferred in terms of average CO_2 equivalent emissions. These also show an advantage in unit cost. Shifting to hydropower schemes and creating energy

Table 3: Energy consumption of the four sources

Source	*Energy consumption (kW/m^3)*
Mechanical devices used during operation	$E_1 = \left(\frac{5000000/365}{897139.8}\right) = 0.01526$
Chemicals used during operation	E_{ch} (PAC) = 7259.7 × 10.93 = 79349.373 E_{ch} (Alum) = 1103.87 × 0.17 = 187.658 E_{ch} (Chlorine) = 1790.13 × 13.54 = 24238.807 $E_{ch}\text{ (Total)} = \left(\frac{79349.373 + 187.658 + 24238.807}{897139.8}\right) = 0.11567$
Diesel used for water supply and transportation	NA
Materials used during construction	na
Total	**0.13093**

Key: NA - Not Applicable; na - not available

Primary Data - Calculated using models in Table 1 and values in Table 2.

Table 4: GHG emission from the four sources

Source	*GHG emissions (kg CO_2 eq/m^3)*
Mechanical devices used during operation	$G_1 = 0.81 \times 0.015 = 0.01236$
	G_{ch} (PAC) = $7259.778 \times 13.54 = 98297.394$
	G_{ch} (Alum) = $1103.87 \times 0.05 = 551.938$
Chemicals used during operation	G_{ch} (Chlorine) = $1790.163 \times 1.124 = 2012.143$
	$G_{\text{ch}}\,(\text{Total}) = \left(\dfrac{98297.394 + 551.938 + 2012.143}{897139.8}\right) = 0.1124$
Diesel used for water supply and transportation	NA
Materials used during construction	na
Total	0.12476

Key: NA - Not Applicable; na - not available
Primary Data - Calculated using models in Table 1 and values in Table 2.

Table 5: Total energy consumption and GHG emissions

Source	*Energy (kW/m^3)*	*GHG emissions (kg CO_2 eq/m^3)*
Mechanical devices used during operation	0.01526	0.01236
Chemicals used during operation	0.11567	0.1124
Diesel used for water supply and transportation	NA	NA
Materials used during construction	na	na
Total	0.13093	0.12476

Key: NA - Not Applicable, na - not available
Primary Data - Calculated using data given in Tables 3 and 4.

by using water that had required the energy in the first place is also a remarkable option.

Conclusion

The Haiderpur Water Treatment Plant utilises highest amount of solar power in comparison to other WTPs in Delhi yet energy consumption in this plant is quite high. The total energy used by the water treatment plant was calculated to be about 0.13093 kW/m^3 while the GHG emissions was 0.12476 kg CO_2 eq/m^3. It can be entrenched through this study that the water sector contributes to climate change, and therefore carbon footprint calculation can be a controlling element in environment cognizance and make the associated people environmentally aware of the present and future projects.

Also, it is imperative that energy consumption in this infrastructure will increase at a tremendous rate due to the declining amount of usable water in Delhi. This is due to the existing and ever-increasing pollution of both surface and groundwater water sources; more energy is required to treat water and make it safe for consumption.

An initiative to reduce energy footprint brought in by tankers is to install pipelines throughout the city. This would also improve the water quality supply as electric consumption in the final stages would decrease.

While resource/energy recovery can assist in reducing overall environmental impact, greater benefits would be difficult to achieve unless electricity is generated using renewable energy sources such as solar, wind, gas, or nuclear power. A substantial amount of reduction in energy and GHG footprint in Wastewater Treatment Plants can thus be achieved through adopting recovery methods. It should be noted that common water reuse via effluent recycling has been discovered to be inadequate to achieve a net-zero effect on the total environment of WTPs.

Organic energy recovery i.e. the recovery of PAC can contribute in reducing injurious environmental impacts, which can be achieved through conventional anaerobic digestion or incineration. These energy recovery methods are generally disregarded in developing countries because of the lack of funds or lack of maintenance of the supply networks.

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