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Water-Energy-Nexus in Water Supply: A Case Study on Greenhouse Gases Emissions Trends of a Water Utility Company in Johor, Malaysia

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Carbon Footprint (CF) assessment of water utility company (WUC) was originally initiated in 2011. The WUC carried out a holistic assessment of the impact of WUC operations on the environment on activities ranging from water treatment, supply activities, administration and interaction with its stakeholders. The aim of this study is to determine the WUC's operational CF for the years 2012 - 2014 in units of kg CO_{2eq}/m^3 of raw water. The aim of this paper is threefold: (1) to examine the direct emissions of diesel usage for electricity generation, diesel and petrol usage for a fleet vehicle (2) to examine the indirect emissions from purchased electricity and (3) to investigate the indirect emissions of chemical usage at WTP. The carbon footprint measurement is carried out to identify the sources of Green House Gas (GHGs) emissions from the various WUC's operational and administrative activities. The Intergovernmental Panel on Climate Change (IPCC) standard was used to calculate the CF of WUC for the years 2012 - 2014 based on the identified sources of emissions. The results showed that the purchased electricity (85 - 90 %) has the highest overall carbon emission for three consecutive years (2012 to 2014). Second, petrol usage was the major contributor for staff commuting (3 – 4 %) and for transporting chemicals from producer to the WTP (6 – 7 %). The analysis showed that in 2014 the carbon footprint was similar to the situation in 2013. In 2014, the green gas emission increased to 207,295.73 Mt CO_{2eq} due to the increase in WTPs numbers (that is from 27 to 42) with a capacity to treat 579,481,988.42 m^3 of water. The outcomes of this study would serve as a guideline and benchmark for other water industries, especially in the Malaysia context.

1. Introduction

The "water-energy nexus" is a broad label for the set of interactions caused when humans develop and use water and energy (Griffiths-Sattenspiel and Wilson, 2009). The nexus manifests itself in many ways, revealing substantial trade-offs and opportunity costs associated with the ways we use water and energy. A large amount of energy is expended to supply, treat and use water, meaning that water-oriented strategies can result in significant reductions in energy use and greenhouse gas emissions. In most circumstances, GHG emissions cannot be directly measured (EPA, 2016). The primary exception to this generalisation is electric utilities and other facilities that operate continuous emission monitors (CEMs) to track regulated air pollutant emissions that also directly or indirectly measure carbon dioxide (CO_2) emissions. GHG emissions must be calculated using measured "activity" data for parameters such as quantities of fuel combusted, electricity consumed, or vehicle miles driven.
According to the revised GHG Protocol by World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), GHG emissions are divided into three categories, which are Scope 1 (Direct GHG emissions), Scope 2 (Indirect GHG emissions from utilities) and Scope 3 (Optional Indirect GHG emissions that covers all other releases), that are an indirect consequence of the entity's operations, or which could be within the sphere of influence of the entity (WRI, 2004) and (WBCSD, 2011). From a global perspective, several

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developed countries in Europe such as Finland, Denmark, Netherlands, Sweden and India in Asia had imposed carbon tax on fuels consumed in the country (Kenny et al., 2009). With this, industry is seen as paying their share towards a more competitive environment. A CF assessment of water production can be important when considering economic, social, and environmental aspects of any project or water production cycle. Economic assessment can be tied to the CF analysis through an evaluation of the cost to proceed with a more environmentally friendly (i.e., Lower CO_2 emissions) alternative.

2. Methods

The main aim of this study is to determine the WUC's operational CF for the years 2012 - 2014 in the unit of $kgCO_{2eq}/m^3$ raw water. The carbon footprint measurement is carried out to identify the sources of Green House Gas (GHGs) emissions from the various WUC's operational and administrative activities. The objectives of the project are to calculate the CF of WUC for years 2012 - 2014 based on the identified sources of emissions utilising Intergovernmental Panel on Climate Change (IPCC) standardised method that has been used for the previous assessment of CF; 2 and to propose mitigation strategies towards future reduction and better management of WUC's GHGs emissions (IPCC, 2014). The CF measurement of 2012 - 2014 involves the assessment of 44 water treatment plants, district administration offices as well the WUC headquarters in Johor Bahru.
The expected outcome will be the evaluation of carbon emission from water treatment processes, supply system and business activities (administrative, logistic, etc.) in the unit of kg carbon dioxide equivalent/unit raw water ($kgCO_{2eq}/m^3$ raw water). Based on the identification of the hotspots and analysis of findings, mitigation strategies will be proposed towards WUC efficient carbon management in the years to come. As for this study, Greenhouse Gas Protocol (GHG Protocol) developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) was used in estimating GHG emissions. Table 1 explains the boundaries to which the carbon emission factors are measured for each of the contributing sources divided into three scopes according to the GHG Protocol models (WRI, 2004).

3. Results and Discussion

The results are separated based on the scopes, categories, and districts for each reporting period. The data collected from WUC allows assessment of the emissions across the organisation where information is available on site. The emissions are primarily shown at the operational level for the whole organisation of WUC Holdings.

3.1 Analysing the carbon intensity by scopes

Table 1 depicts the operational boundaries of GHG emission, meanwhile, Table 2 represents the summarised value for Scope 1, Scope 2 and Scope 3 carbon emissions. Two categories are included in Scope 1 (Table 1), which is WUC fleet vehicle (petrol and diesel) and diesel consumption for electricity consumption. The total carbon emission per RW has significantly reduced from 0.0090 kg CO_{2eq}/m^3 RW in 2012 to 0.0061 kg CO_{2eq}/m^3 RW in 2014. The diesel consumption in a WUC fleet vehicle represents a more significant proportion of the emissions with more than 50 % contribution for each reporting year. The carbon emissions from fuel consumption for a WUC fleet vehicle and diesel for electricity generation increased from 2012 to 2014, in line with the increasing of WTPs and pump houses in 2014. In terms of Scope 2, one category has been included, which is purchased electricity from main power line. The total Scope 2 carbon emissions are increasing each year from 2012 to 2014. The increase in amount of carbon emission from 2012 to 2013 signifies less efficiency of purchased electricity consumption in 2013 as shown in Table 2. However, the purchased electricity has been managed well in 2014 compared to 2013 with consideration of 44 WTPs operated in 2014.
The amount of carbon emission from 2012 to 2013 signifies less efficiency of purchased electricity consumption in 2013 as shown in Table 2. However, the purchased electricity has been managed well in 2014 compared to 2013 with consideration of 44 WTPs operated in 2014. In Scope 3, four categories were incorporated, which are chemical usage in WTP, staff commuting (petrol), chemical transport (diesel) and paper consumption. The carbon emissions for Scope 3 have increased from 2012 to 2014, respectively. However, the carbon emissions per RWP has decreased from 0.0475 kg CO_{2eq}/m^3 in 2012 to 0.0379 kg CO_{2eq}/m^3 and 0.0363 kg CO_{2eq}/m^3 in 2013 and 2014, signifying better carbon. The carbon emission from chemical consumption has multiplied in 2014 compared to 2012 with the addition of 15 WTPs in 2014 but reduced in terms of carbon emission per RWP. By comparing carbon emission from chemical consumption and transportation in 2012 and 2013, higher values were observed, although the numbers of WTP in 2012 and 2013 are the same. A4 paper consumption has contributed less than 1 % in Scope 3 suggesting less significance in total carbon emissions.

3.2 Analysing WUC's three-year trend carbon intensity for year 2012 – 2014

WUC's carbon emissions are evaluated for consecutive three years from 2012 to 2014 in this study. Carbon accounted in year 2011 is taken as base year. Figure 1 and Figure 2 show the three-year trend of carbon dioxide equivalent emission Mt CO_{2eq} and kg CO_{2eq}/m^3. Table 3 summarises the values of carbon accounting for all three years and base year. In 2011, WUC operated 27 WTPs, while the number increased to 29 in 2012 and 2013. Carbon emission in 2012 is increasing compared to base year by 32 %, which is 112,649.84 Mt CO_{2eq}. This is due to increasing number of WTPs. Two water treatment plants are added, namely Sg Johor WTP and Batu 2 WTP under Kota Tinggi district. The capacity of WTP of Sg Johor is bigger compared to other plants, making it one of the major carbon generators by its operational activities. As raw water treated doubled in 2012 compared to 2011, the total carbon footprint in 2012 is reduced to 0.3507 kg CO_{2eq}/m^3. This shows WUC has taken some options to reduce carbon footprint in water treatment stages while treating more water in 2012. Carbon emission in 2013 increased from previous years with the same number of WTPs and higher amount of raw water treated. The production of carbon rises by 170,564.00 Mt CO_{2eq} to treat 475, 407,922.80 m^3 of raw water. Figure 1 shows this amount has almost doubled compared to base year 2011. Total carbon footprint in 2013 increases slightly from the previous year and recorded as 0.3588 kg CO_{2eq}/m^3. In this year, some maintenance services in pipeline of transmission of water were done. The synchronisation of new development leads to extra carbon emissions with more water production. In 2014, the carbon footprint sustained and dropped a little to 0.3577 kg CO_{2eq}/m^3. In 2014, WUC owned and operated 42 WTPs and treated 579,481,988.42 m^3 of water. Higher number of operating WTPs is considerable with increased greenhouse gases emission of 207,295.73 Mt CO_{2eq}. Some WTPs started to facilitate water treatment for half year, which less significantly represents the whole year's carbon footprint.

Table 1: The operational boundaries of GHG emission

Scope	Activities	Description
Scope 1 Direct emissions from organisation	Diesel usage for electricity generation	Diesel is used as the fuel to power the treatment plants in case of power disruption, and it is categorised under electricity
	Diesel & petrol usage for fleet vehicle	Transportation activities involved in business operations contributed directly to aid operations of WUC. The carbon emission factor for diesel and petrol consumption is followed as in Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors, Department for Environment. Food and Rural Affairs (Defra) (Hill et al., 2012).
Scope 2 Indirect emissions from organisation	Purchased electricity	Purchasing energy such as electricity as indirect source of emission is used to power all the water treatment plants, pump house and district offices. The carbon emission factor for electricity is specified for Malaysia was taken from CDM Electricity Baseline (Nazily, 2012).
Scope 3 Indirect emissions from organisation	Chemical usage at WTP	Various chemicals are used in WTP to treat the raw water. The carbon emission factor for chemicals is derived from the background impact of the chemical processing and production. The carbon emission factor for various chemicals are extracted from the Eco invent database: The overview and methodological framework was reported by Friscknecht (2005) and IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2014).
	Diesel usage for Chemical transportation to WTP	Transportation involved in supplying of chemical used in WTP from chemical plant or distributor to WTP.
	Petrol usage for staff commuting	A4 paper was consumed in administration offices. The carbon emission factor from UNDP reference that includes the life cycle assessment of paper from extraction of the natural resources to its production, but exclusive delivery to customers.

Table 2: Carbon emission for each category from 2012 to 2014

Year / Category	2012 $kgCO_{2eq}/m^3$	2012 $MtCO_{2eq}$	2013 $kgCO_{2eq}/m^3$	2013 $MtCO_{2eq}$	2014 $kgCO_{2eq}/m^3$	2014 $MtCO_{2eq}$
Scope 1						
Diesel for electricity	0.0014	460.95	0.0008	358.23	0.0016	898.52
Diesel usage WUC fleet vehicle	0.0045	1,445.64	0.0035	1,685.75	0.0034	1,969.31
Petrol usage WUC fleet vehicle	0.0030	976.77	0.0016	773.36	0.0011	661.03
Total Scope 1	0.0090	2,883.37	0.0059	2,817.34	0.0061	3,528.85
Scope 2						
Purchased electricity	0.2942	94,515.91	0.3149	149,729.26	0.3153	182,729.54
Total Scope 2	0.2942	94,515.91	0.3149	149,729.26	0.3153	182,729.54
Scope 3						
Chemical usage at WTP	0.0212	6,824.11	0.0192	9,146.81	0.0217	12,590.31
Petrol usage for Staff commuting	0.0256	8,235.93	0.0183	8,682.08	0.0142	8,204.62
Diesel usage for chemical transportation	0.0004	140.48	0.0003	155.14	0.0003	190.28
Papers	0.0002	50.04	0.0001	33.36	0.0001	52.13
Total Scope 3	0.0475	15,250.56	0.0379	18,017.39	0.0363	21,037.34

Table 3: Summary of carbon footprint 2011-2014

Year	Number of WTP	Raw water treated (m^3)	Carbon Emission ($MtCO_{2eq}$)	Carbon Intensity ($kgCO_{2eq}/m^3$)
2011	27	156,092,717	84,745	0.5713
2012	29	321,213,179.24	112,649.84	0.3507
2013	29	475,407,922.80	170,564.00	0.3588
2014	42	579,481,988.42	207,295.73	0.3577

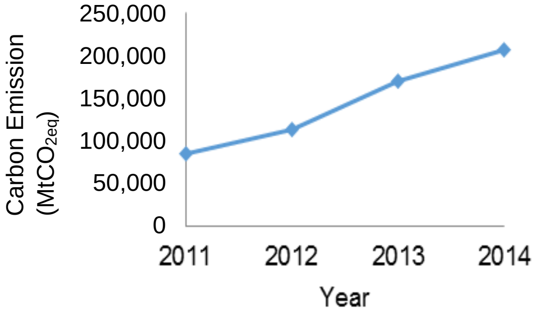

Figure 1: Three-Year trend of total carbon emissions from 2011 - 2014

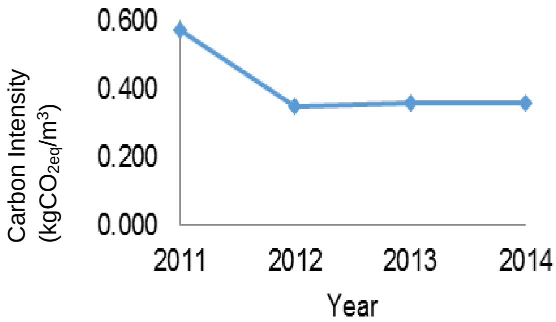

Figure 2: Three-Year trend of total carbon intensity from 2011 - 2014

The years 2012 - 2014 recorded an average carbon emission of 0.3557 kg CO_{2eq}/m^3. The trend of these three years lies within this average value. The difference between the carbon footprint value for all 3 y and the average value does not exceed 0.5 %. This indicates the carbon footprint is within the range and carbon emission is manageable. The ratio of increasing carbon emission to increasing amount of raw water treated holistically balanced the carbon account. Value in base year is very high compared to the analysed three years. The average for carbon footprint in 2011 - 2014 is 0.4096 kg CO_{2eq}/m^3. It could be that the 3 y average value dropped compared to 4 y of average value. The carbon intensity reduces compared to base year and is associated with the improved efficiency of WUC's water treatment.

Figure 3 illustrates the annual carbon intensity of WUC for three reporting years (2012-2014) based on year 2011. WUC has decided to use the carbon emission calculated for year 2011 as fixed base year for the three inventory years. According to GHG protocol, fixed base year has the advantage of allowing emissions data to be compared on a like-with-like basis over a longer time period than changing (rolling) base year. Carbon intensity in 2012 has reduced by 38.61 % compared to 2011. However, this carbon reduction value decreased in 2013 by 37.19 % and slightly increased in 2014 by 37.38 %. The target carbon reduction baseline of WUC by 2017 is 5 % based on 2011 baseline. The assessed results show carbon intensity has been lowered more than the targeted baseline.

Figure 3: Annual Carbon Intensity ($kgCO_{2eq}/m^3$) for 2011 – 2014

4. Conclusion

While the full degree of the water–energy nexus in water treatment framework is challenging to survey, in this report a foot-shaped impressions philosophy is consider to provide a way to understand how WTPs collaborate with energy resources and operations in view of the water–energy nexus and, as such, more complete data is obtained. WUC's carbon emissions are in this study are evaluated for three consecutive years from 2012 to 2014. Carbon emissions from scope 1 have shown reduction from 2012 to 2014 where diesel consumption for WUC fleet vehicle represents a more significant proportion of the emissions with more than 50 % contributions for each reporting year.

The total Scope 2 carbon emissions increase each year from 2012 to 2014. The purchased electricity has been managed well in 2014 compared to 2013 with consideration of 44 WTPs operated in 2014. The carbon emissions for Scope 3 have increased from 2012 to 2014 but reduce in term of carbon, signifying better carbon emission performance in Scope 3 due to higher number of operating WTPs in 2014. HQ category has the lowest emissions within 3 years reporting due to smaller categories included in the carbon emission calculations. Carbon footprint assessment of three years (2012 - 2014) helps WUC to reveal water treatment efficiency and renewability of water treatment framework at the expense of vitality utilisation. In view of that, the study evaluated the efficiency of the vitality usage of the 42 genuine cases WTPs in WUC as updated in 2014. It is found that the water qualities, treatment technologies and additional administration frameworks have a noteworthy impact on the effectiveness of vitality use in lessening carbon footprint via these WTPs. This work is expected to add to a better arranging and operation of WTPs of WUC by considering the water– energy nexus.

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