Integrating Water-Energy-Nexus in Carbon Footprint Analysis in Water Utility Company

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Abstract: ***The purpose of this paper is to highlight the water-energy-nexus within the context of carbon footprint methodology and water utility industry. In particular, the carbon management for water utility industry is crucial in reducing carbon emission within the upstream water distribution system. The concept of water-energy nexus alone however can be misleading due to exclusion of indirect and embodied energy involved in the water production. The study highlights the total energy use within water supply system as well as embedded carbon emission through carbon footprint methodology. The case study approach is used as a research method. The carbon footprint analysis includes data collection from water utility company; and data identification of direct and indirect carbon emission from corporation operation. The result indicates that the indirect and embodied energy may not be significant in certain operation area but the energy use may be ambiguous when these elements are excluded. Integrating carbon footprint methodology within the water supply system can improve the understanding on water-energy-nexus when direct and indirect energy use is included in the analysis.***

This paper aims to benefit academics, government agencies and particularly water utility companies in integrating carbon footprint analysis in water production..

Index Terms**:** ***Carbon Footprint, Carbon Management, Water-Energy-Nexus, Water Utility Industry.***

I. INTRODUCTION

Climate change occurrence is now widely accepted and mounting concerns about its threat are shown around the world. International institutions such as the Intergovernmental Panel on Climate Change had advocated mitigation steps in reducing carbon emissions in order to limit global average temperature rise to 2°C above preindustrial levels (Intergovernmental Panel of Climate Change, 2007). Various approaches such as life cycle assessment (LCA) and carbon footprint (CF) have been developed and proven as valuable tools to assess the greenhouse gas (GHG) emissions and guiding for target setting and mitigation measures (Wiedmann and Minx, 2008). Focusing in climate change impact, CF provides indicators based on entity activities that contribute to GHG emissions (Wiedmann and Minx, 2008). Globally, CF method has become pertinent in organizations due to its realism in identifying the potential areas for future carbon mitigation plan (Matthews et al. 2008). Carbon footprint is frequently known as a concept of describing a certain amount of GHG emissions to a certain activity, product or population (Wright et al. 2011). Wiedmann and Minx (2008) redefine carbon footprint as a measure of the total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product. In this term, all direct (on-site, internal) and indirect (off-site, external, upstream, downstream) activities that contribute to carbon emission are included (Lee, 2011). Moreover, the use of this term has been well accepted by media, industry, government and nongovernmental organizations. This trend has attracted the interest of policymakers as well as corporations and consumers in reducing the climate change impact (Wiedmann and Minx, 2008).

In the context of corporations, carbon footprint has been seen as a new frontier for businesses to remain competitive as a number of different industry sectors have started to distinguish their carbon emissions throughout their product supply chain (Hult et al. 2007). Indeed, McKinsey Global Survey (2008) has reported that higher management in various sectors has acknowledged the climate change issues as a business reality right now (McKinsey, 2008). Various voluntary carbon emissions reporting schemes have been established by institutions around the globe. This includes mounting demand from investors and other stakeholders for the acknowledgement of product or service carbon emission related information. As a consequence, an increasing number of companies have measures and are reporting their carbon emission to identify the potential threats as well as prospect for their organizations (Kaufman et al. 2012). With the aim to standardize the carbon footprint evaluation, various methods, standards, requirements and tools for GHG accounting have been published to support carbon footprint

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reporting among organizations. Carbon footprint generally is part of impact categories in life cycle assessment (LCA) which is focusing on global warming or climate change impact. LCA itself is a valuable tool in understanding the environmental performance of a product or system (Hafizan et al. 2016). Therefore, ISO 14040 Standards that are commonly applied for LCA study have been proven practicable and accepted as a guideline for performing CF calculation (EU, 2007). LCA itself is commonly used among policy makers and industry players as a decision-support tool in evaluation the impacts generated from product or process (Mikulcˇic´1 et al., 2016). Several other carbon footprint reporting guidelines such as the GHG Protocol Product Life Cycle Accounting and Reporting Standard (WRI and WBCSD, 2011), PAS 2050 (BSI, 2011) and the ISO/TS 14067 (ISO, 2017) have been developed in monitoring and reporting organization's CF. In terms of procedure, the GHG protocol and PAS 2050 have a similar approach in dealing with multifunctional processes. However, PAS 2050 has specific requirements in dealing with allocation related with energy recovery (Garcia and Freire, 2014).

Carbon footprint accounting is based on three scopes (scope 1, scope 2 and scope 3) as defined in GHG Protocol Product Life Cycle Accounting and Reporting Standard (GHG Protocol Initiative (2004). Scope 1 generally covers direct GHG emissions from operation controlled by the organization such as combustion from operation vehicle. Scope 2 includes GHG emissions from utility consumed by the organizations such as purchased electricity (generated outside the organization's operation) and tap water. Scope 3 covers GHG emissions from activities which are not owned or controlled by the organizations such as staff vehicle and purchased material transportation. GHG Protocol has set a minimum requirement to report scope 1 and 2 in carbon footprint assessment for organization. Globally, the government policy on climate change actions has pushed the organizations within local institutions to evaluate their carbon emissions (Kaufman et al. 2012). Even though many government schemes on carbon reporting has been applied by organizations, the terms scope 1, 2 and 3 as defined by the GHG Protocol has become the standard carbon reporting baseline. Various motivations have lead governments, companies and investors to calculate their carbon emissions. Governments develop carbon reporting schemes to evaluate and incorporate emission data to enlighten future policy (PWC & CDP, 2010). For companies, two main reasons for carbon reporting are good company image as well as operation cost reductions. By maintaining good image, the companies can maintain their competitiveness as well as attracting new business prospect. Moreover, reduction of energy saving from carbon mitigation plan which directly reduces operation cost is the core for carbon reporting within companies even without authoritarian pressure (OECD, 2010). In the investor's point of view, carbon reporting gives transparency on company's abilities in climate change adaptation as well as to measure climate risk assessment and prospect into their business strategy (Kaufman et al. 2012).

This study aims to emphasize carbon footprint relations with water-energy-nexus with the case of water supply system. A case study approach is employed based on water utility company in Malaysia. One fundamental question is how carbon footprint analysis helps to provide understands on the water-energy-nexus issues within water utility company. In particular, the mutual relation within water and energy production is rarely being discussed especially in policy perspectives. This study highlights water-energy-nexus in water utility companies to enlighten future resource policy.

A. The Water-Energy-Nexus

Water and energy are the most valuable resources in the world. These two resources have changed the world's geopolitics since the existence of humans. Freshwater resource is a condition for population development, as well as agriculture and industry. To produce processed water, energy is consumed in water extraction, treatment, distribution and disposal processes (Siddiqi and Anadon, 2011). Equally, energy production uses huge amounts of water in different ways such as reservoir in hydropower, drilling fluids for fuel extraction as well as cooling medium for fuel combustion. Thus water and energy resources are extremely intertwined. This has brought to water-energy nexus concept within water and energy production. In the simplest form, this concept can be expressed as energy for water and water for energy (Perrone et al. 2011)

Traditionally, water and energy issues are separated across the industrial design and operation as well as government policy (Siddiqi and Anadon, 2011). In recent years, the trends have changed where the discussion to integrate both water and energy has intensified (NETL, 2009). Various efforts have been shown in understanding this relation. In Spain, intense study on energy consumption for urban water treatment and seawater desalination has been sponsored by the Spanish Institute for Diversification and Energy Conservation (IDEA) in finding new technologies and data for future policy (Fundacio´n OPTI & IDAE, 2010). The U.S. Department of Energy has established Water Energy Technology Team (WETT) to understand the water energy relation (DOE, 2006).

Energy is crucial in every phase of water production. This includes extraction, transportation, treatment, distribution, consumption and disposal (Williams and Bouzarovski, 2014). The water energy relation imposed for each aspect of water system is contributed from direct and indirect energy use. Kenway, 2013 describes this direct and indirect link of water-energy nexus. Direct energy use is defined as energy requirement of water production system (extraction, treatment, distribution and disposal) while indirect energy use is contributed in consumer stage such as through domestic heating or cooling. Within the life cycle perspective, indirect energy use may come from background energy use for production of material use in water production phase such as chemical production for water treatment. The direct energy use for water production system can be different due to geographical, physical and technological factors (Siddiqi and Anadon, 2011). In terms of geographical and physical aspect, in the water extraction phase, an area with lower water table may need more energy for groundwater pumping as compared to surface water pumping. The result may vary when the water resources is conveyed in extreme long distance (Plappally, 2012). Technological factor such as desalination intensively consumes energy more than conventional water treatment (Plappally, 2012). Glassman et al. 2011 has separated water use for energy production into three critical dimensions which are consumption, withdrawal and quality. These dimensions are also relevant in understanding the element of energy consumption in water production system. This study defines consumption as the amount of water generated for domestic, industrial and agricultural use; withdrawal as extraction process and quality as water resource quality. The high density and growth population of an area will need large energy consumption to support the water accessibility. Furthermore, Hof and Schmitt (2011) has shown that consolation factor also significantly contributes to higher water consumption and indirectly energy use, in which it was reported that water use in low density tourist area is higher compared to high density residential or mass tourist due to outdoor uses of water such as swimming pools and garden watering. In term of water quality, changes in water resource may change the water treatment operation and its indirect energy use or embodied energy (Santana et al. 2014).

In term of water capacity, naturally it is an abundant resource. However, in current years, water scarcity incidents have rapidly occurred due to water pollution as well as climate change. The reduction in water table has not only affected water for basic human need but also energy production. As an example, a decline of lake water in Colorado River has threatened the energy production system through hydropower and potentially risks to depower electricity distribution to Las Vegas (Webber, 2008). In China, the plan to build coal-to-liquids (CTL) plants was compromised due to drought and water quality concern (Xinhua News, 2006). Furthermore, Grubert and Kitasei, 2010 stressed out that reduction in water accessibility will limit energy production choices.

B. Integrating Carbon Footprint in the Water Utility Industry

Climate change occurrence has changed our outlook on water and energy resources. Report by Statistics, I.E.A. (2015) has shown a 40% increase of CO_2 concentration in 2014 as compared with 1800s. The other GHG (methane, nitrous oxide) emissions are also observed in increasing pattern. Moreover, energy is the highest contributor among the anthropogenic activities. In a water production system, large amounts of energy are consumed in supply, treatment and use. Thus, water-oriented measures can significantly reduce the carbon emissions embedded in water supply system. Carbon emission evaluation on water supply chain can highlight the water energy relations and identify the carbon reduction potential from water supply system. The main factor that contributes to the carbon emissions in water supply system is energy sources for electricity production. Different compositions of energy sources may apply in each country around the world. Composition of energy sources may vary due to resource availability, energy demands and policy choices. Moreover, Burke, 2010 added one more factor which is country income. Low-income countries' electricity mix mostly consist of hydroelectricity and oil-fired electricity generation, while high-income countries have more various options such as coal, natural gas, nuclear power and wind power. Furthermore, recently the fuel substitution trends have increased in reducing coal-fired electricity due to high carbon emissions within the system. As example, Malaysia's current economic growth path which is heavily reliance on oil and natural gas has induced the government to formulate policies and strategies to encourage venture in renewable energy (Yatim et al. 2016). Report on carbon emission from energy use in electricity and heat generation for 2013 (Statistics, IEA, 2015) has indicated that coal-fired electricity produces a total of 3,534.2 Mtonnes of CO_2 as compared with oil and natural gas with 221.5 Mtonnes of CO_2 and 166.2 Mtonnes of CO_2 respectively. A research by Baldwin, 2006 has shown that renewable energy such as biomass, photovoltaic, wave, hydro, wind and nuclear has lower carbon emission (237-3 gCO$_2$eq/kwh) as compared to fossil fuel such as coal and gas (1070-398 gCO$_2$eq/kwh). This has brought to the sustainability ideology which is currently one of the main driving forces in energy production (Hafizan et al. 2014). Thus, in recent years, more efforts towards sustainability is expected in aiming for less emissions in production (Jamin and Mahmood, 2015).

The carbon emission in water supply system starts with the extraction of water from natural resource such as rivers. The water from these resources will require conventional treatment for the removal of micro-organisms and suspended solid and advance treatment when required. However, these processes relatively do not consume a lot of energy as compared with desalination process (Plappally, 2012). The thermal processes involved in the desalination system has highly contributed to this cause (Narayan et al. 2012). The end use phases in which separating from water supply system can generate carbon emission through various activities such as washing and water heating. It is also noteworthy to find that the end use phase is the major carbon emission contributor in water life cycle (Plappally, 2012). With concern on anthropogenic pressure and climate change occurrence, long-term solutions are crucial in managing these issues (Mikulcˇic´1 et al. 2016). Carbon footprint analysis which considers long term scenarios (Masera et al. 1997) is identified as a valuable tool in connecting these elements. Several factors (as mentioned in Sec. 2.0) such as water consumption, water withdrawal, water quality and water treatment technologies can be used as linkage in understanding the water-energy nexus in terms of carbon emission.

II. RESEARCH METHODS

A. Backgound: Water Utility Company

A review of literature indicates that there are various studies that relate energy use within water supply system as well as embedded carbon emission. However, only few studies describe the critical elements of water-energy nexus with the presence of carbon footprint indicators. A case study on water utility company in this study is to gain better understanding of these relations. The results cover contextual dimensions of water-energy nexus in terms of carbon emissions. Data were collected through site visit and extensive interviews with company administration. The data included an assessment of 44 water treatment plants, district administration offices as well as the water utility company's headquarters. The primary data collected directly from utility company increased the accuracy of the study. There are varieties of international guidelines available for calculating GHG emissions such as the GHG Protocol Product Standard (WRI and WBCSD, 2011), PAS 2050 (BSI, 2011) and ISO/TS 14067 (ISO/TS, 2013). Furthermore, some countries have developed their own carbon analysis framework such as the Japanese CFP Communication Program (JEMAI, 2012) and MYCarbon Programme by Malaysia's government (MYCarbon, 2012). Different frameworks apply different methodological approaches, which can result in different direction on product comparison (Whittaker et al. 2011). As for this study, Greenhouse Gas Protocol (GHG Protocol) developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WRI and WBCSD, 2011) was used in estimating GHG emissions. The model is chosen because it is the most applied method globally as well as proved as evaluation tool for government and organizations to calculate and manage carbon emissions.

In GHG protocol approach, the operation of organization is characterized based on three scopes which are Scope 1, Scope 2 and Scope 3 (GHG Protocol). In this particular study, Scope 1, Scope 2 and Scope 3 is shown in Table I. It can be observed that Scope 1 includes direct carbon emission from company operation which is diesel usage for electricity generation and diesel and petrol usage for fleet vehicle. Scope 2 incorporates indirect carbon emission from company utility while Scope 3 covers indirect carbon emission from chemical usage at water treatment plant (WTP), chemical transport to WTP (Diesel), staff commuting (Petrol) and A4 paper consumption. In the data collection phase, selected measurement indicators based on source or material consumption were applied. The carbon emission is calculated based on general carbon footprint calculation which is the amount of consumption multiplied with emission factor. The total CO_2 emission of water supply production is measured by adding the carbon emission for each scope.

Table I: The operational boundaries of GHG emission

Scope	**Activities**	**Description**
Scope 1 Direct emissions from organization	Diesel usage for electricity generation	Diesel is used as the fuel to power the treatment plants in case of power disruption, and it is categorized 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 organization	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 Energy Secretariat 2012 (CDM, 2012)
	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 (Frischknecht et al. 2005) and IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2014).
	Diesel usage for Chemical transportation to	Transportation involved in supplying of chemical used in WTP from chemical plant or distributor to WTP.

Scope 3 Indirect emissions from organization	WTP Petrol usage for staff commuting	A4 paper was consumed in administration offices. The carbon emission factor from Ecoinvent database (Frischknecht et al. 2005) that includes the life cycle assessment of paper from extraction of the natural resources to its production, but exclusive delivery to customers.

III. RESULT AND DISCUSSION

A. Summary

In this study, the carbon footprint analyses were done to identify the energy use and carbon emission in the treated water production. In particular, Scope 1, 2 and 3 are applied at districts handled by the water utility company. In this study, the amount of raw water used to produce water supply are used as a baseline for carbon calculation. The scope for the study is defined in Section 4.1. Fig. 1 illustrates the total carbon emission by district from 2012 to 2014.

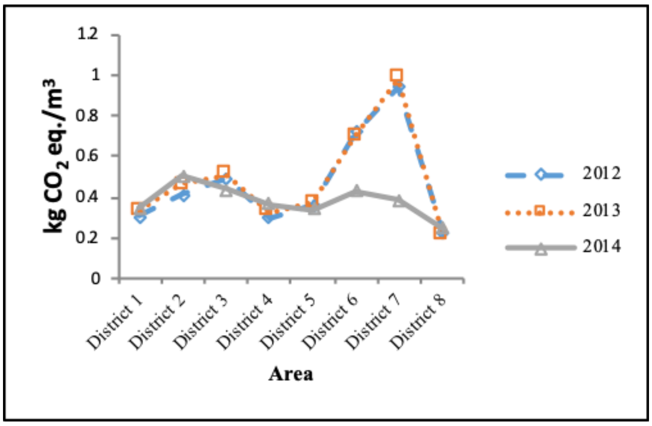

Fig. 1. Carbon emissions by district for Water Supply Production from 2012 to 2014

In summary, in 2012, District 7 has the highest carbon emissions with 0.9437 kg CO_2 eqv /m^3 followed by District 6 with 0.7202 kg CO_2 eqv /m^3. Similar trend is observed in 2013. In 2014, significant reduction was observed in District 7 with 0.3878 kg CO_2 eqv /m^3 and District 6 with 0.4297 kg CO_2 eqv /m^3. This indicates that, the water utility company has managed to implement energy management strategies strongly to cut down vitality usage. In depth study in District 7 which owns the highest portion of carbon emission of all districts in 2012 and 2013 has shown significant cutting in carbon emission due to increasing volume of raw water treated with minimal energy usage which literally cut down the carbon footprint reading in 2014. Based on the outcome, the company can identify the issues that significantly contribute to carbon emission as well as preparing a carbon mitigation plan for future policy set up.

B. Lesson Learned from Carbon Footprint Assessment

1) *Energy Efficiency*

A huge amount of energy is consumed in water supply production with consideration of its operating almost throughout the year. The high carbon emission ratio with raw water uptake (Fig. 1) can signify the huge amount of energy used to produce water supply. This is justified by electricity consumption percentage throughout the whole water supply production which is within 83% to 88%. This is not including other energy use such as petrol and diesel in fleet vehicle and diesel for electricity generation. Increase in energy efficiency in the system not only reduces the energy consumption, but allows the company to produce the same amount of treated water with less energy.

There are much potential to improve energy efficiency in water supply production system. These are categorized into three categories (US EPA, 2013) which are 1) equipment upgrade, 2) operational modifications and 3) modifications to facility buildings. In equipment upgrades, the existing equipment such as pumps are replaced with more efficient models. Within operational modifications, reduction on energy consumption is done by process optimization. Operational modifications generally offer higher energy reductions as compared with equipment upgrade as well as low or zero capital investments (U.S. EPA, 2002). Modifications on facility buildings are focusing on equipping the building with energy efficient system such as installing energy efficient air conditioning equipment. As for equipment upgrade, in most wastewater area operation, commonly, pumping activity is the largest energy consumer (US EPA, 2013).An ill-maintained water pump and other equipment significantly consume more energy compared to well-maintained equipment. As shown in District 6 (Fig. 1), the mitigation measures which include replacing the existing pump and good maintenance record successfully cut down the carbon generation over the years into almost more than half compared to previous year. Report by US EPA (2012) indicates that installing an energy-efficient equipment will require less maintenance compared to older equipment due to longer service life. However in recent operation, maintenance of existing equipment is more favourable due to capital investment involved in replacing new equipments.

Operational modifications can be seen in a broader view. It can be applied through all the water production operation including indirect energy use such as staff transportation. In depth study within scope 3 activities has shown the carbon emission or indirect energy use for staff commuting contributes 39% to 54% of carbon emission for year 2012 to 2014. The petrol use in staff commuting can be reduced by providing residence within the plant area. The percentage is followed with chemical usage at WTP which covers from 44.75% to 59.94% from 2012 to 2014. Lee, 2011 indicated that carbon footprint evaluation of a product across the supply chain is crucial for companies to decrease their carbon emissions. In water utility company, the carbon footprint information on chemical

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supplier is crucial in helping companies to make strategic decisions in terms of carbon footprint in supply chain management.

In terms of building modifications, retrofitting on facility buildings ultimately relies on capital (Buzzeli, 2009). Harvard University has developed the Harvard Green Building Standards to set a baseline towards green building scheme (Harvard University, 2014). The standard identifies an essential component in design and process requirement in moving towards sustainability in building facility. Six categories, based on project tiers (Tier 1, Tier 2A, Tier 2B, Tier 2C, Tier 3 and Tier 4) are developed based on magnitude of change needed on the building facility as well as capital investment involved. The scope in Tier 1 involves new building or major renovation, while Tier 2 incorporates partial renovation and lower requirement which is partial improvement in building interior such as replacing the old lighting system with energy efficient lighting system. Tier 2 is further separated based on amount of investment needed. Tier 3 involves renovations on system only such as lighting replacement and control upgrades. While requirement in Tier 4 is lowest which only involves renovation of finishes and furnishings that have no or limited energy and GHG impact. Within the utility company, Tier 2 project in the main administration office involving centralised air conditioning and LED lighting replacement has significantly reduced the electricity consumption.

2) Water Quality Issue

Water in catchment area is crucial as a supplier for water supply production. Changes in water quality may affect the amount of water intake process and water treatment operation (Santana et al. 2014). This also indirectly influences the associated direct energy or embodied energy use within the WTP. A study by Santana et al. 2014 has indicated that changes in water intake quality have increased 14.5% of the total operational embodied energy. The main cause of higher energy use is due to higher chemical dosages to overcome the reduced intake water quality. In the case study, changes of water quality in catchment area occur mainly due to sewage and run off fertilizer contamination. Commonly in the case study area, WTP will try to overcome this intake water quality reduction by optimising chemical dosage and operation modification. When effluent quality does not meet the standard water supply quality, water supply distribution through pipeline will stop to the consumer. In terms of direct energy use, significant reduction was observed due to limited WTP operation. However, indirect energy may significantly increase due to water distribution to consumer through water tank trailer.

3) Effect of Consumption

There are many factors that contributed to water demand such as country income (UNESCO, 2003), population density, consolation factor (Hof and Schmitt, 2011), water tariff (Rogers et al. 2002) and public education (Nieswiadomy, 1992). A report by UNESCO, 2003 indicated that water consumption is mostly used in industrial area while low and middle income countries are using water more for agricultural use. Population density will directly increase the water demands, however the consolation factor which is described by consumer behaviour has been found to significantly contribute to water consumption (Hof and Schmitt, 2011 and Domene and Sauri, 2006). Increase in water tariff can significantly reduce the water demands but very difficult to apply due to economic constraint. Public education or awareness on water conservation can reduce water consumption through efficient use of water by consumer. In the case study, the increasing of WTP number in 2014 has directly increased the energy consumption and total carbon emission for the water utility company. However, with carbon intensity being reduced due to high water supply production. This indicates that, WTP efficiency is crucial in balancing the energy use in the rising water production.

4) Effect of Energy Source

Energy is crucial in any operation specifically WTP operation. By the fact of its importance, 65% of greenhouse house gas emissions in the world are due to energy consumption and production (IEA, 2008). The energy distribution usually consists of different energy sources which are fossil fuel such as heavy oil, natural gas and coal; and renewable energy such as hydropower. Report by Baldwin, 2006 indicated that fossil fuel such as coal is the highest carbon contributor (766 gCO_2/kwh to 1,070 gCO_2/kwh) as compared to renewable energy such as energy from biomass (25 gCO_2/kwh to 237 gCO_2/kwh). This illustrates that; fossil fuel is the major contributor in energy production. Thus the higher percentage of fossil fuel in energy distribution or energy mix, the higher carbon emission is expected. Furthermore the energy source from waste recovery such as energy from waste incinerator plants has shown potential for primary energy source (Pavlas and Touš 2009). Marero (2010) prediction on energy model has indicated that shifting to renewable energy in energy mix would significantly reduce the carbon emissions. However, shifting to other energy sources is not an easy move. It will need extensive study, intervention policy and economic ability.

5) The Important of Carbon Footprint in Water-Energy Nexus

Water-energy nexus is a concept where the relation of energy for water and water for energy is highlighted (Perrone et al. 2011). In this paper, the relation of energy for water is emphasized. The concept of water-energy nexus alone however can be misleading due to exclusion of indirect and embodied energy involved in the water production. Hence, the total energy use remains unclear and deserves further examination. Carbon footprint methodology which adopts life cycle assessment (LCA) procedure has been found useful in identifying the total energy involved in water production. ISO 14040 standards which is commonly used in LCA and carbon footprint study comprehensively assesses both direct and indirect activities within water production. Thus it is crucial to underline the concept based on life cycle perspective.

In order to examine the direct, indirect and embodied energy within the water supply production, total energy involved for the water production for the water utility company were identified and analyzed for year 2012. A comparison of the total direct and indirect energy is shown in Fig. 2 based on 7 district administered by the water utility company for year 2012. The direct energy includes purchased electricity, diesel for electricity generation and fleet vehicle (diesel and petrol); while indirect and embodied energy consist of energy embodied in chemical usage, staff commuting (petrol) and chemical transportation (diesel). The embodied energy in chemicals consumption were measured in Gabi 6 software based on total energy use in the chemical production (Frischknecht et al. 2005). Three chemicals which are chlorine, soda ash and caustic soda where included, while others are excluded due to data limitation. It can be observed that on average, the direct energy is higher compared to indirect energy except in District 6 and 7.

In-depth study on District 6 and 7 has found that, the high indirect energy consumption comes from staff commuting. This indicates that the distance within the staff residential and working area is an important element in minimizing the energy use to produce water. Even the staff residential area is not fully company jurisdiction, the company can encourage the staff to stay nearer to the working area by providing benefits or incentive. De Schepper et al. 2014 have shown another potential in cost-efficient emission reduction from transportation sector where grid powered battery electric vehicles (BEVs) has lower carbon emission as compared to petrol fuelled vehicles. However, few considerations should be made with the limitations of BEVs such as limited driving range, long charging times. Embodied energy in chemical use for water treatment consumes 8% to 17% of total energy production. This result highlights that the indirect and embodied energy may not be significant in certain area but the energy use may be ambiguous when these elements are excluded.

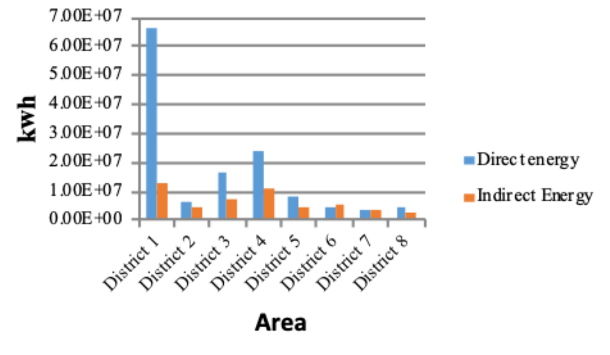

Fig. 2. Energy use by districts for water supply production for year 2012

Besides comprehensively addressing both direct and indirect activities in water production, the method is crucial in identifying the environmental impact associated with water production. Huge amounts of energy are consumed in conventional water production operation and even more when ground water pumping and desalination process is included. These amounts of energy significantly contribute to environmental impact especially climate change. Failure in addressing the issue may limit the understanding on the water-energy nexus.

IV. CONCLUSIONS

Energy is consumed to produce water and water is consumed to produce energy. This relation is simplified as water-energy nexus. In water production, huge amounts of energy are consumed throughout the water production starting from pumping activities from water intake until water distribution to consumer. The amount of energy needed to produce water depends on geographical, physical and technological factor. Energy production and consumption is known as the major factors of carbon emission that contributes to climate change. In evaluating the carbon emission from water production, carbon footprint has been found practical in assessing the whole water production system operation. The mitigation steps in reducing energy consumption in water production can significantly reduce the climate change impacts. In the case study, it can be done by replacing an older pump in WTP and pump house with new energy efficient pump and good maintenance records. This includes improvement in the administration office by installing efficient energy lighting and heating or cooling system.

In term of water-energy relations, the concept alone cannot give us the full understanding of this relation. This is due to exclusion of indirect and embodied energy in the water-energy nexus study, which is involved in the water production system. The study has shown that by relying on water-energy nexus alone may mislead the result as indirect energy has been found to be significant in certain area. The indirect energy use such as for staff commuting is found to be critical elements in the water productions. The result answering an important question how carbon footprint helps to provide understands on the water-energy-nexus issues within water utility company. The total energy use and carbon emission in water production system is highlight in which is crucial for future resource policy.

The others important lessons from carbon footprint assessment on water utility company are the effect of energy efficiency, water quality issue, effect of water consumption and effect of energy source to the carbon emission. Energy efficiency within water production system can be achieved through 1) equipment upgrade, 2) operational modifications and 3) modifications to facility buildings. In term of water quality, changes of water quality in catchment area will cause of higher energy use due to higher chemical dosages to overcome the reduced intake water quality. When effluent water quality does not meet the standard water supply quality, indirect energy may significantly increase due to water distribution to consumer through water tank trailer. The increase of water consumption will directly increase the energy

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consumption and total carbon emission for the water utility company. However, low carbon intensity indicates that, WTP efficiency is increase by balancing the energy use in the rising water production. The energy source for electricity production can effect through the composition of fuel in electricity mix. The higher percentage of fossil fuel in energy distribution or energy mix, the higher carbon emission is expected.

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