A Framework to Measure Water and Energy Footprint at Demand Side

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Abstract

There is no doubt that water is an essential part of human life. Unfortunately it is often neglected and is not managed well. Flood and drought in many areas in Indonesia are examples of serious deficiency in water management. Urban areas, in particular, have serious threats in water sustainability due to the dramatic increase of population. Regrettably, there is little knowledge on water infrastructure in macro to micro level, peopleỗs attitude toward water, stakeholdersô inter-connectivity in water management, institutional capabilities in managing water management, and appropriate technologies to use water wisely in different settings. At the demand side alone, complexities can be found in water usage infrastructure. A pilot survey found that more than 65% household in Surabaya installed water pump to access clean water. This means that the total environmental impact of water usage has to incorporate energy footprint in the equation, in addition to the water footprint itself. This paper will present a developed framework to portray the tangle between water and energy at the demand side and how to measure its environmental impact. Benefits of its implementation and potential future work will be discussed and outlined.

Keywords: *Water Footprint, Energy Footprint, Framework*

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1. INTRODUCTION

Indonesia is considered as the biggest archipelago country in the world by inheriting more than 13,466 islands[1]. Around 63% of its surface is ocean which is the abundant water resource. It has 76 rivers with the maximum flow rate around 5.226 m^3/second. Infrastructure Reform Sector Development Program (IRSDP), BAPPENAS stated that Indonesia has 3.22 trillion m^3 water resources per year to be further proceed become consumable clean water[1]. However, these high diversity and amount of water resources could not secure the sustainability of clean water provision to Indonesia citizen.

Water-related disasters regretfully often happen in Indonesia including drought and flood. In 2015, extreme drought happened in 4,913 sub district in Java, North Sulawesi, West Nusa Tenggara and East Nusa Tenggara as shown in Fig. 1[2]. In August 2015 (shown in Fig. 2), an extreme drought not only happened in rural areas but also in cities where water provision of citizen is handled by Clean Water Enterprise (PDAM)[2]. This case clearly demonstrated that there were serious problems in Indonesian water management while the available raw water sources are more than sufficient.

Another miserable water related disaster commonly happen in Indonesia is flood. Flood happens almost thoroughly in raining season, particularly in urban area. Jakarta, the capital city, is one of the Indonesia cities which experiences regular flood every year. There are very limited catchment areas to harvest rain water in Indonesia. This poor water management have caused lot of amount of potential and valuable rain water is directly dumped to ocean. Fig. 3 shows that in 2015, there were 1,681 disaster events in Indonesia and flood, landslide as well as tornado[3].

All these miserable disasters could not be separated from the impact of rapid and continuous increasing number of population, particularly in urban area. High population growth has influenced the quality and quantity of natural resources including water. When the awareness to maintain the sustainable environment is still neglected, quality of life will start to decline. Research, investment and policy establishment have been focused to increase the quality of life in various sectors including health, trade, energy and others. However, little has been done in water management, for instance on how water is managed to sustainably meet human needs, on how community should response to water pollution and deficiency, and to integrate water related infrastructure to energy and other infrastructure.

The concept of water footprint has been introduced as one of the strategies to measure the amount of water consumption. At the end it will be used as the basis indicator showing the sustainable use of water. If the value of water footprint is too high, it indicates the unsustainable use of water that have to be addressed immediately.

In Indonesia the clean water provision undoubtedly relies on water pump generated by electricity. Hence, this study aims to investigate and develop close connectivity between water and energy which constructs environmental impact.

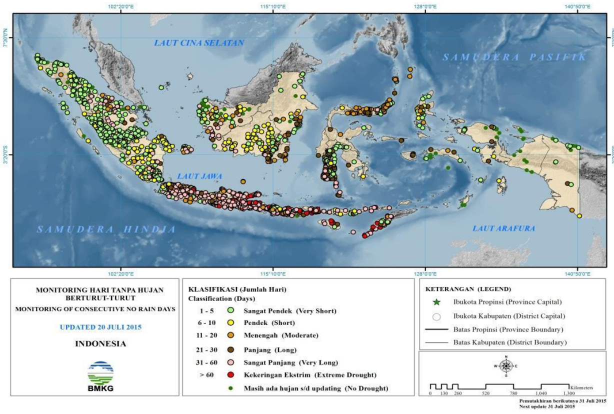

Fig. 1. Locations of Extreme Drought in Indonesia in 2015[2]

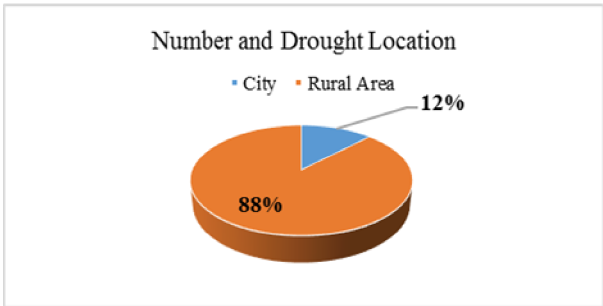

Fig. 2. Number and location of drought in Indonesia[2]

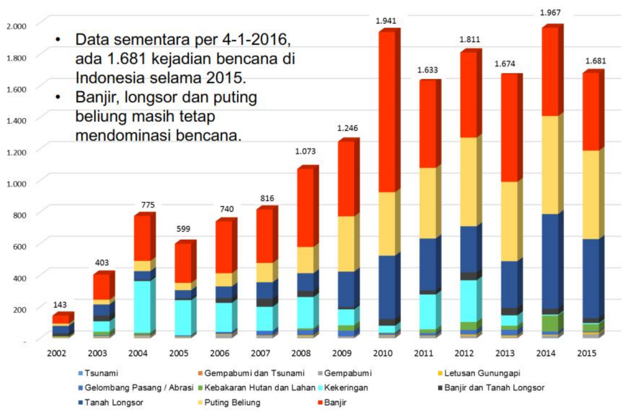

Fig. 3. Trend of disasters in Indonesia from 2002-2015[3]

2. WATER FOOTPRINT

Water is no doubt an essential part of human life. It is needed in various aspects of human life not only for direct usage for instance drinking, cooking, shower, but also including to produce goods and services which being consumed by human. As continuous decreasing of availability and sustainability of clean water, particularly which are affected by lack of human awareness to maintain environment, the concept of water footprint have been introduced by Hoekstra in 2002[4]. The water footprint aims to measure the amount of water being used and consumed along the way of its supply chain [5]. It is a comprehensive indicator of water usage which consider direct use of water as well as indirect use of water in specified geographically and temporally which defined as a total volume[5]. It is usually measured in cubic meters per ton of production, per unit of currency, per hectare of cropland or in other functional units. Understanding the water footprint is essentially very important as warning signal on how much and from where the water is taken later on being consumed. It could portray the consequences of certain degree of water consumption of the whole water system. It helps to analyze how human activities as well as particular processes to produce a product are directly connected to the water pollution and deficiency.

The basic concept of water footprint is not only measure the water withdrawal from water sources but also include the water pollution. Hence, water footprint has three main components i.e. green water footprint, blue water footprint and grey water footprint. Blue water refers to the surface or groundwater resources which are available both in ground surface water body and water catchment area. The blue water footprint measures the losses of water of those water resources along the supply chain of a product or activity. Losses is defined as condition when the water is incorporated in a product, evaporates or flows to another catchment area, for instance to the sea[6]. The green water footprints has similar definition with the blue water footprint. The main distinction comes from the source of water itself, which the water resource is stored in the root zone of the soil. Whereas, the grey water footprints refers to pollution. It relates to the amount of required freshwater to assimilate the degree of pollutants to meet specific water quality standards[6]. Hence, water footprint of consumers or produces is the sum of all direct water use and indirect water use which include green, blue and grey water footprints as shown in Fig.4.

The water footprint concept has been implemented by UNESCO-IHE to measure the national water footprint around the globe[8]. The research has been done in 2011 by UNESCO-IHE gave a surprisingly result. The study showed that in USA average water footprint per capita is 2,842 m^3/year.

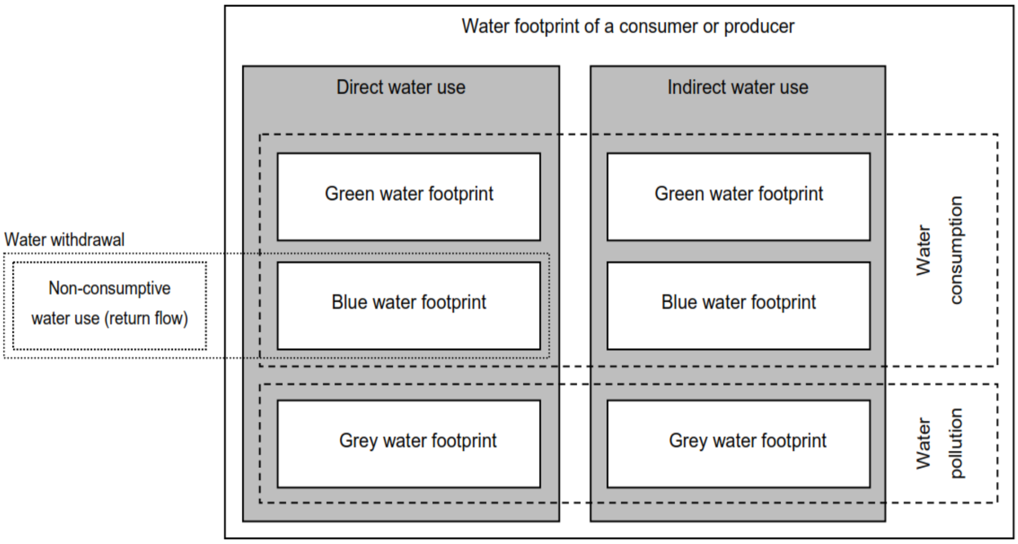

Fig. 4. Water Footprint Concept[6]

It is equal to 7,786 litter of water per capita per day. This amount is sufficient to fill an Olympic swimming pool[7]. This study also explained that in period of 1996-2005 the global water footprint was 9,087 Giga m^3/year which consisted of 74% green, 11% blue and 15% grey water footprint. Fig.5. shows the comparison of water footprint among several nations.

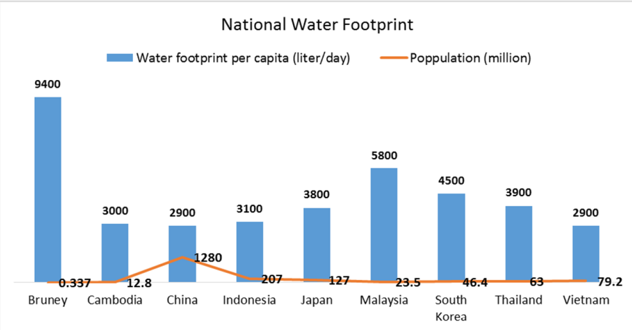

Fig. 5. National Water Footprint[7,8]

From Fig.5 it can be concluded China has better water saving compare to Indonesia since even the number of population is 6 times compared to Indonesia, but its water footprint is 200 litter more efficient that Indonesia.

3. ENERGY DEPENDENCY IN WATER PROVISION

In metropolitan cities or urban areas, clean water is mainly produced and supplied by Clean Water Enterprise, in Indonesian case, the enterprise is called *Perusahaan Daerah Air Minum* (PDAM). There are very limited direct access to ground water particularly in household area. It is caused by several factors, mostly because of the significant lack of reserve clean ground water as well as land subsidence. As response to that condition, the dependency of household to water provided by Clean Water Enterprise is very high, for instance in Surabaya 84% of household is the permanent customer of PDAM[9] which is presented in Fig.6. Along with this fact, another potential environmental problem arise i.e. water provision by PDAM service is extremely rely on energy. In Indonesian case, energy is only defined as electrical energy which is generated using coal and distributed by electricity grid. Electrical energy is used to pump raw water to clean water installment as well as to distribute the clean water to all customers. Fig. 7. shows how clean water installment indeed rely on electricity to be run every day.

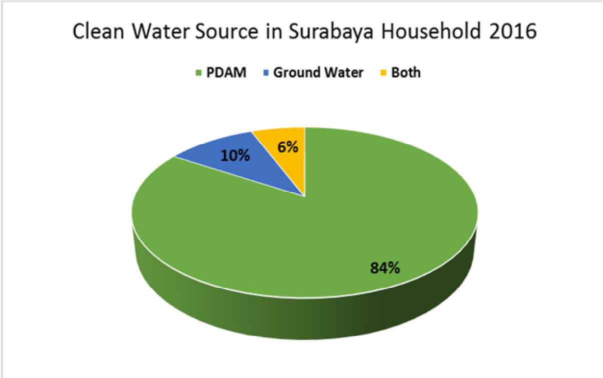

Fig. 6. Clean water sources in Surabaya household[9]

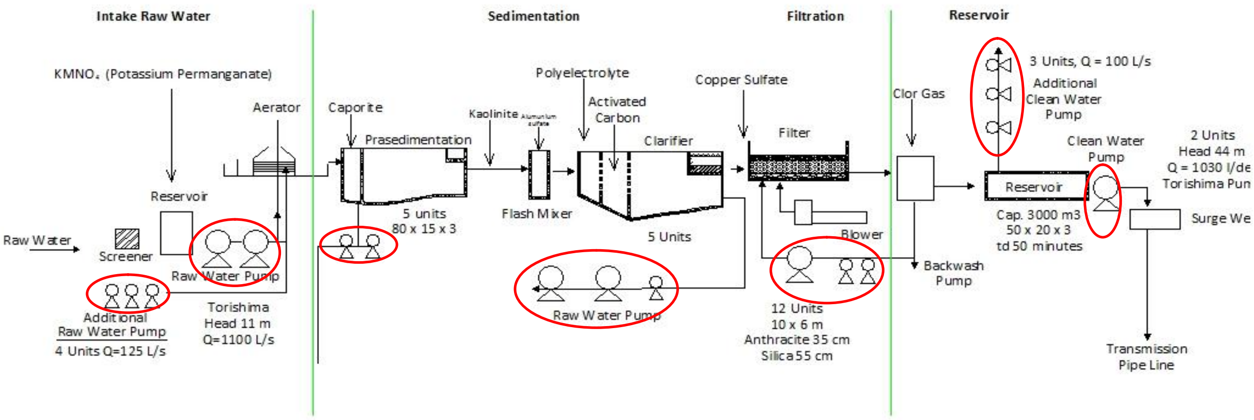

Fig. 7. PDAM Karang Pilang installment[10]

From the Fig.7, it is clear that one unit clean water installment owned by PDAM utilizes several types and numbers of water pumps. If the electricity goes off, the water production will completely stud down as well. In addition, the energy dependency in water provision in Indonesia is also happened in household scale. A pilot survey conducted showed that 65% of household in Surabaya utilize a household water pump to ensure the stability of water pressure so the water will continuously and smoothly flow to their house[9]. Fig. 8 and Fig. 9 show two possible scenarios how water pump being used in Indonesian household.

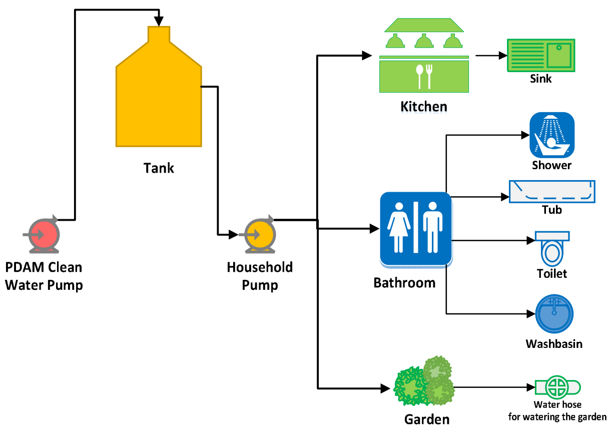

Fig. 8. Water Pump Installment in Household Scenario A

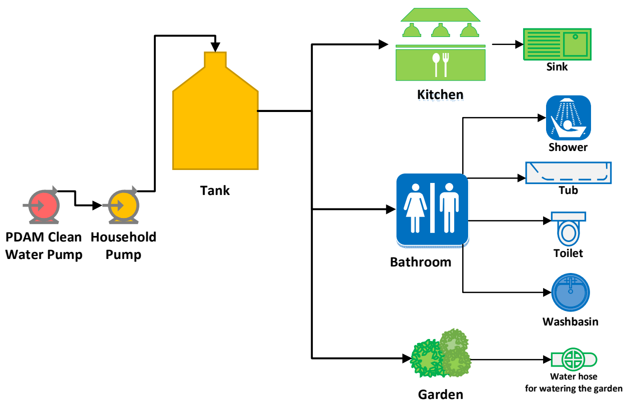

Fig. 9. Water Pump Installment in Household Scenario B

4. THE PROPOSED FRAMEWORK TO MEASURE ENERGY-WATER FOOTPRINT

As explained in the introduction section, the availability of clean water to support human being becomes very crucial. In this context, the measurement of water footprint becomes important. Water footprint is basically a measure of human consumption as well as human impacts on clean water system and the environment as a whole. By measuring the water footprint of nation, city, community, household, individual, and a particular geographical area, people will be able to recognize and understand problems like water shortages and pollution more clearly[6]. Ultimately people could address those problems more thoroughly and provide more sustainable solutions.

Literature suggest several typologies used in water footprint measurement such as:

- Direct and indirect use of water
- Consumption and pollution, or intake and outflow of water
- Green, blue, and grey water

In the reference, direct use of water includes the use of water for drinking, cooking, and washing; while indirect use or virtual water includes water for producing things such as food, paper, cotton clothes, and other goods or commodities. Consumption of water reflects water intake either direct or indirect; whereas pollution reflects water discharged from any human activities. For the classification of water, there are many literatures discussing these classification. However, in a simple definition, green water can be defined as water that is stored in soil, while blue water refers to surface water, and grey water represents polluted water. Green and blue water are categorized as sources of water. The schematic structure of water footprint incorporating those typologies is depicted in Fig. 4.

Observing the condition explained in previous section, it is intended to introduce a new typology into the framework, which is the electricity dependency in water provision. In rural area, for instance village and forest, with water spring or water stream, people can directly access water without electricity. People can build a piping system to get water and use gravitation or simple hydrodynamic installation. However, in urban area, water provision depends heavily to the electricity as shown in Fig. 7, Fig. 8 and Fig. 9. In Surabaya City case, in particular, the high dependency to electricity occurs in both supply and demand side.

Therefore by incorporating energy into the water footprint measurement, more insight on how unsustainable use of water can be understood. The framework later could be used as an analytical tool to understand how the selection of water related infrastructure and water related activities relate to the total environmental impact.

To explain the concept clearly, the framework development adopts the steps in Life Cycle Assessment (LCA), i.e. goals and scope, inventory analysis, impact assessment, and interpretation. At this stage, focus was put on the first two steps of LCA. Each step is explained below.

4.1. Goals and Scope

The goal of the proposed framework is to involve electricity into the water footprint measurement. The proposed framework is expected to provide better understanding on the interconnectivity between water and energy thus can better measure the sustainability of water use towards the total environmental impact.

Graphically, the introduction of energy into the scheme can be seen in Fig. 10. Energy has relationship to all other categories, i.e. direct and indirect use, intake and outflow, and three types of water. For example for direct use for washing, people can take water directly from river, lake, or basin, or people must use electricity pump to get the water out. Indirectly, people can grow crops using rainfall or use piping with electricity pump to water the crops.

To illustrate the concept in a simple and easily understandable context, the proposed framework is firstly deployed for:

- Household
- Water consumption
- Demand side
- Direct use
- Blue water

Household is usually family or group of people who live together in a house. Each house has a particular infrastructure of water intake as describe in the previous section. Therefore the selection of household as the unit of analysis in the proposed framework is appropriate.
To provide water for household, there are two alternatives. Firstly, household access water by themselves, for example taking water directly from spring water, river, lake, or well. It usually happens in rural area. In urban, in contrast, household get water from services provided by the government or clean water enterprise. The processing of water to be ready to use, as shown in Fig. 7, is not included in the current proposed model. Model will focus on the demand side of the household. The discharge of the water is also not included in the model.

Furthermore, the use of water in the household consists of direct and indirect uses. The direct use can be classified into personal use, support function, and cooking and drinking. For personal use, there are some activities like shower, toilet, and washing. For support, activities like gardening, car washing, and cleaning are included. For direct use the type of water used is mainly blue water.

The illustration of the scope and the deployment of the activities related to the scope in a household are shown in Fig. 11. Using this model, calculation of the total environmental impact can be formulated. Later, the model can be enhanced into larger scope.

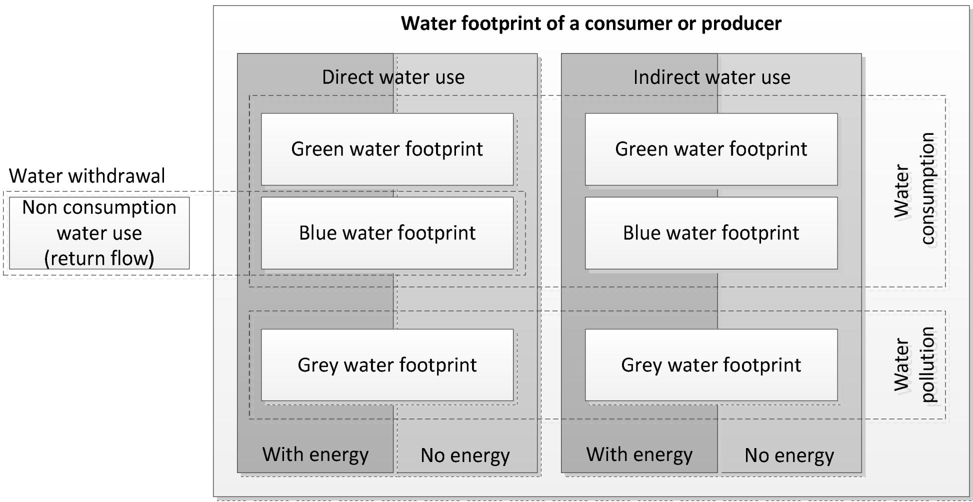

Fig. 10. Energy in water footprint measurement scheme

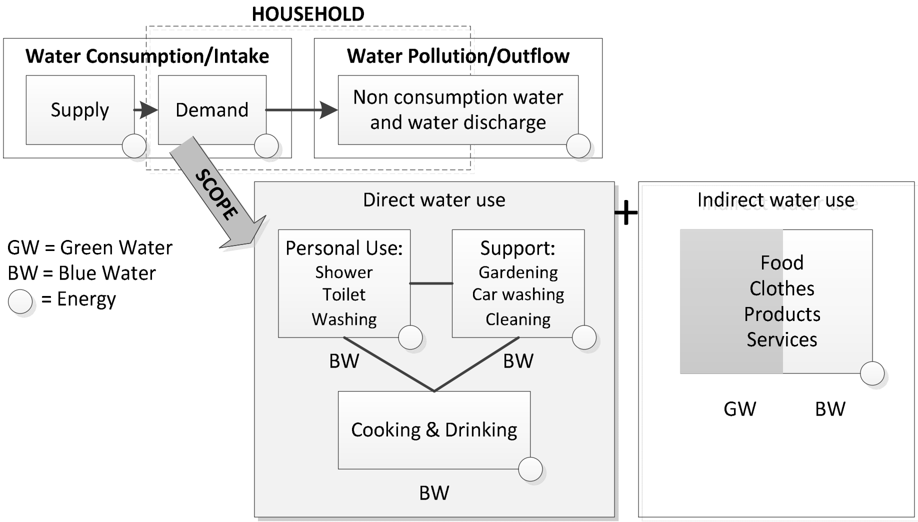

Fig. 11. The scope of the proposed framework

4.2. Inventory analysis

For each activities data collection should be done for each individual in the household. Two main data that should be collected are the water use and the electricity use to get the water. For data collection, a form has been developed in excel to ease the calculation processes later on. The example of that form is shown in Table 1. For household analysis, the data should be collected daily up to yearly. The data then can be used to calculate the water footprint for community in a particular area (group of some households), district, and city.

Table 1. Excel form for data collection of household water usage

Household No:		Number of bathroom:		Number of toilet:		Type of washing:	1. Manual
Number of people in the household:		Type of bathroom:	1. Tank	Type of toilet:	1. Squat toilet		2. Washing maching
Type of rese	1. Underground		2. Shower		2. Toilet		2a. Top loader
	2. Roof		3. Bath-tub	Type of flushing	1. Single flash		2b. Front loader
Number of pum installed:		Type of Shower:			2. Dual flash	Type of dryer:	1. Manual
Power:		Type of drinking water used:		Equipment used in garden watering:			2. Dryer machine
Average use daily (hours):		1. Boiled from tap		1. Manual			2a. Integrated with the washing machine
Operation ti	1. Start	2. Branded mineral water		2. Sprayer			2b. Separated
	2. End	3. Not branded mineral water					
		4. Advanced processing of water					

	Personal Use							Support Activities						Cooking	Drinking	Total water use per week	Total water use per month	Total water use per year
	Shower		Toilet		Washing			Cleaning		Garden watering		Washing Cars						
Household No:	Frequency per day	Water use per activity (l)	Frequency per day	Water use per activity (l)	Frequency per week	Load (kg or rating)	Water use per load category per activity (l)	Frequency per week	Water use per activity (l)	Frequency per week	Water use per activity (l)	Frequency per week	Water use per activity (l)	Average water used (l)	Average water taken (l)			
1	$Freq_s$	Vol_s	$Freq_t$	Vol_t	$Freq_w$	$Load_w$	Vol_w	$Freq_c$	Vol_c	$Freq_{gw}$	Vol_{gw}	$Freq_{wc}$	Vol_{wc}	Vol_c	Vol_d	$T.Vol_w$	$T.Vol_m$	$T.Vol_y$
...																		
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It is important to realize that sometimes in particular areas, particular ethnic group, particular religion, and other distinctive community, the attitude towards water and the pattern of water use are very much different. For example, for Muslim people, they use water extensively for wudhu (preparation for *sholat* or prayer). Thus the water footprint may increase significantly.

4.3. Impact assessment

Based on the collected data, the calculation of water footprint can be undertaken. Basically water footprint of a person is the sum of water footprints of all activities done by the person and water footprints of all products consumed by the person. In other word, it is the sum of direct and indirect use of water by an individual. Mathematically, the formula of water footprint (WF) calculation is shown in Equation 1.

$$WF_{individual} = WF_{individual,direct} + WF_{individual,indirect}\ [\frac{volume}{ind.time}] \quad (1)$$

Following the same pattern, water footprint of household can be calculated as following:

$$WF_{household} = WF_{PU} + WF_{SA} + WF_{DC} \quad [\frac{volume}{household.time}] \quad (2)$$

$$WF_{PU} = \sum_{i=1}^{n} WF_{S_i} + \sum_{i=1}^{n} WF_{T_i} + \sum_{i=1}^{n} WF_{W_i} \quad (3)$$

$$WF_{SA} = WF_{Cl} + WF_{G} + WF_{W-C} \quad (4)$$

$$WF_{DC} = \sum_{i=1}^{n} WF_{D_i} + \sum_{i=1}^{n} WF_{C_i} \quad (5)$$

$$WF_{S} = WF_{T} = \frac{freq}{day} x \frac{day}{month} x \frac{vol}{activity} \quad (6)$$

$$WF_{D} = WF_{C} = \frac{vol}{day} x \frac{day}{month} \quad (7)$$

$$WF_{Cl} = WF_{G} = WF_{W-C} = \frac{freq}{week} x \frac{week}{month} x \frac{vol}{activity} \quad (8)$$

Where:

- PU is personal use, SA is supporting activity, and DC is drinking and cooking
- S represents shower, T represents toilet usage, and W represents washing
- Cl represents cleaning, G represents garden watering, and W-C represents car washing
- DC represents drinking and cooking, while D and C stand for drinking and cooking respectively
- i represents each household member with the maximum number of n

From the above equations, it can be seen that WF_{PU} and WF_{DC} are accumulation of individual WF_{PU} and WF_{DC}, while WF_{SA} is not an accumulation of individual WF but the WF of the whole household. The time window in this analysis can be selected from daily to yearly. Accordingly the multiplication will follow the selected time window.

The above calculations do not include the energy that involves in the water provision yet. Consequently, the WF of people who live in rural area and urban area that have different dependency to electricity to get water will not be reflected by the calculation results. If, for example, households in urban area have the same WF to households in rural area, there will be no analysis to reduce the water consumption due to its interconnected to electricity usage because there is no indication what so ever in the calculation. In order to distinguish the energy reliant water and energy self-reliant water, a new index is proposed. The index is written as:

$$[I_{WF} : I_{EFWP}] \quad (9)$$

Where:

- I_{WF} expresses the index of Water Footprint. This index is computed based on the concept of normalization, which is:

$$I_{WF} = \frac{WF_{Actual}}{WF_{Target}} \quad (10)$$

  WF_{Actual} is the value of Water Footprint based on current calculation. In the case of household, it is the value of $WF_{Household}$. Furthermore, WF_{Target} is the value of WF that used as the reference point. For example, the standard of WF for household is 300 liter/day, thus the value of WF_{Target} equals to 300 liter/day. If the $WF_{Household}$ resulted from the calculation is 400 liter/day, then the value of I_{WF} is 1.33.

- I_{EFWP} expresses the index of Energy Footprint for Water Provision. Similar to the computation of I_{WF}, I_{EFWP} is computed based on the concept of normalization, which is:

$$I_{EFWP} = \frac{EFWP_{Actual}}{EFWP_{Target}} \quad (11)$$

$EFWP_{Actual}$ is Energy Footprint for Water Provision. It is a measure of energy needed to provide water for users, thus is expressed in [energy/volume]. When energy used in the household is electricity, then EFWP is measured in [kwh/volume].

In urban area particularly in the modern society like nowadays, generally there are several steps to provide water for household. Those steps can be viewed in Fig. 12.

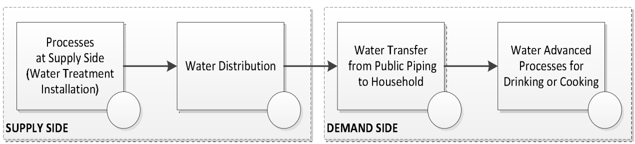

Fig. 12. Energy in water supply chain

EFWP basically measures total energy required to provide certain volume of water for users. Since the focus in this paper is only at the demand side, the value of EFWP in a household can be calculated based on this formula:

$$EFWP_{Household} = EFWP_{Transfer} + EFWP_{Adv.processing} \quad (12)$$

$$EFWP_{Transfer} = \left[watt_{Pump}\, x\, \frac{operation\ time}{day}\right] : 1000 \quad [kwh] \quad (13)$$

$$Watt_{pump} = volts\ x\ amps \quad (14)$$

$$EFWP_{Adv.processing} = \left[watt_{devices}\, x\, \frac{operation\ time}{day}\right] : 1000 \quad (15)$$

$EFWP_{Transfer}$ relates to WF_{PU} and WF_{SA}, while $EFWP_{Adv.processing}$ usually related to WF_{DC}. For example, if there is an electric pump (1,100 watts) installed in a household to transfer water from public piping to the bath room and it works averagely 10 hours a day to fulfill the water need for the whole household, thus the value of $EFWP_{Household}$ is 11 kwh per day.

Furthermore, $EFWP_{Target}$ is the value of EFWP that used as the reference point. For example, the standard of EFWP for household is 10 kwh/day, thus the value of $EFWP_{Target}$ equals to 10 kwh/day. In this illustration, the value of I_{EFWP} is 1.1.

4.4. Interpretation

The index yielded from the calculation, [I_{WF} : I_{EFWP}], can then be interpreted as follows:

- First, the first index, I_{WF}, shows how efficient the water use of a household or a group of households compared to the standard. There are three possible values of IWF and its interpretation i.e:
    - $I_{WF} < 1$ means that the water use is efficient
    - $I_{WF} = 1$ means that the water use is normal
    - $I_{WF} > 1$ means that the water use is not efficient and above the standard

- Second, the second index, I_{EFWP}, shows how efficient the energy footprint in providing water in a household or a group of households compared to the standard. Similar to the first index, there are three possible values of I_{EFWP} and its interpretation i.e:
    - $I_{EFWP} < 1$ means that the energy used in water provision is efficient
    - $I_{EFWP} = 1$ means that the energy used is normal
    - $I_{EFWP} > 1$ means that the energy used is not efficient and above the standard
- Third, the interaction of both indexes has to be analyzed. There are three sets of possible combination i.e:

Table 2. The possible combinations of I_{WF} and I_{EFW} index

Water Footprint	Energy Footprint	Interpretation
$I_{WF} < 1$	$I_{EFWP} < 1$	Both water and energy footprints are efficient, an ideal condition to be maintained.
	$I_{EFWP} = 1$	Water footprint is efficient, while energy footprint is normal, an ideal condition to be maintained.
	$I_{EFWP} > 1$	Water footprint is efficient but at the high energy dependency. Reduction of energy through infrastructure evaluation and improvement is suggested.
$I_{WF} = 1$	$I_{EFWP} < 1$	Water footprint is normal at the high efficiency of energy, an ideal condition to be maintained.
	$I_{EFWP} = 1$	Both water and energy footprints are normal, an ideal condition to be maintained.
	$I_{EFWP} > 1$	Water footprint is normal but at the high energy dependency. Reduction of energy through infrastructure evaluation and improvement is suggested.
$I_{WF} > 1$	$I_{EFWP} < 1$	Water footprint is not efficient but energy self-reliant. Reduction of water use should be done through life style changes and infrastructure improvement.
	$I_{EFWP} = 1$	Water footprint is not efficient at the normal level of energy footprint. Reduction of water use should be done through life style changes and infrastructure improvement.
	$I_{EFWP} > 1$	Both water and energy footprints are not efficient. An urgent condition to be improved through multi-aspects evaluation and improvement.

5. CONCLUSIONS AND FUTURE WORKS

In this paper an introduction of energy dependency in water provision has been explained and inserted into the framework of water footprint typology. A new index representing the interaction between water and energy footprint has been developed. By following the steps in LCA, set of equations to compute water and energy footprint at the demand side of a household has been presented along with the interpretation.

Having the new developed index, it is possible to distinguish and to more deeply analyze two values of water footprint with different level of energy reliant. More effort have to be made to reduce the footprint when there is a significant dependency to energy in water provision. Because water is fundamental in supporting human life, efforts should be made towards the accomplishment of energy self-reliant water.

More exercises are required to enhance the applicability of this framework to a larger scope, for instance business, city, and nation. Incorporating supply side into the calculation will also be required to compute the total energy dependency. In addition, implementation of the framework into more case studies have to be undertaken in the near future.

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