Life Cycle Assessment for Assessing Carbon Footprints of Five Water Supply Systems in Taiwan

Allen H. Hu*, Ching-Yao Huang* and Ching-Wen Fan*

*National Taipei University of Technology, Taiwan, R.O.C., allenhu@ntut.edu.tw

ABSTRACT

This study is designed to calculate the carbon footprints of five water supply systems in Taiwan. Each water supply system has different characteristics in terms of topography, scale, raw water quality, and purification process according to the process life cycle assessment (PLCA) methodology. In addition to PLCA, this study performed an input-output life cycle assessment (IO-LCA) to calculate carbon footprint of product (CFP) of two water supply systems (among the five water supply systems included in this study). The scope of inventory and assessment covers intake, purification, and distribution stages as well as infrastructure and chemicals that are associated with these stages. The carbon footprints are calculated based on the unit water sold (m^3). The discrepancy of the results as well as the advantages and disadvantages of both methods are discussed in the paper. Some recommendations for future studies are also proposed.

Keywords: water supply system, carbon footprinting, input-output life cycle assessment, process life cycle assessment

1 INTRODUCTION

Recent studies indicate that global warming is worsening, greatly affecting our environment. According to the Intergovernmental Committee of Experts on Climate Change (IPCC), average temperature is rising and this would seriously affect our environment [1]. Hence, the reduction of CO_2 emissions is one of the most important issues we need to address to protect our environment. Among our natural resources, water is one of the most vital resources. Water is the new oil and carbon is the currency that drives the water industry to make significant changes by reducing its carbon emissions [2].

Considering life cycle assessment (LCA), a complete, complicated water supply system comprises infrastructure and purification facilities as well as other related processes. The water supply system also contains substantial embedded carbons. Numerous benefits can be obtained from the total carbon footprints in a complete water supply system and the unit carbon footprints of treated water (such as kg CO_2 eq/m^3). Some of these benefits include water supply efficiency and opportunities for reducing carbon emission after a thorough inventory. In addition, the calculation of CFP has become increasingly important for global enterprises. The carbon footprints of public utilities, such as electricity and treated water, are needed to complete CFP. Few studies have been conducted on carbon footprinting of water supply systems. Thus, this study is designed to calculate the carbon footprints of five water supply systems in Taiwan. Each water supply system has different characteristics in terms of topography, scale, raw water quality, and purification process according to the PLCA methodology. In addition to PLCA, this study performed an IO-LCA to calculate CFP of two water supply systems (among the five water supply systems included in this study).

Based on Taiwan Carbon Footprint Calculation Guidance for Products and Services, experience from other countries, extended literature review, and expert consultations, the boundary and scope of carbon footprint calculation of water supply systems was decided [3]. The five water supply systems comprise a traditional purification plant, a purification plant with highly turbid raw water, a multi-process purification plant, an advanced purification plant, and a desalination plant. Currently, five water purification plants with different characteristics are being applied to do inventory and to calculate carbon footprints. The results will be used in the future as estimates and reference materials for Taiwan's carbon footprinting of its water supplies.

2 LITERATURE REVIEW

The concept of the carbon footprint came from the ecological footprint assessment created by Wackernagel [4], which considers humanity's energy and resource throughput and converts these data into area units. The ecological footprint and the carrying capacity can then be directly compared because they are measured using the same units. Carbon footprint can be defined as a measure of the exclusive total amount of carbon dioxide emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product [5]. Thus, reducing energy consumption and carbon emissions entails committed action through sustainable management practices based on a life cycle perspective. The LCA methodology enables the calculation of environmental burdens in a systematic and scientific way by regarding all inputs and outputs of a system [6]. LCA is mainly used for assessing systems and identifying options for improvement and, in some cases, for developing sustainability indicators [7]. It is a systematic tool used in analyzing and assessing environmental impacts, as well as energy use, over the entire life cycle of a product, which generally includes raw material extraction, manufacture, product use, recycling, and final disposal [8][9]. LCA approaches could be categorized as PLCA, I–O LCA and hybrid LCA.

In 2010, the Environmental Protection Administration (EPA) made an announcement about calculating the carbon footprints of Taiwan: “Taiwan Carbon Footprint Calculation Guidance for Products and Services” (Taiwan’s Product Category Rules, Taiwan’s PCR), which established the LCA methods and the reference PAS 2050 in step with the spirit of carbon footprint assessment [10]. Besides, the Global Type III Environmental Product Declarations Network (GEDnet) published “Water Distribution Through Mains, Except Steam and Hot Water PCR Draft”. This document provides PCR for the assessment of the environmental performance of water distribution through mains, and it was developed by the Emilia-Romagna Development Agency (ERVET) [11]. Details of this water distribution boundary are shown in figure 1.

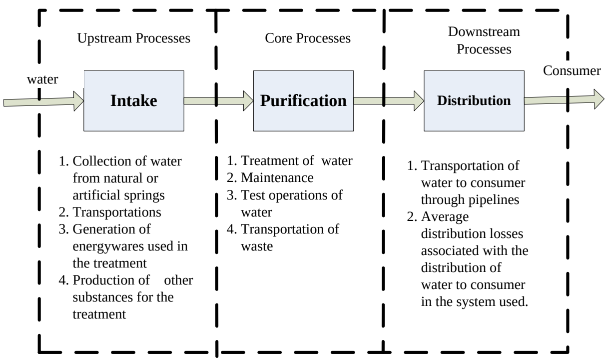

Figure 1: Water distribution through mains, except steam and hot water PCR draft

3 RESEARCH METHODOLOGY

According to the PCR of ERVET, experience from other countries, extended literature review, expert consultations, and Taiwan’s PCR in Figure 2 [12][13][14][15][16][17][18] have decided the boundary and the scope of assessment, including intake, purification, distribution, chemicals, consumables, transportation at each stage, and infrastructures.

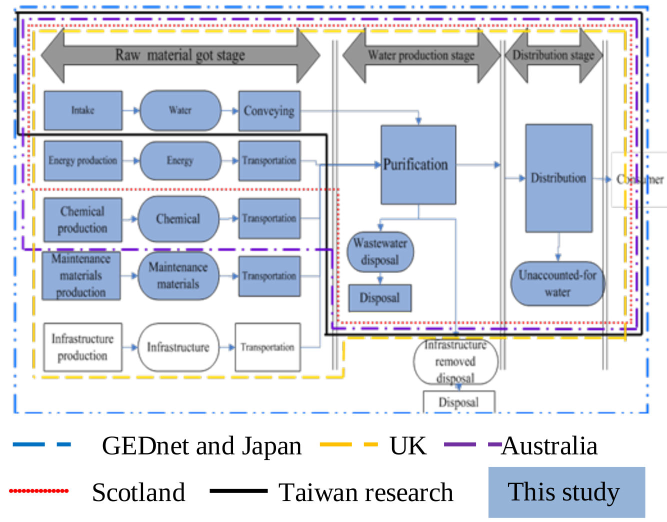

Figure 2: Water supply system boundary of each country researched

It shows the boundary and the inventory of one treatment plant whose inventory time is one year (in 2010). The carbon footprints are calculated based on the unit water sold (m^3).

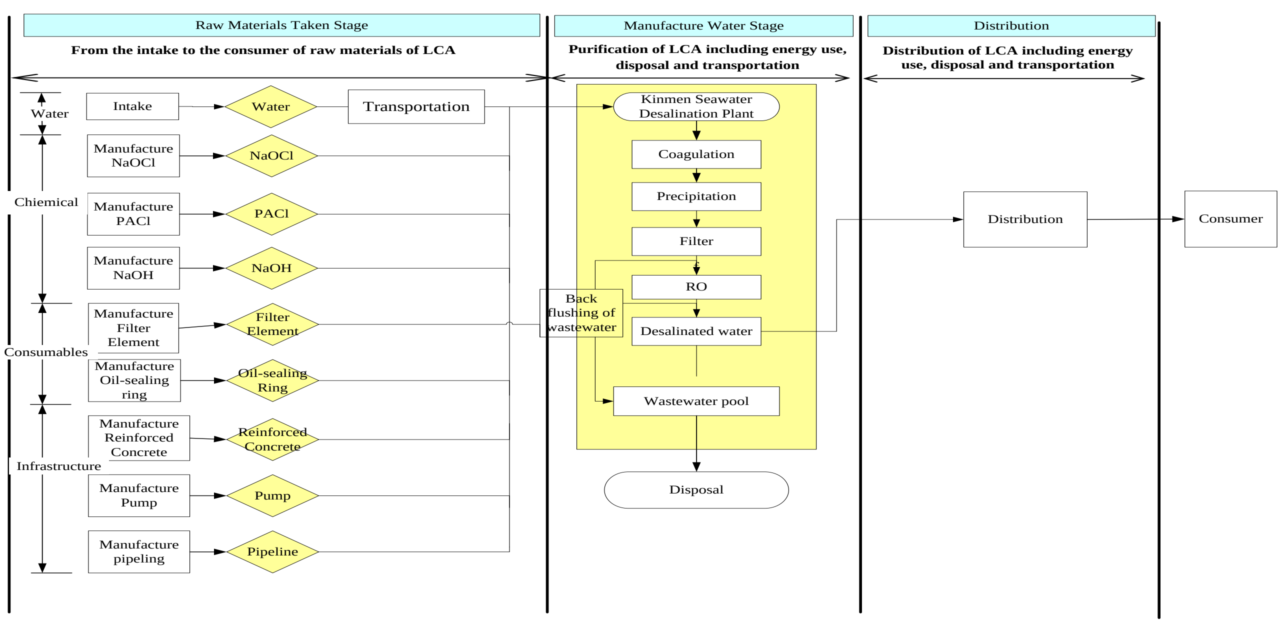

Figure 3: Boundary and inventory of the Kinmen seawater desalination plant (KSDP)

4 RESULTS AND DISSCUSSION

This study chose the Simapro 7.2.3. Its database is from Eco-invent, and the model used is IPCC 2007 GWP 100a. The electricity coefficient is 0.612 kg CO_2/m^3, which is from the Bureau of Energy, Ministry of Economic Affairs. Figure 4 and show greenhouse gas emissions from different stages, including intake, purification, and distribution stages, for every 1 m^3 of water produced by each treatment plant by PLCA methodology.

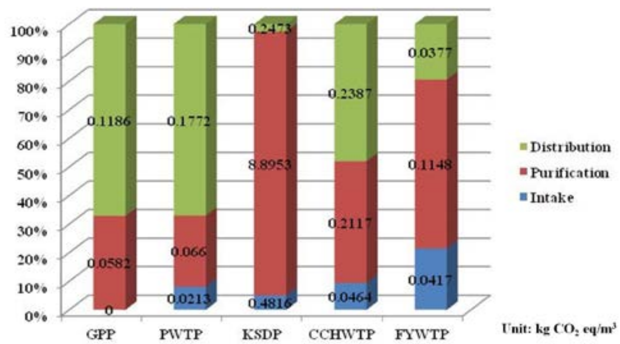

Figure 4: Carbon footprints of five water supply systems in Taiwan from PLCA

This paper includes the study of boundaries, infrastructures (including construction [steel and concrete]), mechanical and electrical equipment (motors), and pipelines into the calculation scope. The lifetimes of infrastructures are assumed to be 58, 12, and 38 years [19], respectively. To collate data, the calculations of the each plant's carbon emissions are as follows:

(1). **Gongguan Purification Plant (GPP):** The intake stages contain distribution wells. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain two parts, namely, mechanical equipment and cast-iron pipes. The total carbon emission is 0.1768 kg $CO_2 eq/m^3$.

(2). **Panhsin Water Treatment Plant (PWTP):** The intake stages contain mechanical equipment. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, and cast-iron pipes from the 12th branch of the Taiwan Water Corporation. The carbon emission is 0.2646 kg CO_2 eq/m^3.

(3). **Kinmen Seawater Desalination Plant (KSDP):** The intake stages contain reinforced concrete storing cisterns and mechanical equipment. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, High-density polyethylene (HDPE) pipelines, and ductile iron pipelines. The carbon emission is 9.6305 kg CO_2 eq/m^3.

(4). **ChengChingHu Water Treatment Plant (CCHWTP):** The intake stages contain mechanical equipment. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, and cast-iron pipelines from the 7th branch of the Taiwan Water Corporation. The carbon emission is 0.4969 kg CO_2 eq/m^3.

(5). **FongYuan Water Treatment Plant (FYWTP):** The intake stages contain reinforced concrete storing cisterns. The purification stages contain reinforced concrete pools and mechanical equipment. The final distribution stages contain mechanical equipment, PVC pipelines, ductile iron pipelines, and cast-iron pipes from the 4th branch of the Taiwan Water Corporation. The carbon emission is 0.1942 kg CO_2 eq/m^3.

On the overall, carbon emissions in the consumption of electricity are the main emission sources. For example, electrical consumptions at the GPP, the PWTP, and the CCHWTP are about 67.39%, 67.27%, and 48.19%, respectively. In the purification process, the different processes have different results. For instance, carbon emissions of chemicals in the Gongguan Purification Plant, such as PAC, NaOCl, and NaOH, are about 84%. Carbon emissions of electrical consumptions are about 16.15%. The main carbon emissions are from such chemicals as PAC, NaOH, and liquid chlorine from the PWTP, which are about 83.75%. Carbon emissions from the reverse osmosis system is the main emission source in the KSDP, whose electrical consumption in the purification stages is about 99.75%. In the CCHWTP, chemicals, such as NaOH, $Al_2(SO_4)_2$, liquid chlorine, H_2SO_4, and others are the main sources of emission, which are about 67% in the purification stages. Carbon emissions of electrical consumption are about 33%. Finally, in the FYWTP, carbon emissions of chemicals used, such as PACl and liquid chlorine, are about 62.73% in the purification stages. Carbon emissions of electrical consumption are about 36.99%. The solar PV electricity generation systems of GPP would reduce about 0.0017kg CO_2 eq/m^3 in 2010.

In addition to PLCA, this study performed an IO-LCA to calculate CFP of two water supply systems, FYWTP and KSDP. It integrated their consumption of energy and environmental elements into national sector-by-sector economic input–output interaction, the scope of assessment included the energy, material, chemical and waste. The carbon footprints according to IO-LCA for FYWTP and KSDP are 7.4692 and 0.0591 kg CO_2 eq/m^3. Comparison between PLCA and IO-LCA of carbon footprints for FYWTP and KSDP are shown in figure 5.

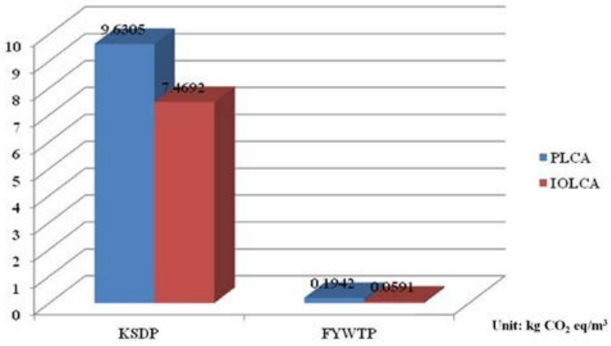

Figure 5: Comparison between PLCA and IO-LCA of carbon footprints for FYWTP and KSDP

5 CONCLUSION

For the traditional purification plant (GPP), the purification plant with highly turbid raw water (PWTP), the desalination plant (KSDP), the advanced purification plant (CCHWTP), and multi-process purification plant (FYWTP), the carbon footprints according to PLCA are 0.1768, 0.2646, 9.6305, 0.4969, and 0.1942 kg CO_2 eq/m^3, respectively. In IO-LCA, the carbon footprints for FYWTP and KSDP are 7.4692 and 0.0591 kg CO_2 eq/m^3, respectively. Reverse osmosis contributes significantly higher greenhouse gas emissions than other purification processes during the life cycle of water production. On the overall, the generation of electricity for pumping and for water delivery accounts for a large proportion of greenhouse gas emissions during the life cycle of 1 m^3 of water production.

REFERENCES

[1] Intergovernmental Panel on Climate Change (IPCC), "Working Group III Report Mitigation of Climate Change," Complete online versions, 2007.

[2] I. Caffoor, "Perspective: a vision of a low-carbon water sector in 2050," Proceedings of the ICE - Engineering Sustainability, Vol. 163, 9-14, 2009.

[3] A. H. Hu, L-H. Wang, Y-Z. Lin, C-W. Fan, J-H. Lin, K-F. Yao, J-G. Ao, Y-T. Feng, W-M. Guo, "Carbon Footprint Assessment of Water Supply Systems in Taiwan," EcoDesign 2011, 7th Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2011.

[4] M. Wackernagel and W. E. Rees, "Our Ecological Footprint - Reducing Human Impact on the Earth," New Society Publishers, 1996.

[5] T. Wiedmann and J. Minx, "A Definition of 'Carbon Footprint'," ISA^{UK} Research Report 07-01, 2007.

[6] W. Klöpffer, "Life Cycle Assessment-from the Beginning to the Current State, " Environ Sci Pollut Res Int, Vol. 4, 223-228, 1997.

[7] M. E-S. M. Mahgoub, N. P. v. d. Steen, K. Abu-Zeid and K. Vairavamoorthy, "Towards Sustainability in Urban Water : a Life Cycle Analysis of the Urban Water System of Alexandria City, Egypt," Journal of Cleaner Production, Vol. 18, 1100-1106, 2010.

[8] B. Maurice, R. Frischknecht, V. Coelho-Schwirtz and K. Hungerbühler, "Uncertainty Analysis in Life Cycle Inventory: Application to the Production of Electricity with French Coal Power Plants," Journal of Cleaner Production, Vol. 8, 95-108, 2000.

[9] H. L. MacLean and L. B. Lave, "Evaluating Automobile Fuel/propulsion System Technologies," Progress in Energy and Combustion Science, Vol. 29, 1-69, 2003.

[10] Environmental Protection Administration, Taiwan, "Taiwan Carbon Footprint Calculation Guidance for Products and Services," 2010.

[11] Emilia-Romagna Development Agency, "Water Distribution through Mains, except steam and hot water," GEDnet, 2009.

[12] W. K. Biswas, "Life Cycle Assessment of Seawater Desalinization in Western Australia," World Academy of Science, Engineering and Technology, Vol. 56, 369-375, 2009.

[13] Scottish Water, "Scottish Water Carbon Footprint Report, 2007-2008," 2009.

[14] Scottish Water, "Scottish Water Carbon Footprint Report, 2008-2009," 2010.

[15] Environment Agency, "Greenhouse gas emissions of water supply and demand management options," Science Report- SC070010, 2008.

[16] E. Friedrich, S. Pillay and C. A. Buckley, "Carbon footprint analysis for increasing water supply and sanitation in South Africa: a case study," Journal of Cleaner Production, Vol. 17(1), 1-12, 2009.

[17] River Network, "http://www.rivernetwork.org."

[18] National Science Council, Taiwan, "The Study of Carbon Dioxide Emission of Piped Water in Taiwan," 2006.

[19] Japan Water Research Center, "Study on the establishment of advanced water treatment technology (e-water 2)," 2008.