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Evaluation of monthly environmental loads from municipal wastewater treatment plants operation using life cycle assessment

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ABSTRACT
Life cycle assessment (LCA) methodology can be used to assess impacts on the environment that might be generated during treatment of wastewater and sludge treatment. In this work, LCA methodology was suggested to evaluate monthly environmental impact of wastewater treatment plants (WWTPs). Two field scale WWTPs, A2/O process and conventional activated sludge process (CAS), were selected as target plants and the operational data were collected from those plants. As the function units, the unit volume of treated wastewater of 1 m^3 and 1 kg T-N eq. removed were selected. The environmental effect of target WWTPs operation were assessed as impact categories such as global warming potential, eutrophication potential, and so on. From monthly profiles of each index, it was shown that the environmental impact of WWTPs has seasonal patterns influenced by the influent flow rate variation causing higher impacts in winter than summer. This is due to the fact that there were no significant increase in the electricity consumption and chemical usage during the summer while the treated volume of wastewater was increased.

Keywords: Eutrophication potential, Global warming potential, Human toxicity, Life cycle assessment(LCA), Marine aquatic eco-toxicity, Wastewater treatment plant

1. Introduction

Although wastewater treatment plant has been regarded as a plant for pollution reduction, it also consumes energy and various chemicals essentially and generates negative impacts such as noise, odor, and sludge to be finally disposed as incineration or landfill. This means that the amount of pollution transference by existing wastewater treatment plant should be assessed for more advanced management of it. In this sense, the main focus is now on the sustainability assessment from wastewater treatment plants and sewers [1-3].

Life cycle assessment (LCA) has been widely used to assess environmental effects of production process, usage and disposal of a product. It has been adapted to an industrial plant from plant construction to shut down as well. Especially for the wastewater treatment plant (WWTP), LCA has been used to compare the different sizes of wastewater treatment plants or various technical solutions by estimating the environmental loads from wastewater systems [4-8]. The negative impacts on the environment that might be generated during treatment of wastewater and sludge could be evaluated as various indexes meaning the amount of emissions into the atmosphere, energy demand and toxicity potential for human and aquatic environment [9-12]. Additionally, LCA can provide means to fill a gap in pertinent information towards more sustainable decision-making [13]. Obviously, operational decision making of WWTPs significantly depends on the changes of disturbances such as influent loading and temperature. However, it is hard to find a case focusing on the seasonal variations of the environmental effect of the WWTPs operation.

In this research, the environmental effects of the subparts of a large scale wastewater treatment were explored as global warming potential and human toxicity potential. The large scale WWTP was divided as 5 subparts as wastewater treatment, sludge treatment, biogas incineration, effluent discharge and sludge disposal. And then, LCA was applied monthly for the assessment of two field-scale WWTPs operation for comparison. The environmental impacts indexes such as global warming, eutrophication, eco-toxicity were analyzed and compared between two field-scale WWTPs. As function units of LCA analysis, the unit volume of treated wastewater (1 m^3/mon) and 1 kg T-N eq. removed/mon were used. The results showed there were significant difference caused by the characteristics of WWTPs unit process and composi-

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tions of sludge treatment processes. Also, the seasonal pattern of WWTPs operation brought about diverse index values for every month. Although more research is needed to be applied directly to the field WWTPs' decision support, LCA based monitoring showed its potential as a useful tool to provide objectified information of operational status and environmental effects ongoing.

2. Materials and Methods

2.1. Goal and Scope Definition

One of the goals of LCA in this work is to explore the environmental effect of each compartments of a large scale of WWTP which were divided as power used for wastewater treatment (named as "electricity 1"), power used for sludge treatment (named as "electricity 2"), biogas incineration, treated wastewater discharge and sludge disposal as incineration. It is to assess the environmental effect of power consumption and effluent discharge to natural receiving body, related to global warming and eutrophication respectively.

The other goal is to compare two different WWTPs as environmental effect in terms of global warming, freshwater aquatic eco-toxicity, marine aquatic eco-toxicity and eutrophication potential. To identify the monthly changes of environmental loads, the monthly inventory data was used.

2.2. Target Wastewater Treatment Plants

As target processes, two field scale WWTPs having different kind of biological wastewater treatment process were selected. One is A2/O process and the other is conventional activated sludge process (CAS). S wastewater treatment plant (WWTP-S) has 680,000 m^3/d inflow rate and consists of A2/O process with sludge digestion process. The produced biogas generated from anaerobic sludge digestion can save about 20% of the operating power per day. WWTP-S was analyzed as representing a large scale WWTP. H wastewater treatment plant (WWTP-H) has 65,000 m^3/d inflow rate and consists of standard activated sludge processes and sludge incineration process. The treated effluent from WWTP-S was discharged to a neighboring river and that from WWTP-H was discharged to the ocean. In this study, the system boundary (Fig. 1, Fig. 2) was defined as including main inputs and outputs such as electricity, water, and sludge. In the system boundary, all the unit processes from the entrance of wastewater into the wastewater plant to the final discharge as well as the sludge treatment were included and all the possible procedures to its final disposal were considered. The brief information of WWTP-S is listed in Table 1.

Table 1. Main Information of the Wastewater Treatment Plants

Process	Treated Size m3/d Designed	Treated Size m3/d Operated	Energy kWh/d	Population cap	Discharge -
WWTP-S (A_2O)	680,000 (designed)	419,865 (operated)	113,855	1,171,500	Nakdonggang (River)
WWTP-H (CAS)	65,000	39,327	16,983	135,959	South Sea (Ocean)

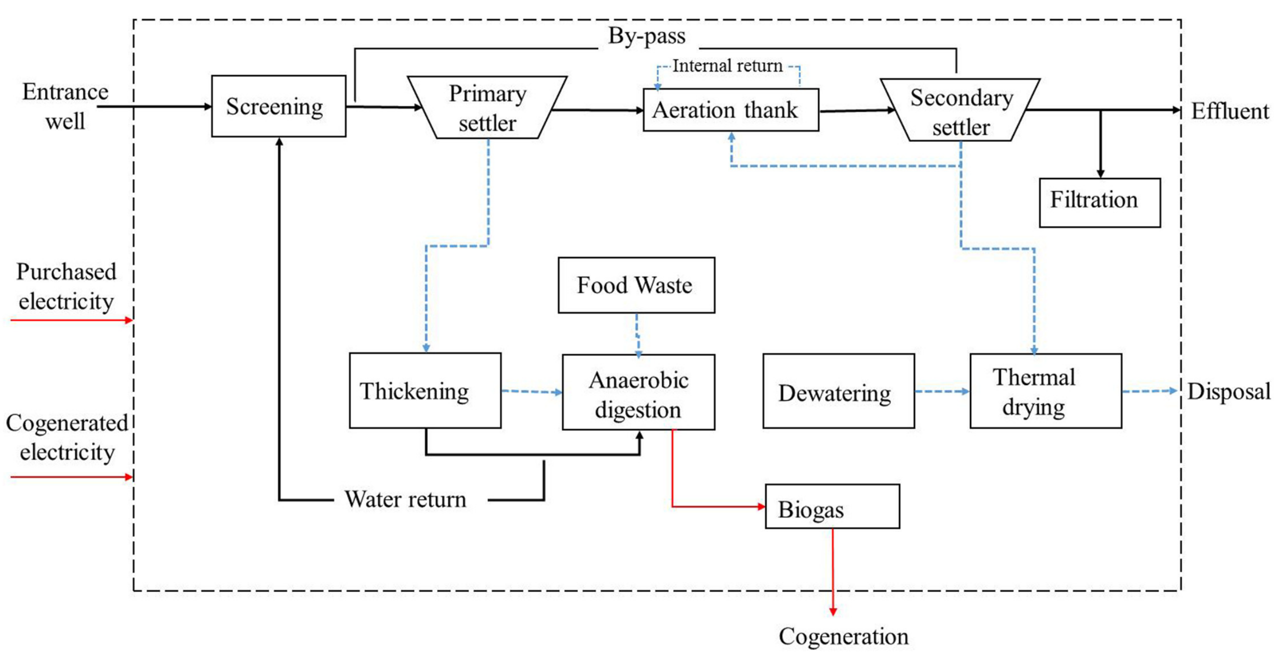

Fig. 1. System boundary of WWTP-S.

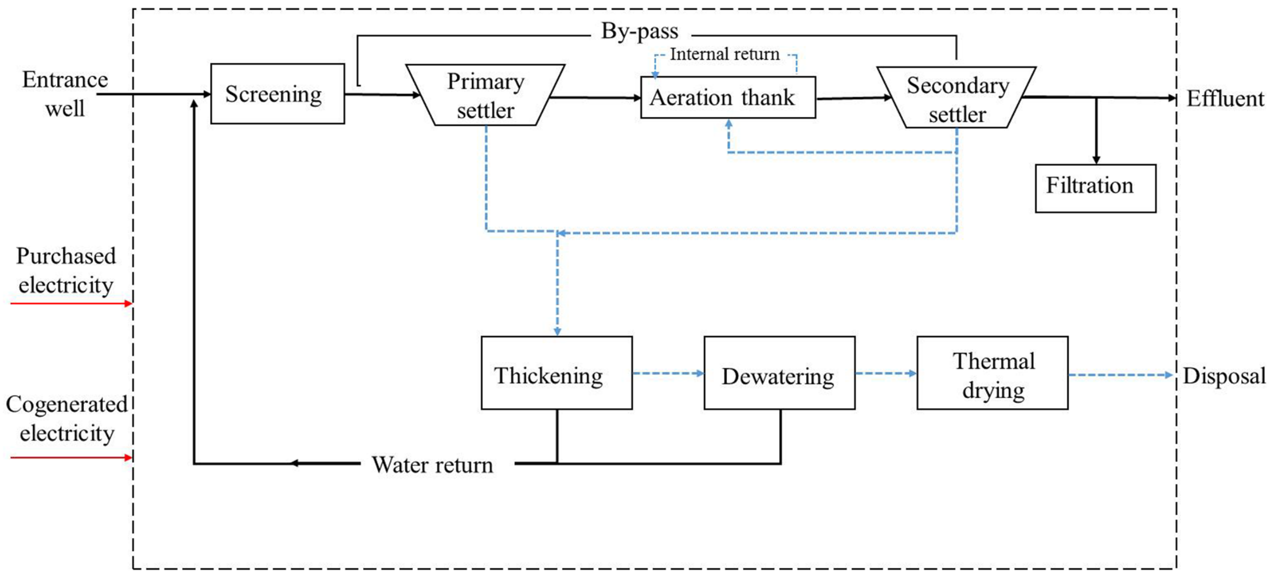

Fig. 2. System boundary of WWTP-H.

2.3. Function Units of LCA

In many LCA studies, a function unit is usually selected as the volume (m^3) of the treated water or a one person equivalent (PE) for WWTP. However, in the case of the influent collected through combined sewer system, the quantity of inflow was influenced by seasonal variations as rainfall which makes the choice of the volume of the treated water as the function unit of a WWTP unsuitable. In this sense, two kinds of function units (FU) were selected in this study. The first FU was the unit volume of treated wastewater (1 m^3) and the second one was 1 kg T-N eq. removed.

2.4. Life Cycle Inventory Analysis

The first step of inventory analysis is to obtain material consumption and production data for each processing stage as the basis of the next step of impact assessment. The types of material consumption considered are wastewater, purchased and cogenerated electricity, reagents and air. The productions covered effluent, primary and secondary sludge, dewatered sludge, biogas, CO_2 and so on. Operational data was obtained from the field wastewater treatment plant. In this study, the provided inventory data were collected from real site data of the operation of the plant for the period of one month in May, 2010. All Inventory data presented in Table 2 is the annual averages for year 2010. This data was used to explore the environmental effects of S-WWTPs operation of 2010.

Inventory data for monthly analysis of two WWTPs was obtained as monthly averages for the year of 2010. Regarding the sources, data for direct production stage was provided by the company and additional background data was borrowed from Gabi databases. Collected datasets consist of the influent and effluent data of BOD, COD, TN, TP, electricity, chemical consumption, sludge, and biogas data. And the background data includes in chemical products, direct emissions from sludge disposal and electricity production, and import and export data. After standardization of inventory data according to the function unit, the LCA inventory data was classified and characterised using impact categories and characterisation factors. The impact categories are global warming potential (GWP), eutrophication potential (EP), marine aquatic eco-toxicity and freshwater aquatic eco-toxicity.

Table 2. Life Cycle Inventory of the Wastewater Treatment Plant of WWTP-S

Parameter		Unit	Value
Wastewater Influent	BOD	mg/L	107.4
	COD	mg/L	54.2
	SS	mg/L	104.0
	T-N	mg/L	25.6
	T-P	mg/L	3.0
Energy	Cogenerated electricity	kWh/d	780
	Purchased electricity	kWh/d	113,075
Reagents and additional products	Coagulant	kg/y	192,576
	Activated carbon	kg/y	-
	PAC	kg/y	-
	Disinfectant	kg/y	-
	Deodorant	kg/y	-
Wastewater effluent	BOD	mg/L	1.8
	COD	mg/L	7.9
	SS	mg/L	5.2
	T-N	mg/L	9.5
	T-P	mg/L	1.4
Wastes	Primary effluent	m^3/d	2,421
	Secondary sludge	m^3/d	3,399
Other outputs	Biogas	m^3/d	14,747.5
	Ocean disposal	t/y	51,465

3. Results and Discussion

3.1. Life Cycle Impact Assessment of WWTP-S

In order to simplify the inventory results and make them more understandable, the CML Classification method was used and evaluated with a set of environmental indicators from well–established Dutch LCA methodology [12]. The impact categories are global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP) (Table 3). Assessment of the potential environmental impacts of the inventory results were identified, classified and characterized using impact categories, category indicators and characterization factors. According to the goal of the research the Global Warming and Human Toxicity indexes were evaluated, because they are main categories related to wastewater treatment process among various impact categories. According to the definitional boundaries of the system and inventory analysis data, the potential environmental impact of the sewage treatment plant process operation could be classified as wastewater line, sludge treatment line, biogas incineration, effluent discharge and sludge disposal. Data for classification and characterization of inventory is listed in Table 4.

The major environment impact as global warming was from energy consumption accounting 90.29% of total kg CO2-equiv. Compared to the electricity consumed at sludge treatment line of 42.79%, the combustion of biogas in the cogeneration engine accounts for a minor part (2.09%). Other parts, wastewater treatment and sludge disposal as incineration did not occupy significant amount of kg CO_2-equiv.

However, for the human toxicity potential, sludge disposal by incineration took major impact as accounting 46.98%. The sludge treatment process also had significant impact as 25.05% due to H2S emission at the anaerobic digest process. The environmental loads by wastewater treatment and sludge treatment were caused by their electricity consumption having CO_2 and heavy metals emissions to air at electric generation process. Fig. 3 shows that the sludge treatment part has the largest contribution to the human toxicity, whereas that of the treated wastewater discharge is almost zero.

In conclusion, the factor having major impact as a term of the global warming potential was the electricity consumption and the most of the human toxicity potential was made from sludge disposal process. Human toxicity potential was caused by H_2S emission at the anaerobic digest process and electricity generation process having heavy metals emissions to air.

Also, it can be said that the most relevant factors to the potential environmental impact of the WWTP are electricity consumption and CO_2 emissions related with incineration.

3.2. Comparison of Monthly Environmental Effects of Two WWTPs According to FU1

The environmental impact based on the unit volume (1 m^3) of

Table 3. Environmental Impact Category of the Wastewater Treatment Process

Impact category	Environmental Load	Source
Global warming	CO_2, NO_x, CH_4, CO	Transport, Consuming electricity, Sewage treatment process
Eutrophication	N, P	Discharge
Freshwater Aquatic Eco-toxicity	Heavy metals	Sludge treatment process
Human toxicity	Heavy metals, NO_x, SO_2	Discharge Sludge treatment process

Table 4. Classification and Characterization of the Inventory Results of WWTP-S

		Electricity 1 (wastewater line)	Electricity 2 (sludge line)	Biogas incinerat-ion	Wastewater treatment	Sludge disposal
Global Warming Potential	kg CO_2 Equiv.	2.55E + 04	2.29E + 04	1.12E + 03	1.00E + 03	3.06E + 03
	%	47.50%	42.79%	2.09%	1.86%	5.71%
Human Toxicity Potential	kgCO_2 Equiv.	7.51E + 02	6.76E + 02	3.66E + 00	0.10E + 00	1.27E + 03
	%	27.80%	25.05%	0.14%	0.01%	46.98%

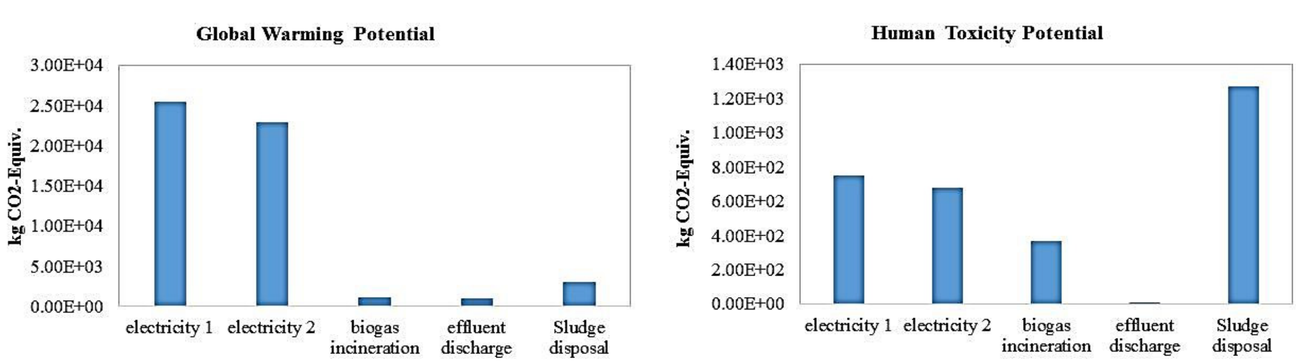

Fig. 3. Global warming potential and human toxicity potential of WWTP-S.

treated wastewater as function unit has been influenced by seasonal factors such as rainfall. That is due to the fact that the operational conditions which had no significant changes against increased flow rate at rainy season. Also it can mean to secure effluent quality regulations was possible without any operational changes for facing increasing inflow. The trend of the environmental impacts was generally higher in winter than summer because the amounts of electricity and chemical production have not changed in spite of the decreased flowrate compared to summer season. The result of the environment impact based on the FU1 was shown in Fig. 4. The WWTP-H presents a noticeably high impact in eutrophication potential, global warming potential and freshwater aquatic eco-toxicity. It can be analyzed as caused by higher nutrient concentrations of effluent than WWTP-S. Also, as seen in Fig. 5, the impact of inorganic emissions to air was higher than the emissions to water due to the sludge digestion gas and the sludge incineration. The value of marine aquatic eco-toxicity in WWPT-S showed negative impact to ocean and was positive in WWTP-H, conversely. The possible reason of negative effect of WWTP-S can be considered as the small amount of landfill of sludge incineration ash, whereas the positive effect of the WWTP-S was caused by ocean dumping of dewatered sludge.

3.3. Comparison of Monthly Environmental Effects of Two WWTPs According to FU2

Based on the 1 kg T-N removed quantity as second function unit, the result of the main environment impact is presented in Fig. 6. The environmental impacts were not affected by the seasonal factors and every monthly impact results have similar trend. According to the results based on FU2, the average values of Eutrophication potential and Freshwater Aquatic Eco-toxicity po-

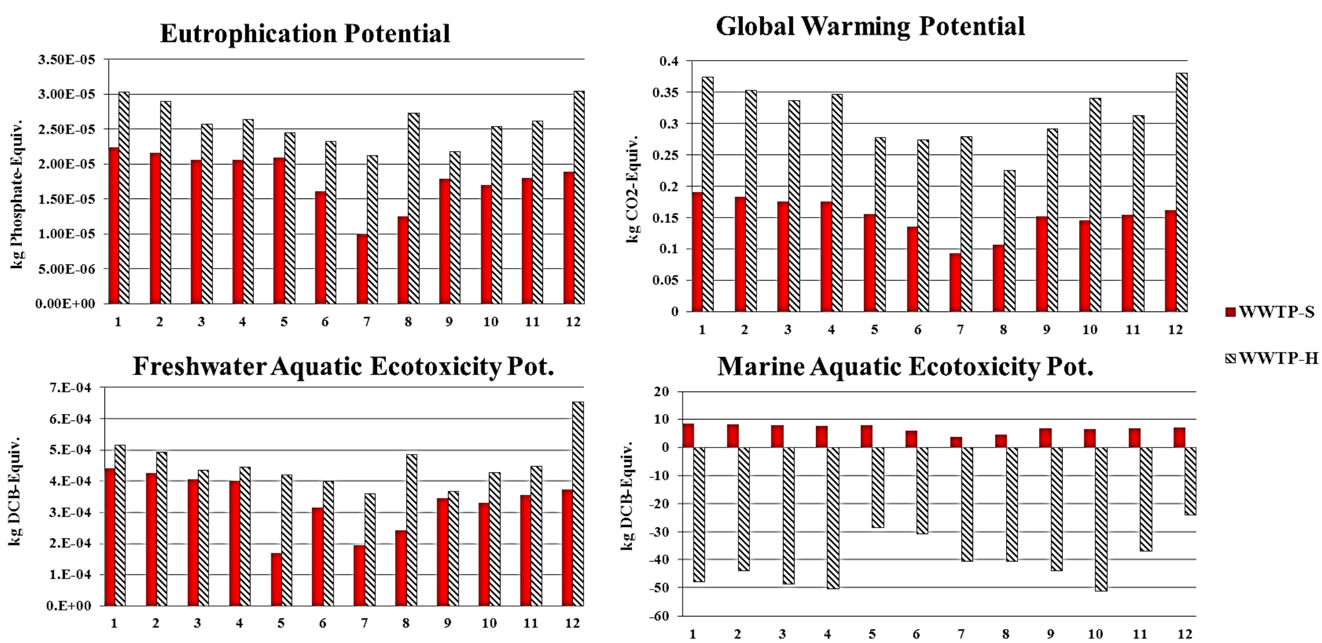

Fig. 4. Comparison of the environmental impact of the WWTP-S and WWTP-H based on FU1.

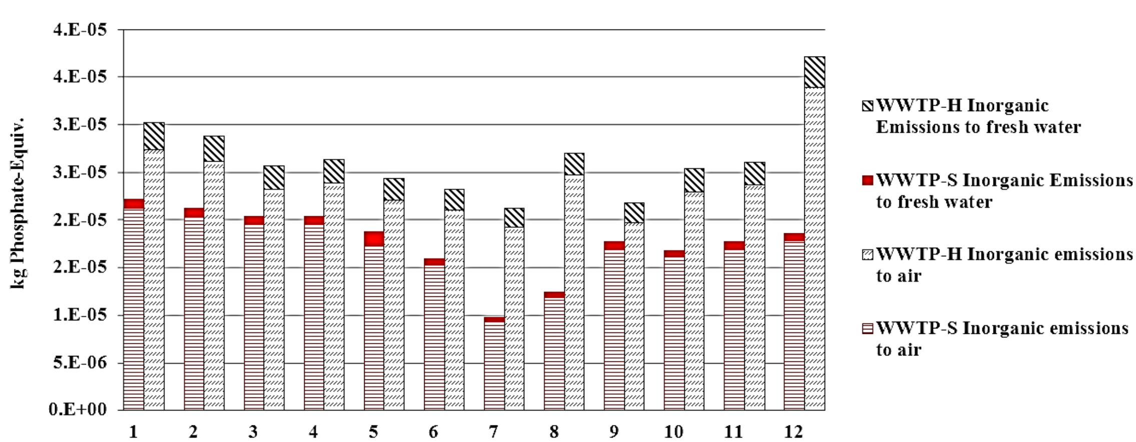

Fig. 5. Eutrophication potential of the WWTP-H and WWTP-S based on FU1.

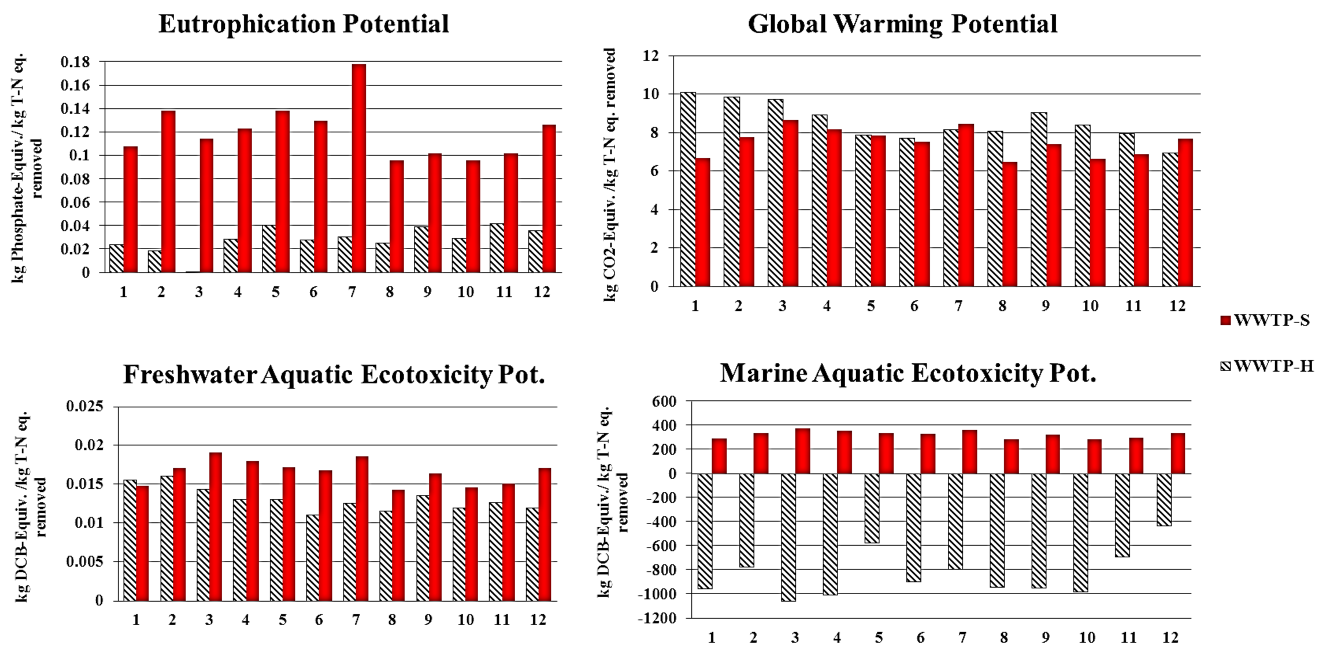

Fig. 6. Comparison of the environmental impact of the WWTP-S and WWTP-H based on FU2.

tential impact in WWTP-S are obvious higher than in WWTP-H. The main reason of higher potentials of WWTP-S is that the plant, based on A2/O process, showed higher nutrient removal rate than WWTP-H. The phosphorus, BOD and COD were the main causes in the two WWTPs and accounted for 97% and 99% of potentials, while the contributions of the power generation and pharmaceutical manufacturing count for only 0.85% and 2.6%.

4. Conclusions

In this study, using LCA method the global warming and human toxicity of WWTP processes were evaluated. The most negative effect was caused by power consumption and sludge treatment phase accounting for 90.29% and 5.71%, respectively. For the human toxicity potential the sludge treatment phases occupied 47% of the total. This means that it is necessary to find some alternatives to save energy and search for other ways to reduce the emissions to the environment from the WWTPs.

The environment impact index using two function units presented different characteristics of the wastewater treatment facility and sludge processing methods with unified indices. As the environmental potentials calculated based on the 1kg T-N removed, LCA methodology could generate more appropriate comparison results for the efficient operation of the WWTPs.

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