Life Cycle Assessment of a Water Treatment Plant: A Review

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Abstract: ***We study the Life Cycle Assessment (LCA) of a Waste water treatment Plant (WWTP) in a university campus located in India. The emissions of the WWTP along with their impact factor are analysed using Umberto NXT universal utilizing Eco-invert database v3.0, which is a LCA software. According to the report, there is a positive impact on the assessed categories by the recycled water from the plant. In the categories like global warming potential, terrestrial eco-toxicity potential, fossil depletion potential and particulate matter formation, the effect of treatment system is overriding the effect of recycled water.***

1. Introduction

Water being the main source of livelihood and survival takes high importance for existence of life. When it comes to the water scarce arid and semi-arid regions, this becomes even more important. The water scarcity problems are getting worse because of reduced rainfall, higher demands for rapidly growing population, exhaustive depletion of water resources, and a missing legal framework for water management. Either we should discover alternate source for fresh water or the waste water treatment techniques are to be developed to provide the adequate supply of water. The latter option is important as various treatment techniques can be developed where waste water can be treated and can be used for purposes such as gardening and bathing.

The purpose of WWTP is to treat the waste and dirty water coming from various sources such as homes, offices, labs and sanitation facilities. These treatment plants are developed and operated by the public owned departments. However, large organizations that require huge amount of water on daily basis operate personal WWTP.

WWTP comprises of two processes: primary and secondary. There are further sub-units, each of which is mounted to carry out a specific process. The untreated waste water from various sources get accumulated in the collection tank where floating solid impurities and debris get removed. The water then moves into the aeration tank, which has chemicals of high nutrient content such as diammonium-phosphate (DAP). Most of the microbial actions take place in this unit in presence of air. This aerobic oxidation in this unit causes the degradation of the organic matter in the presence of microorganisms. Besides, the sludge and water are separated in the clarifier region.This participates in the secondary treatment process. The separated sludge in collected and air-dried before storing it for further use. For the semi-treated water, the next functional unit is the chlorination tank. Inside this tank, disinfection takes place, which is then paced through a dual filter media, from where the treated water goes for further storage.Untreated sewer cannot be disposed without treatment as it has drastic social and environmental impacts.

The waste water treatment is also not an eco-friendly process since it consumes a lot of energy and some form of chemicals. Thus, proper analysis is required for the environmental benefits of water saving and environmental damage of water treatment.

A tool which can do such analysis is life cycle assessment LCA, that is based on complete understanding of the amount of realistic data feed to it.Life Cycle Assessment (LCA) is defined as the compilation and evaluation of the outputs and potential environmental impacts of a product system throughout its life cycle. It studies aid in deciding the best technique to minimize the ill-effect on the environment.

There are four phases of an LCA study:
1) Goal and Scope definition
2) Life Cycle Inventory Analysis (LCI)
3) Life Cycle Impact Analysis (LCIA)
4) Interpretation

LCA of water treatment finds its importance due to its holistic approach.There are several studies on LCA of waste water problem, one such being on comparing the different waste water treatment techniques: aerobic versus anaerobic, chemical versus combined chemical and biological.It is reported that the recycling of phosphorus to agricultural land due to its fertilizer potential,outshine the use of sludge incineration to bring down the impacts of fossil fuel depletion and climate change. Other study conducted on LCA of WWTP in China revealed that while using renewable energy like wind, as in this case, the enhancement of effluent quality would bring down the environmental impacts. This study also shows the importance of generating electricity from renewable sources to minimize fossil fuel depletion and emission of pollutants.

In the present study, the focus has been on the understanding of the WWTP and carrying out the LCA for primary & secondary treatment section. The various units that waste water treatment plant consists are collection tank, aeration tank, clarifier, dual media filter, chlorine dosing tank, treated water tank and sludge collection tank. Focus is also put on the collection of treated water which otherwise was getting wasted.

2. Materials and Method

Life cycle assessment framework methodology provided by the International standard organization (ISO) 14040 is utilized to assess the environmental impacts of a sewage water treatment process.The impacts are assessed by a simple LCA tool which is carried out to visualize and analyse the environmental impact of the sewage water treatment process. The material flow and energy flow modelling is achieved using a software tool named Umberto NXT Universal having Eco-invent dataset v3.0. The well-known ReCiPe method for both midpoint and endpoint assessment is utilized for the same.

3. Objective

- To assess the environmental impacts of a sewage wastewater treatment process.
- The approach applied in the work for carrying out LCA is 'Gate-to-Gate'.

4. Purpose of the Study

For proceeding with our study, we should know the location of the place where our study is done. The university campus is located in the northwest part of India, state of Rajasthan.The semi-arid region of India lacks water resources. The two mere sources of water in this region are rain and the ground water.The geographical condition of the study area plans a key role in scarcity of fresh water.

The establishment of the waste water treatment plant is estimated for a life span of 50 years and used on 24-hour basis. We aspire to estimate the environmental impacts of wastewater treatment process by LCA approach and identify hotspots in the process.

5. System Boundary

The system boundaries consist of wastewater treatment process at the sewage treatment plant and re-distribution of the purified water for irrigational purpose. The system boundary including the basic LCA material and energy flow model is shown in Fig. 1. It shows the whole water supply system of the campus and a small section drawn with lines in drawing is the system boundary under consideration. Two different study have been conducted for environmental impact analysis of water purification and water supply system of the university campus.

<u>Gate-to-Gate approach</u>:
This means that the system boundary is considered when the water is received from the campus to plant site, in the collection tanks, and this ends with the treated wastewater re-distributed for the irrigational purpose. Also, the generation of sludge was considered until it is thickened and dewatered in the sludge treatment plant prior the incineration. The main phases of waste water treatment process consist of:

- water collection
- sludge activation
- treatment
- purification
- re-distribution.

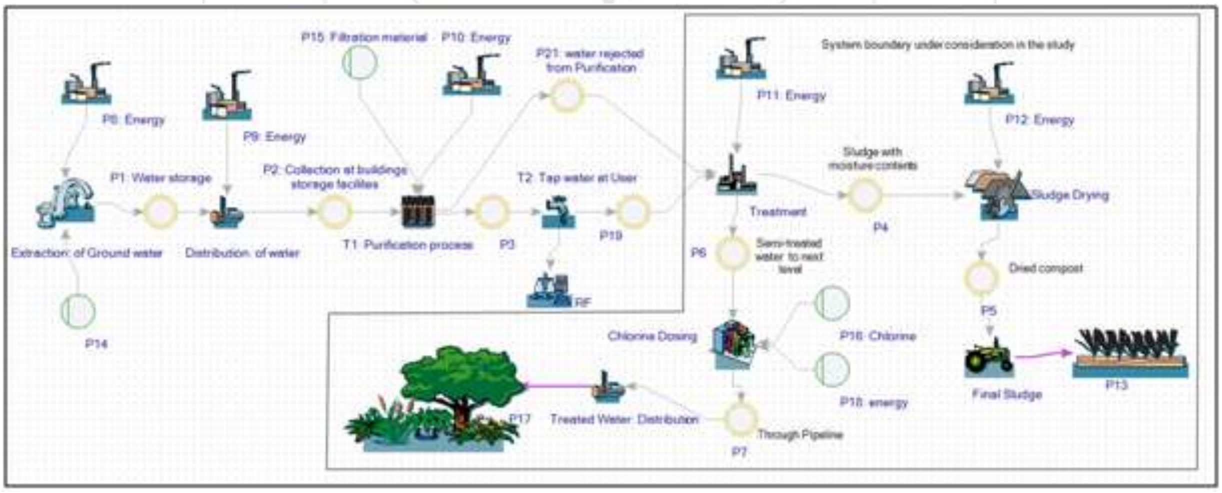

Figure 1

Functional Unit
The functional unit of present study is the quantity of wastewater inflow and treated by the sewage treatment plant per day, that is 1500 m3 of wastewater per day with 24 h and 365 days working of plant and with working life of 50 years.

Life cycle inventory
The collection of data was performed during the operation of plant for repetitive times. The operational inputs and quantity of wastewater inflow was measured at different times of the year to get the mean values respectively. The process specific or treatment related data was obtained by conducting semi-structured interviews with the working staff at plant. The secondary data for modelling the material and energy flow was collected from internet, datasheets etc.

The following assumptions were made:

- The diesel used for electricity generation at plant is of same quality throughout the year.
- The input quantity is taken as average for monthlyproduction.
- Bullock cart or camel cart are used for the transportation of sludge, Thus, their impact are neglected.

Life cycle impact assessment

The LCA study of the product and process with integration to eco-invent dataset is supported by Umberto NXT Universal software. The LCA modelling of this study was carried out in 5 phases: water collection, sludge activation, treatment, purification, and re-distribution. The energy inputs of the study are fulfilled by Indian electricity mix and diesel generators. The well-known ReCiPe method for both midpoint and endpoint assessment was used.

In LCA, the analysis deals with three areas of scientific knowledge and reasoning. These are also called "spheres", which are as follows:

- Technosphere: the explanation of the life cycle, the emissions from processes, the distribution procedures are based on causal relations.
- Ecosphere: the modelling of changes (damages) is inflicted on the environment.
- Valuesphere: the modelling of the perceived seriousness ofsuch changes (damages), as well as the management of modelling choices that are made in Technosphere and Ecosphere.

The LCA model is constructed on the following basis:

- Inventory table from technosphere
- Visualization of energy and material flow model in ecosphere is utilized to link the inventory analysis table with the damage categories.
- Valuesphere modelling is used to weight the three endpoints to a single indicator.

The midpoint assessment provides result a various damage category which is utilizing the ecosphere modelling whereas the endpoint assessment method is basically top-down approach, through which the environmental burdens of the product and process can be explained in a single score. The end point categories are the culmination of midpoint categories. For example, the end point category human health is effected by ozone depletion, human toxicity, ionizing radiation, smog, particulate matter, and climate change which are measured in the midpoint categories. Similarly, ecosystem at end point is effected by terrestrial ecotoxicity, terrestrial acidification, land occupation, marine and fresh water ecotoxicity and eutrophication, and climate change at midpoint. Resources at end point are effected by fossil fuel, minerals and water consumption measured at the midpoint level.

6. Results and Discussions:

In our study, the operational units are measured terms of electricity, diesel burned for generating electricity, urea, and chlorine. Chlorine is used through a dosing pump to kill the bacteria and other microbes remaining in the treated water but chlorine is a highly toxic substance.

Endpoint assessment

ReCiPe method provides results in three main endpoint categories: ecosystem quality, human health and resources. The ecosystem quality has nine sub-categories: agricultural land occupation, climate change, freshwater eco-toxicity, freshwater eutrophication, marine eco-toxicity, natural land transformation, terrestrial acidification, terrestrial eco-toxicity, and urban land occupation. In human health there are six subcategories: climate change (human health), human toxicity, ionizing radiation, ozone depletion, particulate matter formation and photochemical oxidant formation. In the end resources have, two sub-categories: fossil depletion and metal depletion.

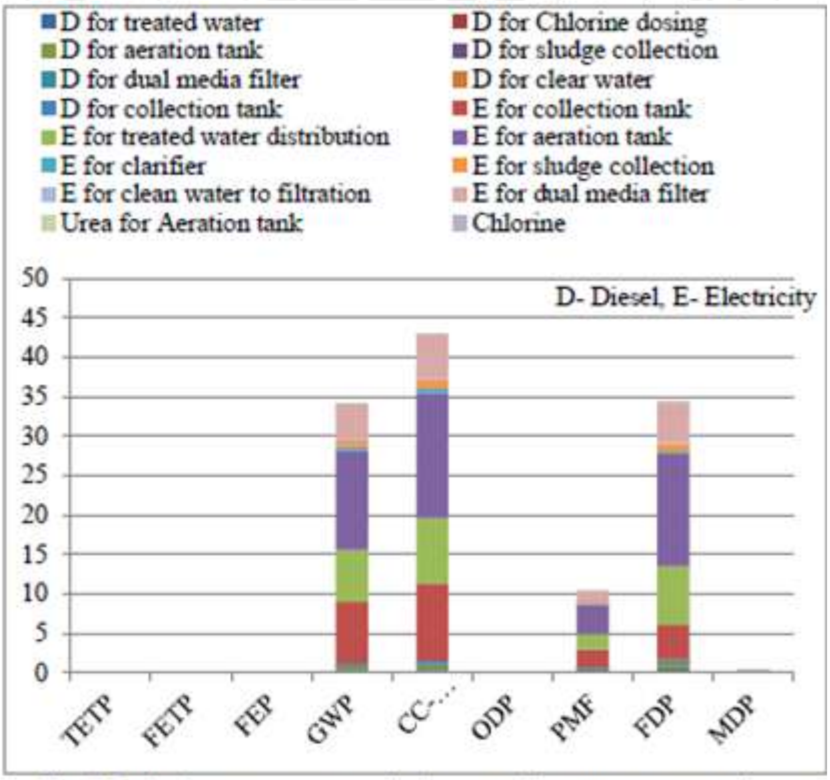

Fig. 2 Endpoint assessment results in terms of treatment process phases

In present study, nine categories were selected to show the environmental impact of wastewater treatment process. The selected nine categories with abbreviation are: terrestrial ecotoxicitypotential (TETP), freshwater eco-toxicity potential (FETP), freshwater eutrophication potential (FEP), climate change or global warming potential (GWP), Climate change human health (CC-HH), ozone depletion potential (ODP), particulate matter formation (PMF), fossil depletion potential (MDP), and metal depletion potential (MDP).

The Fig. 2 of the study is visualizing the results of the five waste water treatment process phases. According to the results it is found that GWP and CC-HH are most impacting categories in ecosystem quality and human health respectively. Whereas in resources the fossil depletion is most impacting category. The second significant impact in human health is of PMF category. It is observed that burning of diesel for generating electricity causes, emission of particulate matter, sulphur dioxide, and nitrogen oxides to the environmental.

These emissions cause the damage to the ambient air quality and ultimately to human health. The impact of FDP is due to the significant amount of fossil fuel required for the energygeneration. At the end the emission of CC-HH and GWP is due to the electricity consumption and fossil fuel consumption.

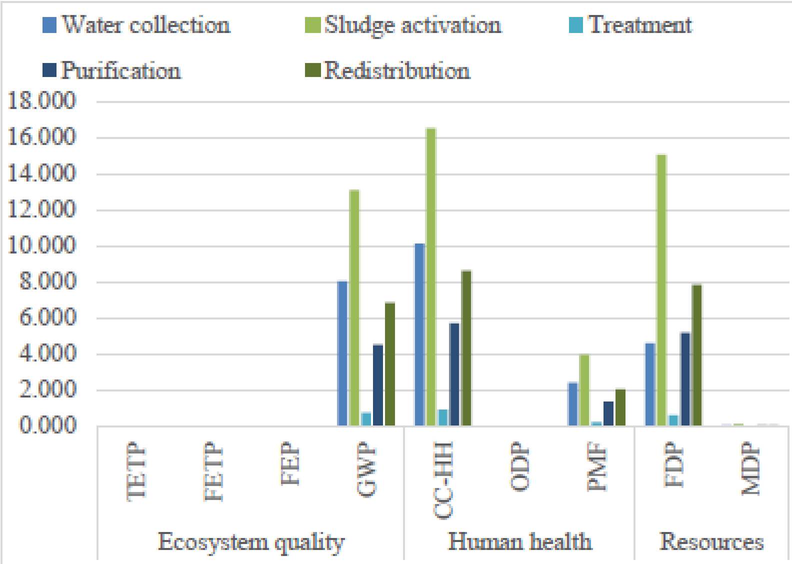

Fig. 3 Endpoint assessment results in terms of energy and material consumption

The more impacting treatment phases are water collection, sludge activation, and redistribution in all categories. To make a clear picture of these environmental impacts each of the material and energy transitions are plotted in terms of the same endpoint categories as shown in Fig. 3. It is found that the energy requirement for the aeration tank, treated water distribution, collection tank, and dual media filter is significantly effecting the environment in GWP, CC-HH, PMF, and FDP category. The actual results values of the endpoint assessment of the treatment phases are tabulated in table 1.

Table 1 Midpoint assessment results of the study (in points)

	Ecosystem quality				Human health			Resources	
	TETP	FETP	FEP	GWP	CC-HH	ODP	PMF	FDP	MDP
Water collection	0.014	0.002	0.008	8.048	10.12	0.000	2.435	4.608	0.073
Sludge activation	0.023	0.004	0.013	13.11	16.49	0.000	3.962	15.04	0.123
Treatment	0.002	0.000	0.001	0.736	0.945	0.000	0.246	0.609	0.024
Purification	0.008	0.001	0.005	4.536	5.707	0.000	1.372	5.194	0.041
Re-distribution	0.012	0.002	0.007	6.852	8.621	0.000	2.081	7.862	0.062

Midpoint assessment

ReCiPe method provides results in 18 different midpoint categories named: agricultural land occupation, climate change, fossil depletion, freshwater eco-toxicity, freshwater eutrophication, human toxicity, ionizing radiation, marine ecotoxicity, marine eutrophication, metal depletion, natural land transformation, ozone depletion, particulate matter formation, photochemical oxidant formation, terrestrial eco-toxicity, urban land occupation, and water depletion.

In this study out of these 18 categories, nine categories are selected to show the environmental impact of wastewater treatment process. The selected nine categories with abbreviation are: climate change or global warming potential (GWP), freshwater eco-toxicity potential (FETP), freshwater eutrophication potential (FEP), human toxicity potential (HTP), metal depletion potential (MDP), ozone depletion potential (ODP), particulate matter formation (PMF), terrestrial eco-toxicity potential (TETP), and water depletion potential (WDP).

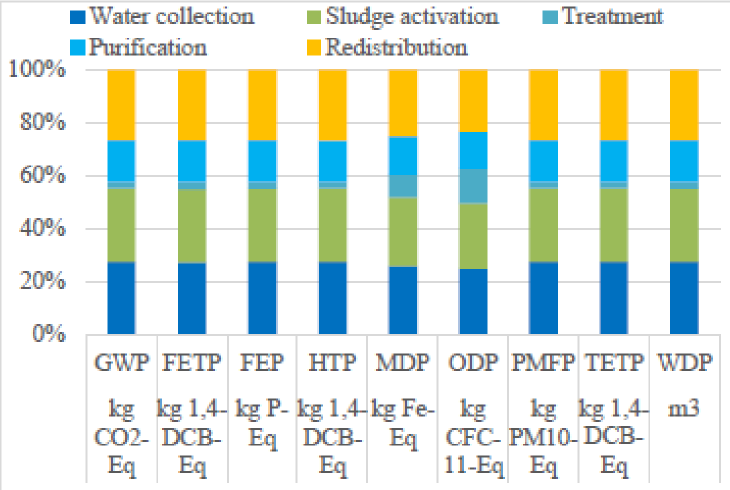

Fig. 4 Midpoint assessment results for five phases

The Fig. 4 shows the results of midpoint assessment, similarly as in endpoint assessment. As it is not possible to compare the results on same scale/axis in case of midpoint assessment due to different units of measurement. Thus, the percentage distribution result of the midpoint assessment shows that the treatment phase of the wastewater treatment process is having almost negligible effect on environment as compare to the other phases. Second all the other phase shows a similar patterns of impact in all the categories. Similarly, as in the endpoint assessment, more impacting treatment phases are water collection, sludge activation, and redistribution. The result of the midpoint assessment is tabulated in Table 2.

Table 2 Midpoint assessment results of the study

Unit ➡	kg CO2-Eq	kg 1,4-DCB-Eq	kg P-Eq	kg 1,4-DCB-Eq	kg Fe-Eq	kg CFC-11-Eq	kg PM10-Eq	kg 1,4-DCB-Eq	m3
Phase	GWP	FETP	FEP	HTP	MDP	ODP	PMFP	TETP	WDP
Water collection	295.7	1.8	0.1	3491.4	1.6	0.0	1.0	0.1	0.9
Sludge activation	295.7	1.8	0.1	3491.4	1.6	0.0	1.0	0.1	0.9
Treatment	28.2	0.2	0.0	296.2	0.5	0.0	0.1	0.0	0.1
Purification	166.6	1.0	0.1	1967.7	0.9	0.0	0.5	0.0	0.5
Redistribution	283.2	1.7	0.1	3357.0	1.5	0.0	0.9	0.1	0.9

To visualize these environmental impacts with more clarity, the results are described with all the transitions in terms of the midpoint impact categories as shown in Fig. 5. It is found that the electricity requirement for aeration tank, wastewater collection, treated water distribution, and dual media filter, have more impact in all categories of midpoint assessment.

Whereas chlorine used for the treatment process has shown a little impact in MDP and ODP categories.

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

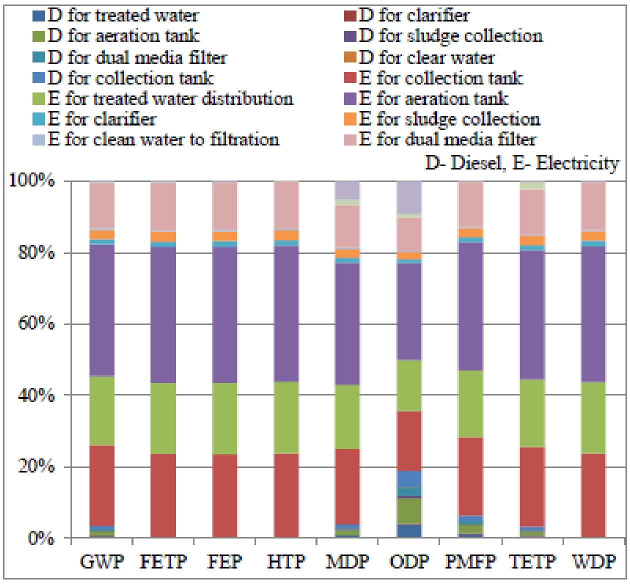

Fig. 5 Midpoint assessment results in terms of energy and material consumption

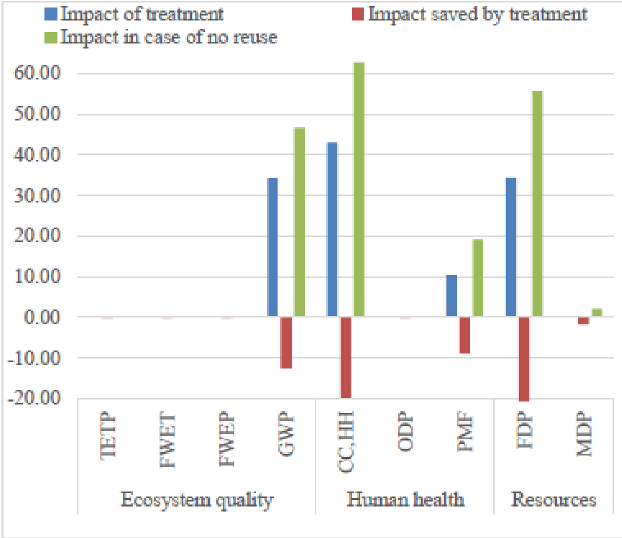

Fig. 6. Endpoint assessment of treatment process, treated water reuse and no reuse

Further, it is observed that electricity required for sludge collection and clarifier also have a little impact in all categories of midpoint assessment.

Impact assessment of water savings

The impact saved due to the reuse of treated water for irrigation purpose (garden, lawns, and field) is discussed in Fig. 6. To visualize the environmental impact by the means of treated water, three conditions are discussed. First condition, if the wastewater is treated and its impact on environmental is assessed. The second condition is a consequence of thewastewater treatment; the treated water is used for irrigation purpose. Hence, the impact of equivalent quantity of freshwater is saved. The third condition shows the impact of treated water if it is not reused. It is observed from the results that the treated water used for irrigation purpose significantly reduce the environmental impact in all the categories (table 3).

Table 3 Results of impact saving through reuse of treated water

Endpoint categories ➡	Ecosystem quality (in points)			Human health (in points)			Resources (in points)		
	TETP	FWET	FWEP	GWP	CC-HH	ODP	PMF	FDP	MDP
Impact of treatment	0.06	0.01	0.03	34.17	43.01	0.00	10.36	34.33	0.33
Impact saved by treatment	-0.05	-0.02	-0.02	-12.45	-19.70	0.00	-8.86	-21.25	-1.75
Impact in case of no reuse	0.11	0.03	0.06	46.62	62.71	0.00	19.21	55.57	2.08

Due to the shear share of GWP, CC-HH, FDP, and PMF categories is more in the all categories. It is showing a significant contribution to reduce the environmental impact in the graphical representation. In the second part of this section, the midpoint impact is also represented as shown in Fig. 7.It is observed that the water depletion potential has shown significant reduction in impact categories, which is but obvious. Second, if the magnitude of the other categories is estimated, it shows a very less or negligible impact in all the categories beside the GWP.

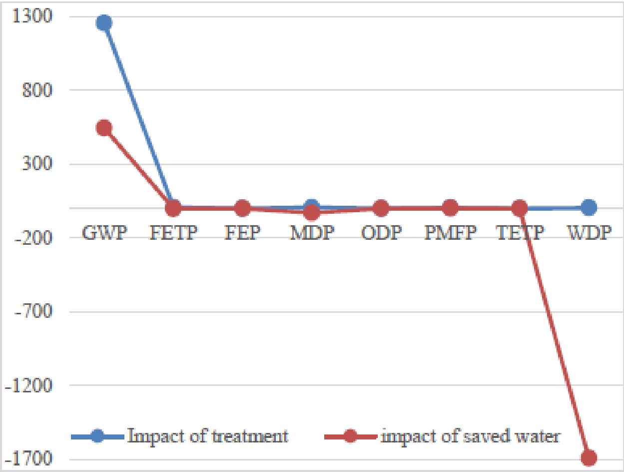

Fig. 7 Midpoint assessment of treated water reuse

7. Conclusion

This paper presents assessment of a waste water treatment plant at a university campus. It has been found that the electricity required to carry out the whole treatment process (water collection, sludge activation, treatment, purification, and re-distribution) has the highest impact in all assessment categories. It has also been observed that the use of treated water for irrigation purpose is mitigating the impact generated by the treatment process to a large extent and ultimatelydecreases the environmental burden. It is to be noted that the global warming potential increases with the treatment but the water depletion potential decreases. This study helps the decision makers to take an informed decision to select between treatment or no-treatment (no reuse) of wastewater. This study limits its analysis within the system boundary under consideration. However, this study has not considered the use of sludge for fields as a replacement of fertilizers. Studies like this can guide the authorities and government to optimize the process parameters to reduce the environmental impact. This wastewater treatment model can be extended to assess the environmental impacts of the larger areas like cities or towns where the wastewater supply and redistribution network also plays a vital role in the energy consumption. It will be interesting to see the combined negative environmental impact of treatment and positive effects of treated water reuse and sludge use as compost for gardening and/or agriculture.

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