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Construction of a large water treatment plant: appraisal of environmental hotspots

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ABSTRACT

The objective of this study is to examine the environmental impacts arising from the construction phase of a large conventional water treatment plant located in Istanbul by adopting a life cycle assessment methodology. The facility has a maximum flow rate of 400,000 m^3/d and serves a population of about 2,600,000. A conventional treatment technology composed of rock and fine screens, aeration, coagulation-flocculation units, clarifiers, filters, chlorination, and sludge handling units, is used in the plant. The functional unit is 1,000 kg (1 m^3) treated water. The investigated environmental impact categories are: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), abiotic depletion potential fossil (ADP fossil), freshwater aquatic ecotoxicity potential (FAETP), human toxicity potential (HTP), marine aquatic ecotoxicity potential (MAETP), and terrestrial ecotoxicity potential (TETP). The main contributors to GWP, AP, EP, and HTP are concrete and structural steel. FAETP and TETP are mostly arising due to the polyvinyl chloride pipelines and membranes, and the concrete used. The main shares in MAETP are concrete, aluminum, and structural steel. Transportation does not have a significant contribution to environmental impacts.

Keywords: Water treatment; Sustainability; Life cycle assessment; Construction; Environmental impacts

1. Introduction

Water treatment plants provide one of the most vital services, especially in metropolitan areas. On one hand, quite a high number of populations reach safe water due to such facilities, on the other these premises impose negative impacts on the environment. Construction, operation (treatment) and demolition (decommissioning) of these plants generate considerable amounts of environmental impacts.

Life cycle assessment (LCA) is a well-established tool for quantifying the environmental impacts of products/functions/services. Depending on the scope chosen, LCA can cover various stages of the lifecycle, such as construction, operation, and end of life. A range of environmental impact categories can be appraised all at once with LCA methodology. The usage of LCA methodology yields a holistic and sound appraisal. Reliable results are obtained especially when the LCA study depends on data of a certain geographical area or collected from the actual site. LCA is widely used to examine water and wastewater systems.

Environmental impacts of water supply systems are investigated in literature via LCA by defining different boundaries. In some of these studies water supply, usage, and wastewater treatment are explored [1,2]; some concentrated on the whole urban system by covering a wide range of activities starting from raw water abstraction and

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purification to wastewater treatment [3,4]; and some just focused on potable water treatment and compared different technologies [5,6]. Studies are targetting only operation stage [4]; construction, and operation phases [7–9]; or the entire life cycle composed of construction, operation, and infrastructure dismantling [10]. Besides LCA is also adopted for benchmarking the current and future environmental impacts of various water systems (i.e. highly purified recycled water vs. tap water) in four decades [11]. Friedrich and Buckley [12] compared conventional and membrane technologies for water treatment in South Africa by investigating the operation and decommissioning stages and excluding the construction phase and determined that for both technologies electricity consumption cause the highest environmental impacts. Environmental burdens of construction, operation and decommissioning phases of a centralized water system composed of water supply and wastewater collection and treatment are subjected to LCA [13]. The environmental impacts of incorporating nanofiltration into a conventional water treatment system are addressed by considering the construction and operation stages [9]. Nanofiltration improves the treated water quality as expected but an elevation on environmental impacts is observed due to the surplus energy and material requirements [9]. Construction and operation phases of drinking water treatment systems based on different ion exchange configurations are investigated in terms of their environmental impacts [7]. For mixed flow ion exchange system environmental impacts of construction are less than 10% of the total impacts for ozone depletion, global warming, smog, acidification, carcinogenic, respiratory effects and fossil fuel depletion categories. Again for the same configuration (mixed flow ion exchange), slightly more contribution (ranging from 20% to 30%) of construction is stated for eutrophication, non-carcinogenic and ecotoxicity due to the production of electronic equipment for control panels [7]. On the other hand, for fixed bed ion exchange system, approximately 20%–25% of the total impacts are originated from the construction phase for carcinogenic and ecotoxicity, namely. Such findings are obtained as a result of using reinforced steel in pumps [7]. Bonton et al. [14] compared a nanofiltration plant in Quebec with a virtual conventional water treatment plant covering construction, operation, and demolition phases. Their results show that the conventional system causes a higher burden compared to nanofiltration even though electricity usage is more in the latter system; this result is explained by hydroelectricity being the main energy source [14]. Igos et al. [15] investigate infrastructure and operation phases of two water treatment plants in France and conclude that usage of fossil resources for electricity generation and activated carbon production are the main causes of environmental burdens. In a recent paper, Garfi et al. [16] analyze water treatment with different methods and mineral water consumption alternatives and concludes that tap water is a better alternative than bottled water in terms of environmental concerns.

It is stated that the results of LCA studies that depend only on data obtained from existing databases and literature can be insufficient in reflecting the local conditions [3]. Therefore, such results might misguide decision-makers [3]. In this respect, the incorporation of local data in LCA is necessary to get concrete, dependable outcomes. Environmental impacts of the operation phase of a water treatment plant are studied in detail by modeling the data obtained from the actual site in Turkey [17]. However, there is not any research performed on the environmental burdens arising from the construction phase of a water treatment plant in Turkey. As indicated earlier, a case-specific comprehensive evaluation based on data collected from the site is of importance in achieving a solid management strategy.

In this context, the objective of this study is to investigate the environmental impacts generated during the construction phase of a large water treatment plant located in one of the most crowded cities in the world, Istanbul. The treatment technology applied in the plant is a conventional one. This study is a pioneering one based on actual data in Turkey.

2. Materials and methods

The LCA methodology is applied by following four iterative steps of goal and scope definition; inventory analysis; impact assessment; interpretation, in line with ISO 14040–14044 standards [18,19].

2.1. Scope of the study

This study focuses on the LCA of the construction phase of the Büyükçekmece water treatment plant in Istanbul. The functional unit is defined as 1,000 kg (1 m^3) potable water and the impacts are calculated per this functional unit. GaBi software version 7.3 is adopted for modeling and a professional database is used for background processes. Both the GaBi software and professional database are developed for LCA modeling by thinkstep AG. Primary data obtained from the facility is fed into modeling. For the classification and characterization stage of LCA, input and output flows are converted to impact categories according to characterization factors in Centrum voor Milieuwetenschappen 2001 methodology, January 2016 version [20]. Chosen impact categories are; global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), abiotic depletion potential fossil (ADP fossil), freshwater aquatic ecotoxicity potential (FAETP), human toxicity potential (HTP), marine aquatic ecotoxicity potential (MAETP), terrestrial ecotoxicity potential (TETP).

Büyükçekmece water treatment plant having a daily potable water production of 400,000 m^3, withdraws water from Büyükçekmece lake which is located on the western side of Istanbul. The facility serves a population of about 2,600,000. The plant treats the water with conventional technology, composed of; screening, inlet pumps, aeration, mixing (rapid and slow), sedimentation, filtration, disinfection, storage, and outlet pumps. The flow chart of the water treatment plant is given in Fig. 1.

Lake water supplied from Büyükçekmece lake with four pumps (of which 3 in operation and 1 in standby) is sent to aeration. Aluminum sulfate is fed to aerated water in the rapid mixing, and flocculation occurs in the slow mixing phase where the polyelectrolyte is added. In the sedimentation stage, flocs settle down and clarified water is directed towards filtration, filtered water is stored in the underground reservoirs and pumped with 7 pumps (5 in operation and 2 standby) to the distribution network. Chlorination is used for disinfection purposes. Detailed information about the treatment plant together with the environmental burdens of its operation phase can be found in the literature [17].

The total lifetime of the plant is considered as 40 years. The system boundary adopted for the LCA study is illustrated in Fig. 2.

As evident from the figure construction phase covers material extraction and processing, transportation of these materials to the construction site and construction works.

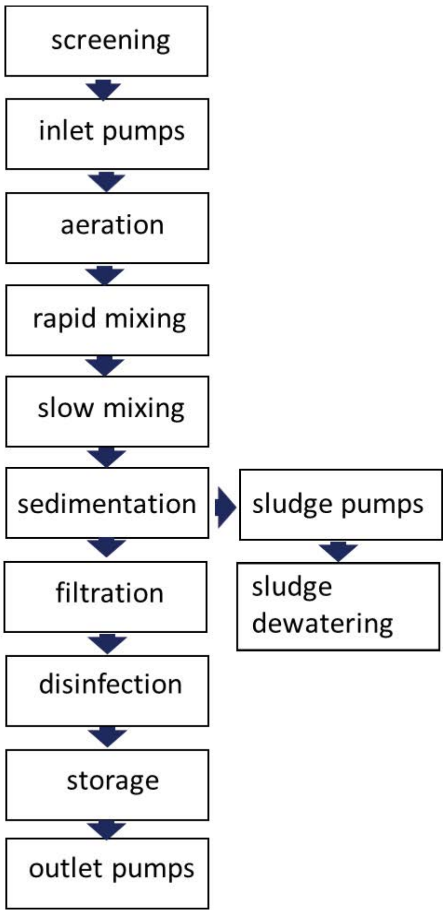

Fig. 1. Process flow chart of Büyükçekmece water treatment plant.

2.2. Life cycle inventory

Construction data of the Büyükçekmece water treatment plant is collected directly from the facility as primary data. The amounts of construction materials are obtained from the original tender documents. Data on soil excavation is estimated based on engineering assumptions using the data on tender documents. Transportation of building materials is also gathered from the data in tender documents.

Construction data is collected both for the units of the water treatment plant and management building. The data on construction is gathered under four subheadings; (a) structure, (b) pipelines, (c) pumps and machines, (d) filters and membranes.

For establishing the water treatment plant, concrete, reinforced concrete and steel are used. Polyvinyl chloride (PVC) pipes with 100, 125, and 150 mm diameter and concrete channels are used as the pipelines.

Data on type of pumps and thickener together with their weight are collected during the site visits. The pumps and sludge thickener are assumed to be made up of 70% steel and 30% copper. The amount of materials used in management building is calculated by using the plans. Electricity consumption during construction is estimated according to the literature [19].

Total amounts of the materials and electricity used together with the information on an excavation in the construction are given in Table 1.

Inventory related to pumps and sludge thickener is tabulated in Table 2.

Transportation of the construction materials is also included in the scope of the study. Data on material transportation is summarized in Table 3. Trucks running with diesel are used as vehicles.

An LCA model is constructed by using GaBi software based on the inventory data collected from the actual facility. A professional database that contains 3908 processes is used for background plans. The following processes obtained from the mentioned database are used in this study: concrete, steel, aluminum, copper, timber, PVC and electricity production, concrete pipe and concrete bricks production, pumping of concrete and excavation processes and lorry transport. These processes include raw material extraction and processing for production.

The electricity of Turkey does not exist as a single process in the used version of the database. As grid mixes and

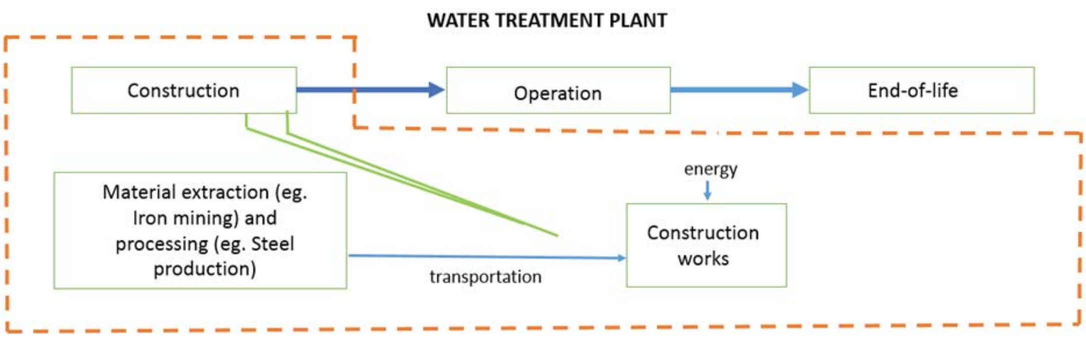

Fig. 2. Investigated system boundary.

their impacts are very different for each country, a new process is created for the electricity grid mix of Turkey based on Turkish electricity generation data [20]. According to the report of The Electricity Generation Corporation of Turkey, energy sources of the Turkish grid mix are made up of 24.7% hydraulic, 32.3% natural gas, 32.9% coal, 5.7% wind, 2.6% solar, geothermal and biomass [22].

3. Results and discussion

Results obtained for the construction are tabulated in Table 4. The contribution of the treatment plant and office building are considered separately.

As evident from Table 4 and Fig. 3, the construction of water treatment units has the highest shares on the environmental impacts of total construction. This contribution is more than 77% for all the investigated environmental impact categories.

The contribution of various factors to the environmental impacts of the construction phase is illustrated in Fig. 4.

Concrete has 41%, 41%, and 33% shares while structural steel has 28%, 28%, and 38% shares to EP, GWP, and AP, respectively. Friedrich [23] indicates GWP of construction mainly arises due to the production of steel and cement for a conventional water treatment plant. The results of this study are by the literature [23], as the main contributors to GWP are concrete and structural steel. The findings of the current study denote that concrete has the highest share in EP and structural steel is among the main sources of AP. A literature study states the production of cement as the main source of AP and EP during construction [23]. In this respect, the outcomes of this study are in line with the literature [23]. From another perspective, 30% and 18% EP arise due to nitrogen oxide emissions during concrete and steel production, namely. CO_2 emissions that take place in concrete and steel production are the main cause of GWP. The main reason for AP is sulfur dioxide and nitrogen oxide emissions during steel and concrete production. On the other hand, the total impact of ADP fossil is made up of structural steel (by 31%), concrete (by 25%), electricity (16%) and; PVC pipes and membrane (14%). From a different angle, 53% and 16% of ADP fossil are generated because of hard coal and crude oil consumption. Hard coal is used during steel and concrete production. Crude oil, on the other hand, is utilized not only during the steel and concrete production but also in other manufacturing processes. Of the total FAETP, 54% arises from PVC pipes and membrane and 22% from concrete. The main contributor to FAETP is vanadium emissions that take place during PVC manufacturing. Around 56% of HTP is of concrete origin whereas 18% of it is from structural steel. Approximately 38% of HTP is generated due to polycyclic aromatic hydrocarbon emissions that take place in concrete production. Arsenic emissions to air originating from both steel and concrete production cause about 15% of HTP. The following items are the ones mainly contributing to MAETP: 24% from concrete, 17% from aluminum ingot, 31% from structural steel and 10% from electricity. Hydrogen fluoride emissions that take place during steel and concrete

Table 1
Total amounts of materials, electricity, and excavation used in the construction of water treatment plant and office building

Material/ Energy	Type	Total amount	Unit
Concrete	Non reinforced cement 15–20	8.43E + 06	kg
	Non reinforced cement-30	9.63E + 05	kg
	Non reinforced cement-35	2.41E + 05	kg
	Reinforced concrete B.300	3.61E + 06	kg
	Blocks	3.65E + 06	kg
Steel	Steel bars, wires	2.30E + 06	kg
	Steel used in doors, windows	7.30E + 04	kg
Aluminium	Aluminium windows, doors	1.10E + 04	kg
PVC	Pipelines	1.29E + 04	kg
	PVC bed for filters	4.00E + 05	kg
Excavation	Excavated soil	1.65E + 07	kg
Copper	Copper	1.82E + 04	kg
Electricity	Electricity	1.86E + 07	kwh

Table 3
Data on transportation of construction materials

Materials	km
Steel (89%)	443
Steel (2%)	512
Steel (9%)	1,270
Wire	1,270
Other construction materials	60
Filter bases	60
Crushed stones	200
Marble	196

Table 2
Inventory of pumps and other machinery

Location of the pump	Number and type	Total kg
Chemical building pumps	5 pumps of $ALSO_4$ - IDEX	200
Chemical building pumps	5 pumps of Polyelectrical - IDEX	200
Main withdrawal pumps	3 pumps - SIEMENS	10,800
Main withdrawal pumps	1 pump - MARATHON MOTORS	3,600
Clean water pumps	8 pumps - SIEMENS	28,800
Sludge thickener	LOHER - GEA Westfalia Separator	13,000

Table 4
Environmental impacts arising from the construction of office building and various units of the water treatment plant

	Total (construction)	Office building	Water treatment units
ADP fossil [MJ]	3.28E-02	7.04E-03	2.57E-02
AP [kg SO_2-Equiv.]	9.48E-06	8.26E-07	8.65E-06
EP [kg phosphate-Equiv.]	1.07E-06	1.04E-07	9.66E-07
FAETP [kg DCB-Equiv.]	1.63E-05	7.09E-07	1.56E-05
GWP 100 years [kg CO_2-Equiv.]	3.71E-03	5.81E-04	3.13E-03
HTP [kg DCB-Equiv.]	6.71E-04	5.88E-05	6.12E-04
MAETP [kg DCB-Equiv.]	2.78E-01	4.93E-02	2.28E-01
TETP [kg DCB-Equiv.]	1.68E-05	3.20E-07	1.65E-05

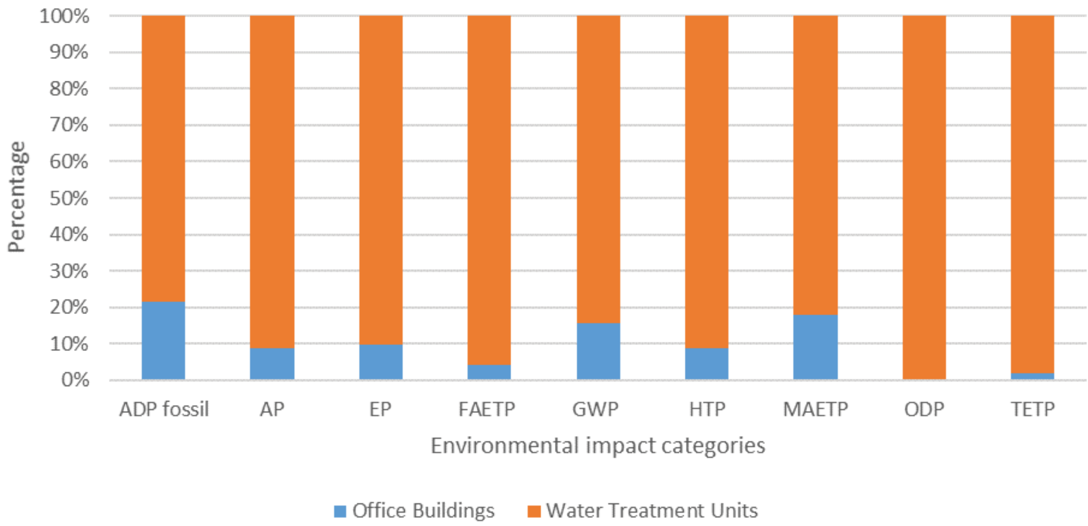

Fig. 3. Percent contribution of water treatment units and office building in environmental impacts of construction.

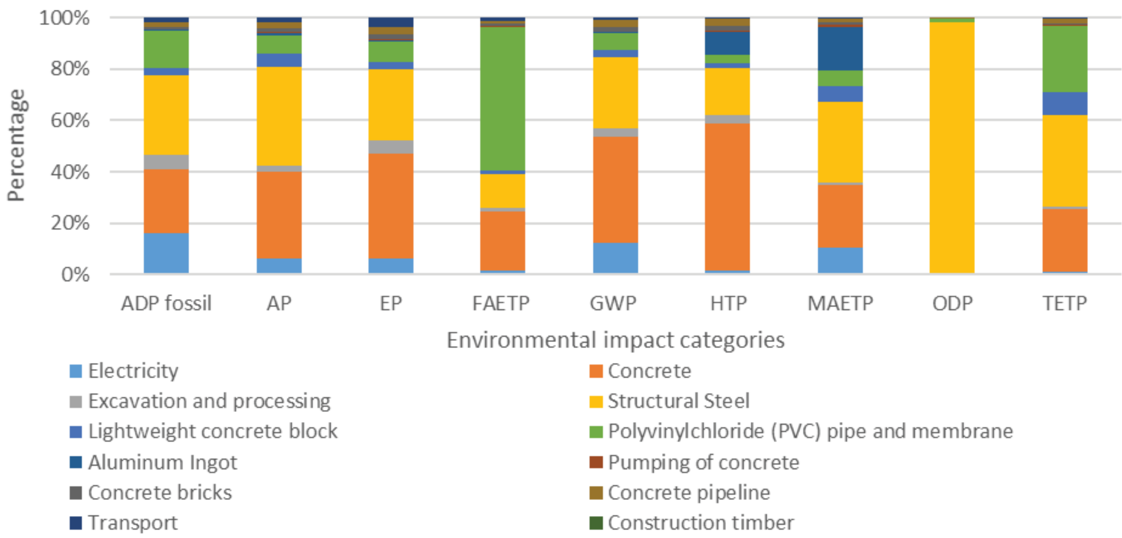

Fig. 4. Contribution of various factors to environmental impacts during the construction phase.

production is the main source of MAETP, as 37% of MAETP comes from the mentioned emissions. Approximately 25% of TETP is generated by PVC pipes and membrane, while 24, 9% and 35% of it is from concrete, lightweight concrete block, and structural steel, respectively. From another standpoint, 27% of TETP is originated from chromium emissions to air during steel production; 17% of it is of mercury emissions to air in PVC manufacturing and 12% is of again mercury emission during concrete production.

For all the environmental impact categories, the contribution of transportation in the construction phase varies between less than 1% to 4%. Therefore, an insignificant contribution comes from transportation. A similar evaluation of the effect of transportation is stated by Friedrich [23].

During the construction phase to evaluate the possible changes in using various energy sources on impact categories, the following alternatives are considered: photovoltaics, wind energy and energy from the combustion of hard coal. The results obtained are illustrated in Fig. 5.

The source of energy does not have a significant effect on TETP and FAETP categories during construction. The usage of wind and solar energy reduce MAETP by 10% and 4%, namely. Energy from hard coal elevates MAETP by 12% in comparison with the grid mix. Wind and solar energy yield around 15% reductions on ADP fossil. However, a 15% elevation in ADP fossil is observed when using hard coal. An increase of about 10% is obtained in HTP due to hard coal. Wind or solar energy usage results in approximately 4% to 6%

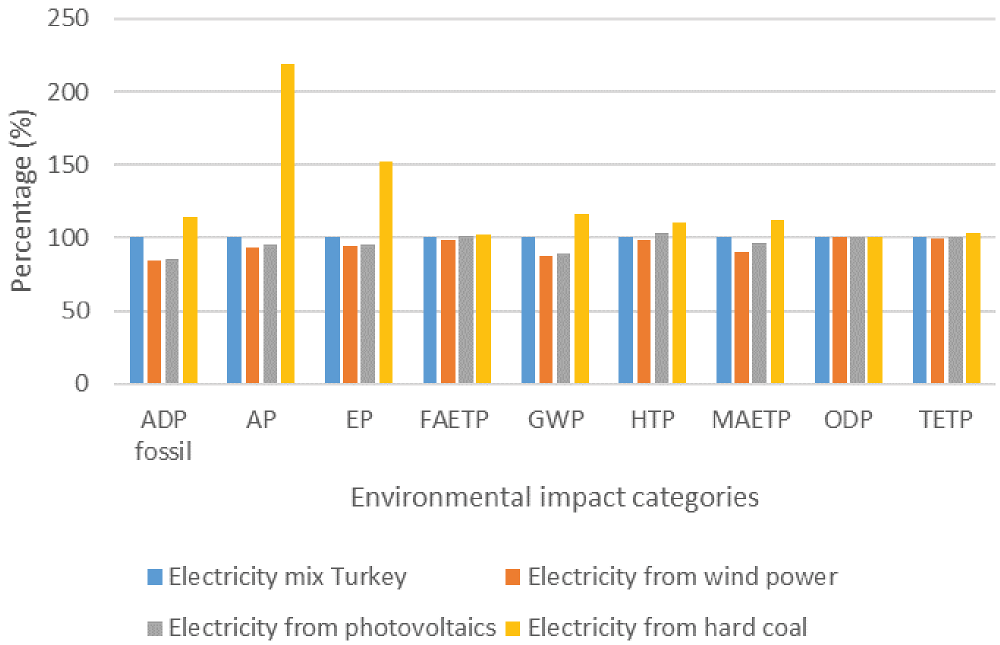

Fig. 5. Relative impacts of various energy sources with reference to grid mix for the construction phase.

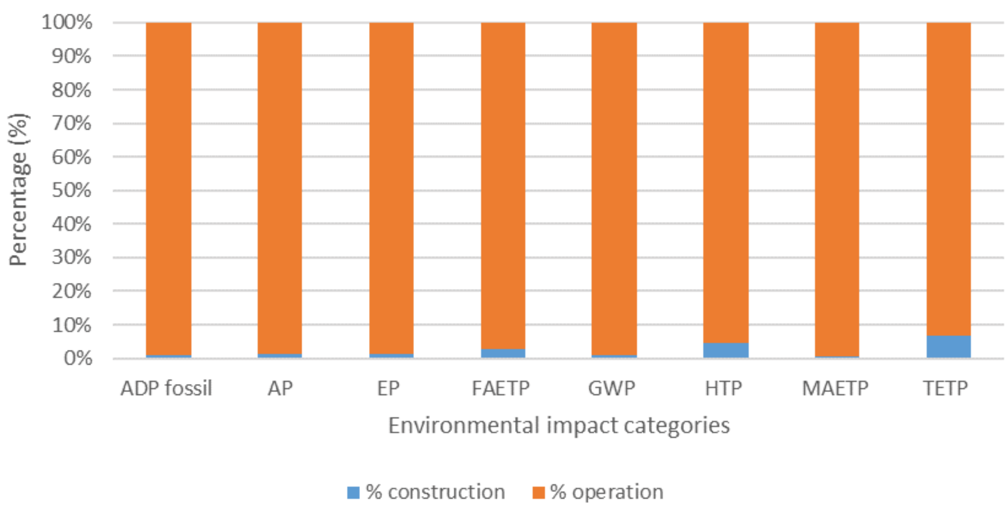

Fig. 6. Percent contribution of construction and operation phases in environmental impacts.

reductions in AP and EP, respectively. The usage of hard coal instead of the grid mix elevates EP by 53% and AP by 120%. Around 12% and 11% reductions are obtained in GWP due to getting energy from wind and solar sources while usage of solely hard coal rather than grid mix increases GWP by 16%.

Fig. 6 illustrates the comparison of the environmental impacts of construction and operation phases. The data related to the operation stage is obtained from the literature dealing with the same water treatment plant [24].

For all the impact categories, the construction stage contributes less than 7% to total when the construction and operation phases are considered together. This finding is in accordance with Igos et al. [15].

4. Conclusions

The following conclusions are obtained from this pioneering study that involves the environmental impacts of the construction phase of a large water treatment plant.

More than 77% of all the investigated environmental impacts arise from the construction of the treatment units. The rest is allocated to the construction of the office building.

During the construction phase, concrete and structural steel are the principal contributors to EP, GWP and AP impact categories. ADP fossil is of structural steel, concrete, electricity and PVC pipes and membranes origin. PVC pipes, and membranes together with concrete are mainly responsible for FAETP and TETP. HTP is mainly generated due to concrete and structural steel usage. Concrete, aluminum ingot, structural steel and electricity inputs are the leading contributors to MAETP.

Transportation has an insignificant share of environmental impacts.

It is recommended to conduct similar research activities by using site-specific data. The rise in such research activities will aid in establishing an LCA database for Turkey.

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