Environmental accounting – a decision support tool in WWTP operation and management

J. Clauson-Kaas*, T.S. Poulsen*, B.N. Jacobsen, T. Guildal** and H. Wenzel*****

* COWI Consulting Engineers and Planners, Parallelvej 15, 2800 Lyngby, Denmark

** Avedore Wastewater Services Company, Kanalholmen 28, 2650 Hvidovre, Denmark

*** Institute for Product development, Technical University of Denmark, 2800 Lyngby, Denmark

Abstract The various emissions to water, air and soil from the municipal wastewater treatment plant of Avedore Wastewater Service Company are accounted for and quantified in terms of the environmental impacts to which they contribute: global warming, acidification, eutrophication, space demand for controlled deposition of residues, as well as persistent toxicity, human toxicity and eco-toxicity. The impacts are expressed on the same scale, namely as fraction of the total per capita loads in a national scenario 1990, also called the person equivalent or PE_{1990}. This provides a compact and informative overview of the environmental impacts and allows for a holistic prioritisation in the operation and management of the plant. The accounting shows that the resulting emissions per person in the catchment area of the plant correspond to 0.5–5.0% of the average Danish PE_{1990} for the impacts in question.

Keywords Wastewater treatment; energy; resources; life cycle analysis; LCA; environmental impact

Introduction

The Avedore Wastewater Services Company is a publicly owned non-profit organisation. The primary function is to treat urban wastewater from ten municipalities situated as suburbs in the west part of Copenhagen, Denmark. Referring to CEN-terminology (CEN, 1997), the plant load corresponds to 365,000 PE_{B60}. With about 240,000 persons connected to the plant, the industrial organic load thus accounts for about 1/3 of the total organic load.

The wastewater undergoes tertiary treatment and meets the Danish national effluent standards as well as the EU Urban Wastewater Directive (91/271/EEC). The treatment processes include biological nitrogen and to some extent phosphorus removal with supplementary chemical phosphorus precipitation before the secondary clarifiers. The sludge undergoes anaerobic digestion, centrifugation and incineration; the residual ash is retained in a deposit area within the plant.

Traditionally, the main objectives and criteria for success in wastewater treatment plant (WWTP) operation have been to obtain compliance with the effluent standards at the lowest cost possible. Optimisation of the operation of a WWTP, thus, traditionally only focuses on the wastewater effluent, and measures for a more holistic optimisation within the frames of the standards are not normally seen. At a certain point, however, further polishing of the traditional parameters in the wastewater may not be the highest priority and may even lead to a higher environmental impact in the overall picture.

An environmental policy has recently been adopted by Avedore WSC. The policy includes the following main headings:

- minimise impact on environment and human health
- minimise resource consumption
- improve occupational health and safety
- prioritise purchases and investments based on both environmental friendliness and cost
- collate, document and communicate environmental know-how

The Avedore WSC has prepared annual Environmental Accounts for 1998 and 1999

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(being processed). It is based on the concept that the organisation is regarded as a company producing treated effluent with wastewater as the raw material. Energy and additives (iron-salts for precipitation, polymer for sludge dewatering) are consumed in the production process. Sludge and biogas are by-products with a potential for reuse. For the accounting, the so-called EDIP-method is used. The WWTP process is shown in Figure 1.

The EDIP method

The EDIP method is a so-called Life Cycle Assessment (LCA) method for assessing the environmental properties of products. It was published in English in 1997 and has since then won recognition worldwide (Wenzel *et al*., 1997). It has become the national method of reference in Denmark and in 1997 it won the Nordic Nature and Environment Prize. It meets the requirements of the recent LCA standards as expressed in the ISO 14040 series.

One of the method's components is the impact assessment part, within which emissions to air, water and soil can be assessed and quantified as impact potentials in various environmental impact categories. The first step of this quantification is to express substances contributing to the same impact category in one and the same unit. As examples, greenhouse gases like CO_2, CH_4 and N_2O are all expressed as CO_2-equivalents, while acidifying substances like SO_2 and NO_x are all expressed as SO_2-equivalents (see Table 1). This facilitates the comparison of individual substances within the same impact category. Subsequently, these impact potentials are all normalised with the background loads from the whole society expressed per capita, thereby showing contributions to all impact categories on the same scale, namely as person equivalents, PE. As normalisation reference the background load for the year 1990 is used, and the unit referred to is thus the PE_{1990}. Table 1 shows the environmental impact categories and contributory substances relevant for this activity.

This method of impact assessment has been found appropriate in many applications, where decision support and the setting of priorities in a holistic way is needed. It is found useful for environmental accounting and decision support in operation and management of Avedore WWTP because it shows the proportions of the various environmental impacts to which the plant contributes and of the various unit operations of the plant compared to each other. The fact that impacts are expressed in person equivalents, which is a concept known to WWTP operators and managers has proven to be of pedagogical value.

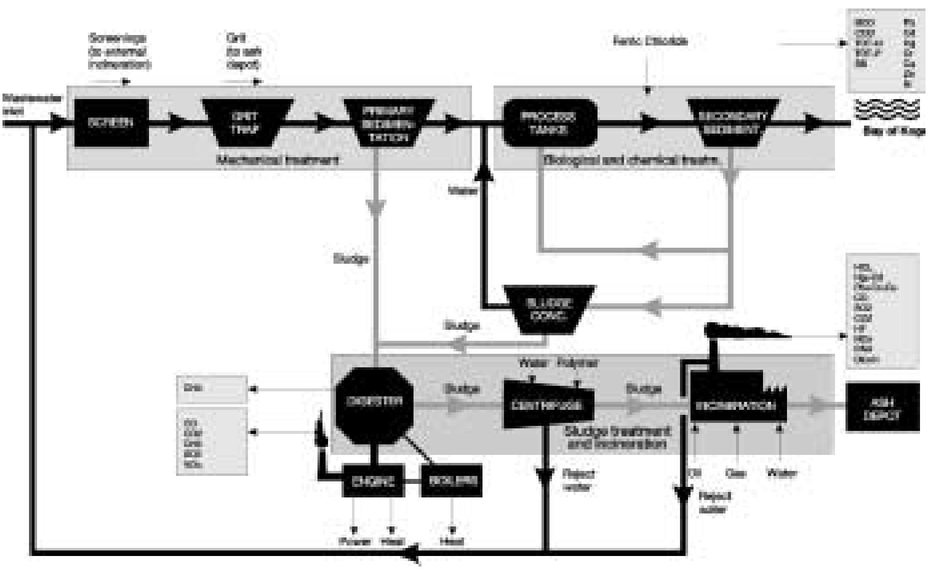

Figure 1 Avedore WWTP-Process, Consumption and Discharges/Emissions

Table 1 Environmental impact category

Impact	Global Warming	Acidification	Nutrient enrichment	Eco-toxicity	Human toxicity	Persistent toxicity	Slag & ashes
Unit	CO_2	SO_2	NO_3	m^3 water necessary for toxic neutralisation	m^3 air necessary for toxic neutralisation	m^3 water necessary for toxic neutralisation	Slag & ashes
Contributing substances	CO_2, CO, CH_4, HC	SO_2, NO_x, H_2S, NH_3, HCl	N, P	Pb, HG, Cu, Zn, Cr, Ni, Se, As, Cd	Pb, Cd, Hg, Cu, Ni, As, NO_x, SO_2, CO, Dioxin, HCl	Pb, Hg, Cu, Ni, Cd, As, Dioxin	Waste from incineration

Results and discussion

The environmental accounting for Avedore WSC includes an overview of the production and consumption at the wastewater treatment plants as shown in Table 2 and a listing of discharges and emissions arising from the various activities related to the plant operation as shown in Table 3. In the environmental accounting, the production and consumption is calculated per m^3 wastewater discharged and per person equivalent (PE_{B60}) treated. This facilitates comparison to other wastewater treatment plants and to previous years of operation. Thus, e.g. the sludge production per PE_{B60} or the power consumption per m^3 of wastewater treated can be compared to previous years' operation to measure if the efficiency of treatment has improved.

The discharges and emissions are calculated for the chemical substances that contribute to the groups of environmental impacts found relevant for a WWTP. The content of the emissions and discharges from individual activities are explained in the following.

Power consumption. The Avedore WSC had in 1998 a total power consumption of 16.3 million kWh, of which 5 million kWh were produced internally from biogas. The consumption of external power produces emissions of CO_2, NO_x and SO_2.

Biogas. Biogas is used for generating power in two gas engines. The exhaust from the gas engines includes CH_4, NO_x and SO_2. The gas engines will also emit CO_2, but this is not

Table 2 Overview of the production and consumption on the Avedore WWTP

	1998 Total	1998 per m^3 wastewater	1998 per PE_{B60}
Wastewater	29,800,000 m^3		
Person equivalents*	365,000 PE		
Overflow during rain	670,000 m^3	22.5 l	1,836 l
Biogas production	3,700,000 m^3	0.12 m^3	10.1 m^3
Power production	4.94 GWh	0.17 kWh	13.5 kWh
Sludge (dry solids)	6,439 t	220 g	17.6 kg
Consumption			
Power consumption	16,340 MWh	0.55 kWh	45 kWh
Oil	1,055 m^3	35 ml	2.9 l
Water	9,362 m^3	315 ml	26 l
Treated wastewater**	1,025,000 m^3	34 l	2.8 m^3
Polymer	43 t	1.44 g	118 g
Ferric Chloride	1,835 t	60 g	5 kg
Pesticide (active)	6.4 kg	–	–

(*) 1 Person equivalent (PE) is defined as 60 g BOD/d and expresses 1 persons average load of organic matter

(**) Treated wastewater which is used for flue gas scrubbing and dissolving polymer included in the environmental account, as biogas is considered CO_2-neutral. (Only fossil fuel contributes to CO_2 build-up). The emission of CH_4 originates from unburned hydrocarbon (approximately 3% of the methane fed into the gas engine).

Heat. When power is produced from biogas, the gas engines also produce heat, which is used for warming up buildings and to keep the temperature at 32°C in the digesters. The WWTP has boilers to provide further needed heating and hot water. The boilers are running on either biogas (from own production) or oil. The most important emissions from the heat production are NO_x, SO_2, CH_4, and CO_2. Only the CO_2 emitted from the oil based heating is included.

Emitted biogas. Surplus biogas is occasionally emitted, in particular during the summer season and when the sludge incineration plant is out of operation for maintenance. In 1998 3.4% of the biogas production was emitted. The plant does not have a surplus gas burner at present, and surplus biogas is emitted directly to the air. The biogas contains about 60% CH_4, which contributes to global warming by a factor of 25 compared to CO_2.

Sludge incineration. When incinerating the sludge, a number of gas components are emitted together with some heavy metals. When calculating the contribution to global warming, only the CO_2-emission arising from using oil in the incinerator is included. CO_2 from burning the sludge is not included. Among the heavy metals of importance included are Pb, Cd and Hg. When incinerating the sludge, ash is produced, which comprises heavy metals. The ash is deposited internally within the plant premises.

Wastewater discharge. When discharging the wastewater into the Bay of Koge, the wastewater contains nutrients that contribute to eutrophication and a range of heavy metals. There is a relatively high concentration of Zn, but also Cu and Cd are notable. The effluent concentrations are, however, at the same level as water quality criteria (Danish EPA, 1996) already before dilution in the receiving water.

Screening. At the inlet of the treatment plant screenings and grit are collected. The screenings (waste disposal) are taken to an external solid waste incinerator, which is emitting SO_2, HCl, and NO_2. This emission also include the reduced emissions of CO_2 from substituting fossil energy, as the screenings have some heating value and heat recovery takes place in the form of district heating.

Pesticides. Pesticides are used for weeding selected parts of the WWTP area.

Data quality. Most of the data used in the green account are collected regularly as part of the monitoring programme for the WWTP. Exceptions are the monitoring of air emissions from the biogas engines and from the sludge incineration. The data are based on a single annual analysis. Another exception is data for discharge of heavy metals with the effluent. These data are based on a weekly composite sample from 1997; the results were at comparable levels to four weekly composite samples taken in 1992.

By applying the EDIP-method to the values in Table 3, the relative contribution from Avedore WSC to environmental impacts can be estimated.

Based on the estimates in Table 3 the normalised environmental impacts from operating Avedore WWTP are shown in Figure 2. The figure is very compact in information, showing three issues in one overview. First, the fractionating of each bar reflects how the various activities related to the plant operation contribute to each of the environmental impacts. Secondly, the length of each bar compares to the size of different environmental impacts. Thirdly, the unit for this length indicates in relative terms the contribution from wastewater

Table 3 Contribution to environmental impact categories from activities at Avedore WWTP, 1998

Activity	Global Warming	Acidification	Nutrient enrichment	Eco-toxicity	Human toxicity	Persistent toxicity*	Slag & ashes
	CO_2 eqv.	SO_2 eqv.	NO_3 eqv.	m^3 water necessary for toxic neutralisation	m^3 air necessary for toxic neutralisation	m^3 water necessary for toxic neutralisation	Slag & ashes
Power, import	8,732 ton	33.7 ton	28 ton	0.8 million m^3 (chronic)	230 billion m^3	*	
Power, biogas	1,505 ton	44 ton	78 ton		510 billion m^3		
Heating	330 ton	1.5 ton	1.4 ton		10 billion m^3		
Biogas release	1,304 ton						
Sludge incineration	2,878 ton	19.2 ton	11.5 ton	200 million m^3 (chronic)	6,000 billion m^3	*	3,594 ton
Wastewater discharge			1,606 ton	5.3 billion m^3 (chronic)		*	
				550 million m^3 (acute)			
Waste disposal (screenings)	–150 ton (substitutes fossil energy)	0.5 ton	1 ton	–14,530 m^3 (chronic)	-6 billion m^3	*	10.6 ton
1 PE_{1990}	8.7 ton	0.12 ton	0.3 ton	38,000 m^3 (acute)	29 billion m^3	*	0.35 ton
				420,000 m^3 (chronic)			

* Persistent toxicity is a composite of partly Eco-toxicity and Human toxicity in water

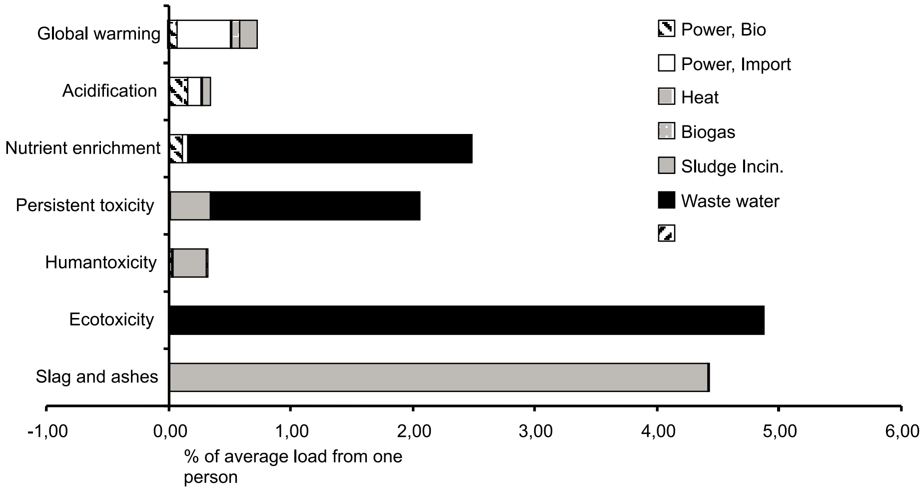

Figure 2 Normalised environmental impact from operating Avedore WWTP

treatment in percentage of the total national per capita environmental impact in question. The remaining contributions arise from e.g. direct discharges from industry, from agricultural activities, diffuse sources, etc.

The total load from the WWTP is divided by the number of persons connected to the WWTP and compared to the average load from one person in Denmark as per 1990 (1 PE_{PE}).

The national scenarios for total environmental impacts are well established for the upper four bars in Figure 2, whereas the scenarios for toxicity are still being developed.

Conclusion

The EDIP method – originally developed for life cycle assessment of industrial products – has proven to be a useful decision support tool in WWTP management and operation. The method provides a way to combine, compare and illustrate contributions from various types of environmental impacts from the most significant unit processes related to WWTP operation.

The method can be used for analysing the combined environmental impact from alternative technical solutions in a holistic approach. Improved effluent quality may be put from the perspective that it is obtained on the compromise of increased consumption of power or additives causing other environmental burdens.

At the Avedore WSC, the results from the green accounting in 1998 have led to an increased focus on establishing better data reflecting eco-toxicity and considerations of the potential for reusing sludge incinerator ash in construction materials.

The EDIP-method has provided the Avedore Wastewater Services Company with a useful tool to operate and manage the WWTP in an overall environmentally efficient manner and to prioritise future development of treatment methods and source control.

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