The use of life cycle assessment for evaluating the sustainability of the Amsterdam water cycle

E. Klaversma, A. W. C. van der Helm and J. W. N. M. Kappelhof

ABSTRACT

Waternet, the water cycle company of Amsterdam and surrounding areas, uses the life cycle assessment (LCA) method to evaluate the environmental impact of investment decisions and to determine the potential reduction of direct and indirect greenhouse gas (GHG) emissions of different alternatives. This approach enables Waternet to fulfil its corporate objective to improve sustainability and to become climate neutral by 2020. Three example studies that give a good overview of the use of LCAs at Waternet and problems encountered are discussed: phosphate removal and recovery from wastewater, pH correction of drinking water with carbon dioxide (CO_2) and materials for drinking water distribution pipes. The environmental impact assessments were performed in SimaPro 7 using the ReCiPe method and the Intergovernmental Panel on Climate Change Global Warming Potential (IPCC GWP) 100a method. The Ecoinvent 2.0 and 2.2 databases were used for the material and process data. From the examples described, it can be concluded that only the phosphate removal case had a significant effect on the climate footprint. The article discusses applications and limitations of the LCA technique. The most important limitation is that the impact of water consumption and the possible impact of effluent compounds to surface water are not considered within the used methods.

Key words | climate footprint, distribution pipes, life cycle assessment (LCA), pH correction, phosphate removal, water cycle

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INTRODUCTION

For Waternet, the water cycle company of Amsterdam and surrounding areas, improving the sustainability of the Amsterdam water cycle is one of the corporate objectives. Therefore, next to, for example, costs and quality, the environmental impact is taken into account when investment decisions are made. Waternet aims to become climate neutral by 2020 (van der Hoek 2011). This objective can be achieved by reduction and compensation of the greenhouse gas (GHG) emissions. Three types of GHG emissions are distinguished (The Greenhouse Gas Protocol 2004, chapter 4):

- Direct GHG emissions (scope 1).
- Indirect GHG emissions from electricity consumption (scope 2).
- Other indirect GHG emissions (scope 3).

From 1990 to 2010, Waternet has halved its climate footprint, mainly by purchasing 100% renewable electricity (reduction of scope 2 GHG emissions). However, the indirect emissions through use of materials and chemicals (scope 3 GHG emissions) have only been slightly reduced since 1990. These emissions are currently the largest contributor to the Waternet climate footprint (Figure 1). To reduce the scope 3 GHG emissions Waternet performs life cycle assessment (LCA) studies to find more sustainable alternatives for materials and chemicals used in water treatment. Examples of previous studies performed by Waternet were published by Barrios *et al.* (2008) and Tapia *et al.* (2008).

The current article discusses three LCA studies to support investment decisions; it is determined whether investigated alternatives contribute to the reduction of the

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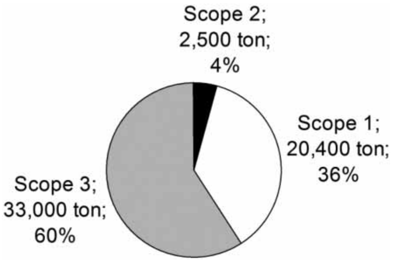


Figure 1 | Contribution of scope 3 to the total GHG emissions of Waternet in 2010.

scope 3 GHG emissions. The examples give an overview of the work performed by Waternet and the problems encountered.

MATERIALS AND METHODS

To take environmental aspects of investment decisions into account, Waternet performed in the past 3 years about 10 LCA studies. Three of these LCA studies and the potential for scope 3 GHG emissions' reduction in the Amsterdam water cycle are described:

- Phosphate removal and recovery in wastewater treatment.
- pH correction with carbon dioxide in drinking water treatment.
- Materials for drinking water distribution pipes.

The environmental impacts of studied alternatives were assessed with LCA, according to the methodology defined by the International Organisation for Standardisation in the ISO-14040 standard (ISO 2000) for the evaluation of the environmental impacts of a product, service or process over its life cycle. In LCA, the inputs into the life cycle (energy and materials) and the outputs from the life cycle (energy, materials, wastes and products) are evaluated for each step of a product, process or service (Ciambrone 1997). For determining the environmental impacts the LCA methodology described by Goedkoop & Spriensma (2000) was followed. The methodology consists of defining the goal for the assessment, the system boundaries, the functional unit and performing the impact assessment. Waternet normally uses the ReCiPe method (Goedkoop *et al.* 2008), because that method evaluates a wide range of environmental problems, like climate change, fossil (fuel) depletion, toxicity and land occupation, and all these problems are weighed by a panel of experts to come to only a single score expressed in eco-points per functional unit. To determine the effect of the scope 3 GHG emissions on the Waternet climate footprint, the Intergovernmental Panel on Climate Change Global Warming Potential (IPCC GWP) 100a method (Solomon *et al.* 2007) was used. Within this method, only the environmental problem climate change is evaluated and the results are expressed in CO_2 equivalents.

The calculations of the environmental impacts with both methods were done with the program SimaPro 7. For the case of phosphate and distribution pipes, the Ecoinvent 2.0 database was used and for the pH correction case the Ecoinvent 2.2 database.

RESULTS AND DISCUSSION

Phosphate removal and recovery in wastewater treatment

Wastewater treatment plant (WWTP) Amsterdam West (~1 million population equivalent) is designed to remove phosphate purely biologically, however, in practice this is not the case. At the moment, ferric chloride ($FeCl_3$) is dosed for extra phosphate removal. Along with this undesirable chemical dosage, the WWTP has problems with blockades of buffers and pipes by struvite (magnesium ammonium phosphate). Another problem is the high phosphate content in centrate. This causes dewatered sludge with a low dry solids (DS) content and a high phosphate load to the WWTP water line. Because of this high phosphate load, more chemical dosing is necessary. To solve these three problems, a study was performed to optimise the additional chemical phosphate removal. An LCA was part of this study.

The goal of the LCA was to compare different chemicals, dosed in the water line or in the sludge line. Phosphate recovery was also taken into account. The following alternatives were compared:

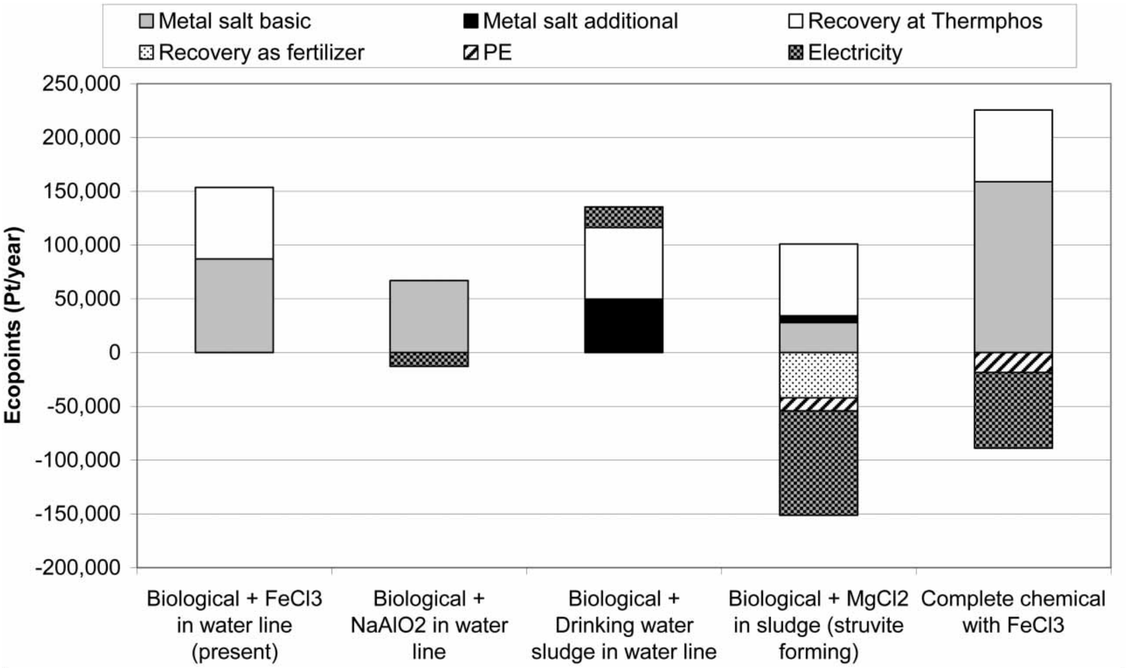
1. Biological phosphate removal with additional $FeCl_3$ dosing in the water line (reference situation).
2. The reference situation, replacing $FeCl_3$ with sodium aluminate ($NaAlO_2$). The advantage of using an aluminium salt instead of an iron salt is that phosphate can be recovered from the ash after the incineration of dewatered

sludge. This recovered phosphate can be used by the phosphorus industry instead of phosphate ore.

3. The reference situation with dosing of iron-rich sludge (a waste product from the production of drinking water) instead of $FeCl_3$.
4. Addition of magnesium chloride ($MgCl_2$) to digested sludge during aeration with compressed air and formation of struvite. In this alternative, the blockage problems are solved by the controlled formation and recovery of struvite. Because of this struvite formation, less chemical ($FeCl_3$) dosing is required in the water line. The formed struvite can be used instead of common phosphate fertiliser, however the quality is less certain, therefore it is assumed that only 75% of the product can be used. A final advantage of this technique is that the dewaterability of the digested sludge increases while a lower dosage of poly electrolyte (PE) is needed. Incineration of dryer sludge generates more electricity.
5. Complete chemical phosphate removal in the water line by $FeCl_3$ dosage. The advantages of complete chemical phosphate removal are a reduction of electricity for mixing and recirculation and a higher DS content of dewatered sludge. This higher DS content results in more electricity production during incineration.

In the LCA, only aspects that differ between the alternatives were taken into account. These aspects are chemicals required, used electricity (e.g., for aeration), produced electricity (by the incineration of sludge) and replaced phosphate ore or common phosphate fertiliser. The building of new installations and transport of the sludge and chemicals were not taken into account, because it is assumed that their environmental impact is negligible. Also the contribution of salt (e.g. chloride) to surface water was not considered, because LCA is not suitable to research local environmental effects. The functional unit used for the calculations was the yearly amount of phosphorus that needs to be removed in WWTP Amsterdam West.

From the total environmental impact expressed in ecopoints (Figure 2), it can be concluded that the most sustainable method for removing phosphate is recovery of struvite (alternative 4). This is caused by the lower $FeCl_3$ dosage, the amount of common fertiliser that can be



Total impact:	154,000	54,000	135,000	-50,000	137,000

Figure 2 | Results of the LCA study on phosphate removal at WWTP Amsterdam West. A negative score indicates a positive impact on the environment.

replaced by the recovered struvite and by the higher electricity production out of dewatered sludge with a higher DS content. Interestingly, complete chemical removal with $FeCl_3$ (137,000 Ecopoints/year) is less polluting than biological uptake with additional $FeCl_3$ dosing (154,000 Ecopoints/year). This is because the extra amount of $FeCl_3$ that is needed is compensated by a decrease in electricity use, a decrease in PE use and an increase in electricity production from the dewatered sludge with a higher DS content.

The yearly scope 3 GHG emission of the reference alternative (1) is 1,210 ton CO_2. For the struvite alternative (4) this is 91 ton CO_2 in scope 3. A potential 1,120 ton CO_2/year (scope 3) can be saved by changing the phosphate removal strategy. This alternative is expected to be implemented in 2013.

pH correction with carbon dioxide in drinking water treatment

At the drinking water pre-treatment plant Loenderveen, hydrochloric acid (HCl) dosage was used for pH correction. There were plans to replace this HCl dosage by carbon dioxide (CO_2) dosage. To quantify the effect of this replacement on the environment, an LCA study was performed. In the LCA the amount of HCl and CO_2 dosed and the transport of both chemicals were taken into account. The impact of building materials was assumed negligible. The functional unit used for the calculations was 1 year of water production at Loenderveen. It can be concluded that the impact of pH correction with CO_2 is lower than with HCl (Figure 3). The transport factor is small for both chemicals. Partly based on this conclusion, Waternet decided to build the CO_2 dosing installation, which is currently in use.

The yearly scope 3 GHG emission of the pH correction with HCl at Loenderveen is 131 ton CO_2. For the alternative with CO_2 dosage this is 49 ton CO_2. Thus, a potential 82 ton CO_2/year can be saved by changing the pH correction process at Loenderveen. Compared to the total scope 3 GHG emissions of Waternet (33,000 ton/year), this is a small reduction.

Materials for drinking water distribution pipes

Waternet yearly constructs approximately 20 km of drinking water distribution pipes. For these pipes mostly ductile iron, poly ethylene (PE) or poly vinyl chloride (PVC) are used. Waternet prefers PVC over ductile iron for pipes with a diameter <315 mm. This policy is based on cost evaluation, applicability, influence of the material on water quality and an internal environmental impact study from 1999. The environmental impact study found that PE had the lowest environmental impact, followed by PVC. However, PE is only used for home connections, because it has a higher biofilm potential than ductile iron and PVC. A higher biofim potential means that the biological stability of drinking water may decrease. The biological stability of drinking water is an important aspect, because no chlorine is used in drinking water distribution in the Netherlands.

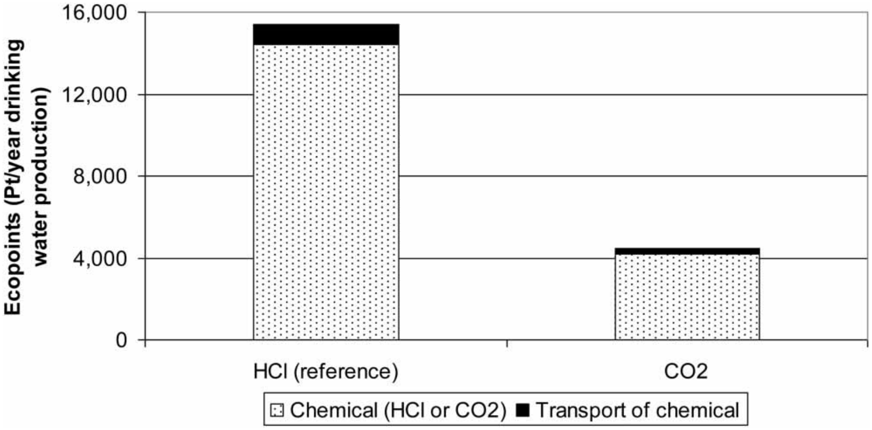


Figure 3 | Results of the LCA study for pH correction with HCl and CO_2.

Waternet wanted to evaluate the current policy on drinking water distribution pipe materials from an environmental impact perspective. Therefore, a new LCA study was performed to investigate the environmental impact of materials most used for distribution pipes. The LCA consisted of the materials extraction, the production of the pipes and junctions, transportation of the pipes to Amsterdam and material recycling. The method of installation is not considered; it was assumed that there is no difference between the materials. Also, pressure loss was left out of the study. The functional unit for the calculations was 1 m pipe including two curves (90°) and junctions (per 100 m pipe, divided by 100). From this environmental impact study it was concluded that PE had the lowest and PVC the highest environmental impact.

Since the conclusion of this recent LCA differs from the impact study performed in 1999, the LCA (with the exact same processes and functional unit) was also performed using the older Ecoindicator 99 method (Goedkoop & Spriensma 2000). With the Ecoindicator 99 method, ductile iron had the highest environmental impact, similar to the earlier (1999) study. In both methods (ReCiPe and Ecoindicator) fossil (fuel) depletion is responsible for a large part of the environmental impact (Figure 4). However, in ReCiPe climate change is also important, while in Ecoindicator this is not the case. In Ecoindicator, mineral depletion is important, and is the reason that the environmental impact of ductile iron is high. Both methods work with a panel of experts that determine the weighting. ReCiPe builds on Ecoindicator 99 and the CML (Institute of Environmental Sciences) handbook on LCA (Goedkoop *et al.* 2008). Apparently in the 10 years time between Ecoindicator and the current ReCipe method, insights into the importance of some of the environmental impact factors changed. Climate change is considered more important and depletion of minerals is considered less important.

According to the recent LCA study, Waternet should choose ductile iron instead of PVC. However, the preferred material has not been changed based on the outcome of the LCA. Waternet is considering how to deal with changes in LCA conclusions as a result of progressive insights in the weight of environmental impact factors over time. It turns out that it is only relevant to perform a (new) LCA when a policy is mainly based on LCA results or if a policy has a large impact on the Waternet climate footprint. Neither reason is valid for this case, as other aspects, such as, e.g., costs and water quality determine the choice of drinking water distribution pipes. The yearly GHG emission for constructing 20 km distribution pipe in PVC is 262 ton CO_2. For constructing all the pipes in ductile iron, this is 197 ton CO_2. A potential 64 ton CO_2/year can be saved, equal to 0.2% of the Waternet scope 3 GHG emissions.

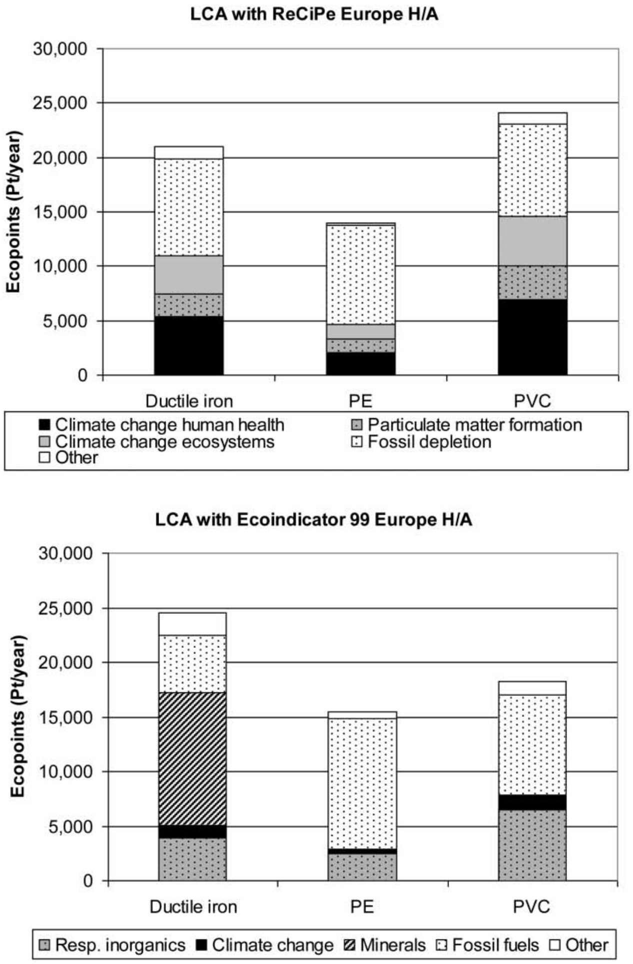


Figure 4 | Comparison between the ReCiPe and Ecoindicator 99 LCA methods. The ecopoints per meter pipe are multiplied by 20,000 m, to get a yearly amount.

Considerations on the use of LCA

In this paper, three LCA studies are described through which Waternet gained insight into the environmental aspects, next to financial aspects, which are commonly calculated during investment decisions. Results of these LCA studies can be used in similar cases; however, the following considerations should be taken into account:

- The environmental impact of electricity use is calculated with a characterisation factor for the Netherlands. Other countries may use more or less renewable energy, which will result in higher or lower characterisation factors.
- Transport is calculated with a distance assumption between the production location and the consumption location. Although in most cases, the impact of transport is low, a longer or shorter distance may influence results.
- The production processes of, for instance, chemicals may be different which may lead to differences in calculated environmental impacts.

The climate footprint approach is widely used, for instance, for benchmarking cities in the United States (Hillman & Ramaswami 2010). The disadvantage of the climate footprint approach is that only climate change based on mostly incomplete yearly average data (i.e., only consumption of energy and chemicals, not the production of waste) is considered. However, the climate footprint still gives a good impression of the environmental impact of an organisation, which makes it possible to pinpoint the most effective areas to reduce the environmental impact.

From the LCA studies presented, the following limitations of LCA studies performed with ReCiPe (and the IPCC method) were found:

- Water use is not considered. The impact on the Dutch situation is small because of the high availability of fresh water. However, other countries may get misleading results when performing LCA studies with ReCiPe or other European methods (Friedrich *et al.* 2007). Pfister *et al.* (2009) calculated the relative importance of water consumption in LCIA and found large differences around the world.
- The effect of discharge of wastewater effluent to surface water (with compounds like nitrogen and phosphorus) is only considered on a global scale. However, LCA studies performed with the Danish EDIP (Environmental Design of Industrial Products) method show these compounds can have a large impact on surface water on a local scale (Clauwert *et al.* 2010; Igos *et al.* 2012). Therefore, it is recommended that the Waternet LCA studies are recalculated, which might affect surface water with the EDIP method, to check whether the right conclusions were drawn.
- Characterisation factors change over time or between methods because of changes in the environment and the perspective on the environment (van Caneghem *et al.* 2010; Pizzol *et al.* 2011). This can result in a lower (or higher) environmental impact, without an actual change in the assets of processes. This was shown in the example of the materials of drinking water distribution pipes.

CONCLUSIONS

Waternet performed LCA studies to evaluate the environmental impact of investment decisions and to find out the reduction potential of the scope 3 GHG emissions. The conclusions of three examples of LCA studies discussed in this article are as follows:

- Phosphate removal at WWTP Amsterdam West should change from $FeCl_3$ addition in the waterline (154,000 Pt/year) to the formation of struvite out of digested sludge by adding $MgCl_2$ (−50,000 Pt/year). This will reduce environmental impact mainly due to the lower $FeCl_3$ dosage, the common fertiliser that can be replaced by the recovered struvite and by the increased electricity production out of dewatered sludge. When this is implemented as expected in 2013, the scope 3 GHG emissions of Waternet will reduce with 1,120 ton CO_2, which is 3% of the total scope 3 GHG emissions of Waternet (33,000 ton CO_2).
- pH correction with CO_2 instead of HCl turned out to be more environmentally friendly (ecopoints respectively 4,000 and 15,000 per year), although the effect on the scope 3 GHG emissions of Waternet is only small (82 ton CO_2 or 0.2%). The change is implemented already, also because of cost aspects.
- Currently, the most environmental friendly material for drinking water distribution pipes is ductile iron (21,000 Pt/year), while 10 years ago, this was PVC. Despite this change Waternet decided to keep on using PVC (24,000 Pt/year) instead of ductile iron, as in this

case the aspects of costs and quality weigh heavier. Besides, the impact of the distribution pipes to the total Waternet scope 3 GHG emissions turned out to be small (64 ton CO_2 or 0.2%).

For Waternet (and other organisations), LCA is a useful tool to evaluate the environmental impacts of different alternatives for investment decisions and to determine the effect on the Waternet climate footprint. The most important limitation of LCA is that the impact of water consumption and the possible impact of effluent compounds to surface water are not considered within the used methods.

From the examples described it can be concluded that only phosphate removal had a significant effect on Waternet's scope 3 GHG emissions. An explanation for this is that the chemicals that contribute the most to the Waternet scope 3 GHG emissions are sodium hydroxide (NaOH) (27%) and $FeCl_3$ (28%). HCl contributes only for 2% and PVC for 3%. Thus, if Waternet wants to reduce the scope 3 GHG emissions, it is advisable to focus on NaOH and $FeCl_3$ use.

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