Climate change mitigation by recovery of energy from the water cycle: a new challenge for water management

J. P. van der Hoek

ABSTRACT

Waternet is responsible for drinking water treatment and distribution, wastewater collection and treatment, and surface water management and control (quality and quantity) in and around Amsterdam. Waternet has the ambition to operate climate neutral in 2020. To realise this ambition, measures are required to compensate for the emission of 53,000 ton CO2-eq/year. Energy recovery from the water cycle looks very promising. First, calculations reveal that energy recovery from the water cycle in and around Amsterdam may contribute to a total reduction in greenhouse gas emissions up to 148,000 ton CO2-eq/year. The challenge for the coming years is to choose combinations of all the possibilities to fulfil the energy demand as much as possible. Only then the use of fossil fuel can be minimized and inevitable greenhouse gas emissions can be compensated, supporting the target to operate climate neutral in 2020.

Key words | climate footprint, energy recovery, greenhouse gas emission, renewable energy, water

INTRODUCTION

The relation between energy and water gains importance. Water can be used as an energy carrier, but water also contains energy itself, either chemical energy or thermal energy. The relation may be used by water companies to operate climate neutral, which means that the balance of greenhouse gas emissions of all activities equals zero. This implies that for inevitable greenhouse gas emissions compensation is needed.

This paper focuses on the recovery of energy from water to operate climate neutral from the perspective of the water cycle company Waternet. The water cycle is a new concept in The Netherlands, based on an integrated approach of all activities in water management. Activities are drinking water treatment and distribution, wastewater collection and treatment, and water system management and control. Waternet, established on 1 January 2006, is the first water cycle company in The Netherlands and is responsible for all these water related activities in and around Amsterdam (van der Hoek et al. 2011).

The ambition is to reduce the emission of greenhouse gases by 50% at the end of 2010, and to operate climate neutral in 2020. Although the water sector has only a very small contribution to greenhouse gas emissions compared to other sectors like energy production or mobility, reduction of greenhouse gas emissions in the water sector is important as all sectors are working on this topic. In The Netherlands the contribution of the water sector (i.e. drinking water production and distribution, and wastewater collection and treatment) to the total global warming potential is 0.8%, while for households the yearly greenhouse gas emission caused by water-related activities (not including heating of tap water) is 3.3% as compared to the emission caused by energy use in households (Frijns et al. 2008).

By energy savings, process optimizations (focusing on the use of better raw materials and chemicals) and by the use and purchase of renewable energy the target of 50% reduction at the end of 2010 has been met. The target to operate climate neutral in 2020 is much more difficult to realize. To operate climate neutral additional measures are required to compensate for the inevitable CO2 emissions, the so-called compensation measures.

Waternet is aiming to make use of energy from the water cycle to compensate for these CO2 emissions. Because the water cycle comprises surface water, wastewater, ground water and drinking water, many opportunities seem possible. In this paper, these possibilities will be discussed and a first estimate will be made of the total potential that energy recovery from the water cycle offers.
METHODS

Greenhouse gas emissions can be calculated based on the international Greenhouse Gas Protocol (The Greenhouse Gas Protocol 2004). This protocol was applied to calculate the emissions by Waternet (Janse & Wiers 2006; Wiers et al. 2009).

RESULTS AND DISCUSSION

The challenge to become climate neutral

The emission of greenhouse gases is shown in Figure 1. The year 1990 is the reference year. At that time the emission was 89,000 ton CO₂-eq. In 2009 the emission has been reduced to 62,800 ton CO₂-eq through energy efficiency measures, through the purchase and use of renewable energy to an amount of 45,000 ton CO₂-eq (‘green electricity’), and through process optimizations, especially with respect to the use of better raw materials. The year 2020 is the target year to operate climate neutral. Assuming a steady purchase and use of green electricity, a compensation is required of 69,000 ton CO₂-eq. For a part this compensation can be reached through additional energy efficiency measures: 15,900 ton CO₂-eq based on an energy efficiency improvement of 2% per year. The remaining compensation, 53,000 ton CO₂-eq, can be realised through the production of renewable energy, e.g. wind energy and solar energy, or through recovery of energy from the water cycle. Waternet, as a water cycle company, it is much more attractive and challenging to recover energy from the water cycle.

Energy recovery from surface water

Energy recovery from surface water concerns the use of thermal energy. That can be heat by using shallow surface water as sun collector, but also cold by using surface water, especially deep lakes, as ‘cooling machine’ (van de Ven et al. 2009). The latter option is most interesting for Amsterdam as the need for cooling is bigger than for heating.

Figure 2 shows the principle of the use of cold from deep lakes. It consists of recovery of cold from the lake and a cooling network in an office building fed with cooling water. In a heat exchanger cold from the water from the lake is transferred to the water in the cooling network and provides cooling of the office building.

Waternet, in collaboration with NUON Energy, already operates such a system. In Amsterdam South-East offices are cooled with water from the lake ‘Ouderkerkerplas’. The ‘Ouderkerkerplas’ is a former sand mine, now filled with water. By removing phosphate from the water during abstraction, the water quality and the ecological quality of the lake is improved at the same time.

Table 1 shows how much energy is saved per year, and how much CO₂ emission is avoided. By using a central cooling machine fed with cooling water from the ‘Ouderkerkerplas’, a reduction in greenhouse gas emission is reached of almost 20,000 ton CO₂-eq/year as compared with separate cooling machines in every office building.

Energy recovery from wastewater

With respect to energy recovery from wastewater, a distinction can be made between chemical energy from wastewater...
and thermal energy from wastewater. Chemical energy concerns the organic compounds in the wastewater. These organics can be expressed as chemical oxygen demand (COD). The energy content of these compounds is about 13.5 MJ/kg COD (van Lier & Raap 2012). Thermal energy is related to the heated wastewater that leaves the house. On an average, about 19.7–21.7 MJ leaves the households via the wastewater per day (Hofman & van Loosdrecht 2013; Sukkar et al. 2009). This concerns heated and used drinking water.

### Chemical energy from wastewater

Chemical energy recovery from wastewater is quite well known and is based on anaerobic sludge digestion and anaerobic treatment of wastewater (Lettinga et al. 1980; Kiestra 2008). The biogas produced is used for the combined production of electricity and heat through combined heat-power generators. Waternet produces in total 13 million m³ biogas per year at 12 wastewater treatment plants, so it has a great potential. The disadvantage of this concept is that the heat cannot always be used, because the heat demand in the summer is very low.

As an alternative, the biogas can be upgraded to Green Gas (Welink et al. 2007). Biogas contains 60–65% CH₄ and 35–40% CO₂. By increasing the methane content up to 88% and by removing sulphur and moisture, Green Gas is produced with a composition that equals natural gas so it can be distributed to households by the existing natural gas network. In addition it can be used as alternative fuel for automobiles. Green Gas thus offers a sustainable alternative to natural gas.

Since 2009 Waternet has operated a Green Gas installation at the wastewater treatment plant ‘De Ronde Venen’, a relatively small plant. The green gas that is produced, 140,000 Nm³/year, is 20% used to heat the buildings and sludge digestion process at this plant. The main part, 80%, is distributed to households by the natural gas network, and in addition used as fuel for company cars.

Table 2 shows the situation in which it is assumed that all biogas which is produced at the wastewater treatment plants is converted to Green Gas. The potential is 7.3 million Nm³/year which equals an avoided greenhouse gas emission of 13,000 ton CO₂-eq/year.

### Thermal energy from wastewater

Besides chemical energy, also thermal energy can be recovered from wastewater. About 54% of the drinking water that is used in a household is heated and leaves the house at an average temperature of 27 °C: water from bathing and shower has a temperature of approximately 38–40 °C, tap water leaves the house at a temperature of 10–55 °C, and water from the dishwasher and washing machine has a temperature of approximately 40 °C (Hofman & van Loosdrecht 2009; Roest et al. 2010). Looking at the heat loss from a modern house, wastewater contributes for 40% to this loss. On a yearly basis this implies a loss of 8 GJ/house, which is equivalent to 450 kg CO₂.

### Table 1 | Reduciton of energy consumption and greenhouse gas emission by use of cold from the lake ‘Ouderkerkerplas’

<table>
<thead>
<tr>
<th></th>
<th>Electricity consumption (MWh/year)</th>
<th>CO₂ emission (tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own cooling machines</td>
<td>29,200</td>
<td>23,900</td>
</tr>
<tr>
<td>Central cooling machine</td>
<td>12,200</td>
<td>10,000</td>
</tr>
<tr>
<td>Central cooling machines with cooling water from the Ouderkerkerplas</td>
<td>4,900</td>
<td>4,000</td>
</tr>
</tbody>
</table>

### Table 2 | Green Gas production at the wastewater treatment plants of Waternet: potential capacity and potential avoided greenhouse gas emission

<table>
<thead>
<tr>
<th>Wastewater treatment plant ‘De Ronde Venen’</th>
<th>Total Waternet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment capacity</td>
<td>1,370 m³/h, 70,000 p.e.</td>
</tr>
<tr>
<td>Biogas production</td>
<td>700 Nm³/day</td>
</tr>
<tr>
<td>Available Green Gas</td>
<td>140,000 Nm³/year</td>
</tr>
<tr>
<td>Use of Green Gas</td>
<td>90 households or 120 automobiles</td>
</tr>
<tr>
<td>Avoided greenhouse gas emission</td>
<td>250 ton CO₂-eq/year</td>
</tr>
</tbody>
</table>
With 320,000 households in Amsterdam this offers a potential of 144,000 ton CO₂-eq/year.

There are several possibilities to recover this thermal energy from wastewater. At residence level, the use of a heat exchanger in the discharge of the shower is a possibility that is already applied in new houses. Another possibility is the recovery of thermal energy at housing estate level. Recently this has been put into practice in Hamburg by Hamburg Wasser.

Full recovery of the thermal energy from wastewater however seems impossible, as there is not only a need for heating of houses and offices, but also for cooling. At the moment 6% of the households and 58% of the of the offices are equipped with air conditioning and it is estimated that this figure will grow (City of Amsterdam 2010).

**Energy recovery from ground water**

Ground water is a third possibility to recover energy from the water cycle. Especially aquifer thermal energy storage (ATES) offers interesting opportunities and is today applied at large scale for cooling and heating of houses and buildings (Sanner et al. 2005). The principle of ATES is based on the use of two wells (a cold well and a warm well), connected by a heat exchanger to recover thermal energy from the ground water. In wintertime, ground water is extracted from the warm well at a temperature of 15–17 °C. It transfers its warmth via the heat exchanger to a heat pump. The cooled ground water is infiltrated in the cold well at a temperature of 6–7 °C. The heat pump transfers the low temperature warmth to a temperature of 40–55 °C, while additional equipment may be used to increase the temperature further for heated tap water purposes. In summertime, the flow of the ground water circuit is the other way round, so cold water from the cold well can be used for cooling purposes.

With ATES a CO₂ reduction can be obtained up to 50–70% as compared with a traditionally heated and cooled building. The advantage of ATES is that it can also be used to store thermal energy in the underground, recovered from sun collectors, surface water, sewer systems and even from drinking water.

In Amsterdam, 80 projects are already installed or under construction, together realising an emission reduction of more than 23,000 ton CO₂-eq/year.

**Energy recovery from drinking water**

Drinking water offers opportunities for energy recovery for both chemical energy as well as thermal energy. Chemical energy concerns the use of methane that can be present in ground water. Recovery of methane from ground water during drinking water production is under development at the moment at Vitens, one of the drinking water companies in the Netherlands (Drijver et al. 2007).

In contrast to Vitens Waternet uses surface water as source for drinking water, but also this situation gives chances for energy recovery. Due to climate change the temperature of the surface water is rising, and the increase in temperature may be used to recover thermal energy from drinking water, produced from surface water.

As an example, Figure 3 shows the temperature of the surface water at three raw water intakes for drinking water in The Netherlands. The year 2003 was a relatively warm year and as can be seen from this figure, the temperature of the intake water reached values up to

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**Figure 3** | Temperature profile of the surface water at three raw water intakes for drinking water in The Netherlands, period 2002–2003.
25 °C and even higher. Of course this affects the temperature of the drinking water that is produced from the surface water.

Figure 4 shows the frequency distribution of drinking water in the distribution system. It concerns drinking water produced from surface water. As in 2003, 2006 was also a relatively warm year, resulting in a high drinking water temperature. Almost 10% of the analyses showed temperatures above 20 °C.

Ideas are being developed to use this high temperature, e.g. to balance an ATES system in a new housing estate near Amsterdam. In this ATES system, there is a surplus of cold. The system can be balanced by regeneration with drinking water. A transport main crosses this new housing estate, and the warmth in the drinking water is used to balance the system. An additional heat exchanger transfers the warmth in the drinking water to the cold well.

An important benefit of this approach is that the drinking water is cooled in the summer and can be delivered to the customers at a lower temperature. Besides higher comfort aspects the hygienic quality of the drinking water is also improved: a lower temperature, below 25 °C, implies a lower risk of microbiological regrowth in the network. This is important, as drinking water in The Netherlands is distributed without a persistent disinfectant (van der Kooij et al. 1995). In addition, in the Dutch drinking water regulation the maximum temperature for tap water is 25 °C (State Journal 2011), in contrast to the European drinking water directive which gives no standard for temperature (European Union 1998).

Future perspectives

The water cycle offers several possibilities to recover energy by which an important contribution can be delivered to operate the water cycle climate neutral. In Table 3 the possibilities are summarized and quantified, focusing on the water cycle in Amsterdam. The energy production is expressed as avoided greenhouse gas emissions. For surface water it is assumed that two projects can be realised comparable with the example of the lake ‘Ouderkerkerplas’. For chemical energy recovery from wastewater it is assumed that all biogas produced by Waternet is converted into Green Gas. For thermal energy from wastewater it is estimated that 50% may be recovered by use of heat exchangers in sewers. For ground water the figure is used of the 80 projects that are already installed or planned in Amsterdam. Because energy recovery from drinking water is at a very early stage of development, this is not included in the calculation. Adding all these figures, it appears that

Table 3 | Energy recovery from the water cycle expressed as avoided greenhouse gas emissions

<table>
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<tr>
<th>Energy recovery from:</th>
<th>Avoided greenhouse gas emissions (ton CO2-eq/year)</th>
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<tbody>
<tr>
<td>Surface water</td>
<td>40,000</td>
</tr>
<tr>
<td>Wastewater (chemical)</td>
<td>13,000</td>
</tr>
<tr>
<td>Wastewater (thermal)</td>
<td>72,000</td>
</tr>
<tr>
<td>Ground water</td>
<td>23,000</td>
</tr>
<tr>
<td>Total</td>
<td>148,000</td>
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Figure 4 | Frequency distribution of the drinking water temperature in the distribution area of Waternet (100 samples evenly distributed over the year).
the potential energy recovery from the water cycles equals an avoided greenhouse gas emission of 148,000 ton CO₂-eq/year. To operate climate neutral, Waternet requires a compensation of 53,000 ton CO₂-eq/year. Hence, energy recovery from the water cycle looks very promising to operate climate neutral.

In this respect it is also interesting to relate this potential reduction of greenhouse gas emissions by energy recovery from the water cycle with the targets of the city of Amsterdam. The city of Amsterdam has the aim of reducing the emissions with 40% in 2025, which means an emission of not more than 2,500,000 ton CO₂-eq/year. To reach this target a reduction is required in the next 15 years of 3,100,000 ton CO₂-eq/year (City of Amsterdam 2009). Energy recovery from the water cycle of Amsterdam thus can deliver a contribution of approximately 5% in realising this target.

CONCLUSIONS

The water cycle offers a wide variety of possibilities to recover energy. Waternet as a water cycle company aims to exploit these possibilities to operate climate neutral. The challenge is to find combinations of all these possibilities able to fulfil the energy demand as much as possible. Only then the use of fossil fuel can be minimized and inevitable greenhouse gas emissions can be compensated, supporting the target to operate climate neutral in 2020.

A first rough estimate reveals that the potential of the water cycle exceeds the required compensation.

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