Water and energy as inseparable twins for sustainable solutions

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ABSTRACT

Although the water cycle is only a minor contributor to the energy demand in society, it is a matter of good housekeeping to minimize the energy need within a sustainable water cycle. Wastewater treatment should not only be applied to purify the water, but also recover the energy present in this water, as well as to recover essential elements like nitrogen and phosphorus. From an energy analysis of the Dutch water cycle it is concluded that creating an energy neutral water cycle by using the heat content or by making use of the organic load of wastewater is within hands.

Key words | drinking water, energy, heat, sustainability, wastewater, watercycle

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INTRODUCTION

Increasing populations and economic growth leads to a growing stress on the availability of fresh water. This stress is further increased due to the effect of climate change. It is therefore more and more important to critically examine the use and wastage of water. Water supply and sanitation are some of the major issues for highly populated areas. The concerns related to water supply and sanitation cannot be separated from another urgent problem: the growing energy demand and the global environmental problems (like e.g. climate change). Although the water cycle is only a minor factor when energy is concerned, water and energy cannot be seen separately if we really want to look for sustainable solutions for the water cycle.

Drinking water supply, sewering and wastewater treatment are mostly completely separated worlds. However, the only way to obtain sustainable solutions for the future is by combining these worlds. Optimization in the drinking water supply and minimizing water wastage separately does not provide a solution to the energy and environmental problems we are facing. They require an integrated approach, including looking at energy efficiency of all processes involved, treating wastewater not only to purify the water, but also to use the energy present in this water, recovering valuable compounds like nitrogen and phosphorus from wastewater, making use of the intrinsic value of the wastewater sludge, and realizing an energy neutral water cycle. Paminger & Kenway (2008) apply the concept of urban metabolism using water, foods, energy and materials as input, and delivering wastewater, stormwater, biosolids and green house gasses as output as a tool to optimize all internal cycles, including the water cycle, to obtain fully sustainable solutions.

DUTCH SITUATION

Water stress in the Netherlands?

Water is available in The Netherlands abundantly. With an average rainfall of approximately 800 mm per year and two important rivers crossing the country (Meuse and Rhine), on average sufficient water is available. On the other hand, due to seasonal variations water quality may change dramatically. Especially at low river discharges, extreme deterioration of water quality has been observed (Zwolsman & Van Bokhoven 2007; Van Vliet & Zwolsman 2008). It is expected that these periods of drought and low river discharge will increase in frequency due to climate change effects.

In the Southwestern estuaries, around the Westerschelde, fresh water is scarce, due to salinization, forcing industrial users and agriculture to utilize alternative sources such as

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treated wastewater or apply desalination technology, both with high energy demand (Mulder & Boks, 2009).

Energy and emission of green house gases in the water cycle

Because of the growing populations, and the increasing use of all kinds of substances like e.g. medicines and pesticides, wastewater and drinking water recourses become more and more polluted with all kinds of chemicals that may harm human health. In the meantime global temperatures are rising, which may result in an increase in the growth of micro organisms in water resources and a deterioration of water quality in general. Techniques are being developed to remove these substances and organisms. However, due to better knowledge of the negative effects of these compounds, more efficient analytical techniques, and the decreasing acceptance of health risks by the public, the demands for purification techniques are becoming stricter and the techniques are getting more complicated. As a result, application of many new purification techniques, like e.g. UV oxidation or membrane technology, will result in an increasing energy demand for water and wastewater treatment, thus increasing the environmental problems, like global warming. Technologies like UV oxidation (Tuhkanen 2004) or membrane filtration (Fritzmann & Löwenberg, 2007) often have a high energy consumption (0.5–2 kWh/m^3) or 5–10 W/cap which in many cases almost doubles the total energy demand if they are applied. Moreover they often have undesired side effects like by-product formation or concentrate disposal. It is clear that these treatment technologies, although they are delivering an excellent water quality, at the long end hamper sustainable solutions.

An integrated approach has to be followed that in the first place prevents contaminants to enter the water cycle. For many compounds, such as pharmaceuticals and hormones, that means treatment at the source, i.e. in wastewater leaving nursing homes, office buildings and homes. This of course also implies that this technology should be robust, simple, effective and cheap, preferably driven on the excess energy in a building. Still many diffuse pollution sources exist and accidental spills can lead to pollution of water resources. For these problems, source control and end-of-pipe solutions are required. Modern adsorption techniques, based on new types of (reactive) adsorbents and liquid-liquid extractions, can be very efficient.

The Netherlands is a small country, with about 17 million inhabitants, and over 7 million households (average of about 2.3 capita per household). The total Dutch drinking water production is approximately 1,150 million m^3 per year. About 789 million m^3/y water is used by people in their homes, which equals an average per capita use of 134 L/d (Geudens 2007). This is almost 70% of the total production of drinking water; the rest is used by businesses and industrial users. In 2006, the total energy consumption of drinking water supply, including raw water intake, treatment and distribution, was 0.47 kWh/m^3 (with 0.16 kWh/m^3 coming from renewable energy sources). (Geudens and Beek 2007). The per capita energy consumption of drinking water supply is 2.6 W.

The carbon footprint of the Dutch water sector is shown in Table 1.

From Table 1 we can conclude that estimated direct emissions (mainly methane and nitrous oxide) from wastewater treatment are important contributions to the total footprint (33%). Even more important is the contribution of

Table 1 | Total annual global warming potential of the water cycle in The Netherlands (tonnes CO_2-equivalents). (Frijns, Mulder *et al.* 2008)

	Drinking water supply	Sewerage	Wastewater treatment	Total
Energy related emissions	335,533	120,300	475,110	930,943 56%
Direct emissions	47,915	3,320	559,110	610,345 36%
Indirect emissions	53,427	0	80,088	133,515 8%
Total	436,875 26%	123,620 7%	1,114,308 67%	1,674,803

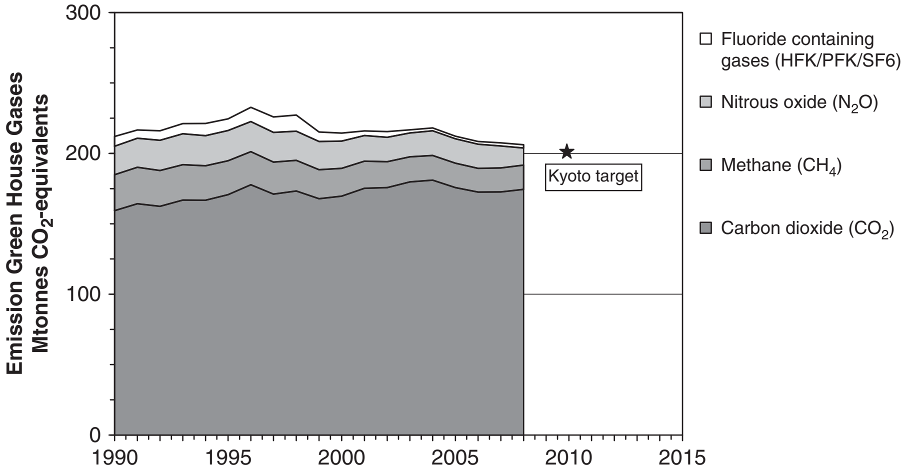

Figure 1 | Green house gasses emission in the Netherlands (PBL 2009).

energy related emissions of the water cycle (56%). In Figure 1 the total green house gases emission in the Netherlands is shown.

In this figure it becomes clear that in the Netherlands we are not very far from the Kyoto objective set for 2010. This means that even a small decrease in emissions can be sufficient to reach this goal. The Dutch water sector emits only a minor part of the total amount of green house gases emitted in the Netherlands, but if it would be possible to obtain a substantial decrease here, that would be enough to reach the Kyoto objective. As the governmental influence in this sector is relatively large, and the government can use this to set an example to other industries, it is very attractive to minimize the carbon footprint of the water sector.

The use of 789 Mm^3/y of drinking water, also results in 789 Mm^3/y of municipal wastewater. This is mixed with rain water and industrial wastewater. As a result the municipal wastewater treatment plants in the Netherlands treat 2.069 Mm^3/y (24.5 million PE). The energy demand of wastewater treatment in The Netherlands is summarized in Table 2. In total 5390 TJ was used in 2007, partly from electrical input, partly from natural gas, and by production from own biogas. About 33% is already generated at the wastewater treatment plant. This means that wastewater treatment costs 7 W/pe or around 4.6 W/pe external energy use.

Very often, the water used in homes is heated to comfortable temperatures, or even higher, for washing and cleaning purposes. In The Netherlands, about 54% of the domestic water use is heated (Geudens and Beek 2007). As a result, the 24 h average temperature of domestic wastewater leaving the house is 27°C, whereas it was 10°C when it entered the house. The actual temperature can fluctuate very much during the day, depending on the water. Figure 2 shows the simulated heat content of wastewater leaving homes (300 stochastic demand patterns). From this figure, it is calculated that the total heat loss through sewage water is about 110 W/cap or 7.7 TJ/y per house. This accounts for approximately 40% of the total heat loss of a modern house. The rest, 13 TJ/y, is lost through walls, roof (100 MJ/m^2.y) and chimney.

This means that the heat loss via sewage is approximately ten times higher than the energy demand from drinking water supply and wastewater treatment together. From this we learn that saving warm water or using solar heaters is a much more effective contribution to create sustainability than optimizing water and wastewater treatment. If we would be able to save 6% warm water or recover 10% of the heat in sewage water, the total energy demand of treatment can be compensated for (Frijns *et al.* 2009).

Wastewater as an energy carrier

As water has a relatively high heat content, it can be concluded that water can also be used as an energy carrier and

Table 2 | Energy input wastewater treatment in 2007 (CBS 2009)

Energy	Amount (TJ/y)
Electrical	2606
Natural gas: 29,574 m^3, $\Delta H_c = -32$ MJ/Nm^3	946
Own biogas: 73,527 m^3, $\Delta H_c = -25$ MJ/Nm^3	1838
Total	***5390***
356 WWTP; 24,462000 PE	7 W/PE

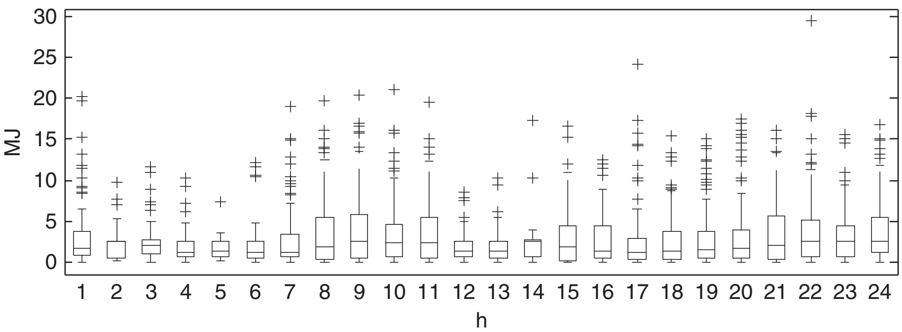

Figure 2 | Heat content in 300 stochastic demand patters from average households. Reference temperature = 10°C, Zero-values omitted (Blokker 2009).

for energy storage. Integrating the water and energy balances on a building level can lead to high energy savings, reduction of greenhouse gas emissions and improved indoor climate control. Technologies that can recover heat from wastewater e.g. shower heat exchangers, and buildings combined with Aquifer Thermal Energy Storage (ATES) systems are already introduced. Especially for new buildings or new neighbourhoods, it can be effective to implement these techniques, in order to establish a more sustainable environment.

Useful application of ''contaminants'' from water

Besides heat, wastewater has a high organic load, mostly expressed as COD (chemical oxygen demand). Besides the organic load wastewater also contains nutrients such as ammonium and phosphate which might be recovered.

In the Netherlands, the total annual COD load of municipal wastewater is 942,000 tons. If we assume that the organics in the wastewater consist of glucose ($C_6H_{12}O_6$), then this is about 4.9×10^9 mol per year, representing a chemical energy by oxidation of 13,800 TJ/y or 18 W/pe (heat of combustion $\Delta H_c = -2808$ kJ/mol). In theory, this energy can be recovered. This is enough to create an energy self-sufficient water cycle. The total energy input of the water cycle is approximately 10 W/pe, so it will definitely be worthwhile recovering at least part of the energy from the organic load.

The best options for energy production from wastewater are production of biogas or using dried sludge for power generation (Table 3). In Figure 3 the final sludge destination is shown for the Netherlands situation. This figure shows that almost all sludge is incinerated in The Netherlands.

Also the nutrients (N,P) in the water represent an energy content (45 MJ/kg N for N-fertiliser and 29 MJ/kg P for P-fertiliser production). Efficient reuse of these nutrients therefore also represents an energy amount, equal to 3138 TJ/y or 6.1 W/cap for nitrogen and 373 TJ/y or 0.7 W/cap for phosphorus.

The pathways along which energy may be recovered from COD are shown in Table 3.

According to (Wiegant, Würdemann *et al.* 2005), the best option to obtain energy from the organic load of wastewater would be to use pre-settling, without digestion, recovering phosphorous by adding alumina, or indirect thermal drying, combined with co-incineration in a cement oven.

CONCLUSIONS

In general, the carbon and energy footprint of the water cycle is not very large. However, by reducing it, it would be relatively easy for the Netherlands to reach the Kyoto

Table 3 | Pathways to recover energy from COD

Technique	Remarks
Microbial fuel cell	Mass transfer limitations at the electrodes; High costs
	Low power density (about 4 W/m^2 of electrode area) (Du, Li *et al.* 2007)
Dark fermentation H_2	Only <30% of organic matter is recovered
Direct fermentation of sewage water	Concentration of organic matter is too low, formed CH_4 is dissolved in water
Sludge digestion	Costs energy to obtain activated sludge, but CH_4 formed can be used (common practice on many WWTPs).
Sludge drying, incineration with P-recovery	Costs energy to obtain activated sludge
	Addition of alumina, to bind phosphorus for subsequent recoverage

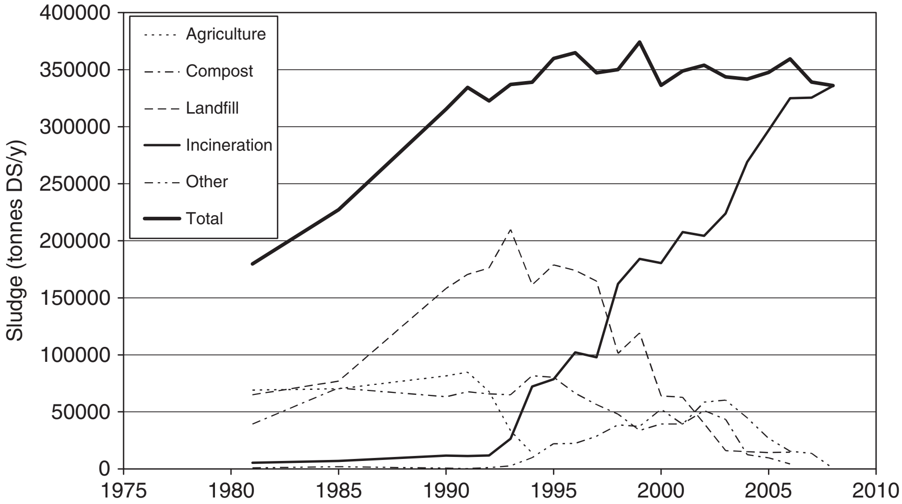

Figure 3 | Final sludge destination in the Netherlands. (CBS 2010).

objective for 2010. There are several alternatives to develop an energy neutral water cycle, by using the heat present in wastewater, or by making use of the organic load of the wastewater. In this way, the energy demand of the drinking water production and wastewater treatment, which are becoming larger, may be fulfilled in a sustainable way. By applying purification techniques in the water cycle at the site where they are most useful, e.g. near the source of pollution, these techniques can become more efficient and thus also more sustainable. Considering the water cycle in combination with energy, can result in an energy neutral water cycle.

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